DESIGN OF HEAT STORAGE SYSTEM FOR PARABOLIC DISH TYPE SOLAR COOKER

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ABSTRACT

Solar energy is available freely and does not create any pollution to the environment. Hence, researchers from all around the world are always working on solar energy applications with enhancement technologies. The solar cooker is one of the largest solar energy application, which is used to cook the food. However, because the solar energy is available only during the daytime, solar cookers are not getting popularity as the main device for cooking. To store the heat during the day, energy storage system is required. Hence, this study presents the design of heat storage system for parabolic dish type solar cooker. Heat storage unit is used to store heat during daytime and use for other than daytime hours. Also, the two types of heat storing materials were considered for analysis and compared. Hence, with proposed heat storage unit the cooking is possible even in the evening with a solar cooker. So that, solar cooker with storage unit is very beneficial for the humans and as well as for the energy conservation

INTRODUCTION

Solar cookers are the means to cook food with the help of solar energy. For this purpose, the solar energy can be collected using solar collector and transferred to the cooking vessel. The solar cooking is in practice since seventeenth century with continuous research efforts to improve the performance of cooker. The solar cooking was started with the solar cooker box and has been developed into various forms in due course of time. But, in the present condition the solar cookers are rarely used. Its main reason limits the usefulness of solar cookers in sunshine time only. The cooking at night or in cloudy days is not possible. This has created a necessity for development of solar cookers which can work at night as well as in cloudy days.

As the energy demand is increasing day by day with increasing population and pollution, the need of renewable energy is becoming the very essential in every field. There are various sources for renewal energy which are being widely used now days. Solar energy is the one of a very popular and easily available source of renewable energy. Still its use is only about 4% of total renewable energy used [1]. This solar energy can be used by means of photovoltaic (PV) cell or solar collectors. It has several uses like drying, space heating, cooking, electricity generations etc. [2–5]. And one of the well-known uses of solar energy is to cook the food [6]. It requires proper mechanism to use this solar energy for solar cooking. And it is done with the help of solar cookers. Till now, lot of solar cookers have been designed and used. It is being developed since seventeenth century [7–9]. Still it needs lot of research before selecting any one type for its use at specific region. It depends on geographical area, type of collector & its area, heat requirement, type of food to be cooked; at what time it is to be cooked etc. [10]. Among all those different designs, a simple solar box type cooker is used commonly due to its simplicity. The use of a solar box cooker is limited because cooking of food is difficult due to frequent clouds in the day or unavailability of solar energy in the evening. So cooking at night by this solar box cannot be done. Some have used hybrid energy also to improve the efficiency of cooker [11]. If storage for solar energy can be provided in a box cooker, then there is a possibility of cooking food in the evening and this will increase the effectiveness and reliability of these solar cookers [12–14]. This leads to need of indoor cooking system [15, 16]. For a solar cooking system to be accepted and adopted in most of the households, the following characteristics have to be satisfied [17–20]:

1. Possibility of cooking at any time of day
2. Cooking time must be comparable with conventional cooking
3. Economical aspect To overcome above cited limitations and gain the desirable characteristics, researchers reported their findings [15, 21].

There are different heat storage systems (Heat Exchangers) available in the market. So, exact selection of most suitable becomes very difficult. Most of the time it become necessary to design and develop customized system which can meet the purpose. The solar collectors are classified as follows [22, 23]:

According to Soteris A. Kalogirou [23], the temperature up to 400° can be obtained by using parabolic trough collector and even more than that is also possible by using parabolic dish reflector. So, taking this as a reference one can select the suitable solar collector. Hence, in such types of systems, energy storage and transportation is the key work. Solar energy has to be transported to the kitchen by

means of a circulating fluid. Therefore, the critical study of heat storage and transfer systems along with their parameters attracts the attention of researchers.

HEAT STORAGE SYSTEMS

Heat collected from the sun is used for the solar cooking but if it is directly supplied to cooking then it will be useful in day time/sunshine hours only. To carry the cooking at any time, one needs to store this heat so that it can be retrieved as and when required [24]. To store this heat the storage system is required which will be able to store the heat with minimum losses, so as to store the heat at least in the range of 200–300 °C [25]. Therefore, for the efficient heat storage systems following parameters must be considered:

i. Type of solar cooking system (heat exchanger)
ii. Heat storage capacity
iii. Size and volume of the storage system
iv. Heat losses and insulation
v. Heat storing Media
vi. Temperature range
vii. Application (direct use or use for steaming) [26, 27]

MATERIAL SELECTIONS

Material selection is also one of the main aspect in the development of Solar cooking system. Material selection should be done for the following component of the system:

i. Material for shell & Tubes (Heat Exchangers)
ii. Heat transfer fluid (HTF)
iii. Material for Storage (PCM)
iv. Material for Insulation.

Table 1 Material with thermal conductivity at different temperature.

Material	Thermal conductivity W/mK			
	At 20 °C	100 °C	200 °C	300°C

Aluminium	204	206	215	228
Brass	111	128	144	147
Copper	386	379	374	369
Cast iron	52	--	--	--
Carbon steel	54	52	48	45
Silver	419	415	412	--

MATERIAL FOR STORAGE (PCM)

For latent heat storage system, selection of phase change material is very crucial. Phase change material can be classified as below:-

i. Organic- Paraffin & Non Paraffin (fatty acids)

ii. Non organic- Salt hydrates and metallic

iii. Eutectics—it's a mixture of two or more component [28]

There are lots of PCM available now days but its selection is very crucial thing [29]. It depends on the availability and applicability of the PCM of the selected purpose. Some of the promising PCM are mentioned in the below Table 2. The paraffins are safe, reliable, predictable, less expensive and non-corrosive. They are chemically inert and stable below 500 °C, show little volume changes on melting
and have low vapor pressure in the melt form. Salt hydrates are the most important group of PCMs, which
have been extensively studied for their use in latent heat thermal energy storage systems. The most attractive properties of salt hydrates are:

(i) high latent heat of fusion per unit volume,

(ii) relatively high thermal conductivity and

(iii) small volume changes on melting.

They are not very corrosive, compatible with plastics. This makes NaOHH2O
and NaNO3 promising PCM for the required range of melting temperature. Sugar alcohols (D- Manitol, Myoinositol, Dulcitol, Erythritol and Sorbitol) are suitable PCM for medium temperature applications. The bases of the selection criterion are mainly on two points:

(1) high phase change enthalpy and

(2) melting temperatures between 150 and 250 °C.

Also, HDPE is non-hazardous and economical, hence it can be used as a PCM.

Table 2 List of various PCM considered by researchers [35][36][37][38][39][40]

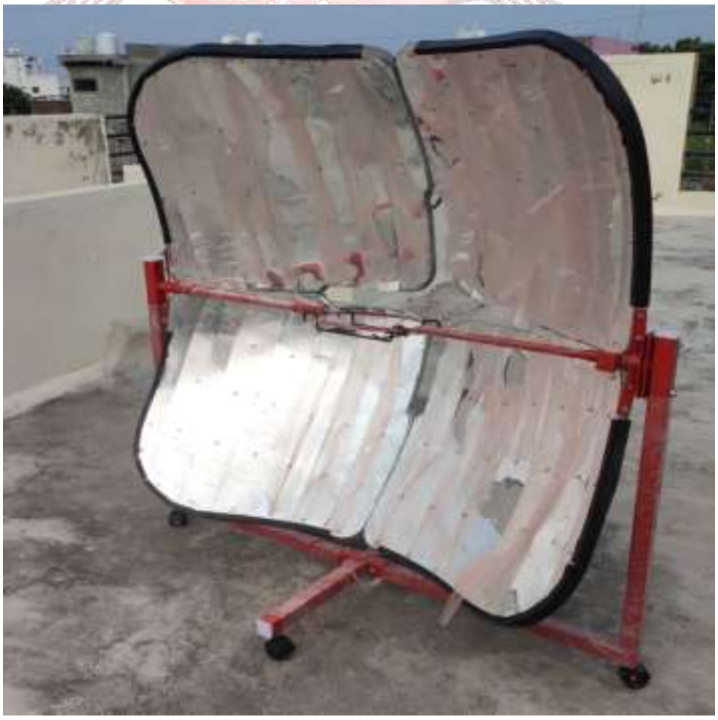
Material	Melting temp °C	Enthalpy (latent heat) of fusion kJ/kg

D-mannitol	138.25	152.6
Myo-inositol	220.34	211.1
Dulcitol	180.07	257.15
Paraffin wax 6106	42-45	189
High density polyethylene (HDPE)	130	211-233
$NaNO_3$	307	172
$NAOH\text{-}H_2O$	64.3	273
$KNO_3\text{-}NaNO_2\text{-}NaNO_3$	141	275

DESIGN OF STORAGE SYSTEM [34]

The Design of the system is specially for existing parabolic dish type solar cooker. In this solar cooker, surface focused is found and the available space for pot holder is about 250 mm diameter as shown in fig. 1. Hence it is preferred to design it volume wise. Depending on above data and based on the application, **coiled type heat exchanger** is selected for the Energy Storage System. [30][31]

Fig. 1 Parabolic dish type solar cooker



Therefore, assume two parameters as below,

Diameter of Shell (D) = 25 cm = 250 mm

Height of Shell (H) = 30 cm = 300 mm

Coil Height:

Minimize the distance 4 cm from the bottom due to supporting clamp & also maintain the clearance distance of 2 cm from top as well as bottom inside the shell.

Height of the coil = 22 cm = 220mm.

Number of turns in a coil (n) = $\frac{Height\ of\ coil}{Distance\ covered\ by\ 1\ turn}$

= 8 turns

Length of first coil, L = $2\pi R_1$ n (where, n is total no. of turns)

= 5.27 m

Volume of shell, $V_1 = \pi R^2 H$

=14.726 ltr =14 litre

Volume of Tubes inside the shell, $V_2 = \pi (r_1)^2 L$

= 0.258 ltr

Therefore,

Volume of Shell with Tubes,

$V_o = V_1 - V_2$

= 14.46 litre

In the present research work, working fluid inside the shell is Hytherm 600, this oil is stored in shell at 200^0C. Therefore, for the Hytherm 600 oil, following are the properties, [32]

At 200° C, Density ρ = 885 kg/m^3

Sp. Heat C_p = 2.19 kJ/kg K

Viscosity = 0.972 mm^2/s

Initial temperature of HTF T_f = 200°C

Initial Temperature of water T_w = 30 °C

As , the working fluid inside the shell is steady, therefore, Natural Convection occurs.

Mean film temp. T_m = (200+30)/2 = 115 ^{0}C

Therefore, for the Hytherm 600 oil, following are the properties,

At 115°C, Density ρ = 9944.5 kg/m^3

Sp. Heat C_p = 1.89 kJ//kg K

Kinematic Viscosity ϒ= 2.825 mm^2/s = 2.825 X 10^{-6} m2/s

Dynamic viscosity μ = 2.67 mPa = 0.00267 Ns/m^2

Thermal conductivity k= 0.11245 W/mK

Coefficient of volume expansion, β = 1/(115=273) = 2.57 X 10^{-3} k^{-1}

Prandtl Number, Pr = μ C_p / k = 44.87

Grashoffs Number Gr = β g ΔT $L_c^{\ 3}$ / $ϒ^2$

For horizontal tube, Characteristic length L_c = diameter of tube= 12.5 X 10^{-3}

G_r = 0.928 X 10^6

Therefore, $G_r.P_r$ = 41.64 X 10^6

Since, $10^4 < G_r.P_r < 10^9$

Therefore, Flow is Laminar

Nusselt number Co-relation is given by,

$Nu = C (G_r P_r)^n C_1$

For Laminar Flow, and through the horizontal tube, following are constants value,

C = 0.47 , n = ¼ , C_1 = .01

Therefore, Nu = 0.119

But Nu = h L_c/k

Therefore, Coefficient of heat transfer h = 1.11 W/m^2 °C

Heat Transfer rate through shell to water Q,

Q = h A ΔT

= 33.93 W or J/s

Maximum heat contained in shell fluid,

For the Hytherm 600 oil

Mass of fluid m_f = Density × Maximum volume of shell fluid

m_f = 8.85 kg

Heat contained in shell fluid Q_s = $m_f \times C_p \times \Delta T$

Q_s = 4612.79 kJ

Heat required in coil to produce 1 kg of steam,

In present work, water is the working fluid inside the coil. Water is circulated inside the tube coil to produce the steam.

Assume the required steam temperature is 110 ^{0}C.

Therefore, for water following are the properties,

At 30° C, Density ρ = 995.70 kg/m^3

Sp. Heat C_p = 4.177 kJ/kg °C

At 110° C, Density ρ = 965.30 kg/m^3

C_p for superheated steam which varies from 2 to 2.3 KJ/kg.K

Consider Sp. Heat C_p = 2.15 KJ/kg.K

Assume, Atmospheric condition for the calculation.

Water inlet temperature T_w = 30°C

Saturation temperature of water T_{sat} =100°C

Required Steam Temperature T_{sup} =110°C

Mass of water m_w = 1 kg

Latent heat of variation (hf_g) = 2257 kJ/kg

Total Heat required for superheated steam = Heat req to heat water from 30°C to 100°C (Q_1)

+ Heat req. to convert water to steam (Q_2)

+ Heat req. for superheat the steam upto 110^0C (Q_3)

Therefore,

$Q_1 = m\ C_p\ \Delta T$

$Q_1 = 291.9$ kJ

Q_2 = Latent heat of variation (hf_g) X mass

$Q_2 = 2257$ kJ

$Q_3 = m \text{ X } C_p \text{ X } (T_{sup} - T_{sat})$

$Q_3 = 21.5$kJ

$Q = Q_1 + Q_2 + Q_3$

$Q = 2570.4$ kJ

Hence heat required to produce one kg of steam is 2570.4 KJ.

Total capacity of steam generation in heat storage unit (Hytherm 600),

= Total heat storage capacity / heat req. for 1kg steam

= 1.79 kg

Similarly, Total capacity of steam generation in heat storage unit (HDPE) = 2.06 kg

HEAT LOSS THROUGH SYSTEM (HEAT LOSS RATE)

Radial heat loss is given in eq. including convective as well as conductive loss, [33]

Consider mineral wool insulation of 7 cm thickness.

$Q_{radial} = (T_{pcm} — T_a / R_{resist})$

Resistance = $R_{resist} = \frac{1}{2\pi h}\left[\frac{\ln\left(\frac{R2}{R1}\right)}{k1} + \frac{\ln\left(\frac{R3}{R2}\right)}{ki} + \frac{1}{hoR3}\right]$

$Q_{radial} = (200\text{-}30)/\ 6.19$

= 27.46 J/s or w

= 1647.81 J/min = 98.86 kJ/hr

And when heatlon foam insulating sheet of 1 cm is wrapped on mineral wool,

Q_{radial} = = 23.64 J/s

= 1418.63 J/min = 85.11 kJ/hr

Heat loss through storage tank (shell) in axial direction is given by

$Q_{axial} = \frac{(Ts-Ta)}{1/\pi\left[\frac{tc}{R2k1}+\frac{tcyin}{R3ki}+\frac{1}{hoR3}\right]}$

= 12.42 J/s

Therefore,

Total heat loss $Q = Q_{radial} + Q_{axial}$

= 129.09 kJ/hr.

For Hytherm 600 oil,

Time to Loss this heat upto 30 °C = Heat Stored in storage system / Heat loss rate

= 4612.79/ 129.09

= 35.73 hrs

For HDPE,

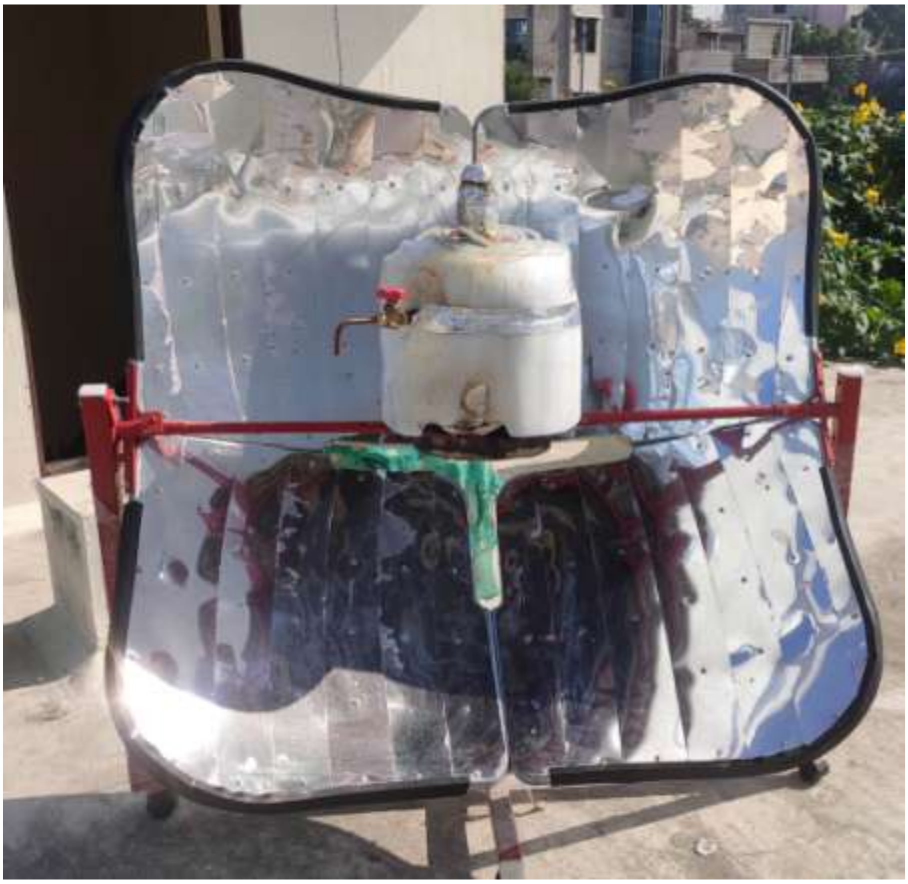
Time to Loss this heat upto 30 °C = Heat Stored in storage system / Heat loss rate

= 5305.9/ 129.09

= 41.1 hrs

The main advantages of presented storage system directly mount on solar cooker, so there is no need of separate heat transfer system required from collector to storage system. The complete set up is shown in fig. 2.

Fig. 2 Parabolic dish type solar cooker with heat storage unit



CONCLUSION

In this research work, heat storage system has been designed and fabricated for specific parabolic dish type solar cooker. The theoretical results the feasibility of using a phase change material 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. The given result is also compared with heat transfer fluid Hytherm 600 oil, it also stored the heat up to 30 ^{0}C for 35.73 hrs. and HDPE material is stored the heat upto 30 ^{0}C for 41.1 hrs. It also provides a nearly constant heat loss through shell at the rate of 129.09 kJ/hr. Also Steam generation calculation is performed, More amount of steam is generated in case of HDPE as compared to Hytherm 600 oil. It is easy to mount on dish directly. There is no need of separate transfer system which transport heat from collector to storage system.

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