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Compatibility of Concentrating and Non Concentrating Solar Collectors with Cooking Applications for Different Cooking Needs

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Abstract*: Amid numerous sources of energy, solar energy possesses calibre to combat energy requisite for various sectors. A lot of significant research work has been carried out on solar energy to maximize its applications and efficiency of available designs. Among many applications, cooking is the one of the dominant application of solar energy. Other than basic design of box type solar cooker, solar collectors are employed in solar cooking system for the feasibility of more effective cooking. This manuscript inhibits various cooking system based on solar collectors like FPC(flat plate collector),ETC (evacuated tube collector),PDC(parabolic dish collector), PTC(parabolic trough collector), fresnel lens based collector and scheffler reflector type collector. Solar collectors based cooker designs render compatibility of cooking regarding cooking load, cost, cooking type, ease of operation and cooking time.

***Keywords* : Concentrating, Solar Collectors, Cooking Applications**

I. INTRODUCTION

Pollution in our ecosystem has been increasing at alarming rate due to the emission of harmful gases resulted from the combustion of fossil fuels [1]. This condition is forcing the developing countries to search the new resources which are capable to fulfil the future energy requirements and also pollution free [2, 3].Only 14% of energy demand is fulfilled by renewable energy sources and has lot more potential for future needs [4-6]. Solar energy is the very viable alternative source than the other renewable sources of energy as the rate of power emitted by the sun is 3.8 × 1023 kW and power intercepted by the earth is 1.8 × 1014 kW [7]. Therefore, solar energy proved its potential for combating the various energy demands of the world as well as decrease in the harmful gases emissions. Fulfilment of global energy demand is feasible by solar energy as it is free of cost and abundant in nature[8] .

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Cooking of food is one of basic requirement of human being on earth which requires energy and that comes from burning of fuel which leads to CO2 emissions. Many countries in Africa and India are still utilizing a significant share of total available energy resource for their cooking needs [9, 10]. Amount of solar intensity in various developing countries of Africa and Asia is 5-7 kWh/m2 and sunny days available for around 275 days a year [11]. Due to this reason use of solar energy for cooking purposes find its place in upper shelf. Apart from the benefit of no use of fuel, solar cooking has other benefits such as high value of nutrition in food, high durability and capability to reduce drugdary [7]. Initially many researchers focused on box type solar cooker and evaluated its various designs experimentally as well as theoretically due to its simplicity [12]. But, other solar collectors also have significant potential in the field of solar cooking due to their countable advantages and feasibility according to the requirement. Kalogirou [13]stated the potential of various solar collectors in numerous thermal energy based applications. The focus of present review paper is to study the use of different types of solar collectors in solar cooking and their compatibility according to cooking load, cooking time, highest temperature achieved and cost.

II. USE OF SOLAR COLLECTORS IN COOKING APPLICATIONS

Solar collectors are the basic requirement for the utilization of enormous amount of solar radiations falling on earth for various applications. Solar cooking is one of the most prominent and feasible application to harness the solar energy. Previous researches on the solar cooking entails the use of various solar collectors having different cooking capabilities. Therefore, use of solar collector is a prime area of concern for the design and development of solar cooking device according to its cooking load, cooking time, initial cost, maintenance cost and ease of operation. Various solar collectors like evacuated tube, flat plate, parabolic dish, parabolic trough, fresnel lens and scheffler reflector are successfully being used for the purpose of solar cooking.

2.1. Flat plate collector based solar cooking systems

It is the most simplest and primitive type of solar collector. It has been used as solar radiation collection medium for solar cookers.

A solar cooking system was developed by Schwarzer and Silva [14] based on flat plate collector. It was comprised of storage tanks, cooking pots and reflecting surfaces as shown in figure 1. Authors developed cooking systems taking collector area for the range of 1-12 m2 and 250 in numbers. Vegetable oil of volume 100 litres was taken when collector area of 12m2 is used and vegetable oil acted as carrier of heat from collectors to cooking pots by thermosyphon phenomenon. The values of heating power/m2 collector area for the presented solar cooking system was able to reach the value of 500 W when the value of solar intensity was in the range of 900 to 1000 W/m2.The main advantage of the presented system was ability of the system to cook in the evening time. Haraksingh et al. [15] experimentally investigated the solar cooking system using flat plate collector having dimensions of 1.83m x 0.91m as shown in figure 2.

Figure 1. Solar cooking system developed by Schwarzer and Silva [11].

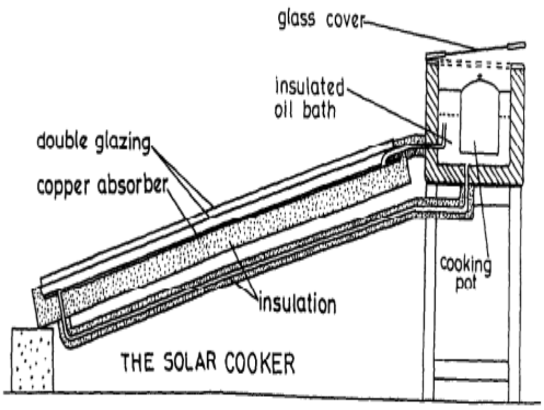

Figure 2.Flat plate based solar cooker [12].

The volume of 22 litres of coconut oil was utilized as heat transfer fluid to heat up the immersed cooking pots by thermosyphon phenomenon. The maximum temperature of heat transfer fluid for clear sunny days and partially cloudy days was noted 1440 C and 1080 C respectively. The cooking of sweet potato and rice was experimentally observed with cooking time of 20 minutes in clear sky days. Authors concluded that after the increment of height of cooking chamber by 30 centimetres, highest temperature of coconut oil was recorded as 1600C-1700C.

2.2. Solar cooking based on ETC(Evacuated tube collector)

Evacuated tube has proved to be an impressive solar radiation collecting medium for solar cooking systems. It has various advantages such as good efficiency even in diffuse radiations and no requirement of tracking mechanism. Stumpf et al. [16] evaluated the performance of solar cooking system based on three different solar collectors. They used single stage heat pipe coupled with flat plat collector, single stage heat pipe coupled with evacuated tube and double stage heat pipe with evacuated tube. The minimum heat up time of 17 minutes was observed for the heating system of double stage heat pipe with evacuated tube. Authors concluded that the presented system is complex but have several advantages like possibility of inside cooking, free from risk of blindness from concentrated sunlight and tracking free mechanism. As shown in figure 3, a community type pressure

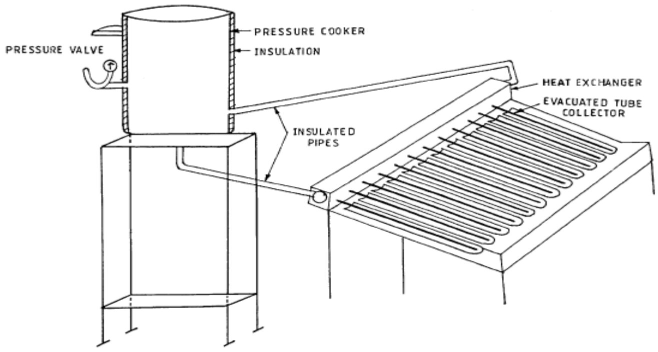

Figure 3. Solar cooking system based on evacuated tubes [17].

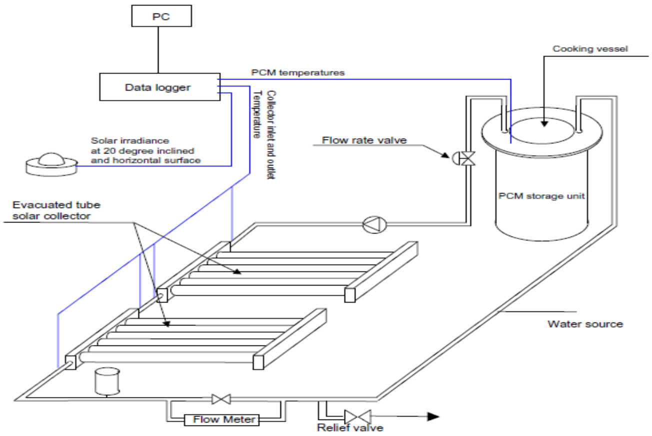

Figure 4. Solar cooker based on evacuated tube collector with phase change material [18]].

cooker based on evacuated tube collector was experimentally evaluated by Kumar et al.[14].The performance of presented solar cooker was predicted also by a developed simulation model. Authors found that the boiling time of 14 kgs of water increases by 40 minutes compared to 4 and 8 kgs of water. Authors concluded that the heat was supplied at approximately 1200C for the presented system of solar pressure cooker with evacuated tube collector and have potential for community cooking applications. Investigation of solar cooker consisted of evacuated tube and phase change material(erithrytol) was performed by Sharma et al. [18] as shown in figure 4. The performance of presented system was studied in variable climatic and operating conditions at Mie, Japan.

Authors conducted experiments at different time and loads for noon and evening time cooking. The maximum temperature of phase change material reached to 125-1300C in the noon and more than 1100C was available for evening time cooking. They concluded that time for evening cooking using phase change material was less than noon cooking time.

2.3 Solar cooking system based on parabolic dish collector(PDC).

Many researchers embedded parabolic dish collector in solar cooking system due to its high concentration ratio which results in attaining high temperatures than other collectors. Less cooking time and high temperature cooking applications such as frying are possible with this type of solar collector. Solar coffee maker based on parabolic dish collector was experimentally studied by Sosa –Montemayor et al. [19] using satellite TV mini dish and expresso coffee maker. Authors evaluated the temperature of water inside cooking vessel by a mathematical model and validation was done with actual experimental results. Authors concluded that the brew time of coffee was 30-50 minutes but temperature evaluation of the presented system was well predicted by the theoretical model. A low cost solar cooking system for frying and cooking of injera bread based on parabolic dish was experimentally studied by Gallagher [20].

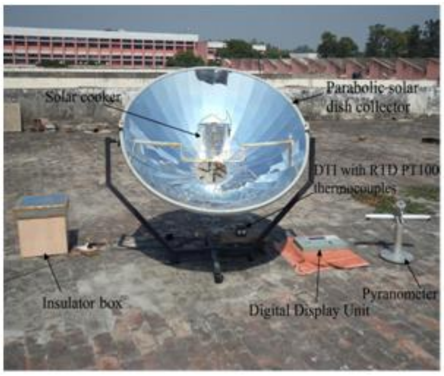

Figure 5. Parabolic dish and phase change material based solar cooker [22].

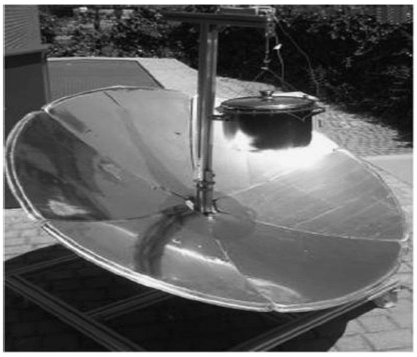

Figure 6. Solar cooker based on parabolic dish [23].

Presented solar cooking system was capable of delivering 640W of heating power which was sufficient to cook injera bread for 150 people per day. Badran et al. [21]used a satellite dish in his experimental work of solar cooking. Reflective aluminium foils were pasted on satellite dish to concentrate the solar radiations. Experimental results revealed by the authors showed that the boiling time of 7 kgs water was reduced by 20 minutes and increment in cooking power by 275% when cooking pot was kept inside a glass box. A solar cooker based on parabolic dish was experimentally studied by Chaudhary et al. [22].

as shown in figure 5.Parabolic dish having aperture area of 1.54 m2 with integration of 40 parabolic segments and having concentration ratio of 33 was investigated for cooking. Performance of solar cooking vessel filled with phase change material in the annular space for different configurations had been evaluated. Authors experimentally analysed the performance of ordinary cooking vessel, cooking vessel with black painted surface and black painted vessel with glazing. Experimental results showed that the storage of heat was found maximum for the solar cooking system based on thermal storage and parabolic trough collector having aperture area of vessel with glazing. Authors also calculated the pay back period and cost of the presented solar cooking system.1-D model of solar cooker based on phase change material and parabolic dish collector was developed by Lecuana et al. [23]. Pictorial view of presented solar cooker is shown in figure 6.Results obtained by the authors showed that lunch and dinner could be cooked for a single family in sunny days of winter and summer seasons. Heat retained by phase change material was utilized for the cooking of breakfast for the next morning.

2.4. Solar cooking system based on parabolic trough collector and fresnel lens based collector

Few researchers studied the performances of parabolic trough and fresnel lens solar collectors for cooking applications. The exergy efficiency of a parabolic trough type solar cooker as shown in figure 8 was investigated by Ozturk [24].A very low exergy efficieny of approximately 1% and temperature difference of 31.56 K for 4 hours was calculated for the parabolic trough type solar cooker. Mussard et al. [25] experimentally investigated the performance of solar cooker having aperture area of 1.54m2 as shown in figure 9. Thermal oil is employed to transfer heat form solar collector to storage unit. Frying of a piece of meat with olive oil was performed on the presented system. Experimental results showed that maximum temperature of meat was recorded as 800C and system restored the heat for several hours. As shown in figure 10, Valmiki et al. [26] presented a solar stove system for outdoor as well as indoor cooking based on fresnel lens. Rotation of lenses in zenith and azimuth angles was done through a tracking system to retain the focus. Mineral oil was used as heat transfer fluid for the transfer of heat from heating chamber to indoor cooking surface.

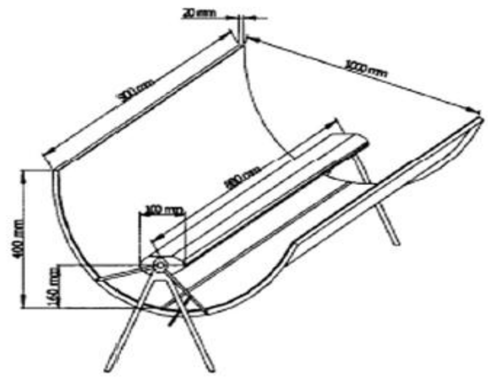

Figure 8. Solar cooker evaluated by Ozturk [24].

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Figure 9. Solar cooking system based on parabolic trough [25].

Authors stated that stovetop temperature for the case of outdoor cooking was recorded as 3000C and1500C for the case of indoor cooking. Energy efficiencies at low temperature and high temperature were calculated as 83% and 40% respectively. Presented solar cooking system could be applied in street food shops, household cooking for urban and sub urban areas. Farooqui [27] presented a solar cooker based on fresnel lens and evacuated tube as shown in figure 11. Collector area of 1.77 m2 is used and lenses were tracked with the help of a tracking mechanism. Fresnel lenses array focuses solar radiation on evacuated tube and thermal oil present in the evacuated tube was used for the transfer of heat from evacuated tube to cooking vessel. Author experimentally evaluated the performance of the system at different cooking loads and calculated the values of exergy and energy efficiencies. Presented solar cooking system achieved the maximum cooking temperature of 2500C and performance of the system was found best at 6 kgs of cooking load having the quality factor of 0.0506.Islam et al. [28] presented a solar cooking system based on fresnel lens for producing steam with the help of cylindrical vessel. A cost effective experimental setup was fabricated with lens available in the market at 50 to 200 USD and scrap metal pipes. Steam was produced for the cooking purposes at the temperature of 1460 C and 3.15 bar. Author determined the heating power of 51.2 W by implementing the international standard for solar cooker performance evaluation.

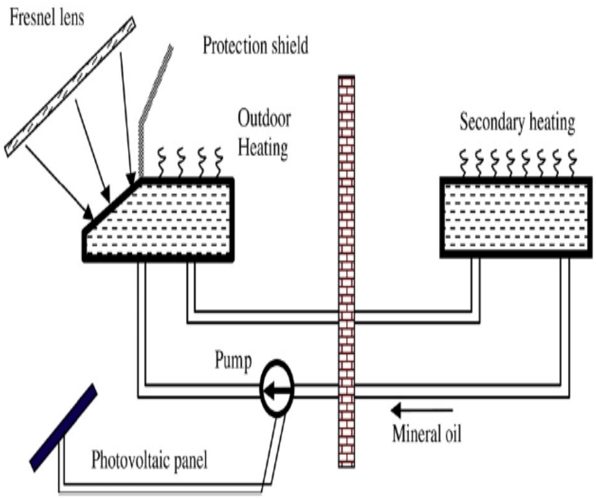

Figure 10. Fresnel lens based solar cooking system [26].

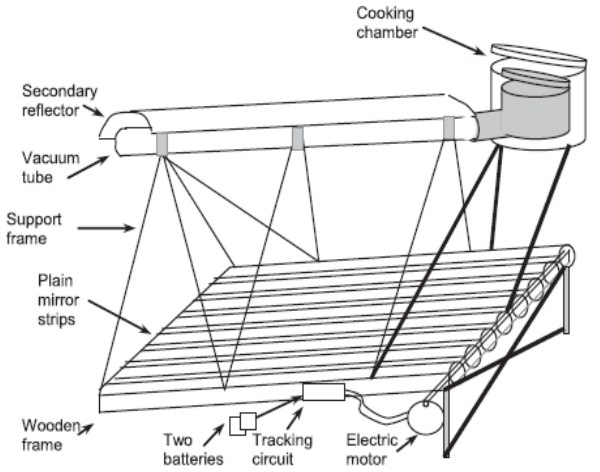

Figure 11. Solar cooker presented by Farooqui [27].

The value of exergy and energy efficiency of boiler used for producing steam was found to be 2.86 % and 30.18% respectively.

2.5 Solar cooking system based on scheffler collector..

Scheffler solar collectors are being already installed in many places in India for community cooking and single family cooking Indora and Kandpal [29].

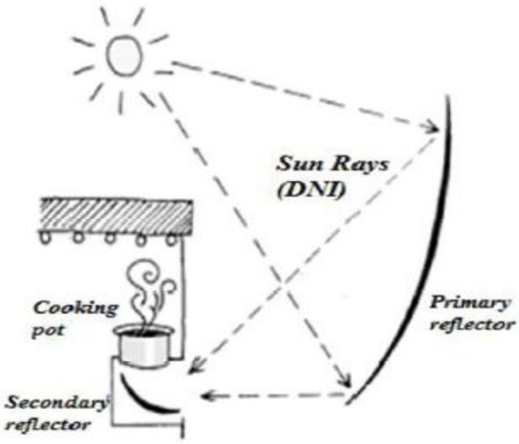

Figure 12. Direct way solar cooking with scheffler reflector [30].

Figure 13. Community cooking using scheffler reflector [29].

Scheffler reflector can be used for cooking in direct and indirect ways. In direct way, primary reflector concentrates the solar radiation on the secondary reflector which further reflects to the bottom of cooking vessel as shown in figure 12. In this way the solar radiation converts into heat and taken by the food in cooking vessel [30]. In indirect way scheffler reflector focuses on the receiver where water converts into pressurized steam and is used for cooking purposes. In this way number of scheffler reflectors can be used for community cooking needs as shown in figure 13. Indora and Kandpal [29] evaluated the performance of scheffler reflector having capacity to cook food for 90-100 persons per batch and installed at three different locations in India. Study by the authors revealed that scheffler reflector with aperture area of 16 m2 was able to cook 59% to 85% of meals regarding those locations. Furthermore, authors estimated the financial performance by considering various cost factors like net present value, discounted payback period and internal rate of return. Authors found the cost of scheffler reflector unattractive and more research was needed for the feasibility of commercialization of this type of reflectors for cooking purposes. Although, CO_2 emmission control and fuel saving attributes were found impressive.

III. CONCLUSIONS

Solar cooking has proved its sustainability for the future use as it requires nil running cost and is fully environment friendly. But, still it is not accepted by the significant share of population in urban as well as in rural areas. Concluded points are as follows:

1. All solar collectors presented have great potential to combat almost all types of cooking needs.
2. Evacuated tubes and FPC takes more time to achieve highest temperature than PDC, fresnel lens and scheffler reflectors.
3. If economic factors regarding initial cost are considered than the use of scheffler reflector is not appreciated, otherwise it can be used for community cooking purposes.
4. Use of evacuated tube and flat plate collector can be used for basic cooking requirements like boiling. Benefit for the user is its very simple construction and easy operation. Whereas, high temperature cooking needs can be satisfied by parabolic dish ,fresnel lens and scheffler reflectors but accompanied by difficult construction and complex operation due to tracking mechanism.

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