International Journal of Engineering Technology Science and Research
IJETSR
www.ijetsr.com
ISSN 2394 – 3386
Volume 5, Issue 5
May 2018

Performance Evaluation of Parabolic Dish Type Solar Cooker Using Different Materials for Cooking Vessel

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ABSTRACT: *Solar cooker is used for cooking foods mainly in rural areas by using solar energy. Parabolic solar cooker having 1.39-meter aperture diameter, 0.45-meter depth and 0.26-meter focal length is designed, constructed and fabricated. The parabolic solar cooker is tested on one litre of water in cylindrical cooking vessel of two different materials namely, aluminium and GI sheet. Thermal performance is done for both types of cylindrical cooking vessel and evaluated the values of heat loss factor, optical effectiveness factor, cooking power, sensible cooking power, Average sensible efficiency, exergy efficiency. On the basis of these performance factors, aluminium vessel is better than galvanized iron sheet vessel.*

***Keywords**: Parabolic solar cooker, cylindrical vessel, cooking power.*

1. INTRODUCTION

Energy is defined as the capacity to do work for any physical system which is very necessary for our environment [1]. Many researchers are working to solve energy-related issues and its consumption which directly affect human life [2]. Fossil fuel energy resources have a higher share in global energy consumption. There are several issues created by using fossil fuels like atmospheric pollution, greenhouse effect and global warming, increasing fuel cost and rapid depletion of fossil fuels. Due to several issues with fossil fuels, researchers have turned to renewable energy. Renewable energy plays an important role in sustainable development of human life [3]. Among these sources, solar energy is a very important renewable form of energy resource which is easily available, unlimited, clean and environment-friendly [4]. Wood is a primary source of energy for cooking which creates ecological problems like, deforestation. In rural areas wood, cow dung, kerosene and agriculture waste are major sources of energy for cooking. These create several health issues like eye disorders, burns, and lung disease created by using fossil fuel [5]. To remove above difficulties caused by using fossil fuels, the solar cooker is the best option [6]. Solar cooker uses clean and low-cost renewable energy for cooking food. Solar cooker uses the heat of solar radiation by concentrating it on solar cooker surface for cooking food [7]. The parabolic dish type solar cooker is a type of solar cooker which is used for cooking food and other application like, solar water heating, baking, grilling etc. [8]. In parabolic dish type solar cooker, incident solar radiation from the sun is reflected by the solar reflector and concentrated at a point of the parabola where the cooking vessel is placed.

2. LITERATURE REVIEW

Mullick et.al worked on the parabolic solar cooker to evaluate the thermal performance of solar cooker and find that thermal performance of solar cooker does not depend on climate variables [9]. Ozturk et.al constructed a low-cost parabolic-type solar cooker (SPC) and tested to calculate energy and exergy efficiency, experimentally [10]. Pohekar et.al studied multi-criteria of cooking devices with special reference to the utility of parabolic solar cooker in India. It was concluded that households cooking energy demand can be fulfilled by parabolic solar cooker [11]. Kaushik et.al performed

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a comparative study between community size parabolic solar cooker and domestic size parabolic cooker. On the basis of its thermal performance, it was concluded that the thermal efficiency of community size is better than domestic size [12]. Petela et.al discussed simple exergy analysis of cylindrical parabolic solar cooker and provided a methodology of detailed exergy analysis of SPC and distribution of exergy losses of the cooker surfaces [13]. Al-Soud et.al performed an experiment on a parabolic solar cooker with automatic two-axis sun tracking system. The problem of tracking was solved which is the main drawbacks of concentrating solar cookers with manual tracking [14]. Ouannene et.al studied the design of parabolic solar cooker and suggested that best cooking hour using parabolic solar cooker is 01:30 PM to 2:30 PM [15]. D. D. Yahya et.al suggested that the new world standard procedure can be used for testing solar cookers to determine thermal performance of parabolic concentrating solar cooker. The new standard defines limits for environmental conditions, specifies test method and performance in terms of cooking power [16]. Safa Skouri et.al worked on a geometrical and thermal study of parabolic solar cooker [17]. Jhalaria et.al designed fabricated and performed a thermal analysis of parabolic solar cooker for cooking purpose and concluded that thermal performance of parabolic solar cooker is better than box type [18]. Zamani et.al discussed an idea to optimize the geometry of the reflective Surfaces of double exposure parabolic solar cookers [19] Hajji et.al worked on the experimental thermal performance of parabolic solar cooker [20]. Pradhan et.al worked on design, development and performance evaluation of a parabolic solar cooker for medium temperature application [21]. Vikrant Yadav et.al performed an analysis of the thermal performance of phase change material (PCM) in a combination of different sensible heat storage materials in a solar cooker based on parabolic dish collector for cooking purpose [22]. Zhongyuan Su et.al performed modelling and simulation of parabolic solar cooker [23].

3. EXPERIMENTAL SET-UP

In this present work, the parabolic dish type solar cooker is constructed for an experiment which is shown in figure-1. Bright anodized aluminium plates are used as reflector material of parabolic dish type solar cooker because of its reflectivity, which is 85% [24]. Experimental set-up consists of parabolic dish concentrator having 1.39 m aperture diameter, 0.45 m depth and 2.04 m^2 concentrator area. The black paint coated cooking vessels are used so that its outer surface acts as an absorber. The focal length of concentrator and rim angle are calculated as 0.26 m and 75.47^0 respectively. Aluminium and galvanised iron sheet are used for the cylindrical cooking vessel.

Figure1: Experimental set-up of the parabolic solar cooker.

4. METHODOLOGY

To evaluate the performance of parabolic solar cooker, there are various parameters.

Focal distance (f) is given as [25]:

$$f = \frac{d^2}{16h}$$

The surface area of the parabolic dish is given as [25] [26]:

$$A = \frac{8\Pi f^2}{3}\left[\left(\left(\frac{d}{4f}\right)^2 + 1\right)^{\frac{3}{2}} - 1\right]$$

The half aperture or rim angle of the parabola is given as [25] [26] [27]:

$$\tan\emptyset = \frac{1}{\frac{d}{8h} - \frac{2h}{d}}$$

Arc length of paraboloidal is [27] [28]:

$$S = \frac{d}{2}\sqrt{\left[\frac{4h}{d}\right]^2 + 1 + 2f\left[\left[\frac{4h}{d}\right] + \sqrt{\left[\frac{4h}{d}\right]^2 + 1}\right]}$$

Length of the circumference of the circular aperture of the parabolic surface [28] [29]

$$= 2\pi R$$

The cooking power is given by [30]:

$$P = \frac{m_w c_w (T_w - T_w)}{\zeta t}$$

The thermal loss factor is expressed as [31]:

$$F_{UL} = \frac{m_w c_w}{A_p * \emptyset}$$

The optical effectiveness factor is given as [31] [32]:

$$F_{\acute{\eta}} = \frac{\frac{(F_U)*A_p}{A_p}\left[\left(\frac{T_w - T_a}{I_b}\right) - \left(\frac{T_w - T_a}{I_b}\right)e^{\frac{-\emptyset}{\emptyset_U}}\right]}{1 - e^{\frac{-\emptyset}{\emptyset_U}}}$$

Sensible cooking power is expressed as [33]:

$$P_s = \frac{m_w * c_w * \Delta T_w + m_v * c_v * \Delta T_v}{\Delta T_b}$$

Average sensible efficiency as [33] [34]:

$$\acute{\eta} = \frac{P}{I_b}$$

Energy output of solar cooker [34] [35] is:

$$Q_h = \frac{m_w * c_w * \Delta T_w}{\zeta T_b}$$

Exergy efficiency of solar cooker [35] [36] is:

$$\acute{\eta}_e = \frac{E \quad o \quad p\ s \quad c \quad (Q\ )}{A \quad o\ s \quad ra \quad *a \quad a}$$

5. PERFORMANCE EVALUATION

Performance evaluation of parabolic solar cooker is based on heating and cooling test. After this, some parameters are evaluated which are listed below.

- Heat Loss Factor
- Optical Effectiveness Factor
- Cooking power
- Sensible cooking power
- Average sensible efficiency
- The energy output of solar cooker
- Exergy efficiency of solar cooker

5.1 HEATING & COOLING TEST

The purpose of the heating test is to determine optical effectiveness factor and overall heat loss factor. For this test, cooking pot is filled with water (1 litre) and kept at the focal point of the parabolic collector. The measurements have been taken at a time interval of 15 minutes. The temperature of water in the cooking pot is monitored till the water temperature reaches to boiling point. After the heating test, the cooling test is performed. The cooling test is performed to calculate cooling time constant which is used to calculate the heat loss factor, optical effectiveness factor. The value of the cooling time constant τ_0 is obtained by calculating the slope of the cooling curve. The slope of the line drawn between ln (Tw-Ta) and time. .Heating and cooling test results are shown in figure 2. Sensible heating time ranges between 11:00 AM to 02:00 PM and sensible cooling time are lies between 02:00 PM to 03:00 PM. In the sensible heating test, water is heated from 30^0 C to 123^0C for aluminium vessel and 30^0C to 105^0C for galvanized iron sheet vessel. The maximum water temperature is found 123^0C and 105^0C for aluminium vessel and GI sheet vessel respectively. it is clear that water in aluminium vessel is heated faster than galvanized iron sheet vessel.

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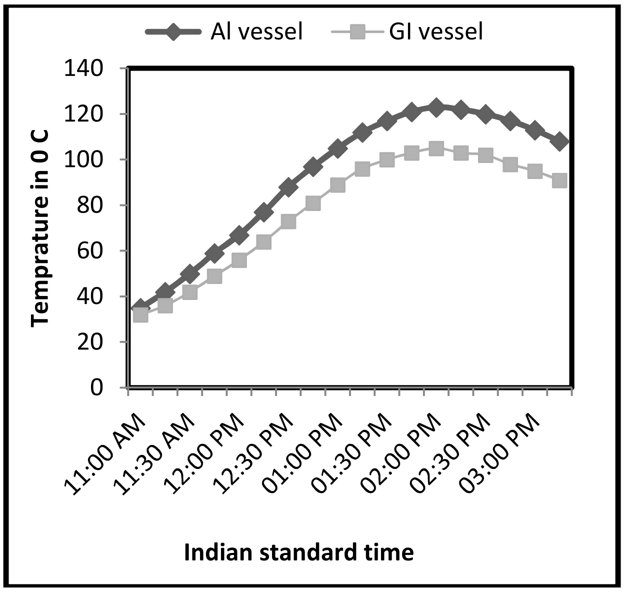

Figure 2: Temperature variations of aluminium and GI sheet vessel with time.

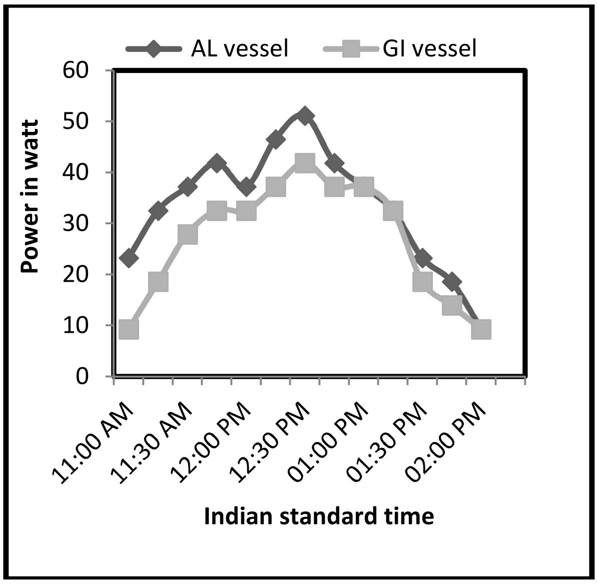

Figure 3: Cooking power variations of aluminium and GI sheet vessel

6. RESULTS & DISCUSSIONS

On the basis of cooling curve analysis cooling time constant is calculated which is **24.63** for aluminium and **20.12** for GI vessel. The boiling time taken by aluminium vessel is **120 minutes** and **150 minutes** by GI sheet vessel. Thermal performance parameter values are listed below for aluminium and GI sheet metal vessel.

- Heat loss factor –

(a) $F_{ULalluminium}$ = 15.26W/m^2 ^{0}K

(b) $F_{UL\ GI}$ = 18.99 W/m^2 ^{0}K

- Sensible cooking power –

$P_{s\ aluminium}$ = 35.16 Watt

$P_{s\ GI\ sheet}$ = 25.52 Watt

- Average sensible efficiency

$ή_{al}$ = 2.2 %, $ή_{GI}$ = 1.60 %

- Energy output of solar cooker

$Q_{h\ aluminium}$ = 34.10 Watt

$Q_{h\ GI\ sheet}$ = 24.25 Watt

- Exergy efficiency of solar cooker

$ή_{exergy\ aluminium}$ = 2.14%

$ή_{exergy\ GI\ sheet}$ = 1.52%

Figure 3 shows that cooking power is maximum at 12:30 PM for both aluminium vessel and for GI sheet vessel because there is maximum difference between the initial and final temperature of water. Lowest cooking power is at 2:00 PM for both aluminium and GI sheet vessel because there is a minimum temperature difference between initial and final water temperature.

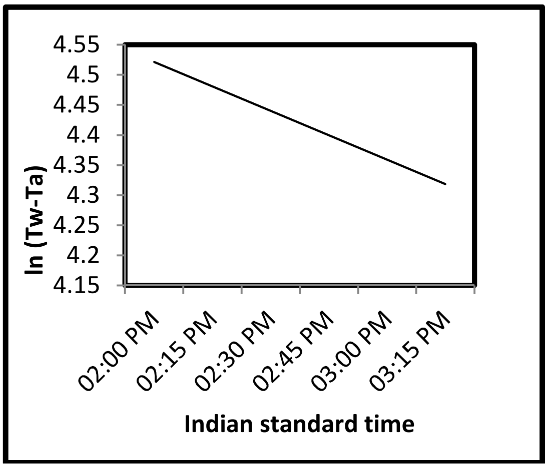

Figure 4: Cooling curve for aluminium

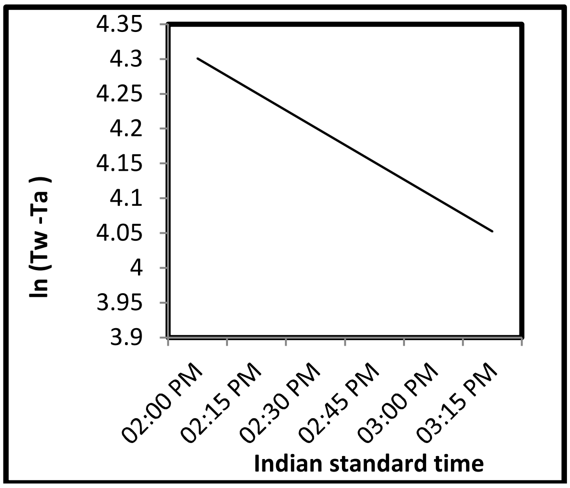

Figure 5: Cooling curve for GI sheet

Figure 4 & 5 shows that cooling curves for aluminium and GI vessel. It is calculated that cooling time constant is 24.63 for aluminium and 20.12 for GI sheet. The cooling time constant of aluminium and GI sheet is reviewed for calculating heat loss factor and optical effectiveness factor.

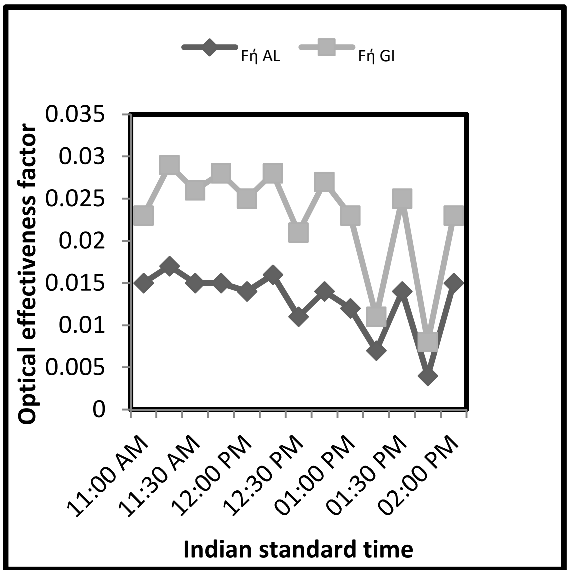

Figure 6: Optical effectiveness factor of the parabolic solar cooker

Figure 6 shows that the optical effectiveness factor of the parabolic solar cooker for aluminium and GI sheet. The average value of optical effectiveness factor is 0.015 for aluminium vessel and 0.011 for GI sheet vessel.

CONCLUSION

In this present work parabolic solar cooker is designed, fabricated and tested. After testing, it is found that parabolic solar cooker can achieve sufficient temperature which is required for cooking different varieties of foods. The parabolic solar cooker has many advantages like ease of manufacture, low price, lightweight and better efficiency. After comparing the cooking vessels of aluminium and GI sheet experimentally, it is found that the time taken to boil the water in aluminium vessel is less than that in GI vessel.

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NOMENCLATURE

d = Aperture diameter of parabola

f = Focal length of parabola

h = Depth of parabola

R = Radius of parabola.

A = Aperture area of parabola

$\leftarrow$= Rim angle of parabola

S = Arc length of parabola

P = Cooking power

P_s = Sensible cooking power

m_w= Mass of water

m_w= Mass of vessel

c_w = Specific heat of water

c_v = Specific heat of vessel

T_{wf} = Final temperature of water

T_{wi} = Initial temperature of water

T_w = Water temperature

T_v = Vessel temperature

T_a = Ambient air temperature

ζT_w = Difference in water temperature

ζT_v = Difference in vessel temperature
∅ = Fixed time interval
∅ = Cooling time constant
I_b = Incident solar radiation
F_{UL} = Heat loss factor
$F_{ή}$ = Optical effectiveness factor
Q_h = Energy output of solar cooker
ή = Average sensible efficiency
$ή_{exergy}$ = Exergy efficiency of solar cooker
ζt = Fixed time interval
ζT_{bw} = Boiling time taken by water