Review on Phase Changing Material as the Energy Storage in Solar Cooker

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Abstract - The solar thermal energy is used for various applications. The application of solar thermal energy include cooking, water heating, space heating, power generation and agriculture drying. This review includes principle and classification, parameters influencing the performance of a solar cooker and energy energy analysis related to solar cooking system. The cooking in the evening or off Sunshine hours in solar devices is possible by operating the cooker on auxiliary power or by using different phase change materials in solar cookers. This study includes correct choice of phase change material that will be suitable for the cooking purpose. This demonstrates the feasibility of using a phase change material as the storage medium in solar cookers.

Keywords - *Phase changing material (PCM), space heating, energy*

I. INTRODUCTION

The sun produces lot of amounts of renewable solar energy that can be converted into heat and electricity, a solar cooker needed solar energy just a free fuel from the sky for operation having the concept to utilize this free fuel from the sun in the mind. All thermal energy storage systems, latent heat thermal energy storage is a particularly attractive technique because of the advantage of high energy storage density and isothermal characteristics of charging and discharging processes [16]. The intensity of solar rays is unpredictable and often plays truant during rainy and winter season. The harnessed energy is transferred and poorly stored this red us the overall efficiency of the device the time required to cooking the food is increase because of lacking in heat storage. As solar energy is renewable and not associated with any environmental and health problems, it could be used as a source of thermal energy for cooking [12]. Solar thermal energy storage for solar cookers allows for cooking of food during periods when the sun is not available, thus enhancing their usefulness. The viable options of storing thermal energy for solar cookers are sensible heat thermal energy storage and latent-heat thermal energy storage [14]. The use of phase change materials for storing the heat in the form of latent heat has been recognized as one of the areas to provide a compact and efficient storage system due to their high storage density and constant operating temperature [1]. PCM are promising candidate for consideration as heat storage media due to their large energy storage capacity. A PCM storage system with small PCM size can be used for rapidly supplying a large amount of heat to the object .Hence, PCM is a good option to store the solar energy during sunshine hours and can be utilized for cooking in late evening or off sunshine hours.

II. Literature Review

Amal Herez et al. (2018) it presents a review on the fundamentals of solar cookers with a detailed description of the influence of several key-parameters on their performance. Energy and energy analysis is presented and environmental and economic studies are developed. The economic study is carried out to compute the payback period for different solar cookers (solar box cooker, solar panel cooker, parabolic solar cooker and evacuated tube solar cooker with thermal storage) and for several scenarios in Lebanon (home, hotel, restaurant and snack), [1] Yeliz Konuklu, et al. (2017) In this research phase change material micro composites was fabricated and characterized. Laurie acid, decanis acid and paraffin were used as phase change materials. Xonotlite was prepared as composite matrix. SEM, DSC, XRD and EDS analyses demonstrate that paraffin was the best suitable phase change material for preparation phase change material composites. Results showed that used PCMs play an imported role in composite morphology and thermal energy storage performances due to the interactions between the PCMs and the matrix of the composites. [2] A.M.K. Prasad et al. (2017) solar cookers with latent heat storage system using phase change materials (PCM) is carried out in the increasing order of the year of work development. As per the work carried out the Paraffin Wax which is having maximum temperature of 156 ^{0}C will be very nearer to the other PCMs which are between 120 ^{0}C to 180 ^{0}C.

III. Phase Change Material

PCM are heat storage media due to their large energy storage capacity. PCM is a good option to store the solar energy during sunshine hours and can be utilize for cooking in off sunshine hours, As the source temperature rises, the chemically bonds within the PCM break up as the material changes phase from to liquid[3]. Latent heat storage can be achieved through liquid to solid, solid to liquid, solid to gas and liquid to gas phase changes. However, only solid to liquid and liquid to solid phase changes are practical for PCMs. Although liquid to gas transitions gaunt has higher heat transformation(processing) than solid to liquid transitions, liquid to gas phase exchanges are impractical for thermal wide storage because golden volumes high press are required to blind the materials in their gas phase. Solid-solid phase exchanges typically very are slow dance and gaunt has relatively low heat transformation (processing)[4]. There are some different types of Phase change materials like stearic acid, acetanilide, Para fine, wax, ethanol, magnesium nitrate hex hydrate, etc.

1. Required melting point of PCM - 105 C to 125 C
2. Name –Acetanilide
3. Melting point-180 C
4. Appearance – White powder
5. Latent heat (L) - 222kJ/kg
6. Specific heat capacity (C_p) – 2 kJ/kg C

PCM mass calculation

Load on the cooker is 1kg of water and change in temperature of load is about 70 to 80° C

Calculation of heat transfer;

$$Q = \int mCpdT$$

$$=1*4.187*70$$

$$Q=293.115 \text{ KJ}$$

So, Mass of PCM required,

$$M = \frac{Q}{Lf}$$

$$= \frac{293.115}{222}$$

$$M_{pcm} = 1.3259 \text{ Kg}$$

Phase Changing Material Properties

Thermal Properties-
Suitable phase transition temperature
High latent heat of transition

Physical Properties-
Favourable phase equilibrium
High density
Small volume change

Kinetic Properties-
No super cooling
Sufficient crystallization rate

Chemical Properties-
PCMs should be non- toxic
Non flammable
Non-explosive for safety

Table 1-Review of recent work on solar cooker using PCM

No	Author	PCM material	Latent heat of fusion(KJ/Kg)	M.P. (° C)	Type collector	PCM
1	Atul Sharma[1]	Stearic acid	161	55	Box	80
2	Buddhi Sahoo[1]	Acetanilide	222	118	Box	130
3	S.D. Sharma[2]	Erythritol	339	118	Evacuated	140
4	A.Lecuona[7]	Paraffin	140	100	Parabolic	164
5	R.M. Muthusivagami[5]	Acetanilide	222	118.9	Parabolic	186

IV. Phase change process

Latent heat storage is the most efficient ways of storing thermal energy. Unlike the sensible heat storage method, the latent heat storage method provides much higher storage density, with smaller temperature difference between storing and releasing heat, every material absorb heat during a heating process while it's temperature is rising constantly. The heat store in the material is release into the environment through a reverse cooling process, the material temperature decreases continuously. During complete melting process, temperature of PCM as well as its surrounding area remains nearly constant. When temperature increases PCM absorb heat and storing this energy in the liquefied phase change material, when the temperature falls the PCM release this stored energy and PCM solidify [6].

V. Experimental Process

In the concentrating solar cookers the cooking jar is placed at the focus of has concentrating mirror. Concentrating type solar cooker is working on one or two axis tracking with a concentration ratio up to 50 and temperature up to 300º C, which is suitable for cooking[7]. Concentrating cooker utilize lenses parabolic concentrators to attain maximum temperatures they are popular among concentrating cookers because the focus is much better and sharper than that of other typical of reflectors drank at the same time it is very sensitive plant to even has slight exchange in the position of the sun and hence the use of such reflectors requires constant tracking This is the most effective type of the collecting the solar radiations [9]. Parabolic cooker reach higher temperature and cook more quickly than solar box type cooker, but are harder to make and use.

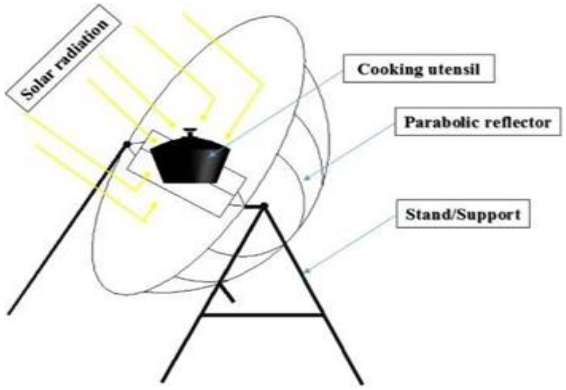

Fig 1- parabolic type solar cooker

1. Parabolic Collector

In parabolic collector's is has type of solar thermal collector's that was curved have has parabola, lined with has polished metal to mirror. The energy of sunlight which enters the mirror parallel to its glides of symmetry is focused along the focal length, where objects are positioned that is intended to be heated. For example, food may be placed at the focal length, which causes the food to be cooked when the trough is aimed so the sun is in its plane [7]. The shape of a parabola means that incoming light rays which are parallel to the dish's axis will be reflected toward the focus, no matter where on the dish they arrive. Light from the sun arrives at the Earth's surface almost completely parallel, and the dish is aligned with its axis pointing at the sun, allowing almost all incoming radiation to be reflected towards the focal point of the dish. Most losses in such collectors are due to imperfections in the parabolic shape and imperfect reflection. Losses due to atmospheric scattering are generally minimal.

Table-2 Specifications of the parabolic dish collector.

No	Parameter	Specification
1	Collector length	1.8m
2	Collector width	0.8m
3	Dish rim angle	45°
4	Focal length of dish	0.45 m
5	Concentration ratio of dish	45
6	Aperture area of dish	1.12m²

2. Cooking Equipment

Cooking vessels are components of solar cooker that are indirect contact with the absorber plate. Both serves in receiving the absorbed useful energy and transmitting it to the food. Various shapes of cooking pots can be utilized; however, the rectangular and cylindrical shaped cooking utensils that are made up of aluminum or copper are recommended [2]. The cooking pot is painted black from outside and placed in the center of the absorber tray to raise the rate of heat transfer by conduction between them. In the vessels, cooking space is surrounded with PCM. For ease of operation and fast cooking proper design of solar cooker is important parameter [4].

Fig 2 -Actual view of cooking vessel

VI. Design Calculations

1. Gravimetric and Volumetric Rice--Water Ratios

The volume of rice, vr1, to be cooked is given as:

$$v_{r1} = \frac{m_{r1}}{\rho_{r1}}$$

The density of rice, ρ_{r1}, varies between 777 – 847 kg/m^3, due to the different varieties of rice. Average value of 812 kg/m^3 is adopted for the design. And noting that $\boldsymbol{m_{r1}}$ = 1kg:

$$v_{r1} = 0.00123\, m^3$$

For the cooking process, the optimum rice-to-water ratio by volume is 1:2. The volume of water, ***vw1***, required to cook ***vr1*** volume of rice is

$$v_{w1} = 2v_{r1} = 2\left(\frac{m_{r1}}{\rho_{r1}}\right)$$

$$v_{w1} = 0.00246 m^2$$

Total volume of food to be cooked, vf1, is

$$v_{f1} = v_{r1} + v_{w1} = 3v_{r1}$$

$$v_{f1} = 0.00369 m^2$$

The mass of water, m_{w1}, required for the cooking is:

$$m_{w1} = \rho_{w1} * v_{w1} = \rho_{w1} * \frac{2m_r}{\rho_{r1}}$$

Where ρ_{w1} is the density of water evaluated at 25 ^{0}C and has the value of 997.01 kg/m3

$$m_{w1} \approx 2.5$$

Total mass of food to be cooked, m_{f1}, is

$$m_{f1} = m_{r1} + m_{w1}$$

$$m_{f1} = 3.2456 kg$$

After the cooking process, the volume of cooked rice (including water) expands to about 3.2 – 3.5 times the volume of dry (uncooked) rice. An average factor of 3.35 is taken for this design. Hence:

$$v_{f2} = 3.35 v_{r1} = 0.004125 m^3$$

The ratio, by volume, of cooked food to uncooked food is:

$$\frac{v_{f2}}{v_{f1}} = \frac{3.35 v_{r1}}{3 v_{r1}}$$

$$v_{f2} = 1.1178 v_{f1}$$

Therefore, after the cooking process the volume of the food increases by about 11.7%. Cooking of rice using conventional methods requires five volume of water to one volume of rice, while cooking using solar cooker requires two volume of water to one volume of rice. In conventional methods, about 25% of the water required for cooking is lost to the surrounding by evaporation. If the amount of water lost is taken as directly proportional to the amount of water required, then the amount of water lost during cooking using solar cookers is 10%. Hence, the mass of water, m_{w2}, remaining in the cooked food is:

$$m_{w2} = 0.9m_{w1} \approx 2.25kg$$

Mass of water lost,

$$m_{w1} = m_{w1} - m_{w2} = 0.25kg$$

Mass of cooked food,

$$m_{f2} = m_{r2} + m_{w2} = m_{r1} + m_{w2}$$
$$m_{f2} = 3.25kg$$

The ratio, by mass, of cooked food to uncooked food is:

$$\frac{m_{f2}}{m_{f1}} = \frac{3.25}{3.2456}$$
$$m_{f2} = 1.001m_{f1}$$

After the cooking process, the mass of the initial uncooked food decreases by about 6.7%. For four cycles of cooking in a day the total mass of cooked food is (4×3.25) kg = 13 kg.

2 .Sizing of the Parabolic Dish Solar Thermal Cooker:

The absorber of the cooker will be a cylinder of external diameter Dabs, external height Labs, internal diameter dabs, internal height labs, and thickness t_x = 0.8 mm. The internal volume of the cylinder is the same as the volume of food, v_{f2}, after cooking. Therefore:

$$\frac{\pi d^3{}_{abs}}{4} * l_{abs} = v_{f2}$$

For simple solution of the equation and optimum design of the absorber, the height L_{abs} is made to be the same as the diameter dabs. Therefore:

$$\frac{\pi d^3{}_{abs}}{4} = 0.004125$$
$$d_{abs} = \sqrt[3]{\frac{4 * 0.004125}{\pi}}$$
$$d_{abs} = 0.17382m \approx 17.38cm$$
$$l_{abs} = d_{abs} = 17.38cm$$
$$D_{abs} = d_{abs} + 2t_x = 0.17382 + 2 * 0.0008$$
$$D_{abs} = 0.17542m = 17.54cm$$
$$L_{abs} = l_{abs} + t_x = 0.17382 + 0.0008$$
$$L_{abs} = 0.17462m = 17.46cm$$

The effective surface area of the absorber is given as:

$$A_{abs} = \frac{\pi D^2{}_{abs}}{4} + \pi D_{abs} L_{abs}$$
$$A_{abs} = 0.1204m^2$$

The shell of the parabolic dish is adopted from a commercially-available, satellite dish of aperture diameter Da = 1.8 m, and height h = 29.0 cm. The geometric concentration ratio is given as:

$$C_{area} = \frac{A_a}{A_{abs}} = \frac{\pi * D^2{}_a}{4 * A_{abs}} = 11.74$$

The focal length, f, of the dish is obtained as:

$$f = \frac{D^2{}_a}{16h} = 0.6983m \approx 69.8cm$$

3. Expected Thermal Performance of the PDSTC

The estimated rate of useful energy absorbed by the food for one cycle of the designed PDSTC is given by:

$$\dot{q}_u = \eta_{th} I_b A_a$$

The efficiency range of most solar concentrators is 40%-60%. The standard solar radiation intensity is 700 W/m2. Hence:

$$A_a = \frac{\pi D^2{}_a}{4} = 2.545m^2$$
$$\dot{q}_u = 0.5 * 700 * 2.545 = 890.8w$$

The rate of energy absorbed by the absorber, P_{abs}, is obtained:

$$\eta_0 = \frac{p_{abs}}{A_a I_b}$$
$$p_{abs} = \frac{\eta_0}{\eta_{th}}(\eta_{th} A_a I_b)$$

Ƞ=0.6(lower of the factor 0.6 to 0.7)

$$p_{abs} = \frac{0.6}{0.5}\dot{q}_u = 1.2\dot{q}_u$$
$$p_{abs} = 1.2 * 890.8 = 1069w$$

In this design, the latent heat of vaporisations of water is considered as part of the useful energy. The useful energy, q_u, for one cycle of cooking is calculated as:

$$q_u = q_{u1} + q_{u2}$$

Where q_{u1} is the heat energy required to raise the sensible temperature of the food to 100 ^{0}C, and q_{u2} is the heat energy required to convert 0.25 kg of water at 100 ^{0}C to steam.

$$q_u = (m_{w1} + m_{r1})c_{pw}(T_{f2} - T_{f1}) = \eta_{th} I_b A_a t_1$$

Where t_1 is the time required to raise the temperature of the food from

$$t_1 = \frac{m_{f1} * c_{pw}(T_{f2} - T_{f1})}{\eta_{th} I_b A_a} = \frac{3.2450 * 4186 * (100 - 25)}{0.5 * 700 * 2.545}$$
$$t_1 = 1143.93sec \approx 19\ minutes$$
$$q_{u2} = m_{w1} L_w = \eta_{th} I_b A_a t_2$$

Where L_w is the latent heat of vaporisation of water at 100 ^{0}C and t_2 is the time required to convert 0.25 kg of water to steam.

$$t_2 = \frac{m_{w1} L_w}{\eta_{th} I_b A_a} = \frac{2.25 * 2.26 \times 10^6}{0.5 * 700 * 2.545}$$
$$t_2 = 634.2969\ sec \approx 10.57\ minutes$$

The cooking time, t_c, is given as:

$$t_c = t_1 + t_2 = 30\ minutes$$

VI. Conclusion

From the review it is concluded that, there are various options to meet the end user needs using both commercial and non-commercial energies. Traditional fuels like wood pellets, dung cakes and kerosene utilization must be minimized with the developed solar cooker. This will lead to a reduction in human drudgery. Such an effort will not only be useful in improving the quality of life but also in environmental protection. This paper focuses on several qualities of solar energy such as; a free fuel from the sky, environment friendly, huge availability of almost places, low or no running cost, good saving, minimization of the monthly electricity bill, accident free, less attention is required etc. Apart this, in the field of solar cooking the available thermal energy storage technology for solar cookers food can be cooked at late evening, while late evening cooking was not possible with simple solar cooker. Every element of solar cooker has great importance and direct effect on the performance of solar cooker in any climatic condition. Many of PCM's are under testing for solar cooking but Acetanilide is commonly used due to easy availability and economically suitable till now. It is more convenient for used in parabolic type solar collector

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