Solar Cooker for Evening / Night Cooking Using Solar Heat Storage Materials

Someshwer Dutt Sharma

CSEM – UAE Innovation Center, Energy & Water Sector, Ras Al Khaimah, UAE

Email: somesh.sharma@csem-uae.com

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Abstract:

In this paper, Use of Phase Change Materials (PCMs) for evening / night cooking is discussed. The use of a solar cooker is limited because cooking of food is not possible due to frequent clouds in the day or in the evening. If storage of solar energy can be provided in a solar cooker, then there is a possibility of cooking food during clouds or in the evening, and the storage will increase the utility and reliability of the solar cookers. Hence, PCM is the best option to store the solar energy during sun shine hours and is utilized for cooking in late evening/night time Phase Change Materials (PCM) are latent heat storage materials. As the source temperature rises, the chemical bonds within the PCM break up as the material changes phase from solid to liquid (as is the case for solid-liquid PCMs, which are of particular interest here). The phase change is a heat-seeking (endothermic) process and therefore, the PCM absorbs heat. Upon storing heat in the storage material, the material begins to melt when the phase change temperature is reached. The temperature then stays constant until the melting process is finished. The heat stored during the phase change process (melting process) of the material is called latent heat. Latent heat storage has two main advantages: (i) it is possible to store large amounts of heat with only small temperature changes and therefore to have a high storage density; (ii) because the change of phase at a constant temperature takes some time to complete, it becomes possible to smooth temperature variations. The comparison between latent and sensible heat storage shows that using latent heat storage, storage densities typically 5 to 10 times higher can be reached. Author has been published few papers on Solar Cooking using PCMs for evening and night cooking. Author intension to write this paper to introduce all of you about this technique. You will find here few designs on this technique, which are published by the author in past.

Design, Results & Discussions

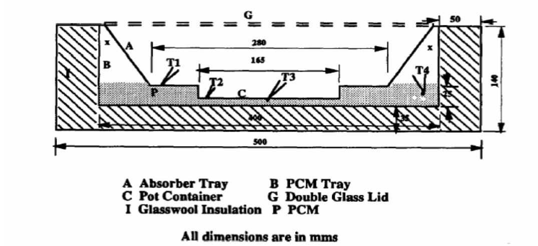


Fig.1:Box Type Solar Cooker with PCM Storage in the Bottom [Buddhi and Sahoo, 1997].

Fig. 1. shows the sketch of a box-type solar cooker for one vessel using a PCM to store the solar energy. In the center of the absorbing plate 'A,' a cylindrical container of 0.165 m diameter and 0.02 m in depth was welded (shown in Fig. 1 by 'C'), and the cooking pot is to be kept tightly in it. This container will provide a heat transfer from the absorbing plate and PCM. Moreover, aluminum fins were also provided at the inner side of the tray and cylindrical container. The outer tray 'B' is also made from the same aluminum sheet. Tray 'B' was filled with 3.5 kg of commercial grade stearic acid (PCM) and it was made sure that the PCM was in good contact with the bottom side of tray 'A.' The experimental results demonstrate the feasibility of using a PCM as the storage medium in solar cookers, i.e., it is possible to cook the food even in the evening with a solar cooker having latent heat storage. It also provides a nearly constant plate temperature in the late evening. The Problem with this design was low heat transfer from PCM storage unit to Cooking vessel.

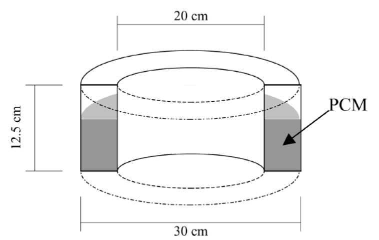


Fig.2 : Latent Heat Storage Unit for Evening Cooking in a Solar Cooker [Sharma et al., 2000].

Buddhi and Sahoo filled the PCM below the absorbing plate of the cooker. In such type of design, the rate of heat transfer from the PCM to the cooking pot during the discharging mode of the PCM is slow, and more time is required for cooking an evening meal. Sharma et al. (Fig.2) designed and developed a cylindrical PCM storage unit for a box type solar cooker to cook food in the late evening. Since this unit surrounds the cooking vessel, the rate of heat transfer between the PCM and the food is higher, and cooking can be faster. They reported that by using 2.0kg of acetamide (melting point 82 °C) as a latent heat storage material, a second batch of food could be cooked if it is loaded before 3:30 PM during winter. They recommended that the melting temperature of a PCM should be between 105 and 110 °C for evening cooking.

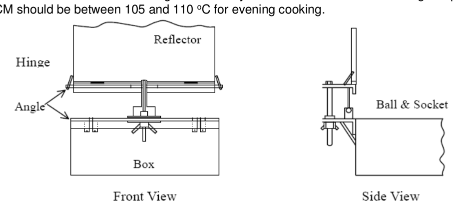


Fig.3:Box Type Solar Cooker with PCM Storage Having Three Reflectors [Buddhi and Sharma, 2003]

As Sharma et al. (2000) recommended that the melting temperature of a PCM should be between 105 and 110 °C for evening cooking. Therefore, there was a need to identify a storage material with appropriate melting point and quantity, which can cook the food in the late evening. To store a larger quantity of heat in a PCM, more input solar radiation would be required. Hence, Buddhi and Sharma (2003) used a latent heat storage unit for a box type solar cooker with three reflectors. They used acetanilide (melting point 118 °C, latent heat of fusion 222 kJ/kg) as a PCM for night cooking. To conduct the cooking experiments with the PCM storage unit, a double glazed (glass covers) box-type solar cooker having a 50 cm × 50 cm aperture area and being 19 cm deep was used. In this solar cooker, three reflectors were provided, i.e., the middle reflector was mounted with a hinge and had rotation only about the horizontal axis. The other two reflectors were fixed by a ball and socket mechanism in the left and right sides of the reflector. This pair of reflectors has three degrees of freedom, i.e., they can have movement about the horizontal axis, and vertical axis and can rotate about both the axes (Fig.3). By these mechanisms, 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. From the experimental results one can conclude that the cooking experiments were successfully conducted for the evening time cooking up to at 20.00 h with 4.0 kg of PCM.

No work has been performed on solar cookers with latent heat storage using ETSC. We tried to develop a solar cooker with PCM storage based on ETSC. For this purpose, there is a need to identify a latent heat storage material with appropriate melting point (>110 oC) for cooking (Sharma et al., 2000). Erythritol (melting point 118 oC, latent heat of fusion 339.8 kJ/kg) was used for that set-up. The prototype was fabricated by a local manufacturer and installed on the roof of the Satellite Venture Business Laboratory, Mie University, Tsu, Japan (Longitude 136 degree 31' and Latitude 34 degree 40 ') for testing thermal performance. We developed a solar cooker based on Evacuated Tube Solar Collector (ETSC) with PCM storage, as shown in Fig. 4. It consists of an ETSC, a closed loop pumping line-containing water as Heat Transfer Fluid (HTF), a PCM storage unit, cooking unit, pump, relief valve, flow meter, and a stainless steel tubing heat exchanger.

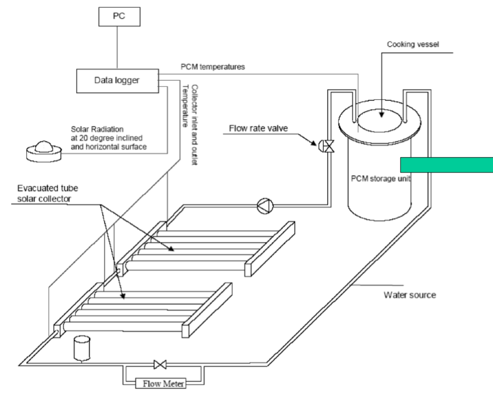
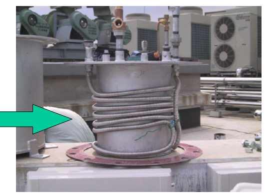


Fig.4 : Outline of the prototype solar cooker based on evacuated tube solar collector with PCM storage unit [S.D.Sharma et al, 2005]



Photograph of the stainless steel tube around PCM heat storage unit.

The PCM storage unit has two hollow concentric aluminum cylinders, and its inner and outer diameters are 304 mm and 441 mm, respectively, and is 420 mm deep and 9 mm thick. The space between the cylinders was filled with 45 kg erythritol (melting point 118 °C, latent heat of fusion 339.8 kJ/kg) used as the PCM. A pump circulates the heated water (HTF) from the ETSC through the insulated pipes to the PCM storage unit by using a stainless steel tubing heat exchanger that wraps around the cooking unit by closed loop. During sunshine hours, heated water transfers its heat to the PCM and is stored in the form of latent heat through a stainless steel tubing heat exchanger. This stored heat is utilized to cook the food in the evening time or when sun intensity is not sufficient to cook the food. They concluded that two cooking times (noon and evening) were in a day. Noon cooking did not affect the cooking in evening, and evening cooking using PCM storage was found to be faster than noon cooking. Experiments and analysis indicated that the prototype solar cooker yielded satisfactory performance in spite of low heat transfer; the modified design of heat exchanger in the thermal storage unit will enhance the rate of heat transfer in the present set-up.

Thermo physical Properties of Various PCMs used for Solar Cooking

ERYTHRITOL

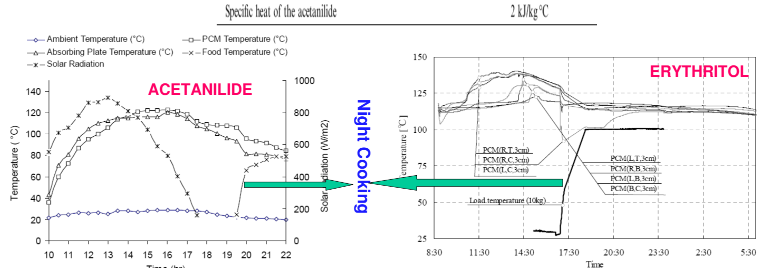
Chemical structure	$C_4H_{10}O_4$
Molecular weight	122.2
Melting point (°C)	118.0
Heat of fusion (kJ/kg)	339.8
Specific heat (kJ/kg°C)	1.38 at (20°C) and 2.76 at (140°C)
Density (kg/dm³)	1.48 at (20°C) and 1.30 at (140°C)
Heat conductivity (W/m K)	2.64 at (20°C) and 1.17 at (140°C)

ACETAMIDE

Melting temperature of acetamide (commercial grade)	82°C[a]
Latent heat of fusion of acetamide (commercial grade)	263 kJ/kg[a]
Density of solid acetamide	1.159 g/cm³
Density of liquid acetamide	0.998 g/cm³
Specific heat of the acetamide	1.94 kJ/kg °C[a]
Heat loss coefficient from top, bottom and side of solar cooker (when solar cooker is closed)	1.00 W/m² K

ACETANILIDE

Melting temperature of acetanilide (commercial grade)	118.9 °C[a]
Latent heat of fusion of acetanilide (commercial grade)	222 kJ/kg[a]
Specific heat of the acetanilide	2 kJ/kg°C



Box Type Solar Cooker with PCM storage Unit for Night Cooking in Indian Climate

Solar Cooker Based on Evacuated Tube Solar Collector with PCM storage Unit for Night Cooking in Japanese Climate

Conclusion

We can conclude that Phase Change Materials (PCMs) is capable for solar heat storage and best option for night / evening cooking. We had designed, developed and tested our cylindrical unit with box type solar cooker having single or three reflectors and found that PCM unit was successfully to cook the food in night 8 P.M. We also tested our cylindrical unit design with evacuated tube solar collector as a indirect type solar cooking and results was satisfactory for Japanese climate.

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Acknowledgement

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