Horizontal Heat exchanger based SK 14 Parabolic solar cooker for off-place cooking

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ABSTRACT

Box type and Parabolic Solar Cooker (PSC) became more popular for the cooking at low and high temperatures. Parabolic concentrator type Solar Cooker has a wide range of applications for making chapattis, baking of food material and for distillation due to its unique property of producing a practically higher temperature of nearly 300°C. But cooking with PSC is inconvenient to the user due to its high amount of glare. The main objective of the present study is to design and use a Horizontal Heat Transfer Fluid (HTF) column as heat exchanger unit and to evaluate the thermal performance of a horizontal cylindrical heat exchanger unit assisted PSC. Experiments were conducted for cooking of food on a normal day. Results show that horizontal cylindrical heat exchanger unit can be used for off-place cooking. Optimization of the system design parameters is under investigation**.**

Key words: Solar Energy, Horizontal heat exchanger off-place cooking, Parabolic solar Cooker

1. Introduction

Box type solar cooker and PSC are commonly used (1) for cooking of food in the noon. Out of them, box type solar cooker is more popular due to its simplicity of handling and operation (2). The major problem of box type solar cooker is that its use is limited (3) for cooking of food through boiling only. Solar concentrators have their applications in preparing chapattis, in increasing rate of evaporation of wastewater, in food processing, and for making drinking water from brackish and seawater. It produces a high temperature around 250°c. The major problem with PSC is that it produces high amount of glare from its reflector and hence will be an inconvenience to the user. Hence it is necessary to design a heat exchanger Unit for SK14 PSC system having a facility of retrieval of heat energy at some distance from the PSC.

Schueider et al (4) have studied laminar natural convection in a cylindrical enclosure at different end temperatures having inclination angles between 0° to 180°.It is found that maximum heat transfer rate and greatest velocities are found for L/D=1 and for the angle from 45-60°c. Popiel et al., (9) have performed experiments on free convection in an isothermal vertical surface of a square cylinder to air for L/D of 1-21 and results are in agreement with the theoretical results. In this paper a cylindrical heat exchanger unit for PSC is designed, fabricated and its thermal performance is evaluated. It is based on the principle of natural convection of HTF within a horizontal adiabatic cylinder. During the present experimentation assumptions made are:

1) SK14 PSC is supplying a constant heat to the cylindrical vessel (S_1) of the HTF system.

2) Specific heat, thermal Conductivity and kinematic viscosity of HTF remain constant.

3) The density of the HTF is temperature dependent.

2. Design and description of the horizontal cylindrical heat exchanger unit assisted PSC

Figure 1 shows the sketch of the horizontal heat exchanger unit for SK14 PSC. The working of the system is based on the principle of free convection. The experimental set up consists of a cylindrical (source) vessel ($\mathbf{S_1}$), cylindrical (destination) vessel ($\mathbf{S_3}$), aluminum cooking pot with lid ($\mathbf{S_4}$), cylindrical tube (C), HTF, PSC (P). A cylindrical vessel ($\mathbf{S_1}$) of height 0.09 m and radius 0.066 m is painted black and it is kept at the focus of PSC and a cylindrical tube (mild steel) is welded at its top. The lower portion of cylindrical vessel ($\mathbf{S_2}$) of height 0.23 m and radius of 0.089 m is joined to a mild steel horizontal cylindrical tube (C) of length 1.385 m and radius 0.019 m. It is used to transfer HTF from source vessel $\mathbf{S_1}$ kept at the focus of PSC to the destination cylindrical vessel S_2.

A concentric cylindrical pot ($\mathbf{S_3}$) of radius 0.072 m and height 0.14 m is fixed in the cylindrical vessel $\mathbf{S_2}$ with a facility of transferring heat from HTF. An aluminum pot $\mathbf{S_4}$ with an airtight lid of length 0.16m and radius 0.07 m and it is inserted in the outer heat transfer pot $\mathbf{S_3}$ tightly in such a way that those two surfaces are in good thermal contact. The cylindrical vessel ($\mathbf{S_2}$) and the cylindrical tube (C) are insulated from surroundings by using glass wool of thickness 0.045 m. A HTF (Soya oil) is used as a medium for carrying heat from cylindrical vessel (S_1) to aluminum cooking pot S_4. The various thermo-physical properties of HTF are given in Table 1.A SK14 parabolic solar cooker (Make TATA BP) is arranged for experimentation. The cylindrical vessel S_1 of the heat exchanger unit is placed at the focus of the PSC.

Table 1. Thermo physical properties of HTF

Variable	Value
C	2200
ρ	1075
K	0.22
β(Volume Expn.coeff.)	6×10^{-4}
μ	69 (at 20^{o}C)
$\nu(= \mu / \rho)$	0.0627
M_{HTF}	3.75

2. Working principle:

A horizontal cylinder (C) contains initially a HTF at the room temperature. Both the ends of the cylindrical enclosure (C) are joined to two cylindrical vessels, cylindrical (source) cessel ($\mathbf{S_1}$) and cylindrical (destination) vessel (S_2) of larger diameter. The cylindrical vessel is blackened and it is exposed to focus of the PSC. When solar radiation is focused, heat energy conducts in HTF, producing temperature difference generating density difference resulting in a natural convection in the fluid column within HTF. With time, convection currents improve their velocity against Inertia producing nearly a constant mass transfer of the HTF leads to constant buoyancy forces within the cylinder (C). As time passes continuous flow of heat energy takes place and the food is cooked.

4. Natural convection and associated empirical relations;

During experimentation, as temperature of the oil is increased, density decreases and natural convection takes place and the various dimensionless numbers associated with the HTF are:

The Grashof Number: $Gr = g\,ß\,\Delta T\,L^3 / \nu^2$

Nusselt's Number: $Nu = hL/k$ and

The empirical relation:

$$Nu = 11.44(1-(1708/Ra\cos\Phi))((1-(\sin 1.8\Phi)^{1.6} + 1708)/ Ra\cos\Phi) + ((Ra\cos\Phi/5830)^{1/3} - 1)$$

(For L/D is large and $0<\Phi<75°$)

5. Experimentation:

The experimental horizontal cylindrical heat exchanger unit assisted PSC is considered. Calibrated thermocouples (Cu-constantan) are inserted at various positions of the experimental system. A known amount of HTF is introduced in the heat exchanger unit. aluminum cooking containing food and water. The tracking of reflector of the PSC is continuously monitored and the temperatures of HTF at various positions are measured with a multimeter. To evaluate thermal performance of the experimental system, various experiments are conducted.

6. RESULTS AND DISCUSSIONS:

6.1 Measurement of temperatures:

On dated 14-05-2012, cooking experiment was conducted with horizontal cylindrical heat exchanger unit assisted PSC. Experiment was started at 10:20 A.M. by exposing the system to solar radiation. initial temperatures of $T_{1,}$ T_{HTF} and T_{Food} were 48.5 °C, 33.5 °C and 29.5 °C respectively. The variation of the solar insolation, ambient temperature and temperature profile of source cylinder, HTF and food at different sections of horizontal cylindrical heat exchanger unit were noted at regular intervals of time and shown in Figure 2 and the results are given table 2.

Table 2. Experimental results

Date	14/5/2012	M_{R+W} (Gms)	600
Starting Time (Hrs:Mts)	10:20A.M	$T_{1\,max}$ (°C)	127
$H_{avg.}$ (W/m^2)	520.8	T_{HTF} (°C)	110
$T_{a\,avg}$ (°C)	30.39	$T_{Food\,max}$ (°C)	95
M_R(Gms)	200	$t_{Totaltime}$ (minutes)	95
M_W(Gms)	400		

6.2 Determination of dimensionless parameters:

During experimentation, variations of heat transfer coefficient h, dimensionless numbers such as GrPr and Nu and temperature is studied and given in Table 3.

able 3. Average values of dimensional numbers

Parameter	Calculated Value
$GrPr_{avg.}$	$6.9X10^8$
$Nu_{avg.}$	44.26
$h_{avg.}$	7.08
$v_{avg.}$	0.01189
$m^{\cdot}_{avg.}$	0.01296

6.3 Determination of velocity and mass flow rate during natural convection:

During the experimentation, as time passes, the temperature of the HTF in the source cylinder is increased, producing density differences in the horizontal HTF column. This density difference produces natural convection within the HTF. The variation of Density of HTF is calculated for a known length of the liquid column in a specific interval of time. By taking the time dependent density values of HTF of a known amount, the velocity of the HTF during natural convection in the horizontal HTF column is calculated for every a specific interval of time (Figure 4) using the formula,

$$\text{Velocity, } v = M/ \rho \, dt \, A$$

The average value of velocity (v_{avg}) during entire experimentation is calculated and is given in Table 3. By taking the volume of the HTF undergoing natural convection and the temperature Dependent density values for a specific time, the mass flow rate of the HTF in the horizontal cylindrical heat exchanger is calculated for every interval of time using the formula,

$$\text{Mass flow rate, } m' = \rho \, V/ dT$$

The average value of Mass flow rate $m'_{avg.}$ of HTF during entire experimentation is found and is given in Table3.

6.4 Evaluation of Thermal Performance:

6.4.1 Measurement of sensible cooking power of the solar cooking unit:

The thermal efficiency of the solar cooking unit is evaluated by calculating the cooking power. The latent cooking power is the rate of energy needed to boil a certain mass of water in the pot. The sensible cooking power (P) is,

$$P = M_w \, C_w \, \Delta T/ dt$$

The calculated value is given in Table 4.

6.4.2 Calculation of energy transport profile:

Calculations are performed for the energy transport phenomenon during the experimentation and given in the Table 4.

7. Conclusions: Thermal energy obtained from a PSC can be transported to comfortable places for cooking with the help of a heat transfer fluid. This phenomenon can be successfully applied for off-place cooking.

Table 4. Energy transport profile

Total incident Energy, KJ	53,31,078
Heat utilized for cooking ,KJ	1,65,060
Un-utilized heat energy in the HTF,KJ	9,25,650
Total energy absorbed by the HTF ,KJ	11,68,981
Total energy transported ,KJ	10,90,710
Absorbed energy out of incident energy (%)	21.9
Transported energy out of Total absorbed energy (%)	93.3
Energy used for cooking out of transported energy (%)	15.13
Energy un-utilized for cooking out of transported energy (%)	84.91
Transported energy out of incident energy (%)	20.45
Energy used for cooking out of incident energy (%)	3.09
Energy un-utilized for cooking out of absorbed energy (%)	79.18
Sensible Cooking Power of the Cooking Unit (P)	23.92

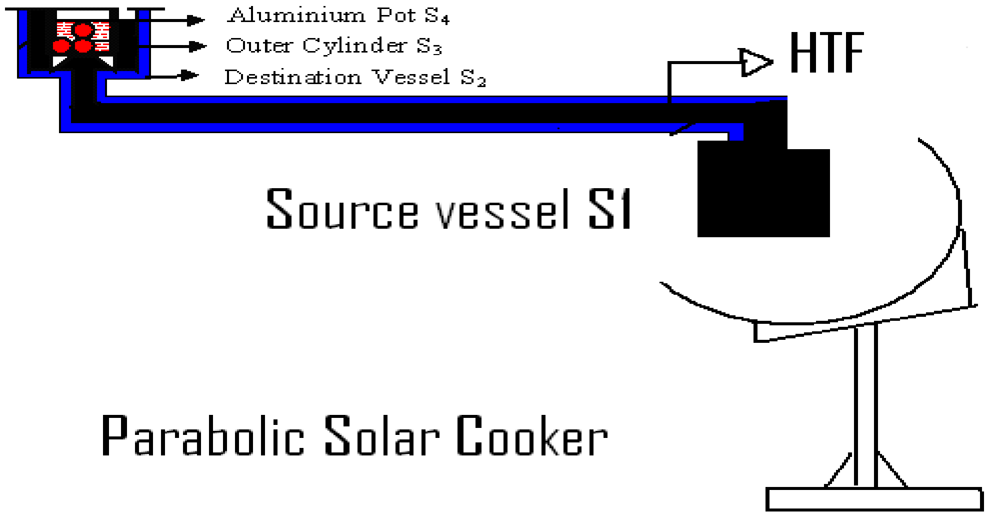

Figure 1 shows the sketch of the horizontal heat exchanger unit for SK14 PSC

8. References:

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