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(Review Article)

Phase change material application in solar cooking for performance enhancement through storage of thermal energy: A future demand

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Abstract

Solar cookers offer a sustainable source of energy that may be utilized for cooking purposes. On the other hand, their major disadvantage is that they cannot be employed when there is a lack of sunshine by using thermal energy storage; it is possible to significantly overcome these limits. This paper analysis specifically the latest advancements in solar cooking, including its many components and the features of heat transmission involved. Over time, many geometric adjustments have enhanced the cooking efficiency, particularly in box-type solar cookers. The utilization of energy storage materials enhanced the efficiency during periods of little sunlight. Phase change materials have a greater impact when used as a storage medium, whereas sensible heat storage mediums are more cost-effective. Improved policy implications are necessary to get social and economic acceptance. Solar cooking technology requires a method for advancement to improve its efficiency, cost, and practicality. The objective of this paper is to give a comprehensive literature evaluation of the uses of phase change materials as thermal energy storage mediums to enhance the performance of solar cookers. This review paper takes a retrospective look at the recent years by reviewing the progress made in the area of phase change materials and their applications in various heat transfer devices such as solar cookers, heat exchange, and thermal storage systems. In addition, the many types of phase-change materials, nanofluids, and the challenges associated with enhancing the thermophysical properties of phase-change materials are discussed.

Keywords: Phase Change Material; Thermal Energy Storage; Solar Cooking; Nanofuilds; Graphene nanomaterial; Latent Heat Storage in Solar Cooking

1. Introduction

Two of the most part pressing global challenges now are the energy crisis and environmental degradation. Greater efficiency in the utilization of renewable energy sources is being propelled by rising fuel costs, steadily increasing energy demand, and the release of greenhouse gases [1]. Problems with health, the environment, society, and the economy have resulted from the use of non-renewable resources, which are particularly prevalent in developing countries. To meet demand in light of fossil fuels' finite supply, renewable energy alternatives must be considered. There are a few drawbacks to using renewable resources, too. These include energy source availability, energy source inconsistency, and require storage of surplus energy. Solar energy has a wide range of possible application; it uses this plentiful energy source. When it comes to thermal uses of solar energy, solar cooking is seen as individual of the majority appealing, easy, and simplest solutions [2].

Environmental concerns, such as climate change and global warming, are compelling humans to seek alternate energy sources to replace traditional ones. Based on the information from many sources, it seems that solar energy has the ability to serve as a viable alternative. It has the potential to significantly become the main energy source in several

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home and industrial applications. Moreover, the utilization of solar energy systems significantly diminishes the release of harmful pollutants such as CO_2, SO_2, and NOx. In addition, it offers a decrease in noise and air pollution. According to a study conducted by A. Reyes et al. [3], the implementation of a "solar city" will result in a reduction of 178 tons of carbon dioxide emissions over a period of thirty years. It is equivalent to the act of planting trees in an area the size of 10 football arenas saving fuel that would have been used to travel approximately 390,300 miles, or preventing the burning of approximately 174,907 pounds of coal. The fluctuating accessibility of solar energy has been a significant obstacle for several investigations in this domain. The researchers have been experimenting with several changes to improve the performance and enhance the use of these devices.

Solar cookers that have thermal energy storage can continue cooking even when the sun isn't directly above, making them more versatile. SHTES and LHTE storage are two workable methods for saving thermal energy for solar cookers. Particularly during the cold and wet seasons, the strength of solar rays may be rather unpredictable.

Solar cooking is a highly beneficial utilization of solar thermal energy. It has the capacity to improve the environment and eliminate health risks for rural communities. However, solar cooking systems are hindered by the low availability of uninterrupted energy supply in some locations. The implementation of geometric and technical enhancements, as well as the incorporation of thermal energy storage mediums and interaction with other systems, has expanded the possibilities of solar cooking technologies. Katlego Lentswe et al. [4] conducted an experimental investigation on a foldable parabolic solar cooker that was combined with PCM. They proposed an option for individuals who rely on firewood for their cooking requirements. The author recommended that future research should prioritize investigating the efficacy of the system. In a study conducted by Yeh, C.Y et al. [5], they introduced the idea of a "modular indoor solar kitchen." The discussion covered several storage media for solar cooking and emphasized the importance of developing appropriate indoor solar cooking methods.

Nevertheless, the difficulty that is linked with certain renewable energy, such as sun and wind, is that they can only occur for a certain period. It is challenging to regulate the supply of renewable energy since it is reliant on weather-related natural phenomena including wind, rain, and sun radiation. It is possible to use renewable energy more effectively it can be stored. This is because storing renewable energy reduces the requirement for fossil fuels, which eventually lowers the amount of energy that might be squandered and lowers the cost of the system. To be able to complete a state of equilibrium between the production and consumption of energy, it is essential to store more energy for either the short or long term. Hence, PCM is a superb choice for accumulating solar energy every day long as well as utilizing it for cooking later on when the sun doesn't shine [6]. A material's ability to absorb or release heat during a phase shift is the foundation of latent heat storage (LHS). Due to its numerous restrictions, PCM cannot be used in solar energy storage, including low specific heat, high melting point, and poor thermal conductivity. Due to their distinct nanoscale characteristics, particles are crucial in this context. It follows that the precise proportions of nanoparticles mixed with phase-change materials can rejuvenate phase-change materials characteristics. The purpose of this research is to present a critical estimation of the current examination to have been carried out about the use of various PCMs regarding the storage space of solar energy during the context of solar cooking. The most recent literature of research and solar cooking systems that are combined with LTES devices are the primary topics of discussion in this study [7].

2. Organization of the chapter

Multiple review papers on the use of solar energy for culinary purposes have been compiled and summarized in Table 1. The majority of the review papers primarily concentrate on the box type solar cooker and its many design alterations. Several researches have examined the utilization of heat storage media and their impact. There has been a limited amount of recent research that has specifically examined the economic implications of using solar cooking in particular situations. Considering the existing literature, there is still a requirement to condense the technologies utilized to enhance the thermal efficiency of solar-powered cooking systems. Furthermore, there is a lack of comprehensive analysis on the integration of latent thermal energy storage medium with cooking systems. This review chapter has the potential to be a valuable contribution to the current literature in the subject field, offering a clear and different perspective. This research provides a comprehensive analysis of the improvements made to solar cooking equipment and their incorporation with energy storage systems. Furthermore, the limitations of these systems have been examined in order to determine the necessary method for enhancing solar cooking systems, hence improving their practicality and cost.

Table 1 Recent review literatures on solar cooking [36-48]

Author (Public year)	**County (Author's country)**	**Title**	**Suggestions/ outcomes**
Hosseinzadeh M et al. [8]	India & UAE	Dissemination of cooking energy alternatives in India—a review	In context to India it was suggested to minimize the use of traditional fuel wood. A revisited approach to make renewable energy more useful technically, socially and economically is suggested.
Harshita et al. [9]	India	Role of Phase Change Materials in Solar Cooking for Thermal Energy Storage Applications: A Review	Various literatures were discussed for late night cooking with solar cooker. This can be realized with integration of heat storage system with solar cooking. It was suggested that this will improve the quality of human life and will help in energy conservation.
Xabier Apaolaza-Pagoaga et al. [10]	India	Solar cookers with and without thermal storage—A review	A modular indoor cooking unit for all time cooking is suggested to solve all problems related to solar cooking.
A. Carrillo-Andr´es, X et al. [11]	India	A thermodynamic review on solar box type cookers	Discussed the developments on the box type solar cooker. Suggested design aspects, heat storage and insulation types for efficient performance of solar cooker.
X. Apaolaza-Pagoaga et al. [12]	India	State of the art of solar cooking: An overview	Review on types, applications, thermodynamics and economics of solar cooking Lower exergy efficiency of solar cookers was reported. The environmental benefits i.e. the reduction in the release of CO2 and conservation of conventional fuels was identified.
A.A. Sagade et al. [13]	India	A review of the thermal performance parameters of box type solar cookers and identification of their correlations	Review to establish interrelation between performance parameters of solar cooker. Fluid temperature, plate temperature, cooking temp. and heat retention rate worked out as objective parameters. Only few parameters can be correlated i.e. climate dependent parameters.
Vengadesan E et al. [14]	Nottingham, UK	A comprehensive review on solar cookers	Various design modifications were suggested i.e. booster mirrors, use of transparent insulation material (TIM) and insulation. Use of thermal energy storage is suggested for cooking during non-sunshine hours.
Arulraj Simon Prabu et al. [15]	Algeria and India	Solar cooker realizations in actual use: An overview	Discussed the major geometric components that have an impact on thermal performance of solar cookers. Double glazing and black painted vessel and plates are suggested. As suggested efficiency and performance improvements are required in solar cooking system for their large scale utilization.
V. Skurkyte-Papieviene et al. [16]	Tanzania and South Africa	A review of thermal energy storage designs, heat storage materials and cooking	Container geometry for heat storage medium used in solar cooking should be optimized.

		performance of solar cookers with heat storage	LHTES having less than 120 ∘C melting point are not effective in cooking
T. Li et al. [17]	India	A comprehensive review of solar cooker with sensible and latent heat storage materials	The use of heat storage mediums improves the performance of solar cookers. LHS store thermal energy for 3–4 h compared to 2–3 h for SHS. Reported that the combination of SHS and LHS is still unattended.
Gu, J et al. [18]	India	Institutional cooking with solar energy: A review	Various aspects of Institutional solar cooking were presented and it was concluded that there is a limited utilization of the resource available. It was also concluded that solar systems must be designed as per local need and local population and availability. Policy and incentivizing measures were also suggested to establish solar cooking.
Poyyamozhi, N et al. [19]	Iran, Italy, China, Thailand and Australia	A review of recent advances in solar cooking technology	Identified that the concentrating cookers are most efficient but not economical. Suggested to work on the design of cookers for their indoor placement and social acceptance.
Khatri, R et al. [20]	India	Cost-effective solar cookers: A global review	Shown an urgent need to improve design and materials for low cost solar cookers.

3. Solar Cooking Technology

Solar cooking, as a prominent use of solar energy, has demonstrated the capacity to substitute traditional cooking methods. In rural regions reliant on wood or cow dung as the primary fuel for cooking, the use of solar energy is necessary to mitigate health risks and prevent deforestation. Solar cooking is an efficient method that may save fuel and is environmentally beneficial. H. Zhou et al. [21] have introduced four types of solar cookers: box type, concentrating solar cooker, collector cooker, and panel cooker. The box type is often used; however it exhibits significant variations in thermal performance and needs frequent maintenance. The concentrating collector cookers have the capability to achieve elevated temperatures and expedite the cooking process [22]. However, they come with a substantial initial cost and necessitate specialized personnel to operate. The panel cookers have the ability to function as many cookers and are capable of reaching high operational temperatures. They depend heavily on reflected beams, resulting in significantly reduced performance under cloudy situations.

Mallikarjuna K et al. [23] conducted a study in 1996 to investigate the usage and significance of solar cookers in promoting social welfare. The study also involved experimental testing of the cooker, which was subsequently introduced to the community. The primary concern related to the implementation of solar cooking on a broad scale is the limited supply of solar energy, particularly during periods of low sunlight. Significant advancements in solar cooker performance have been made in recent years. However, this technique is not successful in enticing the end user to use it as the main energy source for cooking. This report thoroughly examines the current alterations and technologies incorporated with TES. The objective is to concentrate on the potential causes and remedies for problems related to solar cooking technology.

3.1. Global Scenario of the Solar Cooking

In 2018, around 2.65 billion individuals, which is almost one-third of the world population, and approximately half of the population in developing countries, lacked access to clean cooking facilities [24]. Simultaneously, it was approximated that there existed over 3.7 million solar entities worldwide. Appliances used for cooking. It is utilized by a total of 13.4 million individuals, facilitating the distribution of around 7 billion meals on a global scale. The potential of solar cooking is significant in terms of its environmental and economic impact on a global scale. The yearly output of solar thermal energy amounts to 228720 TJ, representing a mere 0.523% of the worldwide energy requirement. The global market value of solar cookers in 2019 was over $1845.0 million, and it is projected to quadruple by the end of

2026. Enhancements to solar cookers, such as greater performance, can be achieved through the implementation of government incentives, cheap tariffs, and the establishment of solar energy policies and laws. The global recognition of the environmental advantages and potential for energy conservation offered by solar cooking is widespread. The literature frequently reports the poor use and minimal influence on human lives of this. Solar cookers with a long lifespan can decrease environmental impact by as much as 65%, however solar cookers with a short lifespan might have negative consequences [25]. In order to ascertain the most recent trends, advantages, and influential recommendations for enhancing the solar cooker industry and technology, a comprehensive analysis of recent literature and its findings has been compiled and provided in Table 1. The current worldwide position of solar cooking indicates its significant potential for enhancing the quality of life for numerous individuals, particularly in places such as Africa and India. The significant environmental impact of this can lead to a substantial reduction in carbon emissions. The inadequate thermal efficiency and limited usage of solar cooking necessitate urgent efforts to enhance its technical, economic, and social viability, as recommended by several studies.

3.2. Status and need of Solar Cooking in India

Although India receives a significant amount of solar energy in most of its states, the implementation of solar energy systems is lower compared to Japan, Europe, and the USA. The availability of solar radiation varies throughout various areas. Fig. 1 depicts India. The solar energy potential for each state is displayed in Table 2. The rural areas of India have a significant potential for obtaining carbon credits. Household energy usage may be replaced by initiatives utilizing biogas, solar cookers, and solar photovoltaic cells. The projected estimate was between 15 and 22 million tons. In June 2015, India's power production from renewable energy sources amounted to 35776.96 MW, accounting for just 13.12% of the overall output. The state of Rajasthan in India has a significant potential of around 4.0-7.0 kWh/m2 area and has roughly 325-355 sunshine days each year. The state of Rajasthan in India is at the forefront in terms of its capacity for solar thermal energy [26].

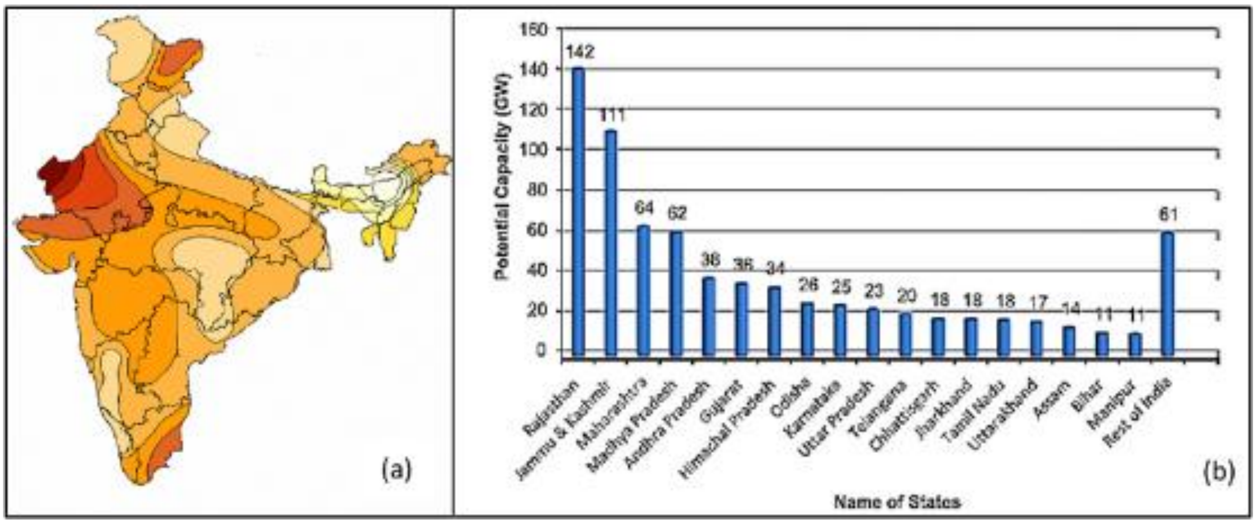

Figure 1 (a) Solar radiation intensity in India (b) State-wise solar energy potential in India [26]

The installation of solar projects faces a significant obstacle in terms of social acceptability. An increase in the temperature of the local area leads to conflict. This challenge can be surmounted by heightened consciousness, adherence to suitable standards, and effective management of financial constraints. The accessibility and appropriateness of land for every new technological endeavour are crucial factors in minimizing the overall expenses. This may encompass factors such as the local climate conditions, characteristics of the land, as well as any human or wildlife activities that may impact the site, all of which are taken into consideration while evaluating its appropriateness. Environmental factors such as wind speed, snow, floods, and earthquakes can disrupt and reduce the efficiency of solar systems.

Hence, it is important to take into account each of these elements when assessing the potential of any novel technology.

Vanish Kumar et al. [27] propose that solar energy is a viable and cost-effective alternative for many applications. Not only does it preserve traditional energy, but it also mitigates health risks and the emission of greenhouse gases. However, a significant portion of the rural people in India remains ignorant of these benefits. A research conducted by Dandan Han et al. [28] in the year 2000 examined the use of solar cookers among 28 families in Gujarat, India. An observation was made that among the 45,000 solar cookers sold; only 12% of the owners utilize them for a period of 7-9 months every year. The author proposed maintaining ongoing contact between cooker developers and end users to optimize productivity. Lulu Fan et al. [29] conducted an additional case study on cooking choices in rural parts of India. It promoted induction cooking as a substitute for traditional cooking methods. Approximately 4000 households in Himachal Pradesh were exposed to induction cooking. The total utilization demonstrated limited efficacy of induction stoves in reducing the consumption of firewood and LPG, despite a high level of electrification. This demonstrates the inherent intricacy involved in substituting the existing cooking techniques.

Solar cooking has been employed at select locations in India when there is a need to cook food for a big number of people. Nevertheless, the true use of solar cooking rests in its ability to supplant traditional cooking techniques. The consumption of solar energy in India is steadily growing each year, however, it remains relatively low in comparison to the country's solar potential, which is 748.98 GWp. Effective usage of energy resources in various states of India may lead to both economic growth and enhanced energy security. In India, there have been no successful endeavours to substitute the conventional 'chulhas' in rural families and certain metropolitan regions. There is a pressing need to create an alternative cooking method that can replace the use of wood or cow dung and become the major source of energy for cooking. Prior to the development and implementation of solar cooking units, it is essential to take into account the specific aspects that are relevant to the local context. This will ensure optimal use and widespread acceptance of the technology within the community.

Table 2 State-wise estimated solar energy potential in India [29]

State	**Solar Potential (GW$_p$)**	**State**	**Solar Potential (GW$_P$)**	**State**	**Solar Intensity (GW$_p$)**
Andhra Pradesh	38.44	Jammu & Kashmir	111.05	Odisha	25.78
Arunachal Pradesh	8.65	Jharkhand	18.18	Punjab	2.81
Assam	13.76	Karnataka	24.70	Rajasthan	142.31
Bihar	11.20	Kerala	6.11	Sikkim	4.94
Chhattisgarh	18.27	Madhya Pradesh	61.66	Tamil-Nadu	17.67
Delhi	2.05	Maharashtra	64.32	Telangana	20.41
Goa	0.88	Manipur	10.63	Tripura	2.08
Gujarat	35.77	Meghalaya	5.86	Uttar Pradesh	22.83
Haryana	4.56	Mizoram	9.09	Uttarakhand	16.80
Himachal Pradesh	33.84	Nagaland	7.29	West Bengal	6.26

3.3. Energy Storage Technologies

Energy storage is a crucial component of renewable energy, particularly in solar energy systems where there is an inconsistent supply of electricity. This section of the current research will concentrate on the utilization of TES media in solar cooking systems. Section 2.8 examines the utilization of LHTES (Latent Heat Thermal Energy Storage) in solar cooking equipment. Standalone solar thermal systems can achieve greater utility and efficiency by using thermal energy storage (TES) media. The integration of TES enhances the reliability of these systems [30]. To effectively resolve the problem of sporadic access to solar energy, energy storage techniques can be employed [31, 32]. The TES media have been utilized in many solar applications such as solar water heaters [33], solar air heaters [34], solar heat pumps [35, 36], solar stills [37], and solar cookers. This has enhanced the heat efficiency of the system, resulting in lower running expenses and enabling extended usage even when there is no sunlight available [38-40]. M.H. Chua et al. [41] studied and evaluated the utilization of several phase change materials (PCM) by researchers in solar cooking applications. They concluded that the incorporation of thermal energy storage (TES) in solar cooking is crucial for the widespread adoption of this technology. A novel solar cooker, constructed utilizing discarded packaging materials, was evaluated for its performance using various geometric configurations, including polyhedral, semi-cylindrical, bi-rectangular, and parabolic forms. The reflector with a parabolic shape had the maximum heating performance while maintaining the lowest level of complexity. The project aims to utilize waste materials in the development of a portable solar cooker for those residing in underdeveloped nations. J.K. Muiruri et al. [42] stated that the cooker has several functions, including heating, cooking meals, boiling water, and purifying water from rivers and lakes. The author also recommended doing a research on a TES-based solar cooker to expand its range of uses.

3.4. Use of Latent Heat Storage in Solar Cooking

The LHTES medium undergoes a phase shift at a specific temperature and has the capacity to store a significant quantity of thermal energy. S. Wang et al. [43] conducted a review on the solar cooker using LHTES. A proposal was made that utilizing a solar cooker equipped with thermal energy storage might offer a more effective alternative for cooking during the late hours of the night. It is advisable to utilize it liberally in order to provide a hygienic and improved cooking environment. LHTES/PCMs are widely used in solar energy applications. Wang, J et al. [44] have analyzed the most recent advancements in solar cookers and proposed the development of an indoor solar cooking unit to enhance its practicality. Abdulazeez T et al. [45] conducted a numerical investigation on a box type solar cooker using magnesium nitrate hexahydrate, stearic acid, acetamide, acetanilide, and erythritol. An investigation was conducted to examine the impact of the material and thickness of the heat exchanger container. The findings indicated that the thermal conductivity of the container material has an impact on the melting time of LHTES, although the thickness of the material is not important. In addition, the author proposed the utilization of stearic acid and acetamide within a box-shaped solar cooker.

The utility of LHTES in solar cooking has been established as highly advantageous in promoting an environmentally friendly and sustainable future. The utilization of paraffin wax in a solar dish collector, specifically with two concentric cylinders as demonstrated by S. Abdelrazik et al. [46], has been shown to enhance cooking efficiency. It decreases the duration of heating during hours when there is no sunlight.

Developed a distinctive design for a solar cooker that incorporates paraffin and erythritol between two coaxial pots. Paraffin exhibited superior heat retention compared to erythritol due to its increased thermal capacity. Nevertheless, the elevated melting point and enhanced conductivity of erythritol were shown to be beneficial for rapid cooking. The researchers, R. Kumar R et al. [47], conducted an experimental study on solar box cooking equipment that was combined with a jar holding 2500 g of erythritol. Four distinct load situations were examined, namely: no load, water load, silicone oil load, and silicone oil load containing erythritol. The study determined that the heating time for the oil with erythritol load was approximately 115% longer than that of silicone oil. The cooling time of the solar cooker increased by approximately 351%, resulting in thermal stability even when there was no sun radiation. S. L. Tariq et al. [48] conducted research on the impact of climate on the efficiency of solar cooking. A 5-10% increase in immediate efficiency was observed during the summer, whereas a 20-40% increase was observed in a colder environment. This indicates that the performance of the cooker was superior in areas with lower temperatures.

Table 3 presents the specifics of the several phase change materials (PCM) and latent heat thermal energy storage (LHTES) mediums that have been studied in relation to solar cooking systems. It includes information on their significant factors and results. The utilization of Latent Heat Thermal Energy Storage (LHTES) media for the purpose of energy storage is widely favoured and very practical. Many studies have found that solar cooking systems that are coupled with LHTES (Latent Heat Thermal Energy Storage) demonstrate quicker cooking times when operating at higher temperatures. The literature reports the availability of energy till night and the next morning. Erythritol and Acetamide are the predominant LHTES (Latent Heat Thermal Energy Storage) materials utilized in solar cooking systems.

The primary thermal properties of LHTES are its exceptional heat retention and efficient heat transmission capabilities. A significant enhancement in the potential for energy conservation and environmental advantages of solar cooking is shown when combined with LHTES media. The primary benefits of LHTES media are their capacity to harness solar energy and utilize it for cooking three meals in the kitchen.

Table 3 Latent heat thermal energy storage mediums used in solar cooking [48-54]

Storage Material Used	Type of Analysis /Investigation	Outcomes
Acetanilide	• Thermodynamic Analysis • Variable Cooking Load • Night Cooking	The temp. of PCM was 106 ∘C in the evening. Well cooked food in the evening using TES.
Erythritol	• Thermodynamic Analysis • Variable Cooking Load • Night Cooking	Maximum PCM temp. was 130 ∘C. Noon cooking does not affect evening cooking.
Magnesium nitrate hexahydrate	• Thermodynamic Analysis • Night Cooking • Design Parameters • Variable Cooking Load	Cooking can be done for special meals require low temperatures and high cooking time. Use of reflectors in solar collector enhance the incident radiation.
Paraffin and erythritol	• Thermodynamic Analysis • Comparative Analysis	Possibility of cooking three meals and the fourth meal next morning with TES. Paraffin performed better than erythritol.
Nitrate salt	• Thermodynamic Analysis • Comparative Analysis • Different food cooked	Potential of solar cooking for replacing the conventional cooking. TES systems are slower than conventional SCs. Quality of heat transfer is better in the system with TES.
Erythritol	• Heating tests • Comparative Analysis	(Heating) charging and (Cooling) discharging time of the PCM based cooking, both increased significantly. TES based system provides thermal stability to the cooking system during non-sunshine hours.
Galactitol	• Bulk Cycling of PCM • Temperature range for solar cooking	Only 90 thermal cycles at temperatures greater than 150 ∘C are feasible with Galactitol. Galactitol was found unstable and not useful for medium temp storage applications.
Aluminum and Oil based NaNO3 - KNO3	• Comparative Analysis • Temperature ranges	Oil-based storage is found better than Aluminum-based storage. Potential for frying and boiling of food.
Paraffin Wax	• Design Improvement • Temperature ranges	The optimum angle of the outer reflector is 30°C. Heating time was decreased by 1 hour.
Therminol 55 as HTF	• Temperature range • Application and Utility • Economic Analysis	Parallel and Series combination for HTF circulation was found useful. The simple payback period comes out to be 1.6 years only.
CaO/Ca(OH)2, Li2K(OH)3, Peritectics (Thermochemical)	• Temp. ranges • Costs • Utility	Innovative Peritectic heat storage was studied. SHS is widely used while LHS and TCES offer high storage capacity with low heat loss. Energy storage for temperature ranges from 40 ∘C to 1000 ∘C have been identified.
Benzoic acid (LHS) Stearic acid (LHS) Palm olein oil (SHS)	• Temp. and Heat Flux • Comparative Analysis	Benzoic acid produced the maximum heat flux among the three storage mediums. 80°C temp. was achieved under solar radiation and around 50°C was sustained without solar radiation.

Magnesium chloride hexahydrate	• Cooking Analysis • Thermodynamic Analysis • Application	The maximum temp. achieved by PCM was 130°C i.e. 12°C above the melting point. 32.66% of the energy stored above 100°C was utilized.
Solar Salt (53 wt% KNO3, 40 wt% NaNO2, 7 wt % NaNO3)	• Thermodynamic Analysis • Comparative Analysis	Thermal stabilization was improved with PCM. Heat retention was increased by 1.86 times as compared to the system without PCM.
Acetamide	• Cooking Analysis • Cost Analysis	Increase in the effectiveness with air flow rate. Airflow rate has a positive relationship with food temperature.

4. Socio-Economic Aspects

The reliance on environmentally harmful cooking methods significantly affects individuals' well-being. Advocating for the adoption of cleaner technology can significantly decrease the emission of pollutants that are linked to several ailments. The lack of consideration for the socio-economic environment throughout the development of solar cooking technology has resulted in its poor use [55]. It is important to focus the price, acceptability, and usage of these technologies. The cooking capacity of solar cookers is equivalent to that of LPG and electric cooking. Solar cookers appear to be more cost-effective than conventional cooking techniques. Several studies have demonstrated the cost-effectiveness and quick return on investment of solar cooking equipment, even when combined with energy storage. This demonstrates the potential of solar cooking as an affordable option. However, a comprehensive economic analysis is required to fully verify the viability of this technology.

4.1. Phase Change Materials: A Demand of Thermal Energy Storage

The use of PCMs in the field of energy efficiency has attracted more attention and emphasis in recent times from researchers. A lot of studies have been conducted to consider the theories, designs, and analyses of PCMs to store latent heat. These are a few of the classifications, kinds, and measures that are going to be addressed in the next paragraphs. Four distinct PCM kinds may be esteemed from one an additional based on their characteristics: solid-solid, solid-liquid, solid-gas, and liquid-gas. As observed in Fig.2, solid-liquid PCMs are the most ideal for storing thermal energy among these four categories. Other forms of PCM include OPCMs, IPCMs, and eutectics.

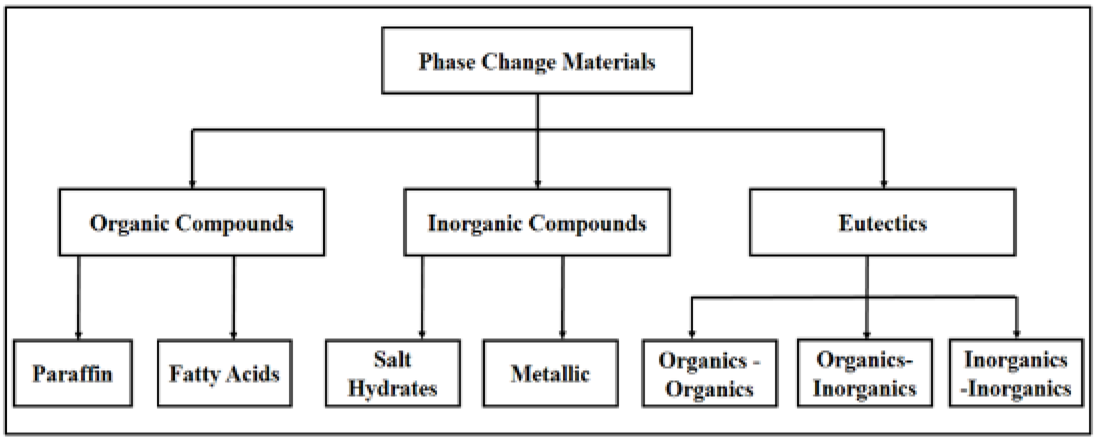

Figure 2 Categorization of PCMs [55]

Organic PCMs exhibit consistent performance and structural integrity, with no observable alterations such as phase separation, even after undergoing several phase change cycles. Furthermore, it is impossible to witness super cooling events in organic PCMs [56]. The categorization of organic PCMs is distinctive. This distinction mostly relies on their respective application environments. Usually, they are divided into two main parts: the first is paraffin, and the other one is non-paraffin. Paraffin is the predominant PCMs (PCMs), but non-paraffinic organic PCMs are recognized as the most extensively utilized groups. Aside from their distinct characteristics in comparison to paraffin, they exhibit very comparable qualities to one another. Scientists have employed many categories of ether, fatty acid, alcohol, and glycol as materials for storing thermal energy. These materials are often combustible and have lower oxidation resistance.

Non-paraffin organic PCMs possess a significant latent heat capacity. However, they are susceptible to drawbacks such as flammability, limited thermal conductivity, low combustion temperatures, and temporary toxicity. Fatty acids, glycols, poly-alcohols, and sugar alcohols are the mainly significant non-paraffinic PCMs. The primary characteristics of inorganic PCMs include a greater thermal conductivity and a large capacity for TES, which is about double that of organic PCMs [57]. They are commonly categorized as both metals and salt hydrates. Among the several inorganic PCMs used in LTES systems, salt hydrates stand out since the highest crucial. The combination of inorganic salts with water is recognized as a salt hydrate. Salt hydrates lose all or almost all of their water during phase shift, which is quite similar to the thermodynamic melting process in other materials.

Other components of inorganic PCMs include metals. Among metals' many benefits, their excellent mechanical qualities and strong heat conductivity stand out. Various metals are accessible throughout a broad melting point range. Further applications include high-temperature PCMs. Metals like zinc, magnesium, aluminum, etc. are used for high-temperature PCMs, whilst indium, cesium, gallium, etc. are utilized for low-temperature PCMs [58]. For very high-temperature systems, numerous metal alloys have been utilized that comprise melting points ranging from 400°C to 1000°C. You may find these metal alloys utilized in solar power systems as high-temperature PCMs. Additionally, they have use in businesses that deal with high-temperature reactors or furnaces that need to be regulated.

As many as two different kinds of phase transition materials are included within a eutectic. The field of eutectics possesses remarkable qualities. Eutectics have melting-solidification temperatures that are normally lower than those of their constituents and phase shifts do not affect the components' separation into their individual components. Because of this, the phenomena of phase partition and supercooling are not observed in these materials. A higher thermal cycle is often associated with eutectics in comparison to salt hydrates. Eutectics that are composed of inorganic and inorganic compounds are the most prevalent type. Also, organic-inorganic and organic-organic variations have garnered increased attention in current research investigations. The commercialization of eugenics is the most significant challenge that they face. Their costs are often up to three times higher than those of PCMs sold in stores [59].

There are a few PCMs that are dissimilar to paraffin in conditions of their latent heat capacity, Table 4, provide an overview of some of these PCMs along with their thermal characteristics.

Table 4 Thermophysical characteristics of various widely used PCMs with elevated Latent heat [60-64]

Type of PCMs		**Materials**	**Melting point (°C)**	**Latent heat (kJ/kg)**	**Density* (kg/m3)**	**Thermal conductivity (W/mK)**
Inorganic salt hydrates		$LiClO_3.3H_2O$	8	253	1720	
		$K_2HPO_4{\cdot}6H_2O$	14	109		
		$Mn(NO_3)_2{\cdot}6H_2O$	25.8	126	1600	
		$CaCl_2{\cdot}6H_2O$	29.8	191	1802	1.08
		$Na_2CO_3{\cdot}10H_2O$	32-34	246-267		
		$Na_2SO_4{\cdot}10H_2O$	32.4	248,254	1490	0.544
		$Na_2HPO_4{\cdot}12H_2O$	34-35	280	1522	0.514
		$FeCl_3{\cdot}6H_2O$	36-37	200,226	1820	
		$Na_2S_2O_3{\cdot}5H_2O$	48-49	200,220	1600	1.46
		$CH_3COONa.3H_2O$	58	226,265	1450	1.97
Non-paraffinic OPCMs	Fatty acids	Formic Acid	8.3	247	1220	
		n-Octanoic acid	16	149	910	0.148
		Lauric Acid	43.6	184.4	867	
		Palmitic Acid	61.3	198	989	0.162

		Stearic Acid	66.8	259	965	0.172
	Polyalcohols	Glycerin	18	199	1250	0.285
		PEG E600	22	127.2	1126	0.189
		PEG E6000	66	190	1212	
		Xylitol	95	236	1520	0.40
		Erythritol	119	338	1361	0.38
	Others	2-Pentadecanone	39	241		
		4-Heptadekanon	41	197		
		D-Lactic Acid	25-54	126,185	1220	
Eutectics	O-O, 0-I, I-I***	$CaCl_2.6H_2o+MgCl_2.6H_2O$	25	127	1590	
		$Mg(NO_3)_2.6H_2O+MgCl_2.6H_2O$	59	144	1630	0.51
		Trimethylolethane+urea	29.8	218		
		$CH_3COONa.3H_2O$+Urea(60:40)	31	226		
	Metals	Mg.Zn(72.28)	342	155	2850	
		Al.Mg.Zn(60:34:6)	450	329	2380	
		Al.Cu(82:18)	550	318	3170	
		Al-Si(87.8:12.2)	580	499	2620	

Due to its substantial ESC and properties such as a quick transfer of a significant quantity of heat to the application region, PCM is a suitable solution for solar heat storage. When compared to ordinary arrangements, the quantity of energy that is lost to the environment and the quantity of energy that is held at a temperature that is stable and that dissipates over time are both appreciably lower. During the charging phase, whenever energy is, the storage's temperature space material increases; during the discharging phase, while energy is discharged, the temperature falls. We may use Eq. [1] to find the storage capacity of a reasonable storage system:

$$Q_{sensible} = \int_{T_i}^{T_f} mC_p dT = mC_p\,(T_f - T_i\,)\text{…………..[1]}$$

2Where $Q_{sensible}$: Storage energy (J) , T_f = final Temperature (K) , T_i inital Temperature (K) , m= mass of the storing material (kg), C_p = Specific heat J/(Kg. K)

Lastly, LHS is the primary emphasis of this evaluation and the last route. The LHS makes utilize of phase-changing materials that undergo a limited degree of thermal energy exchange Fig. 3. The Eq. [2] that provides the capacity of the LHS system is provided below:

$$Q_{latent} = m\,[\,C_{ps}(T_m - T_i) + f\nabla_q + C_{pl}(T_i - T_m)\text{ ……..[2]}$$

Q_{latent} = storage capacity (J), T_m = melting temperature (K), m= mass of the storing material (kg),), $C_{ps} = Specificheatofsolidphase J/(Kg.K)$, $C_{pl} = Specificheatofliquidphase J/(Kg.K)$, f = melt fraction, ∇_q = latent heat of fusion (J/kg).

The term "PCMs" refers to the substances that are utilized in the storage mediums of LHS devices. Substances that undergo phase transitions are known as PCMs because they either release or absorb energy. While solid to gas and liquid to gas transitions offer a high energy transmit, they are seldom employed because of the huge volume shift that occurs during phase change. The phase transitions that are most normally used for heating, cooling, and domestic heat and water applications are solid to solid and solid to liquid [65].

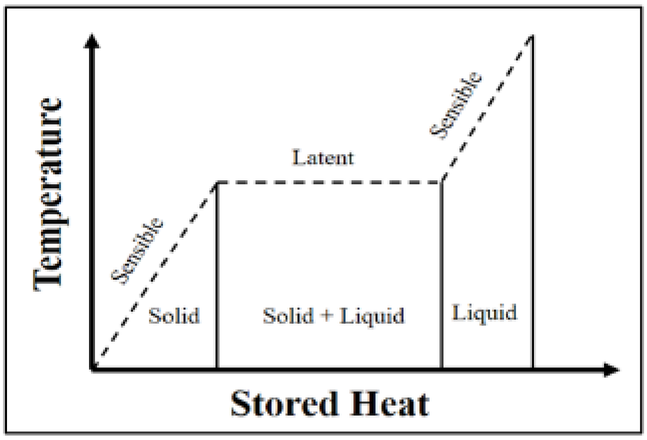

Figure 3 PCM temperature Vs stored heat for LHS system [65]

The PCM's chemical bonds dissolve during the phase transition from solid to liquid, which occurs when the temperature hits a critical point. As a result of its endothermic nature, PCM absorbs energy in the type of heat up in the phase change from solid to liquid. If PCM senses a temperature change of critical value when stored, it will begin to melt. From that point on, the temperature doesn't budge until the melting is fully complete. In a phase transition, LH is the heat that a PCM stores. One way to quantify latent heat retention is by looking at the energy density. By utilizing SH and LH from the exothermic solidification process, the stored energy is once again transported to the crucial area of interest when the temperature begins to decrease as shown in Fig 3.

It is necessary for the temperature of the phase change to be tailored to the specific requirements of each application to assemble the operational demands of those applications. The temperature range of PCMs and applications is shown in Fig 4. The four basic temperature ranges where PCMs operate are as follows. When operating in the first temperature range, which is around 20°C to 5°C, PCMs are usually employed for cooling and refrigeration in homes and businesses. In the second temperature range, which is commonly between 5°C and 40°C, PCMs are used for cooling and heating purposes in buildings [66]. For solar-based heating, hot water production, and electrical applications, PCMs in the third temperature range (+40 °C to +80 °C) are often employed. This covers the ultimate temperature range, which is +80°C to +1200 °C; PCMs find usage in absorption cooling, waste heat improvement, and concentrated solar applications.

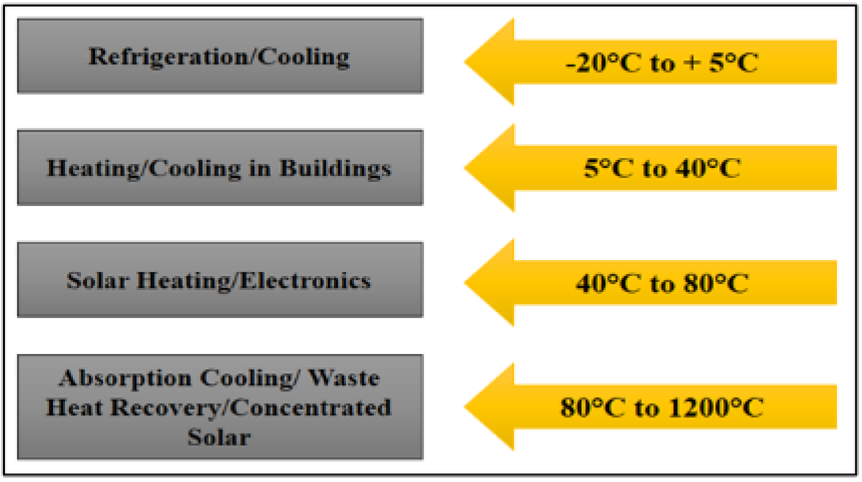

Figure 4 Temperature range of PCM and applications [66]

4.1.1. Required PCM Properties

When designing a thermal storage arrangement, the PCM should have the desired thermo-physical, kinetic, and chemical characteristics.

4.1.2. Thermo Physical Properties

- Optimal melting point within the targeted operational temperature range

- A high LH of fusion content per volume.
- High specific heat to facilitate enormous SHS.
- In solid as well as liquid phases, highly conductive to heat.
- Variations in volume during phase transition and variations in vapor pressure at operating temperatures are negligible,
- Keeping the material's storage capacity constant throughout each freezing and melting cycle requires phase transition materials to melt precisely at the same rate.

4.1.3. Kinetic Properties

- In order to prevent the liquid phase from becoming too cooled, a high nucleation rate is required.
- In order for the system to be able to accomplish the desires of heat recovery from the storage system, a high percentage of crystal development is required.

4.1.4. Chemical Properties

- The stability of chemicals.
- Finish a cycle of reversible freezing and melting.
- A high number of freeze-thaw cycles do not cause deterioration.
- Low cost and non-corrosive to building materials.
- To ensure safety, the materials must not be poisonous, combustible, or explosive.

4.1.5. Material Characteristics

- The unit size should be small.
- Desired low vapour pressure.

4.1.6. Economic Characteristics

- Cheap and large availability.

4.1.7. Selection Criteria for PCM in Solar Cooker Application.

- Installation in a solar cooker necessitates temperatures between 60°C and 120°C, thus it must have critical temperatures within this range.
- The amount of PCM needed can be reduced if it can obtain a high LH of fusion per unit mass.
- An extremely high specific temperature is required of PCM in order to provide optimal sensible heat retention.
- In order to shorten the time it takes to charge and discharge, PCM materials need to have good thermal conductivity.
- During phase transitions, it should have tiny shrinkage coefficients and minimal volumetric expansion.

4.1.8. Challenges in Using PCM Material in Solar Cookers

- The use of PCM increases the overall weight of the solar cooker by 10 kg, making it less portable.
- It makes installing a solar cooker more expensive.
- It is a difficult and laborious process to empty or replenish the PCM storage tank.
- The presence of PCM increases the stored heat within the box, making it imperative to wear gloves when handling pots.
- For real-world use, certain Thermal Energy Storage has extremely low stability and lifetime.

There has been a lot of effort on developing a thermal system that stores heat during the day for use at night, especially for solar cooking. Although PCMs have weak thermal conductivity, which slows down the flow of heat transmission, using a lot of them is impractical [106]. Therefore, during transitions between phases, PCM should be included in a specific method to avoid a sharp decrease in heat exchange rates.

For underdeveloped nations, cooking is the most important energy consumer. The world's problems with finite fuel sources and carbon dioxide emissions may find a solution with solar cookers. To make solar cookers a mainstream alternative to conventional stoves, further studies are required. A decrease in carbon dioxide emissions and an enhancement in the usage of RES are two ways in which solar cookers may benefit the environment. Some societal prerequisites, in addition to economic and performance constraints, are necessary for full commercialization and widespread use. Additionally, solar cookers have the drawback of being ineffective on overcast days or throughout the night, rendering them useless [67]. For this reason, solar cookers need heat storage capabilities to get around these problems and make them work even when the sun isn't shining. To make solar cookers a reality and ready for commercialization, PCM research and marketing campaigns are required.

5. Role of Nano Fluid

The utilization of nanofluids in the extraction of solar energy has been widely implemented in the ongoing advancements of solar energy systems. The dispersion of nanoparticles in the base fluid is a well-established method for improving the pertinent characteristics of the liquid. A nanofluid is a combination of tiny particles that are spread out inside a liquid foundation. It has a greater thermal conductivity than the base fluid. Atul A. Sagade et al. [68] explored the difficulties encountered while implementing nanotechnology in solar applications. The primary challenges observed in the fabrication of nanofluids were the stability of the nanoparticles suspension and related issues. Nevertheless, the primary driving force behind the use of these fluids is the significant increase in efficiency, which is close to 10%. C.V. Papade et al. [69] explored the advantages and difficulties of utilizing nanofluids. The necessity of thoroughly discussing and analyzing nanofluids, specifically focusing on techno-economic analysis and stability at elevated temperatures, has been determined.

Several recent studies have shown that the utilization of nanofluids may greatly enhance the efficiency of solar thermal energy systems [70-71]. Nevertheless, in order to get the intended outcomes, it is imperative to optimize the form, size, and substance of nanoparticles. An experimental study was conducted on a nanofluid-based indirect solar cooker. It was shown that using a 0.5% weight concentration of nanofluid resulted in a shorter boiling time and higher exergy efficiency for solar cooking [72]. The author proposed the concurrent utilization of nanofluid and phase change materials (PCMs) in solar cookers. Ashok k., Sudhir et al. [73] conducted a study on the utilization of thermal oil and thermal oil based nanofluids in a solar cooker. An assessment was conducted to determine the energy and exergy efficiency. According to the paper, the SiC-oil nanofluid improves energy efficiency by 4.27% in comparison to thermal oil. A. Weldu, L et al. [74] used metallic wires containing nanographene to improve the performance of an evacuated tube solar cooker that uses thermal oil. The findings indicated that the inclusion of copper wires with certain quantities enhances the rate of heat transmission, but the utilization of nanographene particles reduces it. The use of nanofluids in solar thermal applications yields a beneficial impact on the overall performance. Nanofluids are mostly used in solar water heaters. Only a limited number of studies [75-77] have investigated the use of nanofluids in solar cooking, and these studies have shown promising results comparable to those achieved with solar water heaters. The researchers are always faced with the task of maintaining stability and adhering to techno-economic constraints. A few illustrative instances are mentioned in Table 5, but there is a lot of more **nanofluid recorded in recent literature.**

Table 5 Application of nanofluid in solar cookers [78-88]

Type of the Solar Cooker	**Type of nanofluid**	**Results**	**Author Name and Ref.**	
Box type Solar cooker	Al_2O_3	A 0.2% weight fraction resulted in a 28% improvement in efficiency.	S. Gorjian et al. [78]	
Parabolic Cooker	Multi-walled carbon nanotubes	Reduced collector efficiency was observed at a weight fraction of 0.2%.	H. Wang et al. [79]	
Tube type Solar cooker	Al_2O_3	Nanofluids have a 7% improvement in thermal conductivity and a 25% improvement in the convective heat transfer coefficient.	S. Awani et al. [80]	
Concentrati-ng Cooker	TiO_2	There was a 2.6% to 7% improvement in solar collector efficiency when compared to using the base fluid.	G. Wheatley et al. [81]	
Panel cooker	SiO_2	An 8% improvement in thermal efficiency was achieved with a 1% content.	K. Dileep et al. [82]	
Box cooker	CuO, TiO_2, SiO_2, and Al_2O_3	Improved thermal efficiency is achieved by reducing specific heat while increasing nanofluid density. Because of this, CuO is the optimal choice for achieving peak efficiency.	B.M.S. Punniakodi et al. [83]	

Indirect Concentraing cooker	CuO/Oil	Compared to oil as the basis fluid, CuO/Oil nanofluid has better absorption.	R. Chargui et al. [84]	
Panel cooker	Al_2O_3/ Synthetic oil	The distortion of the absorber reduces as the concentration of the particle size increases.	A.K. Pandey et al. [85]	
Parabolic, cookers	Cu/H_2O	Thermal efficiency improves for both collectors as absorbed radiation rises.	A.S. Manirathnam et al. [86]	
Box cooker	Multi-walled carbon Nanotube/water	Using nanofluid instead of the base fluid improved the collector's efficiency by nearly 4%.	Y. Addad et al. [87]	
Panel cooker	Single-walled carbon nanotube	A higher mass flow rate is associated with an improvement in efficiency, as is an increase in the volume fraction of nanoparticles.	S.M. Shalaby et al. [88]	

As an end of the numerous models that were built by researchers, a great number of tests have been conceded to contrast these analytical models with the solar cooking experiment results. When it comes to measuring the approximate performance of SC, there are just a few types that can be measured. Some works on TES medium used in different solar cookers is listed below in Table 6 with their results.

Table 6 Studies on Thermal energy storage medium [89-98]

Ref.	**Cooker Type**	**TESM Used**	**Key Finding**
M.J. Alshukri et al. [89]	BTSC	Paraffin Wax	The payback of the cooker was 7.87 year reducing a carbon footprint of 80.541kg CO_2/year
Mohammad Hosseinzadeh et al. [90]	Parabolic type	Sunflower oil & Erythritol	The erythritol pot had a higher heat consumption efficiency (4.8–14.3%) than the sunflower pot (3.7– 6.0%).
Mohammad Hosseinzadeh et al. [91]	Indirect concentric parabolic type	Hydrated salt that melts at 110°C-118°C	Receiver assembly takes approximately 50 min to store desired amount of energy to cook food.
Sasikumar, S. et al. [92]	BTSC	Bayburt stone	Bayburt stone as a TESM significantly enhance the performance of the oven.
Evangelos Bellos et al. [93]	Parabolic dish collector	Acetanilide	PCM's thermal energy storage capacity improves Intensely (i.e. 19.45%–30.38%)
A. Mohandass Gandhi et al. [94]	BTSC	Acetanilide	An enhancement in the cooking energy and the optical performance of about 91% and 124.4% is recorded.
K. Mallikarjuna et al. [95]	Double Glazed BTSC	Acetanilide	The cooking is possible even during the night.
Mohammad Hosseinzadeh et al. [96]	Solar vacuum tubular oven	Solar salt composed of an eutectic mixture of 60% $NaNO_3$-40% KNO_3	The temperature of solar oven increased by30°C– 80°C by using PCM than oven without PCM.
L. Syam Sundar et al. [97]	Parabolic Solar collector	Oxalic acid	If proper insulation provided the PCM can store energy for long hours.

Talugeri, V et al. [98]	Parabolic Solar collector	Nano mixed phase change material	Enhance cooking at night time using nano mixed PCM.

6. PCMs with Graphene-based Materials

Table 7, presents an overview of the research mentioned in this section about nanoparticulate graphene-based fillers for PCCs. High-performance PCCs may be created by directly including graphene, GO, and rGO. Graphene has superior porosity structure compared to other carbon-based materials like CNT and EG. This is attributed to its two-dimensional structure, which results in a large surface area and uniform pore size. Additionally, graphene boasts excellent chemical and thermal stability, and can also contribute to the shape stability of PCMs. The thermal conductivity of graphene-based nano-particulate fillers is compared to that of n-alkanes. It is shown that the thermal conductivity of alkane-doped phase change materials (PCMs) is not sufficiently high for practical applications, despite the presence of a long carbon chain. Incorporating graphene nano-fillers can significantly enhance the thermal conductivity of PCMs. However, due to the propensity of graphene nano-sheets to form clusters, achieving a uniform dispersion of graphene nano-sheets when combined with PCMs is a difficult task. As a result, there was a significant surge in interest in GO and rGO nano-sheets. These nanosheets could be disseminated more effectively and processed in a water-based solution. However, a disadvantage of GO is its decreased thermal and electrical conductivity, which is caused by the reduced presence of sp2-carbon in the basal plane. Furthermore, the impact of graphene and its derivatives on the crystallinity of PCMs can either enhance or diminish the energy storage capacity of graphene-based PCCs.

Table 7 Summary of the thermal properties of PCM / graphene-based aerogel PCCs [99-108]

PCC	GO (mg/ mL)	Melting Temperature (℃)	Melting Enthalpy (J/g)	Solidifying Temperature (℃)	Thermal Conductivity (W/m K)
Paraffin	-	-	207.9	-	-
Paraffin/GA	12	-	-	-	-
Paraffin/GA	16	-	222.5	-	0.81
Paraffin/rGO/ BN	-	55.9	145.2	48.7	-
Paraffin/rGO/ BN	-	55.6	141.6	48.8	-
Paraffin/rGO/ BN	-	55.7	126.5	48.7	1.68
PA60	-	60.0	204.1	-	~3.00
PA70	-	72.2	266.1	-	~3.00
PA80	-	80.0	221.3	-	~3.00
PA90	-	92.0	213.3	-	~3.00
PA60/GA/CF	30	-	133.6	-	~3.00
PA70/GA/CF	30	-	174.6	-	~3.00
PA80/GA/CF	30	-	144.0	-	~3.00
PA90/GA/CF	30	-	140.7	-	~3.00
PW/GnP aerogel/MF/ CNF	-	52.4	147.9	-	1.42
PEG-4000	-	61.1	171.6	41.5	-
PEG-4000/GA	-	61.9	148.5	41.1	-

PEG-4000/ LGA0.5	-	61.0	165.8	41.2	-
PEG-4000/ LGA1.0	-	61.0	168.1	42.0	-
PEG-4000/ LGA1.5	-	61.1	168.7	41.9	-
PEG-10000	-	63.2	154.8	43.2	0.38
PEG-10000/GO aerogel	9	62.7	150.2	42.5	~0.69
PEG-10000/GO aerogel/CNT/ CS	9	62.1	148.4	41.9	~1.07
PEG-10000	-	64.2	182.9	40.8	-
PEG-10000/GO aerogel	20	68.1	199.6	40.3	-
PEG-10000/GO aerogel	40	66.8	173.7	40.2	-
PW	-	55.9	176.7	45.6	-
PW/rGO aerogel	5	56.8	110.9	47.6	0.35

7. Current Issues and Challenges related to Phase Change Material

7.1. The PCMs' Thermal Stability over the Long Period and Associated Issues

Since PCMs do not possess the desired thermo-physical characteristics, their commercialization as LHS systems has not been successful. A big problem with PCMs is that there is no data available on how the thermos-physical characteristics change for the reason of the long temperature cycles. Phase segregation, incongruent melting, impurities, chemical alteration, new compound synthesis, moisture absorption, and other difficulties can lead to variations in thermo-physical characteristics. Multiple heat cycles may cause the PCMs to deteriorate. No PCM is ideal if its thermo-physical characteristics deviate significantly. Reliability of the PCM is defined as the degree to which its physical, chemical, and thermal characteristics remain unchanged following a battery of thermal cycle tests. Even after undergoing several temperature cycles, its qualities, such melting point and latent heat of fusion, shouldn't degrade [109].

7.2. Problems Dealing with Improving the Thermo-Physical Characteristics of PCMs

Low heat conductivity is a big problem with PCMs. The thermal conductivity of paraffin wax is typically 0.19 to 0.35W/mK. This irregularity manifests as temperature decreases in several areas during the energy withdrawal or retrieval process as a result of poor thermal conductivity [110]. This causes the phase transition process (solidification/melting) to occur at an undesirable rate. Simply put, the system is unable to utilize the energy at the desired pace, even if it is accessible to it. When it comes to the thermal system's overall performance, the PCM's improved thermal conductivity is crucial. Adding nanoparticles (nanopowders, nanowires, nanotubes), impregnation, or fin structures are a few of the several methods that might improve the thermal conductivity of the basic PCM. Improving thermal conductivity speeds up the PCM's melting rate, hence this is crucial. Nanoparticles raise the solidification point and decrease the beginning melting. The use of nanoparticles shortens the melting time and makes the basic PCM more thermally uniform. There is evidence that nanoparticle addition increases PCM dynamic viscosity, which mitigates convective heat transfer. The utilize of nanoparticles increases stability with admiration to the melting/solidification cycle, which is another readily apparent benefit. Metals, oxides, and carbon-based compounds make up the bulk of nanoparticles utilized in energy-related applications [111].

8. Research Gap

The current status suggests that a unique approach is required for utilization of the solar energy in cooking, as the research done till date is not able to bring the necessary changes in human life and society.

- The current status suggests that a unique approach is required for utilization of the solar energy in cooking, as the research done to date is not able to bring the necessary changes in human life and society.
- Modifications are required to make solar cooking more useful and less weather-dependent
- BTSCs are mostly used but have limited applications.
- Concentrating cookers produce higher temperatures and faster cooking but are not economical
- The economic feasibility of solar cooking devices with TES is an essential topic that has not been addressed in most of the considered studies.
- An innovative approach is required in solar cooking to increase its usefulness and affordability.
- Modifications are required to make solar cooking more useful and less weather-dependent.
- The priorities of developing solar cooking technology should be set from the viewpoint of the target population. Giving emphasis only on the technical improvement and ignoring the adaptation is a big reason why solar cookers have not been adopted in the field.
- Solar cookers should be designed based on the end user's needs and some financial support must be provided to the rural population to increase its affordability.
- All these factors must be addressed in chorus to enhance the usefulness and adaptability of solar cooking. The most important factor overlooked in many studies is the energy economics. If the solar cooking system is not more economical than the existing cooking system, it can never be established as the primary energy source for cooking.
- Most of the research work focuses on the improvement in the solar collection technology by improving the geometry or focusing on the energy storage mediums. The use of TES has proved to be necessary for the uninterrupted use of solar thermal energy in cooking.

9. Conclusion

A comprehensive analysis of PCMs for solar cooking has covered a lot of ground in provisions of its coverage. To have a solid consideration of the value of PCMs as elements is of the utmost significance. Not a single component is excellent in every aspect. Along similar segments, paraffin is not without drawbacks, the most significant of which is the fact that it has an exceptionally low level of thermal conductivity. It is necessary to combine PCMs with other nano-particles and nano-fluid directly to get better the thermal storage capabilities of each of these materials. Several nano-particles and nano-fluids have been studied in depth, with their benefits and, drawbacks have been analyzed and discussed in detail. There is a tabulation that has been ended that shows the impact that nano-particles and nano-fluid, in addition to a few of the significant PCMs, have on the TES. Before alloying nano-particles with PCMs, it is main to remember that just a limited number of nano-particles are compatible with PCMs. As a result, comprehensive research on a wide range of elements is performed. In conclusion, a discussion has been held on the numerous structural uses of PCM the in framework of the context of the thermal energy storage sectors, in addition to their growth prospects and limits. As the above issues were thoroughly investigated, they think that this thorough study on PCM and their applications will be helpful to upcoming researchers and pave the way for advancements in the market of solar cooking.

Compliance with ethical standards

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Disclosure of conflict of interest

There is no conflict of interest with any financial organization regarding the material discussed in the article.

Data availability

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

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