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Evaluation of thermal performance of heat exchanger unit for parabolic solar cooker for off-place cooking

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Different types of solar cookers developed for cooking are box type and concentrator type solar cookers. A parabolic concentrator type solar cooker has a wide range of applications like baking, roasting and distillation due to its unique property of producing a practically higher temperature of nearly 250°C and hence, it provides inconvenience to the user due to high amount of glare. The main objective of the present study is to incline cylindrical heat transfer fluid column as a heat transfer medium. The thermal performance of a parabolic solar cooker depends on inclined heat exchanger system of mild steel tube of length 157.5 cm and an internal radius 2.07 cm with heat transfer fluid (oil) of density 1075 kg/m^3. Experiments are conducted for cooking of food at a normal day. The results show that inclined convective heat exchanger system can be used for off-place cooking. The optimization of the system design parameters is under investigation.

Keywords: Solar energy, Parabolic cooker, Heat exchanger unit, Off-place cooking
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1 Introduction

The box type and parabolic solar cookers are commonly used[1] for cooking of food in the noon. Among 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 for cooking of food material by boiling. In addition to cooking applications, solar concentrators have their applications in increasing the rate of evaporation of wastewater, in food processing, for making drinking water from brackish and seawater. It produces a high temperature around 250°C and the food gets cooked in less time. The major problem with parabolic solar cooker is that it produces high amount of glare from the reflectors and it is inconvenience to the user and therefore, it is not popular.

Hence, it is necessary to design a heat exchanger unit based on heat transfer fluid (HTF) for parabolic solar cooker by retrieving the heat energy at some distance from the collector. Schueider and Straub[3] have studied laminar natural convection in cylindrical enclosure with different end temperatures at an inclination angles between 0° to 180° and found that the maximum heat transfer rate and greatest velocities are found for *L/D*=1 and angle in the range 45-60 °C.

In this paper, a cylindrical heat exchanger unit for parabolic solar cooker is designed, fabricated and its thermal performance is evaluated. It is based on the principle of natural convection of HTF within an inclined adiabatic cylinder.

During the present investigation, the following assumptions are made:

(1) Parabolic solar cooker is providing a constant heat to the Lower Cylindrical (source) vessel (S_1) of the HTF system; (2) The thermo physical properties of the HTF like specific heat, thermal Conductivity and kinematical viscosity remain constant during experimentation; and (3) The density of the HTF is temperature dependent.

2 Design and Description of Inclined Cylindrical Heat Exchanger system

Figure 1 shows the sketch of heat exchanger unit for SK14 parabolic solar cooker. The working of the system is based on principle of free convection. The experimental set-up contains the following components:

(a) Lower cylindrical (source) vessel (S_1); (b) Upper cylindrical (destination) vessel (S_2); (c) Concentric cylindrical pot (S_3); (d) Aluminium cooking pot with lid (S_4); (e) Cylindrical tube (C); (f) Heat transfer fluid (HTF) and (g) Parabolic solar cooker (P).

A lower cylindrical vessel (S_1) of length 0.15 m and radius 0.063 m is painted black and it is kept at the

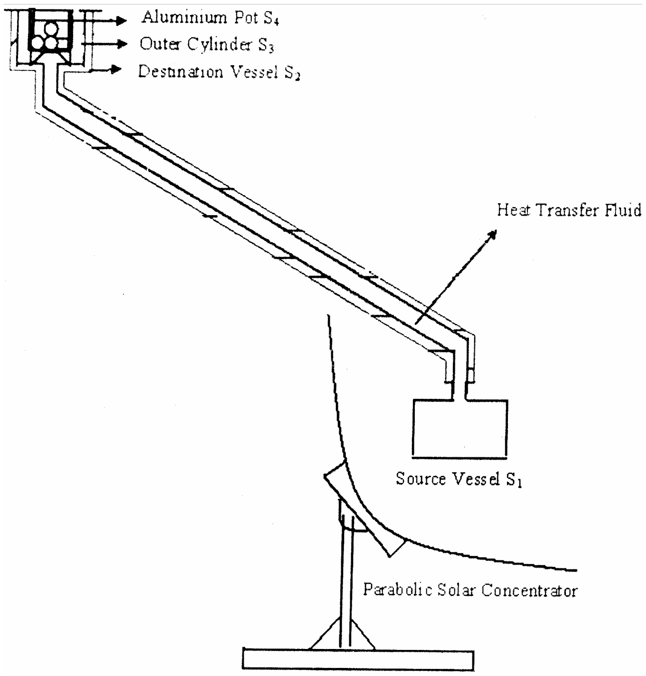

Fig. 1 — Schematic of the inclined heat exchanger unit assisted PSC

focus of parabolic solar cooker (P). It is heated from bottom and a cylindrical tube (mild steel) is welded at its top. The lower portion of upper cylindrical (destination) vessel (S_2) of length 0.22 m and radius 0.020 m is joined to an inclined cylindrical tube (C) of length 0.15 m and radius 0.020 m (of mild steel) making an angle of 22° with the horizontal is used to transfer HTF from lower source vessel S_1 kept at the focus of parabolic solar cooker to the upper cylindrical vessel S_2. This tube has two bends for fixing the cylindrical vessels S_1 and S_2 in a horizontal plane.

A concentric cylindrical pot (S_3) of radius 0.072 m and length 0.014 m fixed in the cylindrical vessel S_2 with a facility of transferring heat from HTF. An aluminium pot S_4 with an airtight lid of length 0.16 m and diameter 0.14 m and it is inserted in the outer heat transfer pot (S_3) tightly in such a way that two surfaces are in good thermal contact. The upper cylindrical vessel (S_2) and the cylindrical tube (C) are insulated laterally from surroundings by using glass wool of thickness 0.039 m. A HTF (soya oil) is used as a fluid for heat exchanger for carrying heat from lower cylindrical vessel S_1 to aluminium cooking pot S_4. The various thermo-physical properties of HTF are given in Table 1.

A parabolic solar cooker (Make: TATA BP) is considered and the lower cylindrical vessel S_1 of the

Table 1 — Thermo-physical properties of HTF

Quantity	Value
C_p	2200 J/kgK
ρ	1075 kg/m^3
K	0.22 W/mK
β (Expn.coeff.)	6×10^{-4} K^{-1}
μ	69 (at 20°C)
ν	0.0627 N/m^{2}s
V_{total}	5 kg

heat exchanger unit is placed at the focus of the PSC. K type thermo-couples are used for the measurement of temperature.The insulated inclined long cylinder (C) contains initially a HTF at the room temperature. Both the ends of the cylinder (C) are joined to two cylindrical vessels lower cylindrical (source) vessel (S_1) and upper cylindrical (destination) vessel (S_2) of larger diameter. The lower cylindrical vessel is blackened and exposed to focus of the parabolic solar cooker. When solar radiation is focused, heat energy conducts in HTF producing temperature difference and 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 that leads to constant buoyancy forces within the cylinder (C). As time passes, continuous flow of heat energy takes place and the food is cooked.

3 Experimental Details

The experimental cylindrical heat exchanger unit assisted parabolic solar cooker was considered. The calibrated thermocouples (Cu-Constantan) were inserted at various positions of the experimental system. A known amount of HTF is introduced in the experimental system. Aluminium cooking pot is inserted along with food and water. The reflector of the PSC was continuously monitored and the temperatures of HTF at various positions are measured with a computer equipped with data logger. To evaluate thermal performance of the experimental system, various experiments were conducted and the results were reported.

4 Results and Discussion

4.1 Measurement of temperatures

The cooking experiment was conducted by using inclined cylindrical heat exchanger assisted parabolic solar system. The experiment was started at 11:50 am and the system is exposed to solar radiation. Initial

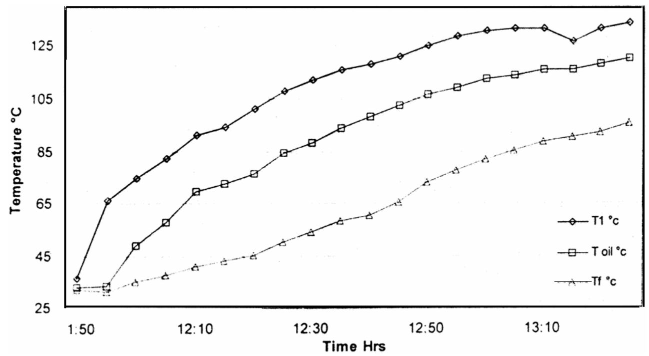

Fig. 2 — Variation of source, oil and food temperature on May 12, 2004

Table 2 — Results of inclined cylindrical HTF system assisted parabolic solar cooker on May 12, 2005

Variable	Value	Variable	Value
Starting time (Hrs)	11:50	T_{1max} (°C)	134
H_{avg} (W/m^2)	565.6	T_{oilmax} (°C)	120
$T_{a\ avg}$ (°C)	31.8	$T_{foodmax}$ (°C)	95
M_R (gm)	200	$t_{Total\ time}$ (minutes)	95
M_W (gm)	400	P	279
M_{R+W} (gm)	600	η	3.47%

temperatures of source, oil and food of the system are T_1, T_{oil} and T_{food} are 36.25, 33 and 32.25°C, respectively.

The variation of the solar insolation, ambient temperature and temperature profile of source cylinder, oil, food at different sections of inclined heat exchangers cylindrical system (T_1, T_2, T_3, T_4, T_5, T_w, T_{oil}, T_{food} and T_a) are noted at regular intervals of time and shown in Fig. 2. The results are presented in Table 2.

4.2 Evaluation of thermal performance

4.2.1 Measurement of thermal efficiency of solar cooking unit

The cooking power and sensible efficiency can represent the thermal efficiency of the solar cooking unit. The sensible or heating-up power represents the rate of sensible energy used to heat up a certain mass of water, and the latent cooking power is the rate of energy needed to boil a certain mass of water in the pots. The sensible cooking power is expressed as:

$$P = M_w\ C_w\ \Delta\ T/\mathrm{d}t$$

The average sensible efficiency is determined as the sensible energy used in heating divided by the average incident solar flux on the collector plate, H_{avg}, times the collector area, A_c. It is expressed as:

Table 3 — Energy transport profile during experimentation

	Value
Total incident Energy, kJ	4726.8
Heat utilized for cooking, kJ	159.2
Un-utilized heat energy in the oil, kJ	1066.8
Total energy absorbed by the oil, kJ	1236.2
Total energy transported, kJ	1226
Absorbed energy out of incident energy, %	26.15
Transported energy out of absorbed energy, %	99.17
Energy used for cooking out of transported energy, %	12.98
Energy un-utilized for cooking out of transported energy, %	87.01
Transported energy out of incident energy, %	25.93
Energy used for cooking out of incident energy, %	3.36
Energy un-utilized for cooking out of absorbed energy, %	86.29

$$\eta = M_w\ C_w\ \Delta T/A_c H_{avg}$$

The calculations are performed with the data of various temperatures of the system with ambient conditions and presented in Table 3.

5 Conclusions

Thermal energy obtained from parabolic solar cooker can be transported to any comfortable place for cooking by using a heat transfer fluid. This phenomenon can be successfully applied for off-place cooking at moderate solar insolation. The reasonably high insolation decreases the cooking time to a very minimum value.

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Nomenclature

A_c	Area of collector, m^2
C	Specific heat, kJ/kg °C
C_p	Specific heat of HTF, kJ/kg °C
D	Diameter of the cylinder, m
H	Solar insolation, W/m^2
H_{avg}	Average solar insolation, W/m^2
K	Thermal conductivity, W/m^2 °C
L	Length of the cylinder, m
M	Mass, Kg
P	Sensible cooking power J
t	Time, s
dt	Time interval, s
T	Temperature, °C
ΔT	Temperature difference, °C

T_a Ambient temperature, °C
T_1 Source cylinder bottom temperature, °C
T_2 Source cylinder top temperature, °C
T_3 Temperature of middle of tube, °C
T_4 Temperature of middle of tube, °C
T_5 Temperature of bottom of destination cylinder, °C
T_w Wall temperature, °C
T_{oil} Temperature of upper layer of oil of destination cylinder, °C
T_{food} Food temperature, °C
V Volume of the HTF, m^3
β Coefficient of thermal expansion, K^{-1}
ρ Density, kg/m^3
μ Viscosity, kg/m s
η Average sensible efficiency

Suffixes

w	Water	R	Rice
food	Food	max	max
avg	Average	oil	
Oil	a	Ambient	

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