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Implementation of Phase Change Materials (PCM) in Solar thermal Cooking

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Abstract— Energy consumption for cooking is unavoidable, though there is continuously increasing the fuel price as well as scarcity of exhausting fossil fuels. Because cooking is the prime priority of human life all over the world. Cooking contributes a major part in sharing of total primary energy consumption in India. Hence it needs an alternative energy source for this purpose. Solar cookers are the best substitute for, heating, cooking and pasteurizing applications. In this work a review has been made to study the existing literature in the field of solar cookers with the latent heat storage system using a particular PCM.

Keywords—Cooking, Solar thermal, Thermal Energy Storage, Phase change material

I. INTRODUCTION

Energy requirements for cooking in the countries like India and China are very high, particularly due to the large population. In India about 47% of the energy comes from wood for the cooking application, and this value is higher than 75% in many African countries, such as Mali or Burkina Faso, it reaches up to 95% [1]. Approximately 34000 and 140,000 solar cookers are used in India and China respectively [2].

Cooking by using solar energy is the best substitute over wood and fuel all over the world. Since solar energy is the most promising alternative energy which is available freely and abundantly. It is free of pollution and as well high nutritional value of the cooked food [3]. Solar cooking is the process of heating food up to boiling temperature of water, and being kept at that temperature for a particular period of time depending upon the characteristics of the food. The Mass flow rate of the gas is 2-3 more at the beginning [4]. As per the principle of Lof [5-6], maximum cooking energy is required during the sensible heating period, and less heat is required for physical and chemical changes. Boiling temperature of food, consumes 20% of heat, the vaporization of water consumes, 35% of heat and 45% of heat goes as convection losses from cooking vessels.

II. RELATED WORK

Solar cookers are broadly classified as (1) Solar cookers without storage and (2) Solar cookers with storage. The solar cookers without storage are again divided into (a) Direct cooking (b) Indirect cooking. And the solar cookers with storage are divided into (i) Sensible heat storage type (ii) Latent heat storage type.

In the present review an attention is given to solar cooker with latent heat of storage type because to solve the problems related to cooking, like cooking at off sunshine hours, cooking at shed and to make cooking as convenient as domestic cooking stoves.

2.1 Solar Cooker With Latent Heat Of Storage

Domanski et al. [7] in the year 1995 developed a solar cooker and investigated for whether cooking is possible during off sunshine hours using Phase change materials (PCMs).They developed a cylindrical shaped cooking unit with a two concentric aluminum (0.0015-m thick), vessel with gap between inner and outer walls, and are connected together at their tops using four screws. The annular gap is filled with 1.1 kg of stearic acid (melting temperature 69^{o}C; latent heat of fusion 202.5kJ/kg; thermal conductivity 0.172 W/moC for the cooking pot is slow, and more time is required for cooking the evening meal. The model is as shown in figure 1.

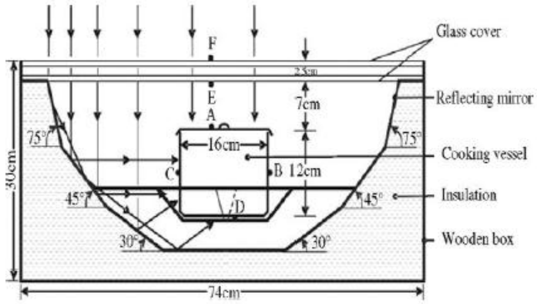

Fig 1. Solar cooker schematic diagram

Buddhi and Sahoo [8] in the year19997 designed and tested a box type solar cooker by using commercial grade stearic acid (melting temperature 69^{o}C; latent heat of fusion 202.5kJ/kg; thermal conductivity 0.172 W/m^{o}C for liquid; Density848kg/m^{3}) as a Phase Change Material to store latent heat. Phase change material was filled below the absorber plate. The authors reported that, during the mode of PCM discharge, the heat transfer rate is very slow from PCM to the Cooking pot. And the time required for evening cooker is more as shown in figure 2.

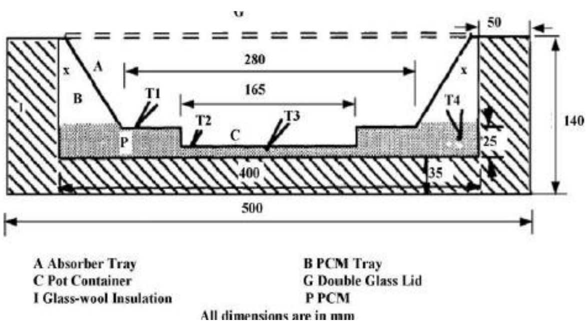

Fig 2.Box type solar cooker

Sharma et al. [9] in the year 2000 developed a cylindrical PCM storage unit for box solar cooker with three reflectors for night cooking. Acetamide (melting temperature 82oC; latent heat of fusion 263kJ/kg; thermal conductivity 0.5 W/moC; density998 kg/m^{3}) is filled in the cylindrical storage unit and it was concluded that by using 4.0kg of acetanilide, cooking can be done up to 8:pm and due the rate of heat transfer from PCM to cooking vessel is high due to this cooking can be faster. The model is as shown in Figure 3.

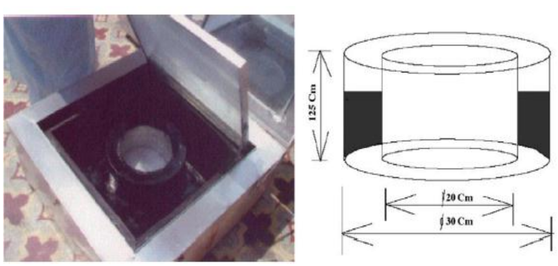

Fig 3. Box type solar cooker with PCM storage

Sharma et al. [10] in the year 2005 developed a solar cooker using evacuated tube solar collector (ETSC) with Erythritol (melting temperature 118^{o}C; latent heat of fusion 339.8kJ/kg;thermal conductivity 0.326 W/m^{o}C; density 1300 kg/m^{3})as Phase change material (PCM) for heat storage .They reported that the heat can be stored whenever sun energy is available and can be used for cooking during off sun shine time. And cooking is possible for two times a day i.e. at noon and at evening time. And during the evening, cooking rate is faster than noon due to use of PCM storage heat energy. The solar cooking unit is as shown in figure4.

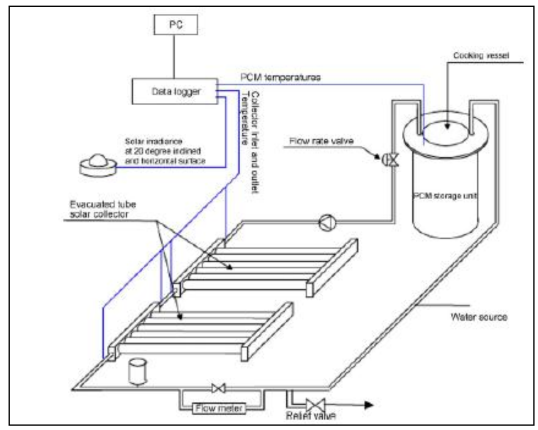

Fig4.Solar cooker based on ESTC with PCM unit

Hussein et al. [11] in the year of 2008 reported a novel indoor cooker by using wickless heat pipe of elliptical cross section kept at outdoor, flat plate solar collector with an integrated indoor PCM thermal storage and a cooking unit. Magnesium nitrate hexahydrate (melting temperature 89.8 ^{0}C, latent heat of fusion 134 kJ/kg) is used as the PCM inside the indoor cooking unit of the cooker. Different experiments have been carried out on solar cooker and results found have reported that present solar cooker can be successfully used for cooking three times meals as well to keep food warm at night and in the early morning. The arrangement of solar cooker is shown in figure 5.

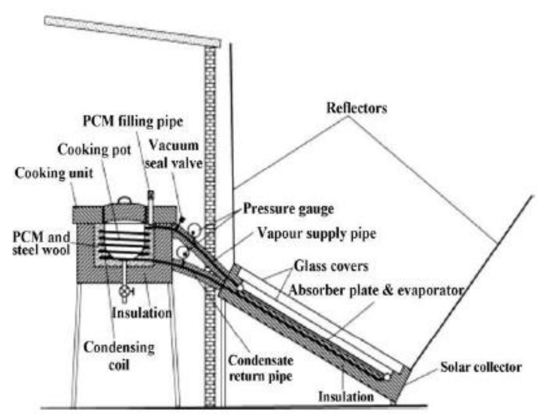

Fig 5. Solar cooker (By Hussein et.al 2008)

Muthusivagami et al [12] in the year 2009 presented a novel concept of solar cooker which is under experimental investigation by using PCM-A- 164. Thermic fluid is selected as the heat transfer fluid to exchange the heat between the collector and the cooking unit. PCM A-164 filled in 1 m long; 22 mm diameter tubes will be made as a heat exchanger to store the energy during sunshine hours and to retrieve the energy during off-sunshine hours.
Oil will be circulated below the finned hot plate to keep the surface temperature around 140–150.8^{o}C. The concept diagram is shown in figure 6.

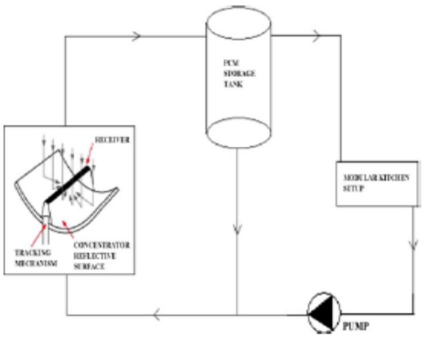

Fig 6. Solar Cooker (muthusivagami et.al 2009)

Kedare et al. [13] in the year 2014 submitted the project named as Arun Dish based solar system to the Ministry of New & Renewable Energy Government of India. The project concludes that, it can prepare 2,000 to 3,000 meals on a clear sunny day and it can save average fuel of 40 to 50 kg LPG on a clear sunny day. It is also reported that the project is more suitable for community use. Arun solar cooker is shown in figure 7.

Fig 7. Arun dish based solar cooker (By IIT Bombay 2014)

Rane et al. [14-15] in the year 2014have reported, solar collector with absorber integrated heat storage that generates steam at 2 to 3 bar. The size of solar collector is 1.7 m^2 and its weight is about 40 kg. Using steam, 28 kg rice was cooked in the first week of January 2017 at IIT Bombay. However, boiling water was initially used, which was collected from other solar collector. Using cold water in the beginning, 12 kg rice per clear sunny day can be cooked. This solar collector is non - seasonal tracking type and costs INR 10,000/m^2 of solar collector. The solar collector is shown in figure 8.

Fig 8.Solar collector with integrated heat storage (By IIT Bombay 2014)

III. METHODOLOGY

Fig 9. Paraffin Wax in PCM Box

In the present work Paraffin wax is used as a Phase change Material (PCM) For paraffin wax boiling point is 370 ^{o} C. The maximum temperature attained in the present work is 156 ^{o} C.

Paraffin wax is a white or colorless soft solid derivable from petroleum, coal or oil shale, that consists of a mixture of hydrocarbon molecules containing between twenty and forty carbon atoms. It is solid at room temperature and begins to melt above approximately 37 °C (99 °F); its boiling point is >370 °C (698 °F). Common applications for paraffin wax include lubrication, electrical insulation, and candles; dyed paraffin wax can be made into crayons. It is distinct from kerosene, another petroleum product that is sometimes called paraffin.

Paraffin candles are odorless, and bluish-white in color. Paraffin wax was first created in 1830 in Germany, and marked a major advancement in candle making technology, as it burned more cleanly and reliably than tallow candles, and was cheaper to produce. In chemistry, paraffin is used synonymously with alkane, indicating hydrocarbons with the general formula C_nH_{2n+2}. The name is derived from Latin parum ("barely") + affinis, meaning "lacking affinity" or "lacking reactivity", referring to paraffin's unreactive nature.

Paraffin wax is mostly found as a white, odorless, tasteless, waxy solid, with a typical melting point between about 46 and 68 °C (115 and 154 °F),[16] and a density of around 900 kg/m^3.[17] It is insoluble in water, but soluble in ether, benzene, and certain esters. Paraffin is unaffected by most common chemical reagents but burns readily.[18] Its heat of combustion is 42 kJ/g.

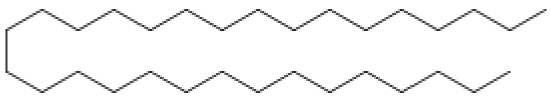

Fig.10. The hydrocarbon $C_{31}H_{64}$ is a typical component of paraffin wax.

Paraffin wax is an excellent electrical insulator, with a resistivity of between 10^{13} and 10^{17} ohm meter.[19] This is better than nearly all other materials except some plastics (notably Teflon). It is an effective neutron moderator and was used in James Chadwick's 1932 experiments to identify the neutron [20][21].

Paraffin wax is an excellent material for storing heat, with a specific heat capacity of 2.14–2.9 J g^{-1} K^{-1} (joules per gram Kelvin) and a heat of fusion of 200–220 J g^{-1}.[22] This property is exploited in modified drywall for home building material: a certain type of wax (with the right melting point) is infused in the drywall during manufacture so that it melts during the day, absorbing heat, and solidifies again at night, releasing the heat.[23] Paraffin wax phase-change cooling coupled with retractable radiators was used to cool the electronics of the Lunar Rover [24]. Wax expands considerably when it melts and this allows its use in wax element thermostats for industrial, domestic and, particularly, automobile purposes [25] [26].

The cross-section of the iron box is about 420mm x 420mm x 100mm. and thickness of the iron is about 1mm. 8 Holes are drilled on the side of the box of about 5mm diameter to close the top surface of the box with absorber plate.

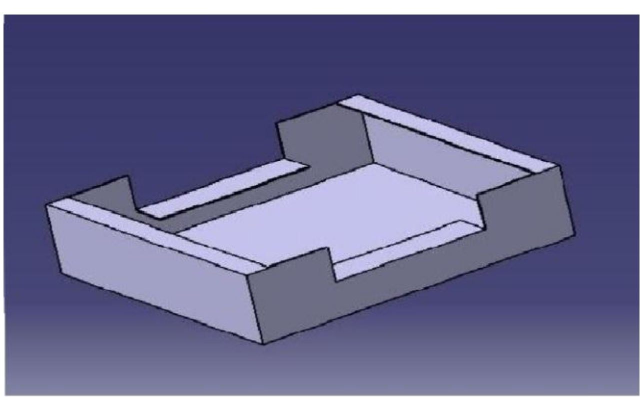

Fig 11. Model of PCM box

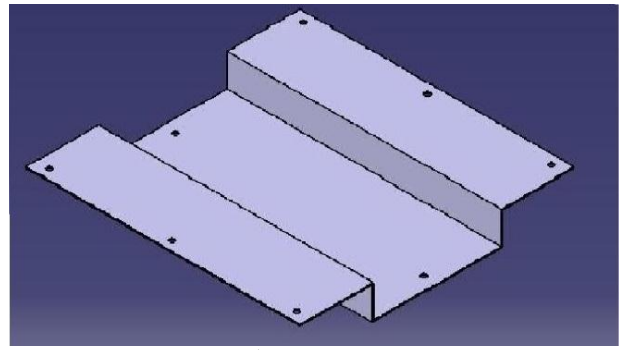

Fig 12. Model of PCM box lid (absorber plate)

The data related to comparison of various Phase change material (PCM) s is shown in below table 1.

Table 1. Summary of review with present work

Reference	**PCM tested**	**Maximum Temperature (^{o}C)**
Domanski et al.	Stearic acid & Magnesium Nitrate Hexa-Hydrate	95
Budhi and Sahoo	Stearic acid	122
Sharma et al	Acetamide	127
Sharma et al	Erythritol	138
Hussein et al	Magnesium Nitrate Hexa Hydrate	140
Muthusivagami et.al	PCM-A-164	140
Kedare	Water	170
Rane et al	-----	130
Present work	Paraffin Wax	156

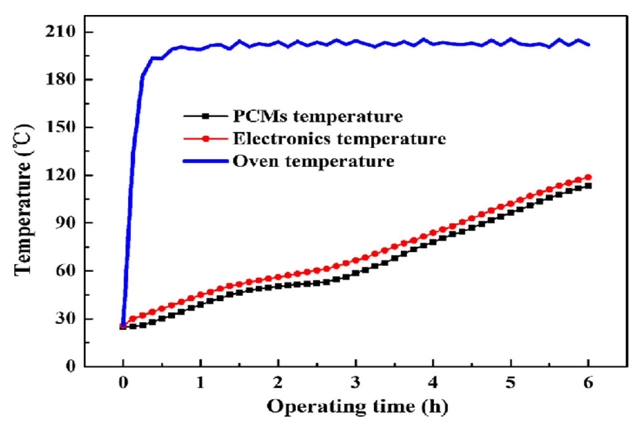

Fig.13.Temperature (Vs) Time for PCM, cooker, Electronics

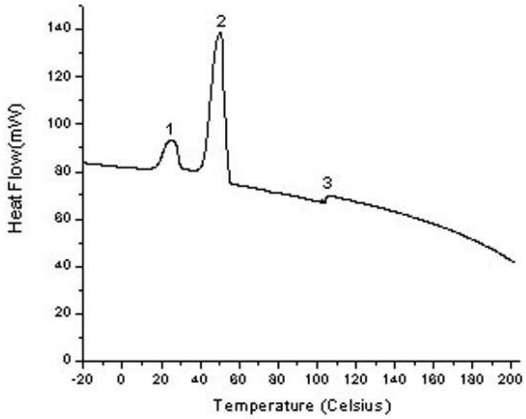

Fig.14. Heat flow (vs.) Temperature for Paraffin Wax

IV. RESULTS AND DISCUSSION

The gain of temperature around 156°C is obtained. This temperature is useful for cooking almost all daily food items that are cooked by domestic gas cookers. The present temperature ranges are around 95°C to 170°C. In the present work the Paraffin wax (PCM) has an advantage of evening as well night cooking.

V. CONCLUSION AND FUTURE SCOPE

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 °C will be very nearer to the other PCMs which are between 120 °C to 180 °C.

The Paraffin Wax at 20 °C ,60 °C and 110 °C the heat flow rates are 90mW,140mW and 70 mW respectively. Hence it is confirmed that these heat flow rates can be useful for best daily cooking needs.

By using Paraffin wax the night cooking also can be performed very smoothly as phase changing is appreciable. The less costly Paraffin Wax can be replaced in place of costly PCMs in the industry.

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