Review article

A review of parabolic solar cookers with thermal energy storage

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A B S T R A C T

Biomass and fossil fuels are mostly used in rural areas of developing countries for cooking. These energy resources have negative impacts on the environment and human health mainly due to deforestation and greenhouse gas emissions. A cleaner and environmentally-friendly form of cooking is solar cooking using the sun's energy. Parabolic solar cookers perform better than other solar cookers such as box solar cookers since higher temperatures are achieved in a shorter duration. These higher temperatures allow most types of cooking processes such as; boiling, frying, roasting, and baking to be possible. The major problem with most conventional solar cookers is that cooking is not possible during off-sunshine periods. Integrating solar cookers with thermal energy storage (TES) makes cooking during off-sunshine periods possible. This paper presents a comprehensive review of parabolic solar cookers with TES which is a sustainable cooking solution for developing countries. Previous work on both parabolic trough and parabolic dish solar cookers with TES is presented. Solar cookers with storage are classified according to the two main types of TES technologies which are; sensible heat thermal energy storage (SHTES) and latent heat thermal energy storage (LHTES). The main conclusions of the review are that; parabolic dish solar cookers with TES are more common than parabolic trough cookers, more studies have been done using latent heat storage as compared to sensible heat storage, limited modelling work has been presented, most of the parabolic cookers used aluminum sheets as the reflecting material, large scale experimental studies are limited and fewer studies tackled the techno-economic and socio-economic aspects. The review also highlights research gaps on parabolic solar cookers with TES in terms of the modelling, combined TES (sensible and latent heat), different reflector materials, large-scale experimental setups, and techno-economic and socio-economic analyses. Other important aspects to consider for parabolic solar cookers with TES include; the choice of sensible or latent heat storage materials, environmental impact, types of food to be cooked, and social acceptance.

1. Introduction

Cooking is a vital method used by human beings to prepare food for survival, and it is responsible for a large amount of energy consumption in many countries. In developed countries such as the United States of America, cooking accounts for about 37 %–53 % of total energy consumption [1]. In developing countries located in Africa, Asia, and South America, a major part of the residential energy consumption is utilized for cooking. A study conducted by Karekezi [2] showed that about 80 % of Sub-Saharan African countries still utilize firewood, fossil fuels, biomass and electricity for cooking food, which results in huge amounts of greenhouse gas emissions and deforestation. This indicates that there is a need for alternative cooking methods that are environmentally friendly and use clean energy resources.

Although only about 14 % of the world's available renewable energy potentials is currently being utilized, the percentage utilization of renewables is projected to increase soon due to concerted global efforts to mitigate against global warming due to greenhouse gases emission [3]. Solar energy has gained prominence over recent years as an alternative energy source for developing countries. It is estimated that the solar radiation flux in the sunniest region of the earth is about 1 kW/m^2, the total global solar radiation per day is about 7 kWh/m^2, and the total amount of solar energy received on earth is approximately 1.8×10^{11} MW [4]. This is about 10 000 times larger than the present energy consumption rate from all other commercial energy sources. This indicates that solar energy can be exploited for a wide range of domestic energy requirements, especially cooking.

Solar collectors can be regarded as devices that help to concentrate/ collect solar radiation by capturing and converting radiant energy from

the sun into thermal or electrical energy. Solar collectors can be categorized into two groups namely; non-concentrated collectors (flat plate collector, evacuated tube collector, etc.) and concentrated collectors (parabolic dish, parabolic trough, etc.). Some of these collectors can be modified easily for solar cooking. A solar cooker is a solar collecting device that uses the energy from the sun to cook food. Although solar cookers are not a recent novel idea, they have undergone several modifications over the years [5]. However, there is still room for improvements in order to achieve higher efficiency, lower cost, greater portability, and further adaptability to different environmental conditions. The three main types of solar cookers are: solar box cookers, concentrated solar cookers, and indirect solar cookers, and these will be discussed in the next section.

1.1. Types of solar cookers

1.1.1. Solar box cookers

There are various types of solar box cookers or oven solar cookers that have been fabricated from previous studies [6, 7, 8]. A common solar box cooker consists of an insulated box with a transparent glass or plastic cover that allows solar radiation to pass through. Solar radiation is absorbed by the inner part of the solar box cooker while the transparent cover prevents solar radiant energy from leaving the interior of the box through the greenhouse effect [9]. In some solar box cookers, the interior of the box is painted black to maximize the absorption of solar radiant energy in order to increase the temperature of the cooking vessel placed inside. The insulated box is connected to reflectors which direct more solar radiation to the cooking vessel, thus increasing its cooking efficiency. Figure 1 shows different types of solar box cookers namely; (a) one without reflector, (b) one with a single reflector, (c) one with double reflectors, (d) one with three reflectors, (e) one with four reflectors, and (f) one with eight reflectors. One of the main reasons why solar box cookers are preferred over other types of solar cookers is that they have different types of uncomplicated designs. The appeal of solar box cookers over other types of solar cookers include the fact that they are easy to construct, they are user-friendly and safe to use, they require limited attention during operation, they utilize both the direct and diffusion components of solar radiation and no solar tracking is required [11]. However, the main disadvantages of solar box cookers are that they require longer cooking periods and cannot be used for roasting or frying food. Another reason is that they cannot cook during off-sunshine hours, and some solar box cookers are affected by prevailing weather conditions such as strong winds which result in slower cooking due to heat losses.

Cooking with solar box cookers has been the most investigated, and well-documented solar cooking method [12, 13, 14, 15]. Solar box cooking experiments have been carried out at intermediate to high temperatures using different test loads and fluids to improve their thermal performance [16, 17, 18, 19, 20, 21].

1.1.2. Concentrating solar cookers

A category of solar cookers that are less popular but more efficient in terms of reaching higher cooking temperatures are the concentrating solar cookers [22]. A standard concentrating solar cooker is constructed with a framework stand to support the cooking vessel at the focal region and also the parabolic reflector. A tracking mechanism is used to position the concentrating solar cooker to face the sun. A solar optical mechanism is also used to direct and concentrate the incident solar radiation to a focal region which enables the attainment of higher temperatures at the focal region. For direct concentrating solar cookers, the cooking vessel is placed at the focal region of the parabolic reflector during cooking periods. One of the most popular direct concentrating solar cookers that is easy to construct and operate is the parabolic dish cooker. A parabolic dish cooker can achieve high temperatures of between 350 °C and 400 °C as compared to other types of concentrating solar cookers [23]. The main disadvantages of the parabolic dish cooker are that it requires constant tracking of the sun, constant attention to prevent the burning of foods and to avoid fire risks during operation. Figure 2 shows a schematic diagram of parabolic dish solar cooker, and a photograph of a square parabolic dish cooker.

Solar concentrating cookers have also been used for intermediate to high-temperature applications using different test fluids [25, 26, 27, 28, 29]. However, these studies do not consider the incorporation of thermal energy storage into these cookers for off-shine cooking.

1.1.3. Indirect solar cookers

Indirect solar cookers use heat transfer fluids such as molten salts or thermal oils to absorb heat from the heat source (at the focal region of the reflector) and transfer the heat to the cooking vessel [30]. The indirect solar cooker is designed in such a way that the cooking vessel is placed separately from the collector. Solar collectors such as a parabolic trough collector/flat plate collector can be placed on a roof or outside a building, and the cooking vessel can be placed indoors. The challenge facing this type of cooker is the high rate of heat loss during the circulation of the heat transfer fluid. However, the main advantage of an indirect concentrating solar cooker is that it can be easily incorporated with a thermal energy storage system for off-sunshine cooking. Figure 3 shows a diagram of an indirect concentrating solar cooker using a flat plate
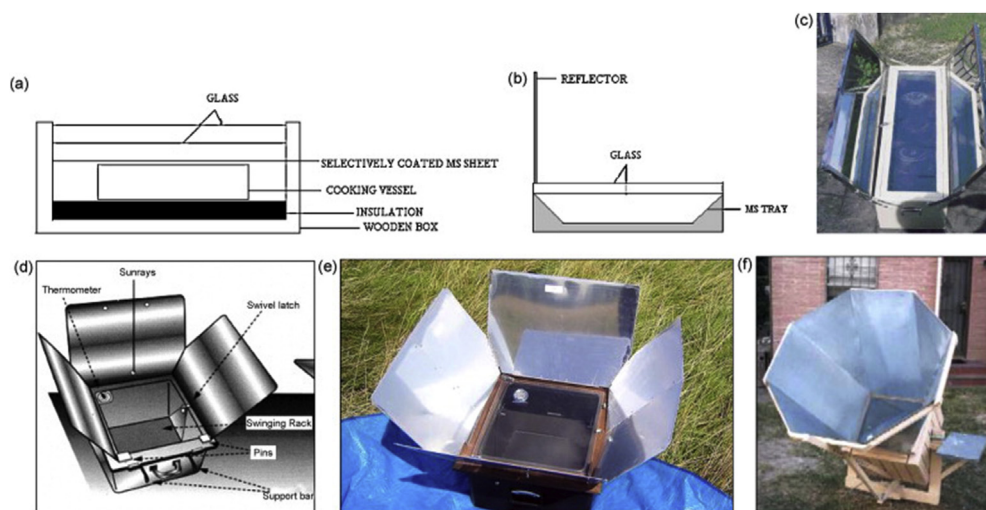

Figure 1. Different types of solar box cookers: (a) without reflector, (b) with single reflectors, (c) with double reflectors, (d) with three reflectors, (e) with four reflectors and (f) with eight reflectors. The figure was reproduced from Ref. [10], with the permission of Elsevier Publishing.
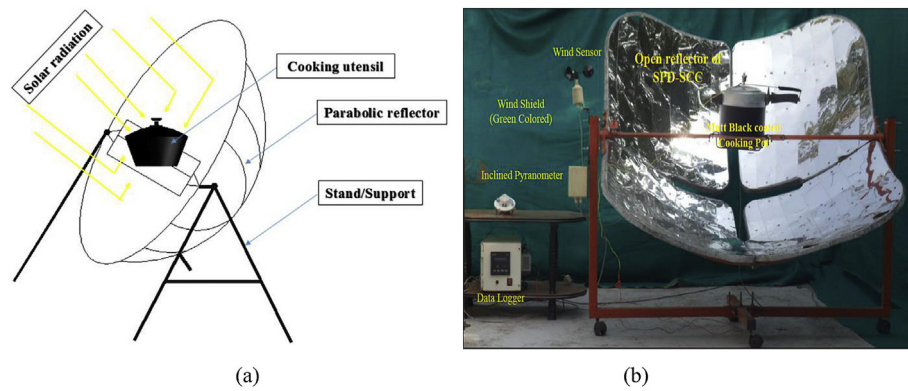
Figure 2. (a) A schematic diagram of a parabolic dish concentrating solar cooker, (b) a square parabolic dish solar concentrating cooker (SPD-SCC) with a pot. (a) was reproduced from Ref. [24], with the permission of Elsevier Publishing. (b) was reproduced from Ref. [25], with the permission of Elsevier Publishing.

collector. The main disadvantage is that indirect solar cookers are expensive to fabricate and maintain. Indirect solar cookers have been used for intermediate to high temperatures for various cooking applications such as cooking vegetables and frying meat [31, 32, 33, 34], using different test loads; and fluids such as sunflower oil and olive oil. Thermal energy storage integrated with indirect solar cookers makes them more versatile for operation during off-shine periods [35].

1.2. Thermal energy storage for solar cookers

Simple solar cookers can be used only when the sun is available as they cannot operate at night, during cloudy days, or when it is raining. However, thermal energy storage (TES) offers a solution for this mismatch between solar energy supply and demand. Combining solar cookers with a TES system enables cooking during periods when the sun is not available. TES can be classified into three main categories which are sensible heat thermal energy storage (SHTES), latent heat energy storage (LHTES), and thermo-chemical thermal energy storage (TCTES). One of the main advantages of a TCTES is that it has high storage densities and heat losses are minimal, but the disadvantage is that it is reported to be expensive [36]. As a result of the expensive nature of TCTES, solar cookers with SHTES and LHTES have only been investigated because of their lower cost and simpler designs. In recent years, a lot of research have reported about SHTES and LHTES systems for solar cookers since these two types of TES systems are economically viable [1, 37, 38, 39, 40, 41, 42].

In a SHTES system, the TES material can store heat and release it as a consequence of the heat capacity of the heat storage material used as its temperature changes. This storage medium may either be in the solid or in the liquid phase. The main reasons why SHTES systems are favored or utilized often is because of their desirable thermal properties, cheapness, and availability. For a given SHTES material, the capacity for storing sensible heat will depend on its specific heat capacity and density [43]. The advantages of SHTES materials are that they are inexpensive and can be sourced locally. The major disadvantage of SHTES is that it requires a large amount of storage space because of the low thermal energy storage density of sensible heat storage materials. Unlike a SHTES material, a LHTES material stores both sensible heat and latent heat as it undergoes phase transition within a given temperature range. The solid-liquid transition is mostly utilized as the liquid-gas transition involves some complexities. The latent heat of fusion which is absorbed by a phase change material (PCM) as it transforms from the solid to the liquid phase and vice versa, presents a high TES density over a narrow temperature range during the nearly-isothermal transition. One of the main advantages of an LHTES system is that it uses a smaller volume of material to store thermal energy compared to SHTES due to its higher thermal energy storage density and large enthalpy. LHTES is however more expensive when compared to SHTES.

1.3. Previous recent reviews on solar cookers

In recent years, reviews on solar cookers have focused on different parameters such as tracking techniques, heat transfer enhancement technologies, thermal storage materials, cost-effective methods, location/country and size of the solar collectors to enhance the performance of solar cookers. Table 1 shows a summary of recent reviews on solar cookers.

It is evident that critical reviews on solar cookers with storage are rather limited, particularly on parabolic concentrating cookers with
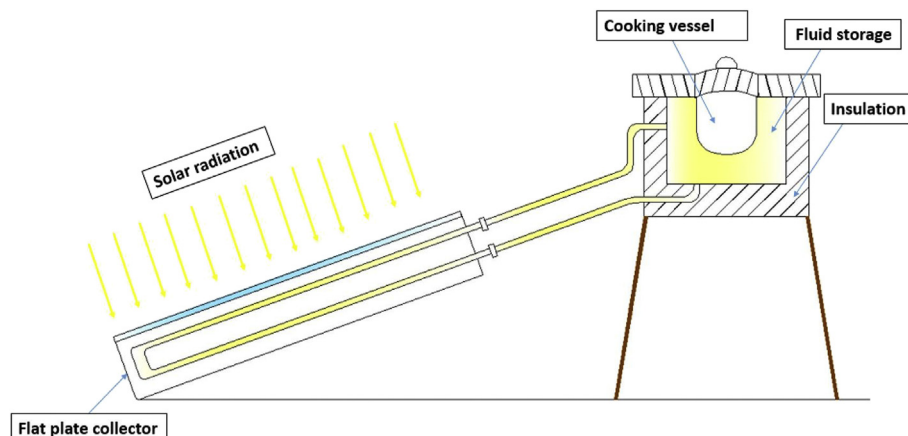

Figure 3. A schematic diagram of an indirect solar cooker. The figure was reproduced from Ref. [24], with the permission of Elsevier Publishing.

Table 1. A table summary of recent reviews on solar cookers.

Author and Year	Title	Focus of study	Results
Lahkar and Samdarshi [44] 2010	A review of the thermal performance parameters of box type solar cookers and identification of their correlations	The aim of the review was to compare the correlations of different performance parameters of solar box cookers.	It was found that none of the evaluated parameters were able to predict heat retention.
Saxena et al. [45] 2011	A thermodynamic review on solar box type cookers	Diverse developments of solar box cookers were reviewed.	Results indicated that solar box cookers were safer to use, save money, and food cooked with solar box cookers was more nutritious.
Panwar et al. [46] 2012	State of the art of solar cooking: An overview	A standard of testing solar cookers and thermal properties (such as energy and exergy) analyses were performed.	It was found out that utilizing solar cookers reduced carbon dioxide emissions.
Farooqui [47] 2014	A review of vacuum tube based solar cookers with the experimental determination of energy and exergy efficiencies of a single vacuum tube based prototype	A review of the progress made with the development of vacuum tube-based solar cookers was presented. Also, energy and exergy analyses of a vacuum tube-based solar cooker were conducted.	The energy efficiency and exergy efficiency of the vacuum tube solar cooker were found to be 20–30%, and 4–6%, respectively.
Yettou et al. [48] 2014	Solar cooker realizations in actual use: An overview	The review focused on the recent advances in the development of solar cooker technologies.	It found that the solar cooking technology has a potential to reduce the rate of energy consumption in the near future.
Harmim et al. [49] 2014	Solar cooking development in Algerian Sahara: Towards socially suitable solar cookers.	The review focused on solar cooking in the Algerian Sahara environment.	It was found that the building an integrated solar cooker was easy to construct, and it was efficient even during the winter season.
Iessa et al. [50] 2017	Unverified assumptions, overlooking of local needs and pro-solution biases in the solar cooking literature	A critical review was studied for solar cooking in Sub-Saharan Africa in order to reduce deforestation, improve health and empower women.	The review showed that solar cooking and its impact are not systematically tested, and may not be strong as claimed.
Herez et al. [24] 2018	Review on solar cooker systems: Economic and environmental study for different Lebanese scenarios	The study focused on previous work done on the economic and environmental impact of solar cookers in Lebanon using different locations and economic backgrounds.	There was a reduction in the emission of carbon dioxide from homes, hotels and restaurants. On the economic aspect, it was found that the dependency on the solar cooker decreased the payback.
Hage et al. [51] 2018	An investigation on solar drying: A review with economic and environmental assessment.	The aim of the study was to determine the role of main components of solar dryers, economic and environmental assessments and parameters affecting them.	When a certain percentage of time was utilized monthly, about $ 780 was saved monthly.
Indora and Kandpal [52] 2018	Institutional cooking with solar energy: A review.	The aim of the study was to evaluate institutional solar cooking using parabolic dishes, scheffler dishes and the ARUN solar cooker.	The awareness of institutional solar cooking must be spread to potential users.
Elsheikh et al. [53] 2019	Modeling of solar energy systems using artificial neural networks: A comprehensive review.	Artificial neural networks models were deployed to predict thermal parameters of solar systems such as solar cookers, solar dryers, etc.	Deploying artificial neural networks may save time and reduce costs.
Omara et al. [38] 2020	Improving solar cookers performance using phase change materials: A comprehensive review.	The aim of this review was to study the feasibility of improving solar cookers when considering geometrical influence and different phase change materials.	Future work must include economic and environmental aspects using solid to liquid PCMs.
Arunachala and Kundapur [54] 2020	Cost-effective solar cookers: A global review.	An investigation of cost-effective solar box cookers and other solar cookers was conducted on a global scale.	Thorough research must be conducted to improve the efficiency of low cost solar box cookers.
Devan et al. [55] 2020	A comprehensive review on solar cookers with a sun tracking system.	An evaluation on solar cooking technology was done.	Installing a tracking system on parabolic dishes enhanced the performance of the solar cooker.
Khatri et al. [5] 2021	Advances in the development of solar cookers for sustainable development: A comprehensive review.	The research focused on the effect of how the main components and heat transfer characteristics affect the overall efficiency.	Social and economic aspects can be improved with better policy implementations.
Gokul et al. [56] 2021	A comprehensive review on solar cooker tracking techniques for performance enhancement	This review discussed tracking systems of solar cookers.	Thermal performance of the solar cookers improved when combined with a tracking system.

thermal energy storage which can perform most cooking processes such as boiling, frying and baking. Additionally, limited studies have reviewed the parameters that affect the performance of parabolic concentrating cookers with thermal energy storage.

1.4. Objective and justification

Solar cookers cannot operate during off-shine periods and besides, some cook relatively slower than conventional cookers. However, integrating solar cookers with TES systems such as SHTES and LHTES can overcome such drawbacks. This review aims to present and critically evaluate previous studies that analyzed the thermal performances of concentrating solar cookers that were coupled with different SHTES and LHTES systems. The review presents the results of different thermal

performance parameters for solar concentrating cookers with TES systems. Solar concentrating cookers with heat storage are more attractive than the other types of cookers since they can perform most cooking processes such as baking, frying, roasting, and boiling. These cookers are also fast cookers that are reasonably priced. From this review, future work on solar concentrating cookers with TES will be suggested based on the shortcomings of previous studies.

2. Parabolic solar concentrating cookers with sensible heat thermal energy storage (SHTES)

2.1. Parabolic trough cookers with SHTES

A solar thermal-powered bakery oven was experimentally evaluated by Mishra et al. [57]. The system was proposed as a model of a combined

solar and electrical powered bakery oven integrated with a solar parabolic trough collector. Duratherm 600 was used both as the heat transfer fluid and the thermal energy storage medium. A CFD analysis was done to analyze the heat transfer of the copper coils and airflow distribution in the oven. Results indicated that the maximum temperature in the storage tank was about 300 °C, while a temperature of about 168 °C was achieved inside the oven cavity. El Moussaoui et al. [58] experimentally evaluated a parabolic trough solar thermal cooker (PTSC) shown in Figure 4. A vacuum tube coupled with a parabolic trough reflector was used as the solar collector. A thermal oil was used both as the heat transfer fluid and the SHTES material. The vacuum tube and parabolic trough reflector were fitted to a solar thermal cooker which contained an insulated cooking box, a cooking vessel, and a storage container. Heat transfer models were developed to evaluate the operation period of the experimental setup, and cooking experiments were conducted. Results showed that potato chips took about 1 h to be cooked while the maximum temperature achieved inside the solar thermal cooker was about 198 °C.

An experiment to test the performance of a parabolic trough solar cooker for indoor cooking was reported by Asmelash et al. [59]. The experimental setup consisted of a parabolic trough with reflecting mirrors, a copper receiver pipe used to absorb sun rays, a cooking pot combined with fins, and a storage tank that stored thermal energy. Soya bean oil was used both as the heat transfer fluid and the heat storage medium. Experimental tests on the effects of the load and varying the diameter of the cooker were performed and analyzed. The results indicated that the maximum temperatures achieved under no-load conditions were about 191 °C for the absorber and about 126 °C for the cooking vessel. However, the maximum cooking efficiency achieved was about 6 %. Dianda et al. [60] reported an experimental investigation of a solar parabolic trough cooker. An indirect parabolic trough solar cooker named the "blazing tube" was used for cooking experiments. The blazing tube was made up of a transparent Pyrex glass vacuum tube, an aluminum parabolic trough reflector, an absorber tube that contained vegetable oil that was utilized as a heat transfer fluid and a heat storage medium, a cooking box that contained a cooking vessel and a storage container. Different cooking tests were performed, such as water heating, frying, and cooking rice, to determine the maximum temperature, the effect of the load, and the duration of the cooking time. The thermal efficiency and output power of the cooker were the parameters evaluated. The results indicated that when the solar radiation was about 930 W/m², the maximum useful power was found to be 1000 W. The maximum efficiency achieved by the experimental setup during the day was about 55 %. Mohan and Vasanthakumar [61] analyzed the effectiveness of solar-assisted steam cooking using a parabolic trough collector. The experiment aimed to develop and analyze the performance of a solar-assisted steam cooking system using aluminum sheets and galvanized iron sheets as the reflector materials. The setup consisted of an insulated tank, a parabolic trough reflector, an absorber tube that contained water (the heat transfer fluid), and a steam cooker. Cooking experiments were conducted using variety of food items such as potatoes, carrots, onions, and beans. This was done to compare the nutritional quality of conventional and steam cooking. The second experiment was done to determine the performance of the steam cooker using different reflector sheet materials. The results showed that the maximum outlet temperature and the maximum cooking temperature achieved were 140.2 °C and 150 °C, respectively in the steam cooker.

Hassen et al. [62] investigated the performance of a solar-powered Injera baking oven for indoors cooking. A laboratory model contained an electrical heater that was used as the heat source, and it was coupled with a heat storage tank and a baking pan that was used to make Injera. A pump was used to circulate the heat transfer fluid (Shell Thermia B) during charging and discharging cycles. Baking and preheating experiments were done, and it took about 1 h to heat the oil, and 40 min to reach the required baking temperature. Results showed that 5 Injeras were baked in time intervals of 2 min for 10 min at temperatures of 220 °C. Goytom [63] modelled a solar thermal
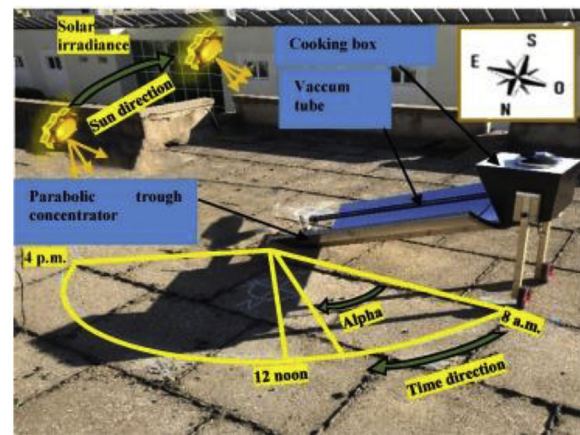
energy-powered Injera baking oven using a finite difference method. The model was aimed to predict the temperature distribution of an Injera baking pan during initial heating up and baking cycles using an unsteady state heat balance model. A parabolic trough was used to collect and reflect the solar radiation onto the receiver tube. An insulated storage tank containing the heat transfer fluid was coupled with a cooking pan. Thermia oil B was used as both heat transfer and storage medium, and a pump was used to circulate the heat transfer fluid in an experimental setup. Simulations were carried out in MATLAB to determine the efficiency of the Injera pan by varying the thickness of the pan. Results showed that there were reasonable heat-up and baking times when the pan thickness was set as 5 mm, and the oil temperature heated up to 300 °C.

A parabolic trough collector integrated with a cooking system was presented by Yilmaz et al. [64]. The system was composed of a parabolic trough solar collector array, a cooking system, a plate-type heat exchanger, an auxiliary heater, water heating tanks, and Fuchs Renotherm 320 was used as the heat transfer fluid. An analysis of the heat required to cook wheat using different system design arrangements was carried out. Results showed that the maximum cooking temperature attained was about 100 °C, and the energy required to cook a specified amount of wheat was determined by the energy value of the nominal solar radiation. Arunachala et al. [65] performed an analysis of a solar cooker for night cooking. The experimental setup was a self-circulating system composed of a compound parabolic trough collector, vacuum tubes, and an oil storage tank that was coupled with a cooker. Engine oil was used as the heat transfer fluid in the storage tank. Cooking experiments were done to determine the energy required for cooking, and rice was used as the cooking load. Results showed that the highest temperature reached by oil was about 110 °C, and it took less than an hour to cook 500 g of rice in the afternoon.

An investigation of a solar cooker with a parabolic trough concentrator was done by Noman et al. [66]. The parabolic trough collector was positioned at a fixed latitude to reflect maximum solar radiation to the absorber tube. The absorber tube was fabricated with black painted copper which was used as a receiver for the cooker. Water was used as both the heat transfer fluid as well as the heat storage material. The results showed that the maximum cooking temperature achieved in 4 h was about 53 °C at an ambient temperature of 31 °C and with the solar radiation being about 927 W/m². Akayleh et al. [29] designed and developed a solar-based cooker with a mechanical sun tracking system. The experimental setup was composed of an automated sun tracking system, hot dish for baking bread, a control unit, a two pulleys connected to the gearbox and a parabolic trough. The objective of the experiment was to determine the efficiency of the solar cooker under various conditions.

Baking experiments were carried out, the highest temperature achieved was found to be approximately 85 °C. Widjaja et al. [67] designed and simulated a concentrated solar thermal system with an integrated concrete storage for continuous heat supply. In this study a concentrated solar system for pasteurization was combined with concrete storage for process heating. The aim of the experiment was to compare a parabolic trough collector and compound parabolic concentrator with a concrete storage under different boundary conditions. Process heating experiments were carried out in four different countries, and the results showed that using a compound parabolic concentrator below 180 °C showed better performance as compared to the parabolic trough collector. Bade and Bandyopadhyay [68] proposed an energy model to determine the characteristics of thermal oil for cooking applications. An energy model based on a cooking system was developed, and therminol 55 was selected as the thermal oil. The proposed energy model was dynamic in nature and used the Euler method predict the temperature. The results showed that saving in fuel, and a possible payback period of 1.63 years. Abd-Elhady et al. [69] studied the thermal performance of solar cookers by using metallic wires and nanographene. The objective of the study was to improve the heat capabilities of the parabolic trough combined with the storage tank. The solar cooker operated on a thermosiphon mode using Mobil-Therm 605 as heat transfer fluid and storage medium. The results showed that adding nanographene particles contents up to 0.34×10^{-3} wt% to the heat transfer medium of solar cookers increased the heat transfer rate.

2.2. Parabolic dish cookers with SHTES

Agrawal and Yadav [70] experimentally investigated a parabolic solar cooker with a storage cooking pot. The experimental setup was composed of a solar cooker that was made up of a hollow-concentric cylindrical pot with sensible heat storage materials, a parabolic dish collector, and an insulator box. Experiments were conducted using different sensible heat storage materials such as sand, stone pebbles, iron grits, and iron balls to determine the thermal performance of the sensible materials. After the solar cooker was charged, it was transferred to the insulated box and loaded with food. Results showed that the food was cooked properly using sand, stone pebbles, and iron grits, and it was partially cooked when iron balls were utilized. Prasanna and Umanand [71] designed and optimized an energy transport system for a solar cooking application. The indirect system was composed of a paraboloid concentrating collector, and a heat storage tank that contained servo-thermal oil which was utilized as a storage medium and heat transfer fluid. Two pumps were used to circulate the heat transfer fluid during charging and discharging, and a heat exchanger was placed in the kitchen for cooking purposes. Simulations and experiments were performed using different pipe diameters to evaluate the overall energy transfer and the thermal performance of the proposed system. Results showed that cooking could be carried out at any time of the day, and the energy collected from the paraboloid concentrating collector was optimized by dynamically varying the flow rate.

Mawire et al. [72] simulated the energy and exergy of the charging of an oil–pebble bed thermal energy storage system for a solar cooker. The proposed system was composed of a parabolic dish concentrator coupled with an absorber coil, and a storage tank that contained oil that was used as a storage medium and heat transfer fluid. A load coil was coupled with a cooking vessel used for cooking applications. Energy balance equations were used to model the indirect solar cooking system. Energy and exergy analyses were carried out to predict the performance of the solar cooking system. Results indicated that a greater degree of thermal stratification and energy stored was achieved by constant temperature charging compared to constant flow-rate charging. Discharging simulations of a thermal energy storage (TES) system for an indirect solar cooker were done by Mawire et al. [34]. The conceptual setup was presented in [72]. The models were validated by experimental results, and reasonably good

agreement was obtained between simulation and experiment. Two methods were utilized for discharging the TES system. The first method discharged at a constant flow-rate, while the second method discharged the TES system by varying the flow-rate to acquire the desired constant discharging temperature. The results showed that discharging the TES system at a constant flow-rate resulted in a higher rate of heat utilization.

An experiment on a portable solar cooker and a water heater was conducted by Badran et al. [73]. The experiment setup consisted of a parabolic dish collector, an absorber, a receiver, and a water storage tank as shown in Figure 5. The experimental setup had two modes of operation; which were the water heating mode and the cooking mode. During the water heating mode, the absorber was placed on the focal point of the dish to absorb heat and transport it to the storage tank. During the cooking mode, the collector was replaced by a cooking pot, and the pot lid was covered with polyurethane foam to reduce losses. Cooking and water heating experiments were done to determine the maximum efficiency and cooking power. Results showed that the boiling point of water was achieved under 1 h, and the maximum efficiency achieved was 77 %.

An evaluation of the thermal performance of the heat exchanger unit for a parabolic solar cooker for off-place cooking was done by Murty et al. [74]. The inclined cylindrical heat exchanger system contained an SK14 parabolic solar cooker, a lower cylindrical absorber, and an upper cylindrical vessel that contained a cooking pot with a lid. Soya oil was used as the heat transfer fluid and storage medium. Cooking experiments were conducted using different types and masses of food. Results indicated that the inclined convective heat exchanger could be utilized during non-shine periods, and the highest temperature recorded for food was around 85 °C. An evaluation of the thermal efficiency of a solar cooking unit was done using food and water. Results showed that high solar insolation decreased the cooking time to a minimum period. Craig and Dobson [75] compared a heat pipe, and a direct copper tube using a parabolic solar cooker for cooking applications. This experiment was aimed at investigating and optimizing heat collection from a parabolic dish collector to a solar cooker using a heat pipe and direct spiral copper tubes. Shell S2 oil was used as the heat transfer fluid. Parameters such as the cooking time, boiling characteristics and the overall heat utilization efficiencies were evaluated and analyzed. Results showed that both systems were satisfactory, but the spiral system was preferred over heat pipes because of the cost of production and the higher temperatures achieved when forced convection was employed. The spiral cooker took about 28 min to boil water, and the heat pipe took 30 min.

A parametric analysis of a parabolic solar cooking system with heat storage for indoor cooking was done by Mbodji and Hajji [76]. The experimental setup was an indirect solar cooking system that was composed of a concentrated solar parabolic dish, a receiver, a heat

Figure 5. A photograph of the experimental setup of a portable solar cooker and water heater. The figure was reproduced from Ref. [73], with the permission of Elsevier Publishing.

storage tank, a circulation pump, and a cooking section. Experiments and simulations were carried out to analyze the parameters of the solar cooking system. The results obtained showed that the daily maximum solar radiation increased the heat storage temperature by 4 °C. It was also found out that the maximum temperature on the surface of the plate was 81 °C which was sufficient for cooking. Senthil and Cheralathan [77] analyzed the thermal performance of solid and liquid energy storage materials in a parabolic dish solar cooker. The experiment was composed of a parabolic dish solar cooker, and the objective of the experiment was to test different sensible heat storage media such as pebbles, sand, and iron grits, steel balls, sunflower oil, olive oil, and coconut oil that were filled inside a storage tank. Water heating experiments were done to determine the thermal performance of each sensible heat storage medium. Results obtained indicated that sunflower oil was the best sensible heat storage material that showed better performance compared to other sensible heat storage materials, and the temperatures it achieved were sufficient for cooking during non-shine periods.

Nyahoro et al. [78] simulated the performance of thermal storage in a solar cooker. The proposed simulated system was an indirect solar cooker which consisted of a parabolic concentrator and a storage block that was coupled with a cooking pot. Mirrored reflectors were used to reflect sun rays to the bottom of a storage block which used granite and cast iron as the storage materials. A finite difference method was used to simulate the thermal performance of the thermal storage unit for solar cooking, and cooking during non-shine periods. Results indicated that cast iron obtained the highest temperature, and it also had shorter cooking periods and had fewer heat losses compared to granite. Lokeswaran and Eswaramoorthy [79] studied a solar parabolic dish cooker with porous media. The cooking utensil that contained metal copper chips was placed on the focal point. This experiment aimed to investigate the heat transfer enhancement of solar parabolic dish cookers using metal copper chips. Stagnation and cooking experiments were done with and without the metal copper chips. Results showed that the maximum temperature achieved was about 118 °C in 15 min with 85 g of eggs fried on the receiver with porous medium, whereas the temperature for the plain receiver was only 98 °C. Kedida et al. [80] analyzed the performance of a pebble bed thermal storage integrated with a concentrating parabolic solar collector for solar cooking. The experimental setup used air as the heat transfer fluid. The heat was transported from the receiver that was mounted on the parabolic dish to the thermal storage unit using the heat transfer fluid. A thermal storage unit was coupled with a cooking vessel. During the charging cycle, the cooking vessel was sealed with a cover plate to reduce heat losses, and during discharging a pot was placed on the cooking vessel. The experiment aimed to investigate the efficiency of a solar cooker using a 1D finite-difference computational model. Results obtained showed that during off-shine cooking periods, 5 L of water took

50 min to reach temperatures between 90 °C and 99 °C. The design and experimental investigation of a solar cooker with thermal energy storage was presented by Wollele and Hassen [81]. The experimental setup was composed of two joined parabolic dish collectors, and a solar cooker storage pot that was placed in between the parabolic dish collectors. Rock and engine oil were used as storage materials for the solar cooker storage pot. Charging and discharging experiments were conducted and water was used as the cooking load. The results showed that during discharging, the maximum temperature reached by water was 81.85 °C under 40 min.

An energy and exergy thermal analysis of a solar bakery unit was done by Ayub et al. [82]. The experimental system was composed of a Scheffler reflector, secondary reflector, a receiver, a PV module, and a baking chamber. Rocks were used as sensible heat material and they were placed in close contact with the receiver using air as the heat transfer fluid. Baking experiments were conducted using different food samples. Results showed that the baking temperature achieved was 180 °C, and it was also found out that the energy efficiency in the receiver increased with the baking time. The development and experimental analysis of a thermal oil-based roasting system were done by Raza et al. [83]. The continuous solar roaster was composed of a Scheffler concentrator, heat receiver, storage tank, and a roasting unit. was stored in the storage unit, and it was used to transfer heat from the heat receiver to the roasting unit. Roasting experiments were carried to investigate parameters such as feeding capacity, conveyor speed, and thermal oil flow rate for achieving a light, medium, and dark quality roasting of groundnuts. The results showed that the recommended time to roast light, medium and dark groundnuts was 14, 20, 29 min, respectively, at an average temperature of 180 °C.

Figure 6 shows a photograph with cooked food and a schematic diagram of a storage cooking pot that was made of stainless steel presented by Mawire et al. [84]. The storage cooking pot had an internal cavity in which the storage material was placed. Experiments were performed to compare two solar cooking storage pots combined with wonderbag slow cookers for off-sunshine cooking. The experiment consisted of two solar storage cooking pots, parabolic dish collectors, and wonderbags. Two similar storage cooking pots were experimentally evaluated and compared using parabolic dish solar cookers for solar cooking and wonderbag cookers for off-sunshine cooking. One storage pot had sunflower oil as the sensible heat storage material, and the other had erythritol as the phase change material (PCM). The results obtained showed that the sunflower oil cooking pot performed better during solar cooking periods taking 1.8–5.6 h with a maximum temperature range of 124–145 °C as compared to the erythritol PCM pot which took 3.8–6.6 h to cook with a maximum temperature range of 118–140 °C. During off-shine periods the erythritol PCM pot outperformed the sunflower oil
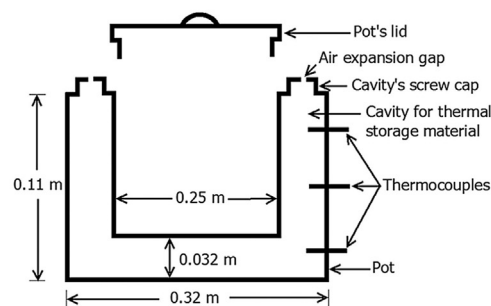
Figure 6. (a) A photograph of a solar cooker pot with cooked chicken and chips (b) A labelled diagram of a solar cooking storage pot. The figure was reproduced from Ref. [84], with the permission of Elsevier Publishing.

pot, as it showed lower temperature drops of 0.1–9.7 °C as compared to the sunflower oil pot that showed temperature drops between 4.8-14.3 °C because of its latent heat of storage.

A novel technique based on artificial intelligence for a solar bread cooker was presented by Nazari et al. [85]. A parabolic dish concentrator was used to reflect solar radiation to the solar cooker. The solar cooker was composed of a stand and cooking plate with an insulated lid. Experimental and numerical studies were carried out to analyze and evaluate the thermal performance of the experimental setup during baking periods. The results indicated that a dough ball weighing 200g attained a temperature of 180 °C in period of 20–25 min.

Table 2 shows a summary of different types of parabolic concentrators, and their applications related to cooking using different sensible heat storage materials.

3. Solar concentrating cookers with latent heat thermal energy storage (LHTES)

3.1. Parabolic trough cookers with LHTES

An experimental investigation of a solar cooker during sunshine and off-sunshine hours using a thermal energy storage unit based on a parabolic trough collector was done by Saini et al. [86]. The experimental setup was composed of a parabolic trough that reflected solar radiation to an absorber tube. The collected heat was transferred to the cooker using a thermosiphon cycle. Water and engine oil were used as heat transfer fluids separately, and acetanilide was incorporated with the cooker and used as the storage medium. The results showed that the maximum temperature of the food was 75.9 °C, and it took 2 h to cook the food fully. Mussard and Nydal [87] experimentally investigated the charging of a heat storage tank coupled with a low-cost small-scale solar parabolic trough for cooking purposes as shown in Figure 7. The experimental setup was a self-circulating system that was composed of a parabolic trough and a storage tank. Two charging experiments were done using two different storage tank setups and TES materials. The main objective of the experiment was to store heat at the highest temperature to utilize it during off-shine periods for cooking purposes. The results obtained indicated that when the temperature was above 200 °C, it became difficult to collect heat energy without insulation on the receiver.

An experimental investigation on improving the heat transfer of cascaded thermal storage systems using different fins was done by Beemkumar et al. [88]. The parabolic trough collector was used as a solar collector, with three storage tanks that contained Therminol-66 that was used as the heat transfer fluid. Encapsulated balls used as fins were filled with three different PCM (d-mannitol, d-sorbitol, and paraffin wax) and welded on the storage tanks. An analysis on different encapsulation shapes (rectangular, annular and pin fin) was done to determine the heat transfer rate. Results indicated that using an annular fin for encapsulation showed a higher heat transfer rate compared to others. The storage temperatures revealed that the solar cooking system had the potential of boiling and frying food. Mussard et al. [89] performed an experimental study of a solar cooker using heat storage in comparison with direct heating. A comparative experimental study of two solar cookers was done, and the surface of the storage unit was combined with a flat plate meant for cooking purposes. The first solar cooker was a parabolic dish cooker, and the second solar cooker was a prototype of a solar parabolic trough using a nitrate salt mixture storage unit. Cooking experiments such as boiling and frying were conducted to compare the performance of these two methods of heat extraction. The results obtained showed that cooking with heat storage using an optimized surface contact area was found to be competitive with standard solar cookers or other cooking devices.

An experimental and numerical investigation of a solar flat plate cooking unit for domestic applications was done by Kumaresan et al. [90]. The experimental setup was composed of a solar parabolic trough collector (PTC), a thermal energy storage (TES) tank, a parabolic trough cooking unit, and a positive displacement pump. Therminol 55 was used as the heat transfer fluid and D Mannitol was used as the phase change material. Cooking experiments were carried out, and dosa (an Indian pancake) was used as the cooking load. Parameters such as energy utilization, instantaneous heat transfer rate, and a detailed energy balance were analyzed and evaluated. Results showed that the maximum temperature reached was 167 °C, and it took 3.5 min to prepare 1 dosa. The experimental analysis of a solar cooker with a parabolic trough enhanced with a PCM-based thermal storage unit was presented by Kumar and Pandian [91]. The main components of the indirect solar cooker were a storage tank that was used to store heat energy, a heat transfer fluid, a manual tracking system, a parabolic trough collector, and a semicircular cooking oven. Stearic acid was used as the PCM storage medium. A heat transfer analysis of the experimental setup was carried out using various mass flow rates. Results showed that using a mass flow rate of 0.45 kg/s gave better energy extraction that could be utilized for cooking applications. The highest temperature achieved was approximately 120 °C in 3 h.

An evaluation of the thermal performance of a parabolic trough reflector with a PCM storage unit for different applications was presented by Abu-Hamdeh et al. [92]. The experimental components that were utilized were a parabolic trough reflector, a solar stove, an air blowing fan, and aluminum capsules that contain acetamide as a PCM. The PCM capsules were placed on the receiver of the parabolic solar reflector to absorb heat from the reflected sunlight. After the PCM melted completely, the capsules were removed from the receiver and transferred to the solar stove. Cooking experiments were done using rice, and the results showed that the cooking process took 60 min. The maximum cooking temperature achieved was approximately 90 °C with an airflow rate of 60 m³/h. A parametric study of a solar parabolic trough collector was conducted by Manikandan et al. [93]. A novel solar system was proposed, and it consisted of a parabolic trough collector that was combined with a TES unit and a cooking unit. Therminol 55 was used as the heat transfer fluid. A thermal analysis was done on parameters such as the mass flow rate, efficiency, useful energy, the concentration ratio of the collector, and the heat removal factor. The results showed that performance parameters such as thermal efficiency and the useful energy gain rate increased as the solar insulation increased, and this was evidence that it can be utilized for cooking and heating applications. Beemkumar et al. [88] performed a comparative experimental study on a parabolic trough collector integrated with a thermal energy storage system by using different reflective materials. The parabolic trough collector system was mainly composed of a parabolic trough collector, a storage tank that contained Therminol-66 oil which was used as the heat transfer fluid, D-mannitol, and a displacement pump to circulate Therminol-66 oil throughout the system. Two reflective materials (glass and stainless steel) were incorporated in the parabolic trough reflector. Experiments were conducted and various parameters were analyzed. Results obtained showed that the use of glass as reflective material showed better gain compared to stainless steel, and the maximum temperature achieved ranged from 220-230 °C.

An experimental and numerical study of a solar collector using phase change material as heat storage was done by Guerraiche et al. [94]. The aim of this experiment was to study the thermal performance of a solar collector combined with a thermal energy storage system. A small-scale parabolic trough was used to reflect solar radiation to the absorber; and the absorber contained a mixture of sodium nitrate and potassium nitrate that was used as PCM. Water was used as the heat transfer fluid, and it was stored in a storage tank. An experimental comparison of the absorber with and without PCM was done. The results showed that during heat retention the highest temperature achieved was 40 °C in a period of 1h:40 min to 2 h. Thermal performance of a coupled solar parabolic trough collector latent heat storage unit for solar water heating in large buildings was done by Lamrani et al. [95]. The experimental setup was composed of a shell and tube latent thermal energy storage system, a parabolic trough collector and a circulating pump. A thermal dynamic model was developed to evaluate thermal performance of the

Table 2. A summary of parabolic solar concentrating cookers with sensible heat thermal energy storage (SHTES).

| Author	Type of concentrator	Application	Type of study	Storage material	Maximum cooking/ storage temperature (°C)	Heat transfer fluid/Working fluid	Test load
Mishra et al. [57]	Parabolic trough	Baking	Experimental	Duratherm 600	168	Duratherm 600	Dough
El Moussaoui et al. [58]	Parabolic trough	Frying	Experimental	Thermal oil	260	Thermal oil	Potato chips(Fries)
Asmelash et al. [59]	Parabolic trough	Cooking	Experimental	Soya bean oil	119	Soya bean oil	Water, eggs and potatoes
Dianda et al. [60]	Parabolic trough	Cooking and frying	Experimental	Vegetable oil	~110	Vegetable oil	Water, potato and mixed rice with ingredients
Mohan and Vasanthakumar [61]	Parabolic trough	Steam cooking	Experimental	Water	150	Water	Potatoes
Hassen et al. [62]	Parabolic trough	Baking	Experimental and Numerical	Shell Thermia-B oil		Shell Thermia-B	Injera (sour flatbread)
Yilmaz et al. [64].	Parabolic trough	Cooking and water heating	Experimental	Fuchs Renotherm 320	100	Fuchs Renotherm 320	Wheat
Arunachala et al. [65]	Compound parabolic collector	Cooking	Experimental and Numerical	Engine oil	110	Engine oil	Rice
Goytom [63]	Parabolic trough	Baking	Numerical	Thermia-B oil	220	Thermia oil B	Injera (sour flatbread)
Noman et al. [66]	Parabolic trough	Cooking	Numerical and Experimental	Water		Water	None
Akayleh et al. [29]	Parabolic trough	Baking	Experimental	None	85	None	Dough
Widjaja et al. [67]	Parabolic trough and compound parabolic concentrator	Process heating	Numerical	Water	75	Steam	Milk
Bandyopadhyay [68]	None	Cooking and frying	Numerical	Therminol 55	202	Therminol 55	Vegetables and roti
Abd-Elhady et al. [69]	parabolic trough	Cooking	Experimental	Mobil-Therm 605	165	Mobil-Therm 605	None
Agrawal and Yadav [70]	Parabolic dish	Cooking	Experimental	sand, stone pebbles, iron grits and iron balls	117	None	Rice
Prasanna and Umanand [71]	Paraboloid concentrating collector	Cooking	Numerical	Servo-thermal oil	None	Servo-thermal oil	None
Mawire et al. [72]	Parabolic dish	Cooking	Numerical	Thermal oil	200	Thermal oil	None
Mawire et al. [34].	Parabolic dish	Cooking	Experimental and Numerical	Thermal oil	100	Thermal oil	Olive oil and Water
Badran et al. [73]	Parabolic dish	Cooking	Experimental	Water	100	Water	Water
Murty et al. [74]	Parabolic dish	Cooking	Experimental	Soya oil	85	Soya oil	Oil, water and rice
Craig and Dobson [75]	Parabolic dish	Cooking and baking	Experimental	Shell S2 oil	100	Shell S2 oil	Water
Mbodji and Hajji [76]	Parabolic dish	Cooking	Experimental and Numerical	Synthetic oil SAE-40	~85	Synthetic oil SAE-40	None
Senthil and Cheralathan [77]	Parabolic dish	Cooking	Experimental	Sunflower oil, sand, stone pebbles, iron grits, steel balls, coconut oil and olive oil	100	None	Water
Nyahoro et al. [78]	Parabolic concentrator	Cooking	Numerical	Granite and cast iron	100	None	Water
Lokeswaran and Eswaramoorthy [79]	Parabolic dish	Cooking and frying	Experimental	Waste metal chips	118	None	Eggs and water
Kedida et al. [80]	Parabolic concentrator	Cooking	Experimental and Numerical	Pebbles	99	Air	Water
Wollele and Hassen [81].	Parabolic dish	Cooking	Experimental	Engine oil and rocks	82	None	Water
Ayub et al. [82].	Scheffler dish	Baking	Experimental and Numerical	Rocks	180	Air	Variety of food
Raza et al. [83]	Scheffler dish	Roasting	Experimental and Numerical	Shell S2 oil	180	Shell S2 oil	Groundnuts
Mawire et al. [84]	Parabolic dish	Cooking	Experimental	Sunflower oil	145	None```	Varieties of food
Nazari et al. [85]	Parabolic dish	Baking	Experimental and Numerical	None	146	None	Bread
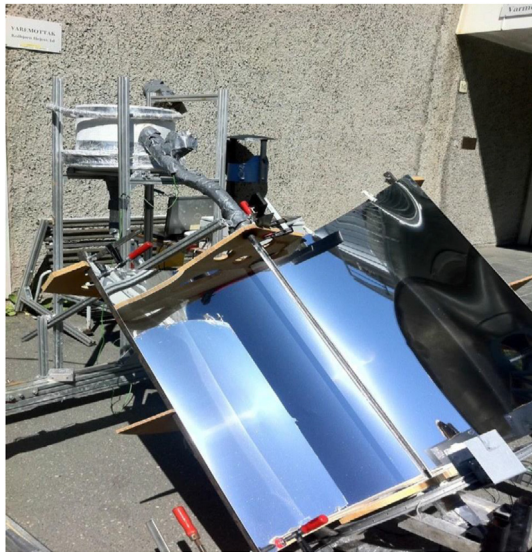
Figure 7. A photograph of a parabolic trough cooker integrated with LHTES. The figure was reproduced from Ref. [87], with the permission of Elsevier Publishing.

experimental system. Three phase change materials (RT-42, RT-55 and RT-65) were used as latent heat storage materials, and these were compared to determine the most suitable PCM. Results showed that using the mass flow rate of 1800 l/h, RT-55 showed better performance compared to RT-42 and RT-65. Furthermore, during daytime and nighttime, the system was able to produce hot water ranging from temperatures of 36–85 °C and 38–63 °C.

The thermal analysis of a solar dryer equipped with a parabolic trough solar collector (PTSC) and PCM using experimental and numerical methods was presented by Alimohammadi et al. [96]. The thermal performance of four fluids (Nano-fluid, engine oil, glycerin and water) used as heat transfer fluid was evaluated. Paraffin wax was used as the PCM, and air was used to transfer heat from the heat transfer fluid pipe to the drying chamber. Experiments and simulations were done using different heat transfer fluids. Results showed that engine oil reached around 80.4 °C, and it performed better compared to other heat transfer fluids.

3.2. Parabolic dish cookers with LHTES

The feasibility of incorporating phase change materials in a collapsible parabolic solar cooker was presented by Keith et al. [97]. The experimental setup consisted of a collapsible parabolic solar cooker with 12 panels, and a cooking vessel integrated with a PCM storage container. The PCM that was used was stearic acid. A comparison experiment with a commercial pot and a modified cooking vessel was done. Rice and pearled barley were used as the cooking loads. The results obtained showed that the cooking vessel integrated with a PCM reached a maximum average temperature of 57 °C for rice, and 59 °C for pearled barley, with cooking times of 131 min and 161 min, respectively. A solar-powered heat storage experiment for Injera baking in Ethiopia was presented by Tesfay et al. [98]. Two experimental setups were investigated and solar salt was used as the PCM. The first experimental setup was an electric-based system that was composed of an electric heating element and a solar salt storage tank coupled with a cooking vessel. The second experimental setup was similar to the first experimental setup and the difference was the pipeline system and a parabolic dish that was used to reflect solar radiation to the absorber tube. The objective of this experiment was to investigate the heat loss, cooking times, cooking temperatures, and temperatures of the PCM storage. Cooking experiments were carried out with Injera and nitrate salt mixtures were used as PCM. The results obtained showed that the useful latent energy and

sensible heat stored were 374.4 kJ and 853 kJ, respectively. Results showed that cooking two Injeras and frying an egg took 32 min during non-shine periods.

Bhave and Kale [99] developed a thermal energy storage type of solar cooker for high-temperature cooking using a mixture of sodium nitrate and potassium nitrate as the PCM. A parabolic dish concentrator was used to direct solar radiation to the solar receiver as shown in Figure 8. The solar receiver was integrated with a cooking cavity and a PCM storage unit. Cooking experiments were carried out, and the results showed that the solar cooker was able to store heat at the PCM melting point of 220 °C in 110 min, with 0.2 kg of potatoes being fried in 17 min at night. Malik et al. [100] designed and fabricated a solar thermal energy storage system using potassium alum as the PCM. The parabolic dish collector's inner surface was made up of small pieces of glass and fiberglass. The heat transfer fluid (HTF) was composed of a mixture of ethylene glycol and water. Charging and discharging experiments were conducted and compared to simulation results. Results showed that thermal energy was stored for 7 h at a maximum temperature of 92 °C which was suitable for cooking and heating applications.

An enhancement of the uniform temperature distribution of a concentrated solar receiver integrated with phase change material was done by Senthil [101]. The parabolic dish reflector was a Scheffler dish with multiple mirrors, and it was used to reflect sunlight to the receiver. The receiver was a cylindrical container that contained a cooking vessel and PCM storage. Sodium nitrate and potassium nitrate were used as the PCMs, and charging experiments were done using an insulated receiver and a receiver without insulation. After charging, water was used as the cooking load. The results obtained showed that the receiver was able to store 30 MJ of energy at a temperature of 300 °C with water completely evaporating. Lecuona et al. [102] experimentally evaluated a portable parabolic dish cooker incorporating a heat storage unit based on PCMs. The experimental setup was composed of two cooking utensils that were combined with storage tanks, an insulated box used for off-shine periods, and a parabolic dish cooker that was used to reflect and direct sunlight to the cooking utensil. Erythritol and paraffin were suitable candidates that were chosen as PCMs because the melting temperatures are close to the boiling point of water. Results showed that the utensil was able to cook three meals for a family, and another finding was that at 100 °C, paraffin seemed to be better adapted for cooking than erythritol. A numerical study on coupling PCMs with a solar dish collector was done by Tao et al. [103]. The paraboloid solar collector was used to irradiate solar radiation to the receiver during sunshine periods. The receiver was composed of heat transfer tubes and PCM storage, and it was placed at the focal point of the paraboloid solar collector. 80.5%-lithium fluorine and 19.5 %-calcium fluoride was the PCM. A Monte Carlo ray-tracing method (MCRTM) and finite volume methods (FVM) models were used to study the heat transfer problem. Results showed that enhancing the PCM thermal conductivity was an efficient way to achieve a more uniform temperature field distribution in the PCM.

Senthil and Cheralathan [104] analyzed the effect of PCM in a solar receiver using a parabolic dish collector. A Scheffler parabolic dish solar concentrator was used to concentrate solar radiation to the receiver, and improve heat transfer in the receiver. The receiver was made up of fins and a storage container filled with magnesium chloride hexahydrate as the PCM. Experiments were carried out to analyze heat transfer from the receiver to the heat transfer fluid with and without PCM. Results obtained showed that integrating PCM in the receiver improved the energy efficiency of the parabolic dish solar concentrator by about 60–65 %, and decreased the time to reach the boiling point of water by about 20 % when compared with the receiver without PCM. An enhancement of the productivity of a parabolic dish solar cooker integrated with PCM was done by Senthil and Cheralathan [105]. The thermal performance of the solar cooker with PCM integrated into a cylindrical pot was investigated to determine the thermal conductivity and storage capability enhancement. Results indicated that the productivity of the cooker during off-sunshine hours was improved with PCM, and water reached its
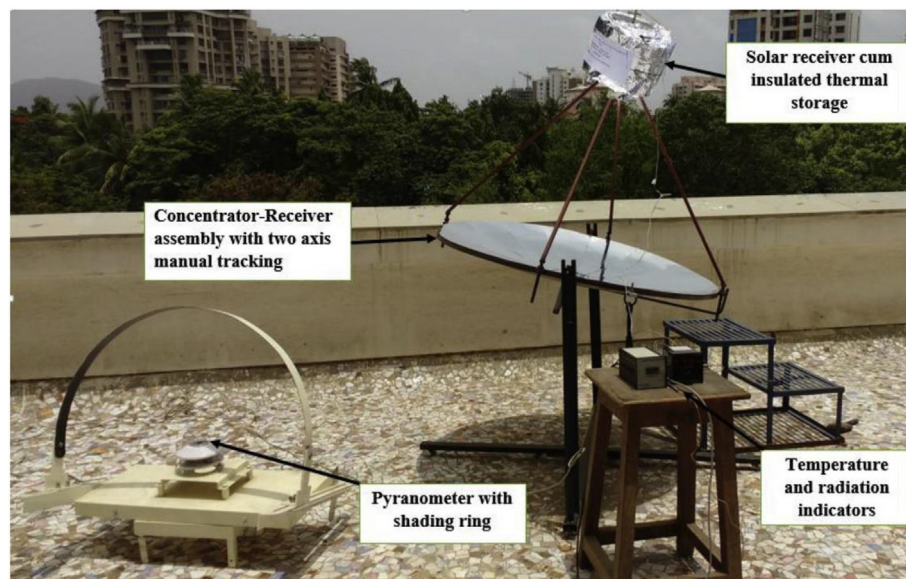
Figure 8. A photograph of an experimental setup of a parabolic dish cooker combined with an insulated solar receiver/thermal energy storage. The figure was reproduced from Ref. [99], with the permission of Elsevier Publishing.

boiling point in 130 min. Tesfay et al. [106] studied solar cookers with latent heat storage for intensive cooking applications. The solar cooker experiment was composed of a parabolic collector with a receiver, a storage system where the baking plate was embedded with stainless steel steam pipes, and aluminum fins. Water was used as the heat transfer fluid and a nitrate salt mixture was used as the PCM. Baking experiments were carried out, and results indicated that Injera could be baked at lower temperatures (110–150 °C) than previously assumed (180–220 °C). An experimental investigation of a solar cooker based on a parabolic dish collector with a PCM thermal storage unit in Indian climatic conditions was done by Chaudhary et al. [107]. The solar cooker system consisted of a parabolic dish collector combined with a flat surface absorber, a hollow-spaced solar cooker, and an insulated wood box filled with glass wool. Acetanilide was used as the PCM, and it was filled in between the hollow space of the inner and outer wall of the solar cooker. Cooking experiments were conducted and water was used as the cooking load. The results showed that during the discharging process, the maximum temperatures of cooking load achieved for an ordinary solar cooker, a solar cooker with the outer surface painted black, and for a solar cooker with the outer surface painted black along with glazing were 52.2 °C, 84.3 °C, and 88.4 °C, respectively.

Yadav and Yadav [108] performed an experimental investigation of a novel solar cooker with a dual thermal storage unit based on a parabolic dish collector. The experimental setup consisted of a solar cooker that was integrated with a sensible heat storage unit (sand) and a latent heat storage unit (acetamide). The objective of the experiment was to evaluate the thermal performance of the solar cooker based on a parabolic dish collector with acetamide and sand as a dual thermal storage media for noon and evening cooking. Cooking was conducted during the daytime as well as in the evening with different cooking loads. Results showed that the rate of evening cooking was approximately 1.5–2 times faster as compared to noon cooking, and also the temperature of cooked food at 20:00 h was found to be in the range of 60.2–70.6 °C. An experimental design of a PCM-based solar cooker for both indoor and outdoor cooking applications was done by Rekha and Sukchai [109]. The experimental setup consisted of a parabolic dish collector used to reflect sunlight to the focal point, and a receiver that was made up of a cooking utensil combined with cylindrical tubes that contained PCM. The gap between the cooking utensil and cylindrical tubes of the receiver was filled with palm oil and salt hydrate was used as a phase change material. Performance parameters such as the heat loss factor, optical efficiency factor, and

cooking power were calculated and analyzed with and without PCM in the receiver. The results obtained showed that the cooking power of the solar cooker with the PCM receiver was 125.3 W and 65.6 W without PCM in the receiver. The maximum temperature reached by the PCM solar cooker was approximately 100 °C. Bhave and Thakare [110] developed a solar thermal storage cum cooking device using magnesium chloride hexahydrate powder as the PCM. A parabolic dish concentrator was used to reflect solar radiation to the receiver. The receiver was integrated with cylindrical PCM tubes and a cooking cavity. Taurus Therm 500 was used as the heat transfer fluid in the cooking experiments. Cooking experiments were conducted with rice as a cooking load. Results showed that it took 30 min to cook 50 g of rice with 100 ml of water, and the maximum storage temperature was 129 °C.

Veremachi et al. [111] designed a PCM heat storage unit charged with a double reflector solar system. The system was composed of a primary parabolic dish reflector, a secondary plane mirror reflector, and a PCM heat storage unit that contained a mixture of sodium nitrate and potassium nitrate. This experiment aimed to evaluate the thermal parameters of the system. Charging experiments were conducted, and the results showed that the PCM in the storage unit melted at around 220 °C which was suitable for cooking or frying applications. Floess [112] developed a solar resource map for a stored solar cooker. A solar cooker named the "Sun Bucket" was used both as a cooking utensil and a PCM storage container. A combination of potassium nitrate salt and sodium nitrate salt was used as the PCM. A parabolic dish collector was used to reflect solar radiation to the solar cooker. Charging experiments were done under different environmental conditions. Parameters such as the heat transfer coefficient and rate were analyzed. Results showed that the combined PCM melted at a temperature of 334 °C which was suitable to cook a full range of foods that an electric stove could cook.

Performance analysis of a solar energy storage unit for cooking was done by Sreepathi et al. [113]. The experimental setup was composed of a "butterfly" parabolic collector and a storage cooking utensil that contained PCM. Oxalic acid was used as the phase change material. The experiment aimed at determining the peak temperature that could be attained. Water heating experiments and cooking experiments were conducted. Results obtained showed that the storage cooking utensil was able to store thermal energy for 3 h at a temperature of 65 °C. Panchal and Sadasivuni [114] investigated and performed an analysis of a Scheffler reflector solar cooking system integrated with sensible and latent heat storage materials. The experimental setup consisted of a

Table 3. A summary of parabolic solar concentrating cookers with latent heat thermal energy storage (LHTES).

Author	Type of concentrator	Application	Type of study	Storage material	Maximum cooking/ storage temperature (ºC)	Heat transfer fluid/working fluid	Test load
Saini et al. [86]	Parabolic trough	Cooking	Experimental	Acetanilide	76	Water and engine	Rice and pulse
Mussard and Nydal [87]	Parabolic trough	Cooking and frying	Experimental and Numerical	Potassium nitrate and sodium nitrate	200	Duratherm 630	Water and meat
Beemkumar et al. [88]	Parabolic trough	Heat storage	Experimental	D-mannitol, d-sorbitol, and paraffin wax	300	Therminol-66	None
Mussard et al. [89]	Parabolic trough and parabolic dish	Cooking And frying	Experimental	Potassium nitrate and sodium nitrate	130	Therminol-66	Meat
Kumaresan et al. [90]	Parabolic trough	Cooking	Experimental and Numerical	D-Mannitol	167	Therminol-66	Dosa (thick pancake)
Kumar and Pandian [91]	Parabolic trough	Cooking	Experimental	Stearic acid	120	Waste engine oil and water	None
Abu-Hamdeh et al. [92]	Parabolic trough	Cooking and water heating	Experimental	Acetamide	90	Air	Rice
Manikandan et al. [93]	Parabolic trough	Cooking	Experimental and Numerical	D-Mannitol	80	Therminol 55	None
Beemkumar et al. [88]	Parabolic trough	Heat storage	Experimental	D-mannitol, D-sorbitol and paraffin wax	~300	Therminol-66	None
Guerraiche et al. [94]	Parabolic trough	Heat storage	Experimental	Potassium nitrate and sodium nitrate	120	Water	None
Lamrani et al. [95]	Parabolic trough	Heat storage and water heating	Experimental	RT-55, RT-42 and RT-65	80	Water	None
Alimohammadi et al. [96]	Parabolic trough	Dryer	Experimental and Numerical	Paraffin was	80	Engine oil	Slices of banana
Keith et al. [97]	Parabolic dish	Cooking	Experimental and Numerical	Stearic acid	59	None	Rice, lentil and pearled barley
Tesfay et al. [98]	Parabolic dish	Cooking	Experimental	Potassium nitrate and sodium nitrate	~237	Steam	Eggs
Bhave and Kale et al. [99]	Parabolic dish	Cooking	Experimental	Potassium nitrate and sodium nitrate	180	None	Potatoes and rice
Malik et al. [100]	Parabolic dish	Cooking and heating	Experimental and Numerical	Potassium alum	92	Ethylene glycol and water	None
Senthil [101]	Scheffler dish	Cooking	Experimental	Potassium nitrate and sodium nitrate	300	None	Water
Lecuona et al. [102]	Parabolic dish	Cooking	Experimental and Numerical	Erythritol and paraffin	170	None	Water
Tao et al. [103].	Paraboloid solar collector	Heat storage	Numerical	Lithium fluorine And calcium fluoride	508	Not sure	None
Senthil and Cheralathan [104]	Scheffler dish	Heat storage	Experimental	Magnesium chloride hexahydrate	160	None	None
Senthil and Cheralathan [105]	Parabolic dish	Cooking	Experimental	Paraffin wax	90	None	Water
Tesfay et al. [106]	Parabolic collector	Cooking and baking	Experimental and Numerical	Potassium nitrate and sodium nitrate	150	Water	Injera
Chaudhary et al. [107].	Parabolic dish	Cooking	Experimental	Acetanilide	85	None	Water
Yadav and Yadav [108]	Parabolic dish	Cooking	Experimental	Acetamide	71	None	Water, rice and pulses
Rekha and Sukchai [109]	Parabolic dish	Cooking	Experimental	Salt hydrate	100	None	Not sure
Bhave and Thakare [110]	Parabolic dish	Cooking	Experimental	Magnesium chloride hexahydrate	129	Taurus Therm 500	Rice
Veremachi et al. [111]	Parabolic dish	Cooking and frying	Experimental	Potassium nitrate and sodium nitrate	220	None	None
Floess [112]	Parabolic dish	Cooking and frying	Experimental and Numerical	Potassium nitrate and sodium nitrate	334	None	Meat
Sreepathi et al. [113]	"Butterfly" parabolic collector	Cooking	Experimental	Oxalic acid	100	None	Water
Panchal and Sadasivuni [114]	Scheffler dish	Cooking	Experimental	Acetamide	57	None	Rice
Abreha et al. [115]	Parabolic dish	Cooking and heat storage	Numerical	Potassium nitrate and sodium nitrate	230	Thermal oil	None
Tesfay et al. [116]	Parabolic dish	Baking	Numerical	Potassium nitrate and sodium nitrate	150	Water	Injera

Table 3 (*continued*)

Author	Type of concentrator	Application	Type of study	Storage material	Maximum cooking/ storage temperature (°C)	Heat transfer fluid/working fluid	Test load
Yadav et al. [117]	Parabolic dish	Cooking	Experimental	Acetamide	70	None	Rice
Hosseinzadeh et al. [118]	Parabolic dish	Cooking	Experimental		95	Behran thermal oil	Water
Senthil [119]	Scheffler dish	Heat storage	Experimental	Potassium nitrate and sodium nitrate	315	Water	None
Thirunavukkarasu et al. [120]	Scheffler dish	Heat storage	Experimental	Potassium nitrate and sodium nitrate	~225	Water	None
Gabisa and Aman [121]		Cooking and heat storage	Experimental	Potassium nitrate and sodium nitrate	300	None	None
Foong et al. [122]	Parabolic dish	Heat storage, cooking and baking	Experimental and Numerical	Potassium nitrate and sodium nitrate	260	None	None

Scheffler reflector, the solar cooker, the latent heat storage unit, a sensible heat storage unit, and an insulator box. Acetamide was selected as the latent storage material, rocks and sand were selected as the sensible storage material. A comparison experiment of acetamide-sand, acetamide-pebbles, and acetamide-iron balls was conducted to determine the thermal performance during off-shine periods. The results showed the maximum temperatures achieved by three materials were 95 °C, 82 °C, and 77 °C, respectively. The cooking process took 3 h achieving temperatures of 58 °C, 57 °C and 56 °C. Abreha et al. [115] did a study on numerical modelling and simulation of thermal energy storage for solar cooking using Comsol multiphysics software. A shell-and-tube heat exchanger-type storage system coupled with a PCM mixture of potassium nitrate and sodium nitrate was used to conduct numerical experiments. 19 heat transfer tubes were selected and integrated with four longitudinal fins. The maximum average temperature of 230 °C was achieved with the total energy ranging from 4.29 MJ to 10.17 MJ. A numerical and experimental analysis of a solar Injera baking cooker coupled with PCM storage was performed by Tesfay et al. [116]. The main components of the experimental setup were a parabolic dish concentrator, a receiver, a tracking mechanism, and an insulated storage tank that contained a mixture of potassium nitrate and sodium nitrate. Water was used as the heat transfer fluid, and Injera was used as the food load. The study determined which baking surface was optimum for baking Injera. Results showed that one Injera was baked at temperatures in the range of 110–150 °C under 3 min.

Thermal performance evaluation of a solar cooker with a latent and sensible heat storage unit for evening cooking was done by Yadav et al. [117]. The main experimental components consisted of a parabolic solar dish collector, a storage solar cooking vessel, and an insulation box. A combination of latent and sensible heat was used in the storage solar cooker. Acetamide was selected as the PCM and sand, iron grits, stone pebbles, iron balls were the selected sensible heat materials. The storage solar cooker was charged throughout the day, and in the evening the storage solar cooker was placed with food in an insulated box. Results showed that a combination of PCM-sand and PCM-stone pebbles stored more energy compared to other combinations. The maximum cooking temperatures that were achieved were 70 °C and 60 °C for a cooking process that took 4 h. Hosseinzadeh et al. [118] performed an experimental study of a nanofluid-based indirect solar cooker. The indirect solar cooker consisted of a parabolic dish collector, a cooking unit, a storage tank, and a pump. Behran thermal oil was used as the heat transfer fluid. The experiment aimed to investigate and compare Behran thermal oil and three other Behran thermal oil-based nanofluids. The three Behran thermal oil-based nanofluids that were considered were; Silicon dioxide-Behran thermal oil, Silicon carbide-Behran thermal oil, and Titanium dioxide-Behran thermal oil. The results obtained showed that Silicon carbide-Behran thermal oil out-performed other candidates,

and it decreased the process of boiling 2 L of water by 17 min. An experiment on the effect of charging of PCMs in vertical and horizontal rectangular enclosures in a concentrated solar receiver was conducted by Senthil [119]. A parabolic concentrator was used to reflect the sun's rays to the receiver. The insulated receiver was composed of fins and a PCM used to store latent heat energy. Water was utilized as the heat transfer fluid, and it was used to transport latent energy from the receiver to the storage tank. A mixture of potassium nitrate and sodium nitrate was used as the PCM. An investigation on the effect of vertical and horizontal orientations was done. Results showed that after charging, the highest temperature achieved by the PCM receiver was approximately 315 °C in the vertical position and 297 °C for the horizontal position.

An experimental investigation on thermal performance of a cavity receiver integrated with short-term thermal energy storage for a solar parabolic dish concentrator was done by Thirunavukkarasu et al. [120]. A Scheffler dish integrated with solar grade mirrors was used to reflect solar radiation to the receiver. The receiver was composed of a double layer walled vessel filled with a salt mixture PCM (sodium nitrate and potassium). Water was used as the heat transfer fluid, and it was circulated from the storage tank to the receiver to absorb the heat with the help of a centrifugal pump. The aim of this experiment was to test the effect of the salt mixture integrated with the receiver and the thermal efficiency of the experimental setup. The results showed that the total thermal efficiency was 24.3 % for an average solar radiation of around 429 W/m². An experimental investigation of solar nitrate salts as solar TES materials for potential cooking applications was done by Gabisa and Aman [121]. Potassium sodium nitrate salts were used as a latent storage material, and an electrical heater was used to simulate solar radiation. The aim of the experiment was to determine the thermal characteristics of the PCM. Experiments were carried out using two local meals, and the results showed 2.38 kWh was required for cooking two meals of five families. Foong et al. [122] investigated a small scale double-reflector solar concentrating system with high temperature heat storage. The main components of the experimental setup were a primary reflector (parabolic dish), a secondary reflector, and well insulated PCM heat storage unit. A combination of sodium nitrate and potassium nitrate was used as the storage heat material. Experiments were conduct to test and evaluate the thermal performance of the PCM heat storage during off-sunshine periods. Results showed that melting occurred after 2.5 h, and the maximum temperatures reached ranged from 230-260 °C.

Table 3 shows a summary of parabolic concentrating collectors using latent heat storage mostly for solar cooking applications.

4. Conclusions

A comprehensive review of solar parabolic cookers incorporating thermal energy storage for off-sunshine cooking has been presented. This

category of solar cookers includes both the parabolic trough solar cookers and the parabolic dish solar cookers. The main conclusions that may be drawn from this review are:

- There are more studies related to parabolic dish solar cookers with storage compared to those of parabolic trough solar cookers with storage indicating that the parabolic dish is a more versatile cooker.
- There are more studies on solar cookers incorporating latent heat storage as compared to sensible heat storage due to the lower energy storage density of sensible heat storage. However, very few research efforts have been geared towards combined both sensible and latent heat storage to utilize the advantages of both storage systems.
- Most studies presented on solar cookers are experimental with limited numerical studies. Meanwhile, modelling reduces the cost of experimentation and ensures optimized designs.
- Most studies utilized aluminum as the material for the reflector (solar collector). Other materials should be investigated for potential competitive advantages.
- Larger-scale experimental setups for the end-users must be designed and tested.
- Very few studies have considered the techno-economic and socio-economic analyses of solar parabolic cookers as compared to conventional cooking methods. This is necessary in order to ensure that the solar cookers are economically competitive and viable and to investigate the level of acceptability in intended communities.

The research gaps identified by this review for further future studies include modelling of the various types of solar cookers, the combination of both sensible and latent heat thermal energy storage materials for use in solar cookers, investigation of new materials for use as reflectors, investigation of more practical end-user experimental solar cooker prototypes, and techno-economic and socio-economic analyses of solar cooker cookers. Other important aspects that may be considered for future work on parabolic solar cookers with TES include the choice of sensible or latent heat storage materials, environmental impact, types of food to be cooked, and social acceptance. The impact of the heat retention time, and the effect of clouds on heat retention for solar cookers with and without storage also needs to be investigated in future work as recently presented in [25].

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References

[1] M. Aramesh, M. Ghalebani, A. Kasaeian, H. Zamani, G. Lorenzini, O. Mahian, S. Wongwises, A review of recent advances in solar cooking technology, Renew. Energy 140 (2019) 1071–1086.

[2] S. Karekezi, W. Kithyoma, Renewable energy strategies for rural Africa: is a PV-led renewable energy strategy the right approach for providing modern energy to the rural poor of sub-Saharan Africa, Energy Pol. 30 (2002) 1071–1086.

[3] A. Demirbaş, Global renewable energy resources, Energy Sources 28 (2006) 779–792.

[4] S.P. Sukhatme, J. Nayak, Solar Energy, McGraw-Hill Education, India, 2017.

[5] R. Khatri, R. Goyal, R.K. Sharma, Advances in the developments of solar cooker for sustainable development: a comprehensive review, Renew. Sustain. Energy Rev. 145 (2021) 111166.

[6] J. Radabaugh, Heaven's Flame: A Guidebook to Solar Cookers, Home Power Publishing, USA, 1998.

[7] K. Schwarzer, M.E.V. da Silva, Characterisation and design methods of solar cookers, Sol. Energy 82 (2008) 157–163.

[8] M. Telkes, Solar cooking ovens, Sol. Energy 3 (1959) 1–11.

[9] M. Wentzel, A. Pouris, The development impact of solar cookers: a review of solar cooking impact research in South Africa, Energy Pol. 35 (2007) 1909–1919.

[10] R. Muthusivagami, R. Velraj, R. Sethumadhavan, Solar cookers with and without thermal storage—a review, Renew. Sustain. Energy Rev. 14 (2010) 691–701.

[11] G. Ngala, M. Maina, M. Tela, Design and construction of a high concentration solar cooker, Int. J. Res. Mechan. Engin. 3 (2015) 1–7.

[12] S. Indora, T.C. Kandpal, Institutional and community solar cooking in India using SK-23 and Scheffler solar cookers: a financial appraisal, Renew. Energy 120 (2018) 501–511.

[13] A.N. Rao, S. Subramanyam, Solar cookers—part-II—cooking vessel with central annular cavity, Sol. Energy 78 (2005) 19–22.

[14] H.A. Zafar, M.Y. Khan, A.W. Badar, R. Tariq, F.S. Butt, Introducing a novel design in the realm of box type solar cookers: an experimental study, J. Renew. Sustain. Energy 10 (2018), 043707.

[15] G. Coccia, A. Aquilanti, S. Tomassetti, A. Ishibashi, G. Di Nicola, Design, manufacture and test of a low-cost solar cooker with high-performance light-concentrating lens, Sol. Energy 224 (2021) 1028–1039.

[16] C. Battocchio, F. Bruni, G. Di Nicola, T. Gasperi, G. Iucci, D. Tofani, A. Varesano, I. Venditti, Solar cookers and dryers: environmental sustainability and nutraceutical content in food processing, Foods 10 (2021) 2326.

[17] B.C. Anilkumar, R. Maniyeri, S. Anish, Optimum selection of phase change material for solar box cooker integrated with thermal energy storage unit using multi-criteria decision-making technique, J. Energ. Stor. 40 (2021) 102807.

[18] G. Coccia, G. Di Nicola, M. Pierantozzi, S. Tomassetti, A. Aquilanti, Design, manufacturing, and test of a high concentration ratio solar box cooker with multiple reflectors, Sol. Energy 155 (2017) 781–792.

[19] F.Y. Gama, B. Azoui, A. Malek, N.L. Panwar, A. Gama, Energetic and exergetic evaluation of solar box cooker in Algerian climatic conditions, Int. J. Exergy 16 (2015) 337–357.

[20] M. Collares-Pereira, A. Cavaco, A. Tavares, Figures of merit and their relevance in the context of a standard testing and performance comparison methods for solar box–cookers, Sol. Energy 166 (2018) 21–27.

[21] P.J. Lahkar, R.K. Bhamu, S.K. Samdarshi, Enabling inter-cooker thermal performance comparison based on cooker opto-thermal ratio (COR), Appl. Energy 99 (2012) 491–495.

[22] K. Reddy, N.S. Kumar, Convection and surface radiation heat losses from modified cavity receiver of solar parabolic dish collector with two-stage concentration, Heat Mass Tran. 45 (2009) 363–373.

[23] F. Yettou, B. Azoui, A. Malek, N.L. Panwar, A. Gama, Generating temperature maps of a solar receiver for a domestic parabolic concentrator for cooking purposes under an Algerian environment, Energ. Better Environ. Imp. Sustain. 2 (2018) 231–257.

[24] A. Herez, M. Ramadan, M. Khaled, Review on solar cooker systems: economic and environmental study for different Lebanese scenarios, Renew. Sustain. Energy Rev. 81 (2018) 421–432.

[25] A.A. Sagade, S.K. Samdarshi, N.A. Sagade, P.S. Panja, Enabling open sun cooling method-based estimation of effective concentration factor/ratio for concentrating type solar cookers, Sol. Energy 227 (2021) 568–576.

[26] R. Wimmer, M.J. Kang, C. Pokpong, A. Mahdavi, Analysis of user needs for solar cooker acceptance, in: Sustainability through Innovation in Product Life Cycle Design, Springer, Singapore, 2017, pp. 151–165.

[27] H. Singh, K. Saini, A. Yadav, Experimental comparison of different heat transfer fluid for thermal performance of a solar cooker based on evacuated tube collector, Environ. Dev. Sustain. 17 (2015) 497–511.

[28] S.M. Ahmed, M.R. Al-Amin, S. Ahammed, F. Ahmed, A.M. Saleque, M.A. Rahman, Design, construction and testing of parabolic solar cooker for rural households and refugee camp, Sol. Energy 205 (2020) 230–240.

[29] A.S. Akayleh, M.S. Al-Soud, S.A. Al-Jufout, Design and development of a solar-based cooker with a mechanical sun tracking system, Int. J. Ambient Energy 41 (2020) 808–812.

[30] W. Prompuge, C. Sirisamphanwong, Technical performance for heat storage of solar cooker using vegetable oil as working fluid, J. Renew. Energ. Smart Grid Techn. 13 (2018).

[31] H.Z. Abou-Ziyan, Experimental investigation of tracking paraboloid and box solar cookers under Egyptian environment, Appl. Therm. Eng. 18 (1998) 1375–1394.

[32] I.L. Mohammed, Field testing and evaluation of a truncated pyramid solar thermal cooker, Int. J. Renew. Energ. Environ. Engin. 3 (2015).

[33] A. Mawire, M. Ramokali, M. Mothupi, A solar thermal experiment with parabolic dish solar cookers for developing countries, Eur. J. Phys. 41 (2020), 055104.

[34] A. Mawire, M. McPherson, R.R.J. Van den Heetkamp, Discharging simulations of a thermal energy storage (TES) system for an indirect solar cooker, Sol. Energy Mater. Sol. Cell. 94 (2010) 1100–1106.

[35] F. Riva, M.V. Rocco, F. Gardumi, G. Bonamini, E. Colombo, Design and performance evaluation of solar cookers for developing countries: the case of M utoyi, B urundi, Int. J. Energy Res. 41 (2017) 2206–2220.

[36] A. Mawire, K.A. Lentswe, D. Okello, K. Nyeinga, R. Lugolole, Energy and exergy performance of three sensible heat storage systems during charging, in: 2018 6th International Renewable and Sustainable Energy Conference, 2018, pp. 1–6.

[37] L. Nkhonjera, T. Bello-Ochende, G. John, C.K. King'ondu, A review of thermal energy storage designs, heat storage materials and cooking performance of solar cookers with heat storage, Renew. Sustain. Energy Rev. 75 (2017) 157–167.

[38] A.A. Omara, A.A. Abuelnuor, H.A. Mohammed, D. Habibi, O. Younis, Improving solar cooker performance using phase change materials: a comprehensive review, Sol. Energy 207 (2020) 539–563.

[39] H. Panchal, J. Patel, S. Chaudhary, A comprehensive review of solar cooker with sensible and latent heat storage materials, Int. J. Ambient Energy 40 (2019) 329–334.

[40] A. Sharma, C. Chen, V. Murty, A. Shukla, Solar cooker with latent heat storage systems: a review, Renew. Sustain. Energy Rev. 13 (2009) 1599–1605.

[41] A.I. Fernández, M. Martinez, M. Segarra, I. Martorell, L. Cabeza, Selection of materials with potential in sensible thermal energy storage, Sol. Mater. Sol. Cell. 94 (2010) 1723–1729.

[42] Z. Abdin, K.R. Khalilpour, Single and polystorage technologies for renewable-based hybrid energy systems, Polygen. Polystorag. Chem. Energ. Hubs (2019) 77–131.

[43] C. Ferone, F. Colangelo, D. Frattini, G. Roviello, R. Cioffi, R.D. Maggio, Finite element method modeling of sensible heat thermal energy storage with innovative concretes and comparative analysis with literature benchmarks, Energies 7 (2014) 5291–5316.

[44] P.J. Lahkar, S.K. Samdarshi, A review of the thermal performance parameters of box type solar cookers and identification of their correlations, Renew. Sustain. Energy Rev. 14 (2010) 1615–1621.

[45] A. Saxena, S.P. Pandey, G. Srivastav, A thermodynamic review on solar box type cookers, Renew. Sustain. Energy Rev. 15 (2011) 3301–3318.

[46] N.L. Panwar, S.C. Kaushik, S. Kothari, State of the art of solar cooking: an overview, Renew. Sustain. Energy Rev. 16 (2012) 3776–3785.

[47] S.Z. Farooqui, A review of vacuum tube based solar cookers with the experimental determination of energy and exergy efficiencies of a single vacuum tube based prototype, Renew. Sustain. Energy Rev. 31 (2014) 439–445.

[48] F. Yettou, B. Azoui, A. Malek, A. Gama, N.L. Panwar, Solar cooker realizations in actual use: an overview, Renew. Sustain. Energy Rev. 37 (2014) 288–306.

[49] A. Harmim, M. Merzouk, M. Boukar, M. Amar, Solar cooking development in Algerian Sahara: towards a socially suitable solar cooker, Renew. Sustain. Energy Rev. 37 (2014) 207–214.

[50] L. Iessa, Y.A. De Vries, C.E. Swinkels, M. Smits, C.A.A. Butijn, What's cooking? Unverified assumptions, overlooking of local needs and pro-solution biases in the solar cooking literature, Energ. Res. Soci. Sci. 28 (2017) 98–108.

[51] H. El Hage, A. Herez, M. Ramadan, H. Bazzi, M. Khaled, An investigation on solar drying: a review with economic and environmental assessment, Energy 157 (2018) 815–829.

[52] S. Indora, T.C. Kandpal, Institutional cooking with solar energy: a review, Renew. Sustain. Energy Rev. 84 (2018) 131–154.

[53] A.H. Elsheikh, S.W. Sharshir, M. Abd Elaziz, A.E. Kabeel, W. Guilan, Z. Haiou, Modeling of solar energy systems using artificial neural network: a comprehensive review, Sol. Energy 180 (2019) 622–639.

[54] U.C. Arunachala, A. Kundapur, Cost-effective solar cookers: a global review, Sol. Energy 207 (2020) 903–916.

[55] P.K. Devan, C. Bibin, S. Gowtham, G. Hariharan, R. Hariharan, A comprehensive review on solar cooker with sun tracking system, Mater. Today: Proceed. 33 (2020) 771–777.

[56] V. Gokul, S. Dhinesh, K. Kalaiyarasu, B. Kalidasan, M. Ravikumar, A comprehensive review on solar cooker tracking techniques for performance enhancement, IOP Conf. Ser. Mater. Sci. Eng. 1059 (2021), 012065.

[57] A. Mishra, S. Powar, A. Dhar, Solar Thermal powered bakery oven, Adv. Solar Energ. Res. (2019) 577–592.

[58] N. El Moussaoui, S. Talbi, I. Atmane, K. Kassmi, K. Schwarzer, H. Chayeb, N. Bachiri, Feasibility of a new design of a parabolic trough solar thermal cooker (PSTC), Sol. Energy 201 (2020) 866–871.

[59] H. Asmelash, M. Bayray, C. Kimambo, P. Gebray, A.M. Sebbit, Performance test of parabolic trough solar cooker for indoor cooking, Momona Ethiop. J. Sci. 6 (2014) 39–54.

[60] B. Dianda, T.S. Maurice, KY. parabolic trough cooker, Int. J. Curr. Res. Key Words 11 (2019) 1869–1874.

[61] B. Mohan, D. Vasanthakumar, Analysis of the effectiveness of solar assisted steam cooking using parabolic trough collector, Int. Res. J. Engin. Techn. 2 (2015) 932–939.

[62] A.A. Hassen, D.A. Amibe, O.J. Nydal, Performance investigation of solar powered Injera Baking oven for indoor cooking, in: ISES Solar World Congress Proceedings, Kassel, Germany, 2011, pp. 186–196.

[63] D. Goytom, Finite difference modelling of solar thermal powered Injera baking oven, Int. Adv. Res. J. Sci. Engin. Techn. 3 (2016) 124–131.

[64] I˙.H. Yilmaz, M.S. Soylemez, H. Hayta, R. Yumruta,s, A process heat application using parabolic trough collector, Int. Cong. Energy Eff. Energ. Relat. Mater. Proceed. Antalya, Turkey (2014) 137–141.

[65] U. Arunachala, A. Jhalaria, M. Sheikh, Design, fabrication and performance analysis of solar cooker for night cooking, Int. J. Renew. Energ. Environ. Engin. 2 (2014) 288–293.

[66] M. Noman, A. Wasim, M. Ali, M. Jahanzaib, S. Hussain, H.M.K. Ali, H.M. Ali, An investigation of a solar cooker with parabolic trough concentrator, Case Studies in Thermal Engineering 14 (2019) 100436.

[67] A.S. Widjaja, K. Löwe, F.S. Costa, Design and simulation of a concentrated solar thermal system with an integrated concrete storage for continuous heat supply, Energy Procedia 155 (2018) 121–135.

[68] M.H. Bade, S. Bandyopadhyay, Energy modelling of thermal oil based cooking system, Energy Procedia 75 (2015) 1746–1751.

[69] M.S. Abd-Elhady, A.N.A. Abd-Elkerim, S.A. Ahmed, M.A. Halim, A. Abu-Oqual, Study the thermal performance of solar cookers by using metallic wires and nanographene, Renew. Energy 153 (2020) 108–116.

[70] H. Agrawal, A. Yadav, Design and experimental testing of a solar cooker with sensible heat storage, J. Energ. Res. Environ. Techn. 2 (2015) 200–204.

[71] U. Prasanna, L. Umanand, Optimization and design of energy transport system for solar cooking application, Appl. Energy 88 (2011) 242–251.

[72] A. Mawire, M. McPherson, R. Van den Heetkamp, Simulated energy and exergy analyses of the charging of an oil–pebble bed thermal energy storage system for a solar cooker, Sol. Energy Mater. Sol. Cell. 92 (2008) 1668–1676.

[73] A.A. Badran, I.A. Yousef, N.K. Joudeh, R. Al Hamad, H. Halawa, H.K. Hassouneh, Portable solar cooker and water heater, Energy Convers. Manag. 51 (2010) 1605–1609.

[74] V. Murty, A. Gupta, N. Mandloi, A. Shukla, Evaluation of thermal performance of heat exchanger unit for parabolic solar cooker for off-place cooking, Indian J. Pure Appl. Phys. 45 (2007) 745–748.

[75] O.O. Craig, R.T. Dobson, Parabolic solar cooker: cooking with heat pipe vs direct spiral copper tubes, AIP Confer. Proceed. 1734 (2016) 160004.

[76] N. Mbodji, A. Hajji, Modeling, testing, and parametric analysis of a parabolic solar cooking system with heat storage for indoor cooking, Energy Sustainabil. Soci. 7 (2017) 32.

[77] R. Senthil, M. Cheralathan, Thermal performance of solid and liquid energy storage materials in a parabolic dish solar cooker, Int. J. Chem. Sci. 14 (2016) 1977–1983.

[78] P.K. Nyahoro, R.R. Johnson, J. Edwards, Simulated performance of thermal storage in a solar cooker, Sol. Energy 59 (1997) 11–17.

[79] S. Lokeswaran, M. Eswaramoorthy, Experimental studies on solar parabolic dish cooker with porous medium, Appl. Sol. Energy 48 (2012) 169–174.

[80] D.K. Kedida, D.A. Amibe, Y.T. Birhane, Performance of a pebble bed thermal storage integrated with concentrating parabolic solar collector for cooking, Journal of Renewable Energy 2019 (2019) 1–12.

[81] M.B. Wollele, A.A. Hassen, Design and experimental investigation of solar cooker with thermal energy storage, AIMS Energy 7 (2019) 957–970.

[82] I. Ayub, A. Munir, W. Amjad, A. Ghafoor, M.S. Nasir, Energy and exergy based thermal analyses of a solar bakery unit, J. Therm. Anal. Calorim. 133 (2018) 1001–1013.

[83] A. Raza, F. Majeed, A. Munir, O. Hensel, Development and experimental results of a thermal oil based roasting system for decentralized processing of groundnuts, Appl. Sci. 9 (2019) 4342.

[84] A. Mawire, K. Lentswe, P. Owusu, A. Shobo, J. Darkwa, J. Calautit, M. Worall, Performance comparison of two solar cooking storage pots combined with wonderbag slow cookers for off-sunshine cooking, Sol. Energy 208 (2020) 1166–1180.

[85] S. Nazari, A. Karami, M. Bahiraei, M. Olfati, M. Goodarzi, H. Khorasanizadeh, A novel technique based on artificial intelligence for modeling the required temperature of a solar bread cooker equipped with concentrator through experimental data, Food Bioprod. Process. 123 (2020) 437–449.

[86] G. Saini, H. Singh, K. Saini, A. Yadav, Experimental investigation of the solar cooker during sunshine and off-sunshine hours using the thermal energy storage unit based on a parabolic trough collector, Int. J. Ambient Energy 37 (2016) 597–608.

[87] M. Mussard, O.J. Nydal, Charging of a heat storage coupled with a low-cost small-scale solar parabolic trough for cooking purposes, Sol. Energy 95 (2013) 144–154.

[88] N. Beemkumar, A. Karthikeyan, D. Yuvarajan, S.L. Sankar, Experimental investigation on improving the heat transfer of cascaded thermal storage system using different fins, Arabian J. Sci. Eng. 42 (2017) 2055–2065.

[89] M. Mussard, A. Gueno, O.J. Nydal, Experimental study of solar cooking using heat storage in comparison with direct heating, Sol. Energy 98 (2013) 375–383.

[90] G. Kumaresan, R. Santosh, G. Raju, R. Velraj, Experimental and numerical investigation of solar flat plate cooking unit for domestic applications, Energy 157 (2018) 436–447.

[91] S.B.S. Kumar, M.C. Pandian, Experimental analysis of a solar cooker with a parabolic trough enhanced with PCM based thermal storage, IOP Conf. Ser. Mater. Sci. Eng. 574 (2019), 012019.

[92] N.H. Abu-Hamdeh, K.A. Alnefaie, Assessment of thermal performance of PCM in latent heat storage system for different applications, Sol. Energy 177 (2019) 317–323.

[93] K.S. Manikandan, G. Kumaresan, R. Velraj, S. Iniyan, Parametric study of solar parabolic trough collector system, Asian J. Appl. Sci. Engin. 5 (2012) 384–393.

[94] D. Guerraiche, C. Bougriou, K. Guerraiche, L. Valenzuela, Z. Driss, Experimental and numerical study of a solar collector using phase change material as heat storage, J. Energ. Stor. 27 (2020) 101133.

[95] B. Lamrani, F. Kuznik, A. Draoui, Thermal performance of a coupled solar parabolic trough collector latent heat storage unit for solar water heating in large buildings, Renew. Energy 162 (2020) 411–426.

[96] Z. Alimohammadi, H.S. Akhijahani, P. Salami, Thermal analysis of a solar dryer equipped with PTSC and PCM using experimental and numerical methods, Sol. Energy 201 (2020) 157–177.

[97] A. Keith, N.J. Brown, J.L. Zhou, The feasibility of a collapsible parabolic solar cooker incorporating phase change materials, Renew. Energ. Focus 30 (2019) 58–70.

[98] A.H. Tesfay, M.B. Kahsay, O.J. Nydal, Solar powered heat storage for Injera baking in Ethiopia, Energy Procedia 57 (2014) 1603–1612.

[99] A.G. Bhave, C.K. Kale, Development of a thermal storage type solar cooker for high temperature cooking using solar salt, Sol. Energy Mater. Sol. Cell. 208 (2020) 110394.

[100] M.S. Malik, N. Iftikhar, A. Wadood, M.O. Khan, M.U. Asghar, S. Khan, T. Khurshaid, K.-C. Kim, Z. Rehman, S. Rizvi, et al., Design and fabrication of solar thermal energy storage system using potassium alum as a PCM, Energies 13 (2020) 6169.

[101] R. Senthil, C. Rath, M. Gupta, Enhancement of uniform temperature distribution on the concentrated solar receiver with integrated phase change material, Int. J. Mech. Eng. Technol. 8 (2017) 315–320.

[102] A. Lecuona, J.-I. Nogueira, R. Ventas, M. Legrand, et al., Solar cooker of the portable parabolic type incorporating heat storage based on PCM, Appl. Energy 111 (2013) 1136–1146.

[103] Y. Tao, Y. He, F. Cui, C. Lin, Numerical study on coupling phase change heat transfer performance of solar dish collector, Sol. Energy 90 (2013) 84–93.

[104] R. Senthil, M. Cheralathan, Effect of the phase change material in a solar receiver on thermal performance of parabolic dish collector, Therm. Sci. 21 (2017) 2803–2812.

[105] R. Senthil, Enhancement of productivity of parabolic dish solar cooker using integrated phase change material, Mater. Today: Proceed. 34 (2021) 386–388.

[106] A.H. Tesfay, M.B. Kahsay, O.J. Nydal, Solar cookers with latent heat storage for intensive cooking application, in: ISES Solar World Congress Proceedings, Daegu, Korea, 2015, pp. 109–118.

[107] A. Chaudhary, A. Kumar, A. Yadav, Experimental investigation of a solar cooker based on parabolic dish collector with phase change thermal storage unit in Indian climatic conditions, Renew. Sustain. Energy 5 (2013), 023107.

[108] V. Yadav, A. Yadav, Experimental investigation of novel design of solar cooker with dual thermal storage unit based on parabolic dish-type collector, Int. J. Energy a Clean Environ. (IJECE) 14 (2013) 295–310.

[109] S. Santhi Rekha, S. Sukchai, Design of phase change material based domestic solar cooking system for both indoor and outdoor cooking applications, J. Sol. Energy Eng. 140 (2018), 041010.

[110] A.G. Bhave, K.A. Thakare, Development of a solar thermal storage cum cooking device using salt hydrate, Sol. Energy 171 (2018) 784–789.

[111] A. Veremachi, B.C. Cuamba, A. Zia, J. Lovseth, O.J. Nydal, PCM heat storage charged with a double-reflector solar system, J. Solar Energy 2016 (2016).

[112] E.M. Floess, Developing a Solar Resource Map for a Stored Solar Cooker, MA Thesis, University of Illinois at Urbana-Champaign, Illinois, USA, 2019.

[113] L. Sreepathi, L. Madhuvanthi, T.S. Sharadhi, G. Chethan, Performance analysis of a solar energy storage unit for cooking, J. Engin. Manag. 1 (2017) 65–73.

[114] H. Panchal, K.K. Sadasivuni, Investigation and performance analysis of Scheffler reflector solar cooking system integrated with sensible and latent heat storage materials, Int. J. Ambient Energy 41 (2020) 1096–1105.

[115] B.G. Abreha, P. Mahanta, G. Trivedi, Numerical modeling and simulation of thermal energy storage for solar cooking using Comsol multiphysics software, AIP Confer. Proceed. 2091 (2019), 20004.

[116] A.H. Tesfay, M.B. Kahsay, O.J. Nydal, Numerical and experimental analysis of solar Injera baking with a PCM heat storage, Momona Ethiop. J. Sci. 11 (2019) 1–13.

[117] V. Yadav, Y. Kumar, H. Agrawal, A. Yadav, Thermal performance evaluation of solar cooker with latent and sensible heat storage unit for evening cooking, Aust. J. Mech. Eng. 15 (2017) 93–102.

[118] M. Hosseinzadeh, R. Sadeghirad, H. Zamani, A. Kianifar, S.M. Mirzababaee, A. Faezian, Experimental study of a nanofluid-based indirect solar cooker: energy and exergy analyses, Sol. Energy Mater. Sol. Cell. 221 (2021) 110879.

[119] R. Senthil, Effect of charging of phase change material in vertical and horizontal rectangular enclosures in a concentrated solar receiver, Case Studies in Thermal Engineering 21 (2020) 100653.

[120] V. Thirunavukkarasu, V.U. Nair, K. Tiwari, M. Cheralathan, Experimental investigation on thermal performance of cavity receiver integrated with short-term thermal energy storage for a solar parabolic dish concentrator, J. Therm. Anal. Calorim. (2020) 1–12.

[121] E.W. Gabisa, A. Aman, Characterization and experimental investigation of NaNO 3: KNO 3 as solar thermal energy storage for potential cooking application, J. Sol. Energy Eng. 2016 (2016) 1–6.

[122] C.W. Foong, O.J. Nydal, J. Løvseth, Investigation of a small scale double-reflector solar concentrating system with high temperature heat storage, Appl. Therm. Eng. 31 (2011) 1807–1815.