International Journal of Research and Innovation in Engineering Technology
Volume: 05 Issue: 09

ISSN: 2394 – 4854
Pages: 19 – 26

IJRIET

A REVIEW ON THERMAL ENERGY STORAGE MATERIALS FOR SOLAR COOKING

Karthick.C[1], Dr. S. Sivalakshmi[2]
[1]PG Scholar, Department of Mechanical Engineering, GCE, Salem
[2]Assistant Professor, Department of Mechanical Engineering GCE, Salem
E-mail-ID: [1]clkarthi@gmail.com, [2]sivalakshmit@gmail.com

Received 11 January 2019, Revised 01 March 2019, Accepted 04 March 2019
Available online 11 March 2019

Abstract

In this 21st century world, the requirement for energy is very high and cooking is the important process for the people to prepare food. It consumes more share of energy in developing countries. So, there is a critical need for the invention or development of alternative, suitable and economical methods of cooking. To reach the demands for further need of energy, solar is the best energy source to accomplish the energy requirements with eco-friendly to nature. The solar thermal collectors using heat storage materials absorb the solar energy and delivers constant heat for the cooking application. This review covers the various solar cooking techniques with different heat storage materials.

Keywords*:* Solar cooking, Phase change materials, Thermal energy storage.

1. INTRODUCTION

In developing countries, 730 million tonnes of biomass is burned each year for cooking, amounting to more than 1 billion tonnes of CO_2 build-up in the atmosphere. Unfortunately there are still millions of people whose deaths are attributed to diseases resulting from smoke inhalation from open cooking fires. Moreover the cutting of firewood for cooking purpose causes deforestation, leading to desertification. Hence, the 'Cook without Wood' i.e. solar cooking is considered the best solution to not only reduce public health risks, but also curtail global warming.

In India wood, agriculture wastes, animal dung cake are the main energy sources for cooking in rural areas and kerosene and liquid petroleum gas (LPG) are main energy sources in urban areas. The cutting of firewood causes deforestization that leads to desertification and use of animal dung cakes pollute the environment. Also, the continuous increase in fuel price and demand for fuel availability indicates that there is an urgent need to utilize the various sources of renewable energy in an effective way for cooking purpose. Fortunately, India is blessed with large amount of solar radiation. Hence, solar cookers have good potential in India. Solar cookers without thermal storage has a limitation of cooking can only be done during sunshine hours. To overcome that limitation solar cookers are provided with thermal storage medium, then only there is possibility of cooking food during off sunshine hours also.

Panwara [1] reviewed on renewable energy sources in environment protection and suggested that solar energy is eco-friendly energy source will not affect climate conditions, human health. But unlike fossil fuel and some other energy sources, which releases green air gases such as CO_2, CH_4, N_2O, and CFCS raising Earth's surface temperature. Major renewable energy gadgets for domestic and industrial applications such as solar water heaters, solar cookers, dryers, wind energy, biogas technology, biomass gasifiers, improved solar cooking systems and biodiesel was made. The use of solar drying of agricultural produce has good potential for energy conversion in the world. The improved solar cooking systems provide better kitchen environment to rural area people and reduces fuel collection burden for them. Atul Sharma [2] reviews applications of a latent heat storage system with phase change materials (PCMs) for an efficient storage of thermal energy also summarizes the investigation and analysis of the available thermal energy storage (TES) systems incorporates with PCMs for different applications. With the storage unit, food can be cooked at late evening, while late evening cooking was not possible with a normal solar cooker. So that, solar cooker with storage unit is very beneficial for the humans and as well as for the energy conservation. This paper presents the past and current research in this particular field of energy storage for solar cookers. Klemens Schwarzer [3] reviewed on solar cooking system with or without heat storage for families and institutions. The solar cooker price is too high and it can only be reduced when a large number of units are manufactured, reducing fabrication costs. Production of just a few units is not cost effective and they should be made in the country where the cookers are to be installed. The large-scale use of solar cookers can only be possible through the development with financial aid. Without this financial assistance, large-scale use of solar cookers in developing countries cannot be made possible. Under these conditions, the described solar cookers have a very good chance for large-scale use in various applications, such as in large families, schools, hospital, food stations, etc. Previous review on solar cookers with and without thermal storage from the review the following conclusions are made. Cooking process requires 36% energy of total primary energy consumption in India. So, there is a critical need for the development of alternative, appropriate, suitable mode of cooking for use in developing countries like India. Thermal energy storage is essential because there is a mismatch between the supply and consumption of energy. Latent heat energy storage in a Phase change material is very attractive because of its high storage density with small temperature swing. For noon meal cooking Box type solar cookers and solar steam cookers are suggested for off- sunshine hours even without thermal storage system. However, a suitable indoor cooking unit for all time cooking similar to the conventional mode is yet to be developed. In the present investigation, the possibility of designing a modular indoor kitchen for commercial and residential application is reported [4].

2. HEAT STORAGE MATERIALS

In this work, the solar cookers reviewed with sensible heat materials and latent heat materials. Sensible heat material stores the only sensible heat but latent heat materials stores both combined sensible and latent heat energies. Properties of these storage materials that were used for different cooking are discussed below.

2.1 Sensible Heat Storage Materials

Materials used for storing heat by increasing the temperature of the material known as sensible heat storage materials. Most commonly used sensible heat storage materials are water, oils and inorganic molten salts derivatives of alcohol. A list of solid and liquid sensible heat storage materials used for sensible heat storage along with their properties is presented in Table 1 [5]. Water is the ideal choice for many low temperature requirements which is below 100°c. Oils are used for intermediate temperature requirements ranging from 100°c to 300°c. Molten and inorganic salts have been considered for high temperature storage application which requires temperature above 250°c. Advantages of using molten salts are high thermal stability relatively low material cost, high heat capacity, high density, non-flammability and low vapour pressure. Liquids, solids and solid – liquid mixtures were used as sensible heat storage materials in TES of solar cookers. Coconut oil and Engine oil were the liquids employed as liquid sensible heat materials.

For sensible heat storage in high temperature application like power production in solar power plants, a non-eutectic molten salt mixture consisting of 60 wt% sodium nitrate ($NaNO_3$) and 40 wt% potassium nitrate (KNO_3) is used. This mixture is commonly known as "solar salt." Because of the increased amount of $NaNO_3$ as compared with the eutectic mixture, the material costs can be reduced. This non-eutectic mixture has a melting temperature of approximately 240°c and the temperature limit for thermal stability is approximately 550°c. The commonly used solid storage materials are rocks, bricks, pebbles, and refractory material/refractory bricks, concrete, dry and wet earth/soil, iron, wood, plasterboard, and corkboard. In general, solids exhibit a lower storing capacity than water. However, the cost of the storage media per unit energy stored is still acceptable for rocks [6].

Medium	Density ρ (kg/m^3)	Specific Heat Capacity, C (J/kg K)	Heat Capacity ρc*10^{-6} (J/m^3 K)
Aluminium	2707	896	2.4255
Brick	1698	840	1.4263
Cast Iron	7900	837	6.6123
Clay	1458	879	1.2815
Calcium chloride	2510	670	1.6817
Copper	8954	383	3.4294
Graphite	2200	879	1.9338
Sandstone	2200	712	1.5664
Soil clay	1450	880	1.2760
Steel, limestone	2500	900	2.2500
Wood	700	2390	1.6730
Engine oil	888	1880	1.6694
Ethanol	790	2400	1.8960
Ethylene glycol	1116	2382	2.6583
Hitec molten salt	1680	1560	2.6208
Isobutanol	808	3000	2.4240
Isopentanol	831	2200	1.8282
Lithium	510	4190	2.1369
Propanol	800	2500	2.0000
Therminol66	750	2100	1.5750
Water	1000	4190	4.1900

Table: 1 Properties of various sensible heat storage materials

2.2 Latent Heat Storage Materials

2.2.1. Thermal properties

(i) Suitable phase-transition temperature.

(ii) High latent heat of transition.

(iii) Good heat transfer.

While selecting a PCM for cooking application, the operating temperature of the heating should be matched to the transition temperature of the PCM. The latent heat should be as high as possible, especially on a volumetric basis, to reduce the physical size of the heat store. High thermal conductivity would assist for the charging and discharging of the energy storage.

2.2.2. Physical properties

(i) High density.

(ii) Favorable phase equilibrium.

(iii) Small volume change.

(iv) Low vapor pressure.

Phase changing stability during freezing and melting would help towards setting heat storage and high density is suitable to allow a smaller size of storage container. Small volume changes on phase transformation and small vapor pressure at operating temperatures to reduce the containment problem.

2.2.3. Kinetic properties

(i) No supercooling.

(ii) Sufficient crystallization rate.

Supercooling makes a trouble for the development of PCM, particularly for salt hydrates. Supercooling of more than a few degrees will interfere with proper heat extraction from the storage medium, and 5–10°C supercooling can prevent it entirely.

2.2.4. Chemical properties

(i) Long-term chemical stability.

(ii) Compatibility with materials of construction.

(iii) No toxicity.

PCM can suffer from degradation by loss of water of hydration, chemical decomposition or incompatibility with materials of construction. PCMs should be non-toxic, nonflammable and non-explosive for safety.

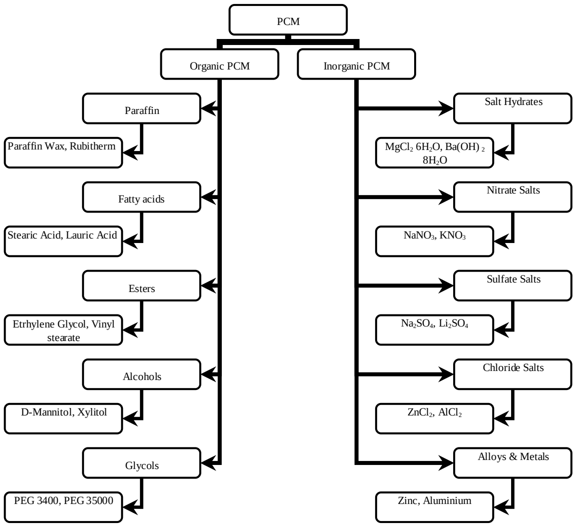

Figure: 1 Tree diagram showing classification of Phase Change Materials

3.TYPES OF LATENT HEAT STORAGE MATERIALS

Some commonly used latent heat materials are Acetanilide, Acetamide, Erythritol, Paraffin wax and Stearic acid. On the other hand Magnesium chloride hexahydrate, sugar alcohols and some other inorganic PCM also experimented as a latent heat material for solar cooking. Latent heat enthalpy of organic PCM was higher, but phase change temperature of organic PCM was less than 120°c. Figure 1 provides a detailed list of classification of phase change materials and the properties of these PCMs were studied by Guruprasad Alva [7].

3.1. Erythritol

A prototype of an evacuated tube solar collector with Erythritol (melting point 118.8°c, latent heat of fusion 339.8kJ/kg) of 45kg as a phase change material was designed by Sharma [8]. The prototype consists of an ETSC with water as heat transfer fluid (HTF), a PCM storage unit, cooking unit, pump and stainless steel tubular heat exchanger. Erythritol filled in a storage unit has two hollow concentric aluminium cylinders of 304 and 441 mm inner and outer diameters respectively and 420 mm deep with 9 mm thickness. The heated water (HTF) circulated by the pump from the ETSC through the insulated pipes to the PCM storage unit by closed loop. During sunshine hours, heat transferred from heated water to the PCM and stored in the form of latent heat. To cook the food in the evening time or when sun intensity is not sufficient to cook the food the stored energy were used. From the experiment they concluded that two times cooking (noon and evening) is possible in a day. Noon cooking did not affect the cooking in the evening and evening cooking using PCM storage was found faster than noon cooking.

Antonia Lecuona [9] reviews relevant issues on solar cooking by evaluating an innovative layout of concentrating parabolic type with a thermal storage. Two options of PCM have been checked as possible are technical grade paraffin and Erythritol. To expand the applicability and possibility of solar cooking on all day with low inventory cost an insulating box used, which allows cooking the dinner with the retained heat and also the next day breakfast.

3.2. Stearic acid

Buddhi and Sahoo [10] fabricated and tested a box type solar cooker with latent heat storage for composite climatic conditions of India to cook food in the late evening. In this design, the phase change material (PCM), Commercial grade Stearic acid (melting point 55.8°c, latent heat of fusion 161kJ/kg) was filled below the absorbing plate. During the discharging mode of PCM the rate of heat transfer from the PCM to the cooking pot is slow and more time is required for cooking food in the off-sunshine hours. They reported that the results could have been better if the cooker was well insulated from the top and bottom and more insulation would also help in reducing the storage size.

3.3 Magnesium nitrate hexahydrate

A novel indirect solar cooker were developed by Hussain with outdoor elliptical cross-section, heat pipes, flat-plate solar collector with an integrated indoor PCM thermal storage using magnesium nitrate hexahydrate (melting temperature 89°C, latent heat of fusion 134kJ/kg) as a PCM and cooking unit. It is analyzed that the average daily solar radiation incident on the collector surface enhanced by the south and north facing reflectors is about 24%. Initially experiments have been performed on the solar cooker at without load condition. Then experiments performed with different loads at different loading times to analyze the benefits of the elliptical cross-section wickless heat pipes and PCMs in indirect solar cookers to cook and keep the food warm at night and in early morning. The results indicate that the present solar cooker can be used for cooking meals at noon and evening times, while it can be used for heating or keeping meals warm at night and early morning [11].

3.4. Acetamide

Sharma [12] designed and developed a cylindrical latent heat storage unit for the cooking pot to cook the food in the late evening with box solar cooker. The cooking vessel is surrounded by the PCM for faster cooking and to increase the rate of heat transfer between the PCM and the food. For this purpose, the PCM container and cooking vessel, a double glazed box type solar cooker with reflector having 50x50 cm aperture area and 15 cm deep was used. PCM container has two hollow concentric aluminum cylinders of diameter 18 and 25 cm and is 8 cm deep with 2 mm thickness. The space between the cylinders is filled with Acetamide (melting point 82.8°c, latent heat of fusion 263kJ/kg) as a PCM. The vessel with 17.5 and 10 cm in diameter and height, respectively were used for cooking and it can be inserted inside the PCM container for cooking purpose. To enhance the rate of heat transfer between the PCM and the inner wall of the PCM container, eight fins (1 cm x 3 cm) are welded at the inner wall of the PCM container. They reported that by using 2 kg of Acetamide as a latent heat storage material, the second batch of food could be cooked if it is loaded before 3.30 p.m. during the winter season. They recommended that the melting temperature of a PCM should be between 105°c and 110°c for evening cooking. Properties of PCMs such as melting point and latent heat of fusion, which are playing important roles in the selection of PCM, were shown in the Table 2. So there was a need to identify an effective storage material with appropriate melting point and quantity, which can cook the food even in the late evening. More input solar radiation is required to store a larger quantity of heat in a PCM.

PCM	Melting Point (°c)	Latent Heat of Fusion, (KJ/Kg)
Paraffin	100	140
Erythritol	118	339
$MgCl_2$ $6H_2O$	118	167
D-Mannitol	169	326.8
Stearic acid	55.8	160
Acetamide	82	263
Acetanilide	118	222
$Mg(NO_3)_2$ 6H2O	89	134
Nitrate salts (KNO_3-$NaNO_3$)	220	146

Table: 2 Properties of various PCMs used for solar cooking

3.5. Acetanilide

Buddhi and Sharma [13] developed a latent heat storage unit for a box type solar cooker with three reflectors and they used acetanilide (melting point 118.8°c, latent heat of fusion 222kJ/kg) as a PCM for night cooking. To find the advantages of three reflectors over the single reflector, they were conducted the experiment for both of the cases. To conduct the cooking experiment with the PCM storage unit, a double glazed (glass covers) box type solar cooker having 50 cm x 50 cm aperture area and 19 cm deep is used. In this solar cooker, three reflectors are provided; (i.e.) the middle reflector is mounted with a hinge and had rotation only about the horizontal axis and the other two reflectors are fixed by a ball and socket mechanism in the left and right sides of the reflector. By these mechanisms, they can have movement about the horizontal axis and vertical axis and can rotate about both the axes. So, efforts were made to keep the reflected solar irradiance on the absorber surface to enhance the incident solar radiation on the glass cover during the course of the sun exposure experiments. A cooking vessel with latent heat storage was designed and fabricated to facilitate cooking food at night. This unit is similar to the cooking unit designed by Sharma [12] except the dimensions and the quantity of PCM used.

3.6. Magnesium chloride hexahydrate

A concentrating type solar cooker used with magnesium chloride hexahydrate (m.p = 118 °C) as the thermal storage material was designed by Bhave for boiling type of cooking. The developed device has ability to store a charge of heat in about 50 min and cook about 140 gm of rice in 30 min from the stored heat. For boiling type of cooking, it was felt a phase change material with a melting point in the range 115–120°C would be needed as it would give sufficient temperature difference for the flow of stored heat from the PCM, through the oil, into the cooking vessel. The PCM temperature reached 135 °C in about 50 min, after which the unit was removed from the concentrator and shifted into the laboratory for the cooking test. The solar absorber surface of the device was insulated with glass wool and the cooking test carried out by adding 100 ml water with 50 gm rice in the cooking cavity of the device, which was then covered with a lid. After about 30 min they get a result as the rice was found to be completely cooked by the stored heat [14].

3.7 D-Mannitol

Performance of flat plate cooking unit integrated with latent heat energy storage system such as energy utilization, instantaneous heat transfer rate and detailed energy balance were studied by Kumaresan [15]**.** The flat plate collector was installed on the roof top of the Institute for Energy Studies building at Anna University, Chennai at the latitude of $13^o00'29''$N and longitude $80^o13'06''$E with the aperture area of $7.5m^2$. The TES tank and piping circuit were loaded with 185L of Therminol 55 oil and PCM was filled in the stainless steel spherical ball of diameter 88 mm and 2 mm. Totally 126 PCM balls were placed inside the TES tank and each ball had 0.45 kg of D-Mannitol within it. During the experiment it is observed that the energy utilized to prepare 35 dosas is only 9% of the energy out from the TES tank and major loss about 45.6% of energy due to lengthy piping circuit. Kumaresan also developed a solar domestic cooking unit integrated with thermal energy storage system. The storage system consists of D-Mannitol from sugar alcohol group as PCM, which has superior thermo-physical properties of melting point (166-169°c) and heat of fusion (326.8kJ/kg). During the cooking experiment for duration of 15 min the olive oil in the cooking unit reaches the temperature of 152°c [16].

4. CONCLUSION

A review of available published literature on solar cooking with thermal storage and relevant aspects have been discussed. From this study it has been concluded that the latent heat systems were found to be more suitable for thermal storage in solar cooking due to their high energy storage density. Low melting point PCMs are only suitable for low temperature application such as water heating. If high melting point PCMs is used in the cooking system, the time required to reach melting was more and it only stores sensible heat only. PCMs which are having melting point range of 100-120°C were suggested for effective cooking of boiling or frying of foods. The PCM which has higher Latent heat of fusion is considered for storing more heat energy.

References

[1] N.L.Panwar, S.C.Kaushik, Surendra Kothari. Role of renewable energy sources in environmental protection: A review. Renewable and Sustainable Energy Reviews 15 (2011) 1513–1524

[2] Atul Sharma, V.V.Tyagi, C.R.Chen, D.Buddhi, Review on thermal energy storage with phase change materials and applications, Renewable and Sustainable Energy Reviews 13 (2009) 318–345

[3] Klemens Schwarzer, Maria Eugenia Vieira da Silva, Solar cooking system with or without heat storage for families and institutions, Solar Energy 75 (2003) 35–41

[4] R.M.Muthusivagami, R.Sethumadhavan, R.Velraj, Solar cooker with and without thermal storage – A review, Renewable and Sustainable Energy Reviews 14 (2010) 691–701

[5] Abhay Dinker, Madhu Agarwal, G.D.Agarwal, Heat storage materials, geometry and applications: A review, Renewable and Sustainable Energy Reviews 14 (2010) 691–701

[6] R.Velraj, Institute for Energy Studies, Anna University, Chennai, TamilNadu, India, Sensible heat storage for solar heating and cooling systems (2016)

[7] H.M.S Hussain, H.H. El-Ghetany, S.A.Nada. Experimental investigation of novel indirect solar cooker with indoor PCM thermal storage and cooking unit. Energy Conversion and Management 49 (2008) 2237–2246

[8] Guruprasad Alva, Yaxue Lin, Guiyin Fang, An overview of thermal energy storage systems, Energy 144 (2018) 341-378

[9] Antonio Lecuona, Jose-Ignacio Nogueira, Ruben Ventas, Maria-del-Carmen Rodriguez-Hidalgo, Mathieu Legrand, Solar cooker of the portable parabolic type incorporating heat storage based on PCM, Applied Energy 111 (2013) 1136–1146

[10] D.Buddhi, L.K.Sahoo, Solar cooker with latent heat storage: Design and experimental testing, Energy Convers. Mgmt Vol. 38, No. 5, pp. 493-498, 1997

[11] H.M.S.Hussain, H.H. El-Ghetany, S.A.Nada, Experimental investigation of noval indirect solar cookerwith indoor PCM thermal storage and cooking unit, Energy Conversion and Management 49 (2008) 2237–2246

[12] S.D.Sharma, D.Buddhi, R.L.Sawhney, Atul Sharma, Design, development and performance evaluation of a latent heat storage unit for evening cooking in a solar cooker, Energy conversion & management 41 (2000) 1497-1508

[13] D.Buddhi, S.D.Sharma, Atul Sharma, Thermal performance evaluationof a latent heat storage unitfor late evening cookingin a solar cooker having three reflectors, Energy Conversion and Management 44 (2003) 809–817.

[14] Atul G. Bhave, Kavendra A. Thakare, Development of a solar thermal storage cum cooking device using salt hydrate, Solar energy 171 (2018) 784-789

[15] 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

[16] G.Kumaresan, V.S.Vigneswaran, S.Esakkimuthu, R.Velraj, Performance assesment of a solar domestic cooking unit integrated with thermal energy storage system, Journal of Energy Storage 6 (2016) 70-79.