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# Thermal Performance Evaluation and Testing of Improved Animal Feed Solar Cooker

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**ABSTRACT**

An improved solar cooker for animal feed was fabricated using locally available materials as bricks, cement, sand and pearl millet hull. The commercial materials used for its fabrication were glass covers, 24 SWG galvanised steel, wood, aluminum sheet, and cooking utensils. Length to width ratio of the cooker was designed as 3:1 for maximum radiation exposure on the glass window at any time in a day. It helped in eliminating the need for azimuthal tracking of the cooker, which is essential for a simple hot box solar cooker. The solar cooker was capable of boiling 10 kg animal feed per day, sufficient for four cattle heads, with efficiency of 26.4 per cent. The thermal performance of the animal feed solar cooker through stagnation and water boiling tests performed during April, 2016 indicated the First Figure of Merit (F1), Second Figure of Merit (F2) and standardized cooking power (Ps) to be 0.089 $m^2.°C.W^{-1}$, 0.288 $J.W^{-1}.°C^{-1}$ and 27.40 W, respectively. It indicates that the developed cooker falls under category "B" of BIS standard, but sufficient for cooking of animal feed once a day.

In developing countries, energy requirement for cooking is generally met through firewood, which is one of the causes of deforestation. Moreover, burning of fuelwood has adverse environmental effects, since it emits large amount of $CO_2$ in the atmosphere. The environmental effects of fuel wood burning have been reported in several literatures (Boehmer-Christiansen, 2000; Brunicki, 2002; Elliott, 2004; Shove, 2004; Tingem and Rivington, 2009; Panwar *et al.,* 2009, 2011; Huttunen, 2009). Keeping in mind these environmental issues of fuelwood uses, a transition towards low-polluting energy sources for cooking in rural areas is required, which will also be suitable for mitigating climate change (Budzianowski, 2012). Cooking with solar energy is a promising option as it is abundantly available in most parts of the world. Moreover, cooking using solar energy can be done unattended once the feed to be cooked is kept inside the cooker, thereby saving considerable time of the person that can be utilized for other activities.

In arid part of Rajasthan, solar irradiations are available in plenty with almost 300 clear sky days. Amount of solar irradiation received in the region is about 7600–8000 $MJ.m^{-2}$ per annum. This is about 7200–7600 $MJ.m^{-2}$ per annum in semi-arid regions, and about 6000 $MJ.m^{-2}$ per annum in hilly areas (Pande *et al.,* 2009).

In the arid western Rajasthan, animal husbandry contributes a major portion of the income of rural people. Livestock provides a range of benefits to them by providing nutritious milk for domestic use, income generation through sale of milk, manures to maintain soil fertility, etc. Livestock are also commonly used for draft power in farm operations (Binswanger and Quizon, 1988). Thus, it plays a major role in generating employment and reducing poverty in the rural areas. However, these benefits are available when digestive and nutritive feeds are given to these livestock animals.

Boiling the animal feed helps in improvement of digestive and nutritional quality of the feed, which in turn improve both the milk quality and quantity. Therefore, rural people in arid western Rajasthan generally boils the animal feed daily before giving it to their livestock. Firewood, cow dung cake and agricultural wastes are commonly used for boiling purpose (Nahar *et al.,* 1996a, 1996b; Panwar *et al.,* 2011). The traditional practice does not necessarily ensure the feed quality because it requires slow cooking. Solar cooking is a suitable option to prepare the animal feed (Panwar *et al.,* 2010, 2012), as it also saves fuelwood. Drudgery involved in conventional boiling process can also be avoided in solar cooking.

Solar cookers commonly available are suitable for cooking twice a day, and consequently the initial cost is high. In addition, commercially available box type cookers have low capacity, and need to be frequently oriented towards the sun. Since animal feed is to be boiled only once a day, it was felt that a low-cost non-track solar cooker should be a better option for boiling animal feed. Considering this, an improved solar cooker using locally available materials (as bricks, cement, sand, and pearl millet hull) was designed, developed and tested for thermal performance in arid zone of Rajasthan.

## MATERIALS AND METHODS

### Improved Animal Feed Solar Cooker

The earlier model of the cooker was improved upon to enhance the life of the cooker with use of locally available materials, and constructed by the village mason and carpenter. The earlier design was made of clay, pearl millet husk and dung; required 3-4 days for construction and had a short life of about 5 years (Nahar, 1994). The improved design can be constructed in 3-4 hours, and the expected life is about 15 years.

The double-glazed improved animal feed solar cooker with reflector was designed and fabricated at the workshop of ICAR-Central Arid Zone Research Institute, Jodhpur, India. The solar cooker comprised of a brick wall (0.1m) plastered with cement sand in the ratio of 1:6. The outer and inner dimensions of the cooker were 1980×760×100 mm and 1870×650×50 mm, respectively. The depth of the cooker was above 300 mm, half of which was packed with pearl millet hull (grain removed spikelets). An absorber plate (painted with dull black paint) was placed above the cooker. Three cooking pots can be kept in the cooker.

The cooker was provided with 150 mm insulation of pearl millet hull. The height of cooking pots from absorber plate was kept at 100 mm, and about 50 mm depth was maintained between the top of cooking pots and the glass sheet. The design was based on the concept of non-tracking solar cooker by designing the length: width ratio as more than 3:1, so that maximum amount of radiation could fall on the glass window at any time in a day. Since three aluminium cooking pots of 550×450×75 mm with lids were used for boiling of 10 kg animal feed material for four animals, the overall inner length and width of the cooker worked out to 1870×650 mm.

A pit of 1980×760×100 mm was dug in the ground (Fig. 1). The base of the earthen pit was of cement-sand (1:6), and the bottom of the pit was filled with 50 mm thick bricks. A 150 mm thick pearl millet hull insulation was provided on the brick bottom of the cooker.

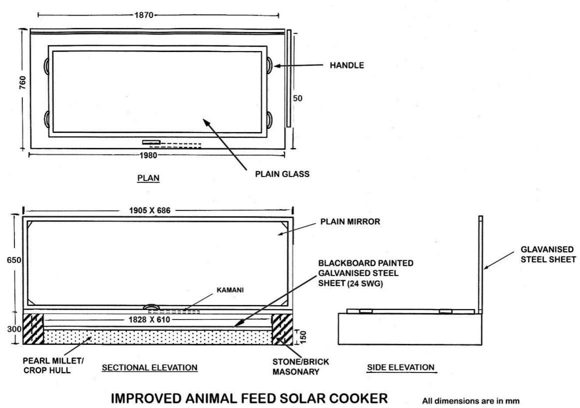


**Fig. 1: Schematic diagram of animal feed solar cooker**

A 24-SWG galvanised steel absorber was put over the pearl millet hull insulation, and the top side was painted with black board paint. Two horizontal glass covers (4 mm thick) fixed on a removable angle iron-wooden frame were provided over it. The spacing between the two glass covers was maintained at 15 mm to avoid thermal losses.

The dead weight of the double–glazed frame of the solar cooker was 25 kg. The frame body of the cooker can be fabricated by an unskilled labour. Actual installation of the animal feed solar cooker is shown in Fig. 2.

### Energy Balance

The design of the animal feed solar cooker was based on the principle of flat-plate solar collector and green house effect. Shorter wave lengths of solar radiation enter the collector to get converted into longer wave length, and get trapped inside as glass is opaque to longer wave length. The energy balance of this solar cooker (neglecting bottom losses) was carried out by the following equation:

**Fig. 2: Animal feed solar cooker installed in the field**

$$\rho V.C_a \frac{dT_r}{dt} = \alpha\tau.SA_f - UA_c(T_r - T_a) \quad ...(1)$$

At steady state,

$$\rho V.C_a \frac{dT_r}{dt} \to 0 \quad ...(2)$$

So,

$$\alpha\tau.SA_f - UA_c(T_r - T_a) = 0 \quad ...(3)$$

$$T_r = \frac{\alpha\tau.SA_f}{UA_c} + T_a \quad ...(4)$$

Where,

$$U = \left[\frac{1}{h_i} + \frac{L}{K} + \frac{1}{h_0}\right] \quad ...(5)$$

Where,

ρ = Density of air, kg.m$^{-3}$,

$V$ = Volume of collector, m$^3$,

$C_a$ = Specific heat of air, J. kg$^{-1}$.$^o$C$^{-1}$,

$T_r$ = Temperature of collector, $^o$C,

$A_c$ = Collector surface area, m$^2$,

α = Absorptivity of absorber,

τ = Transmissivity of glass,

$S$ = Incident solar radiation, W.m$^{-2}$,

$A_f$ = Floor area, m$^2$,

$U$ = Overall heat transfer coefficient, W.m$^{-2}$.$^o$C$^{-1}$,

$T_a$ = Ambient temperature, $^o$C,

$h_i$ = Inside convective radiative losses, W.m$^{-2}$.$^o$C$^{-1}$, and

$h_o$ = Outside convective radiative losses, W.m$^{-2}$.$^o$C$^{-1}$,

L = Thickness of insulation, m, and

K = Thermal conductivity of insulation, W m$^{-2}$.°C$^{-1}$

**Thermal Performance and Testing**

A procedure for testing the solar cookers was used based on existing international testing standards. These include three major testing standards for solar cookers: The American Society of Agricultural Engineers Standard (2003), Bureau of Indian Standards Testing Method (1992, 2000), and the European Committee on Solar Cooking Research Testing Standard and others (1994). Based on the existing international testing standards, three tests were performed on the animal feed solar cooker. These are First Figure of Merit ($F_1$), Second Figure of Merit ($F_2$), and standardized cooking power ($P_s$).

The $F_1$ was determined by conducting the no-load test, $F_2$ by load test (known amount of water is sensibly heated in solar cooker), and the cooking power estimation. The efficiency of the animal feed cooker was also obtained by measuring the rise in temperature of a known quantity of water in a specified time by the method of calculation of efficiency (η) of a solar cooker (Nahar, 2001; Nahar, 2003). The solar radiation, ambient air temperature, base plate temperature and water temperature were taken at a 15 minutes interval in order to determine the $F_1$ and $F_2$, and compared it with the standard. Reflector was not used as per the test protocol and shrouded with black cloth to determine $F_1$ and $F_2$.

**First Figure of Merit ($F_1$) without Water Load (Stagnation Test)**

The First Figure of Merit ($F_1$) is defined as the ratio of optical efficiency, ($\eta_0$), and the overall heat loss coefficient, ($U_L$). A quasi-steady state (stagnation test condition) is achieved when the stagnation temperature is attained. High optical efficiency and low heat loss are desirable for efficient cooker performance. Thus, the ratio $\eta_o/U_L$ can serve as a performance criterion. Higher values of $F_1$ would indicate better cooker performance.

$$F_1 = \frac{\eta_0}{U_L} = \frac{(T_{ps} - T_a)}{G_s} \quad ...(6)$$

Where,

$F_1$ = First Figure of Merit, $m^2.^oC.W^{-1}$,

$\eta_o$ = Optical efficiency, %,

$U_L$ = Overall heat loss coefficient of the cooker, $W.m^{-2}.^oC^{-1}$,

$T_{ps}$ = Maximum plate surface temperature, °C,

$T_a$ = Ambient temperature, °C, and

$G_s$ = Global solar radiation on a horizontal surface, $W.m^{-2}$.

### Second Figure of Merit ($F_2$) with Water Load (Sensible Heat Test)

The Second Figure of Merit, $F_2$, is evaluated under full-load condition (water load), without using reflector and is defined as the product of the heat exchanger efficiency factor ($F'$) and optical efficiency ($\eta_o = \alpha\tau$), Mullick *et al.,* (1996). It can be expressed as:

$$F_2 = \frac{F_1(MC)w}{A(t_2 - t_1)} ln \left[ \frac{1 - \frac{1}{F_1}\left(\frac{T_{w1} - \bar{T}_a}{\bar{G}_s}\right)}{1 - \frac{1}{F_1}\left(\frac{T_{w2} - \bar{T}_a}{\bar{G}_s}\right)} \right] \quad ...(7)$$

Where,

$F_1$ = First Figure of Merit, $m^2.^oC.W^{-1}$,

$M_w$ = Mass of water, kg,

$C_w$ = Specific heat capacity of water, $J.^-kg^{-1}.°C^{-1}$,

$A$ = Aperture area of solar cooker, $m^2$,

$t_1$ = Initial time, s,

$t_2$ = Final time, s,

$Tw_1$ = Initial water temperature, °C,

$Tw_2$ = Final water temperature, °C,

$G_s$ = Average global solar radiation, $W.m^{-2}$, and

$T_a$ = Average ambient temperature, °C.

### Cooking Power Estimation

Funk (2000) discussed two types of test variables for cooking power estimation. These are mainly uncontrolled variables as weather parameters, and controlled variables as design parameters of a cooker. Wind, ambient temperature, pot content temperature, insolation and solar altitude and azimuth are the uncontrolled variables; while loading, tracking, temperature sensing are the controlled variables. From Funk's definition, cooking power, $P$, is defined as the rate of useful energy available during heating period. It may be determined as a product of the change in water temperature for each interval, mass and specific heat capacity of the water contained in the cooking utensil. Dividing the product by the time (600 s contained in 10 min intervals according to American Society of Agricultural Engineers) contained in a periodic interval yields the cooking power as:

$$P = \frac{MC_w dT_w}{dt} \quad ...(8)$$

Where,

$P$ = Cooking power, W,

$M$ = Mass of water, kg,

$C_w$ = Specific heat of water, 4186 $J.^-kg^{-1}.°C^{-1}$,

$dT_w$ = Temperature difference of water, °C, and

dt = Time interval, s.

### Standardized Cooking Power ($Ps$)

Funk (2000) also introduced the term standard or adjusted cooking power, which can be expressed as:

$$P_s = \frac{700 MC_w \Delta T_w}{600 G_s} \quad ...(9)$$

Where,

$P_s$ = Standard cooking power, W,

$\Delta T_w$ = Temperature difference of water load in every 10-minute intervals, °C, and

$G_s$ = Average solar radiation on surface during this time period, $W.m^{-2}$.

It is clear from the Eq. (9) that in order to calculate the standard cooking power, the reference solar radiation should be 700 $W.m^{-2}$ (Funk, 2000).

**Temperature Difference**

This is the difference between the ambient temperature for each interval and the average cooking vessel content temperature for each corresponding interval, and expressed as:

$$T_d = T_w - T_a \quad ...(10)$$

Where,

$T_d$= Temperature difference, °C,

$T_w$=Water temperature, °C, and

$T_a$= Ambient temperature, °C.

**Cooker Efficiency(η)**

The efficiency of the animal feed solar cooker was determined by measuring stagnation plate temperature and rise in water temperature in the cooking utensils in known interval of time. The stagnation plate temperature was measured by putting three thermocouples in the cooking pots on the plate and on air inside the cooking chamber. The temperatures were measured by a portable digital temperature recorder (Make DTM-100), and the averages reported. The initial temperature of cold water was measured, and when it reached near boiling point temperature, the final temperature of hot water was measured along with the time interval. The efficiency of the cooker was found by the following relations proposed by Nahar (2001, 2003):

$$\eta = \frac{(m_1 + m_2 C_p)(t_2 - t_1)}{A\int_0^{\theta} G d\theta} \quad ...(11)$$

Where,

η= Efficiency of solar cooker, %,

$m_1$= Mass of water in cooking utensil, kg,

$m_2$= Mass of cooking utensil, kg,

$C_p$= Specific heat of cooking utensil, kcal.kg$^{-1}$.°C$^{-1}$,

$t_1$= Initial temperature of water in utensil, °C,

$t_2$= Final temperature of water in utensil, °C,

*A*= Absorber area, m$^2$,

*G*= Solar irradiance, kcal.m$^{-2}$.h$^{-1}$, and

θ= Period of test, h.

## RESULTS AND DISCUSSION

Commercially available box type solar cookers are about 80 % costlier, of lower capacity than of the present design, and needs frequent orientation towards the sun.

**Stagnation Temperature Test**

Thermal evaluation experiment to determine the stagnation temperature of the animal feed solar cooker was carried out during clear sky condition as on 23$^{rd}$ April 2016 at Jodhpur (26°1′N and 73°04′E).The stagnation temperature test was started at 10.00 hour and observations were taken till the maximum plate temperature (112 °C) was achieved at 14.00 hour. The increase in stagnation temperature corresponding to the solar radiations is shown in Table 1. From Table 1 the following values were obtained in order to compute $F_1$: $T_{as}$= 37 °C, $T_{ps}$= 112 °C, $G_s$= 840 W.m$^{-2}$. Figure 3 illustrates the variation of plate and ambient temperature with insolation variation. The plate temperature varied between 94 ˚C and 112 ˚C with the insolation ranging from 856 to 914 W.m$^{-2}$ for more than 2.5 h. This was satisfactory for cooking once a day. The First Figure of Merit $F_1$ was calculated using Eq. (6) as per the stagnation thermal performance test. The First Figure of Merit ($F_1$) was 0.089 m$^2$.$^o$C.W$^{-1}$, whereas, as per standard $F_1$ test, if the value of $F_1$ is greater than 0.12, the cooker is marked as A-Grade and if $F_1$ is less than 0.12 the cooker is marked as a B-Grade solar cooker (Mullick *et al.,* 1996). The animal feed solar cooker was thus categorised as a B-Grade solar cooker. The low value of $F_1$ might be due to higher convection and radiation losses from the side walls made of pearl millet hull for cost reduction (Folaranmi, 2013).

**Water Test**

Water heat-up test experiment of the solar cooker was conducted in order to determine the Second Figure of Merit ($F_2$). The test was carried out on 24$^{th}$ April, 2016 under clear sky conditions as per International Standard Procedure. The cooker was loaded with 16 kg of water, equally distributed in three cooking pots. For the full load test water temperatures for $Tw_1$= 54 °C and $Tw_2$= 77 °C were chosen. The ambient temperature, water temperature, solar radiation, and time for the water temperature to increase from $Tw_1$ to $Tw_2$ are given in Table 2. The temperature profile of water, ambient condition and insolation during test are shown in Fig. 4. The trend of water temperature curve shows that as the time of day progressed, the water temperature increased

**Table 1. Stagnation temperature test for First Figure of Merit ($F_1$)**

| Time, hh:min | Plate temp. $T_{ps}$, °C | Ambient temp. $T_{as}$, °C | Solar radiation $G_s$, W.m$^{-2}$ | $F_1$, m$^2$.°C.W$^{-1}$ |
|---|---|---|---|---|
| 10.00 | 61.0 | 32.5 | 668 | |
| 10.15 | 67.0 | 33.0 | 709 | $F_1$ = 0.089 |
| 10.30 | 72.0 | 33.5 | 744 | |
| 10.45 | 78.0 | 34.0 | 782 | |
| 11.00 | 84.0 | 34.4 | 814 | |
| 11.15 | 90.0 | 34.8 | 841 | |
| 11.30 | 94.0 | 35.0 | 856 | |
| 11.45 | 98.0 | 35.2 | 866 | |
| 12.00 | 101.0 | 35.4 | 893 | |
| 12.15 | 103.0 | 35.7 | 906 | |
| 12.30 | 105.0 | 36.0 | 909 | |
| 12.45 | 107.0 | 36.2 | 914 | |
| 13.00 | 108.0 | 36.4 | 911 | |
| 13.15 | 109.0 | 36.5 | 846 | |
| 13.30 | 110.0 | 36.6 | 845 | |
| 13.45 | 111.0 | 36.8 | 864 | |
| 14.00 | 112.0 | 37.0 | 840 | |
| 14.15 | 110.0 | 36.8 | 803 | |
| 14.30 | 108.0 | 36.6 | 792 | |

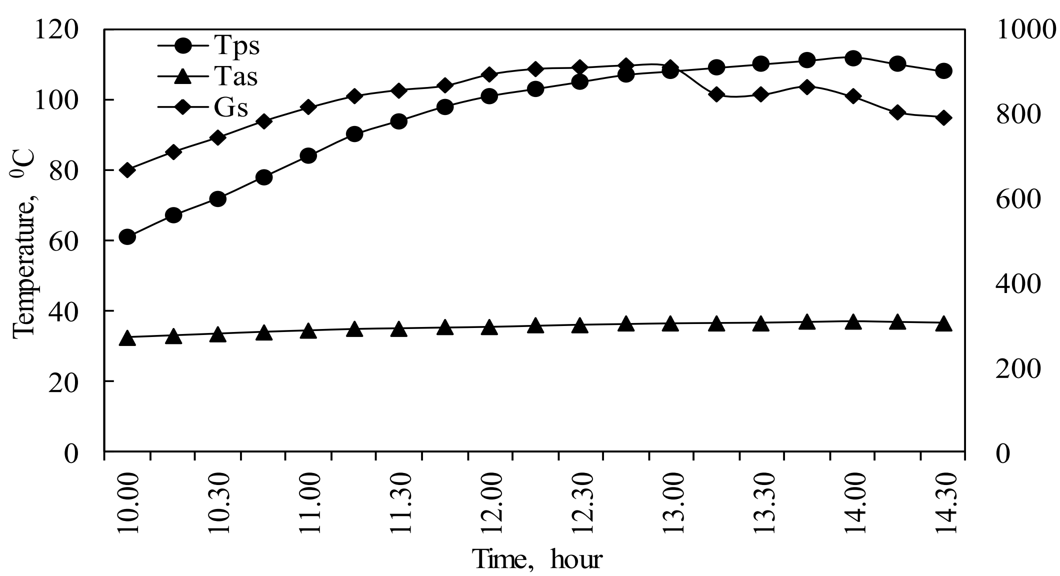


**Fig. 3: Stagnation temperature test of animal feed solar cooker for $F_1$**

with increasing solar insolation. The water temperature reached to 77 ˚C within 2.5 h, which is a sufficient time to cook one meal of animal feed. The average ambient temperature $T_a$ and the insolation $G_s$ for the 2.5 h period were 37 ˚C and 876 W.m$^{-2}$, respectively.

For the computation of $F_2$, the following values were used: $F_1$ = 0.089 m$^2$.°C.W$^{-1}$, $M$ = 16.0 kg, C = 4186 J.kg$^{-1}$.°C$^{-1}$, $t_2-t_1$= 135 min (8100 s), $A$ = 1.21 m$^2$, $Tw_1$ = 54°C, $Tw_2$ = 77°C, $G_{ave}$ = 876 W.m$^{-2}$, and $T_{ave}$ = 37.0 °C. Using Eq. (7), $F_2$ was determined to be 0.288 J.W$^{-1}$.°C$^{-1}$,

**Table 2. Thermal load test, heat-up condition test for Second Figure of Merit ($F_2$)**

| Time, hh: mm | Water temp., $T_w$, °C | Ambient temp., $T_a$, °C | Solar radiation, $G_s$,W.m$^{-2}$ | $F_2$, J.W$^{-1}$.°C$^{-1}$ |
|---|---|---|---|---|
| 10.00 | 34.0 | 33.0 | 628 | |
| 10.15 | 37.8 | 33.5 | 661 | $F_2$ = 0.288 |
| 10.30 | 41.6 | 34.0 | 702 | |
| 10.45 | 45.4 | 34.3 | 740 | |
| 11.00 | 49.1 | 34.6 | 765 | |
| 11.15 | 52.7 | 35.0 | 802 | |
| 11.30 | 56.2 | 35.4 | 840 | |
| 11.45 | 59.6 | 36.0 | 865 | |
| 12.00 | 62.0 | 36.4 | 890 | |
| 12.15 | 64.1 | 36.6 | 910 | |
| 12.30 | 66.2 | 36.8 | 920 | |
| 12.45 | 68.3 | 37.0 | 903 | |
| 13.00 | 70.4 | 37.2 | 909 | |
| 13.15 | 72.5 | 37.4 | 899 | |
| 13.30 | 74.2 | 37.6 | 888 | |
| 13.45 | 75.6 | 37.8 | 868 | |
| 14.00 | 77.0 | 38.0 | 839 | |
| 14.15 | 75.5 | 37.8 | 795 | |
| 14.30 | 73.0 | 37.6 | 749 | |

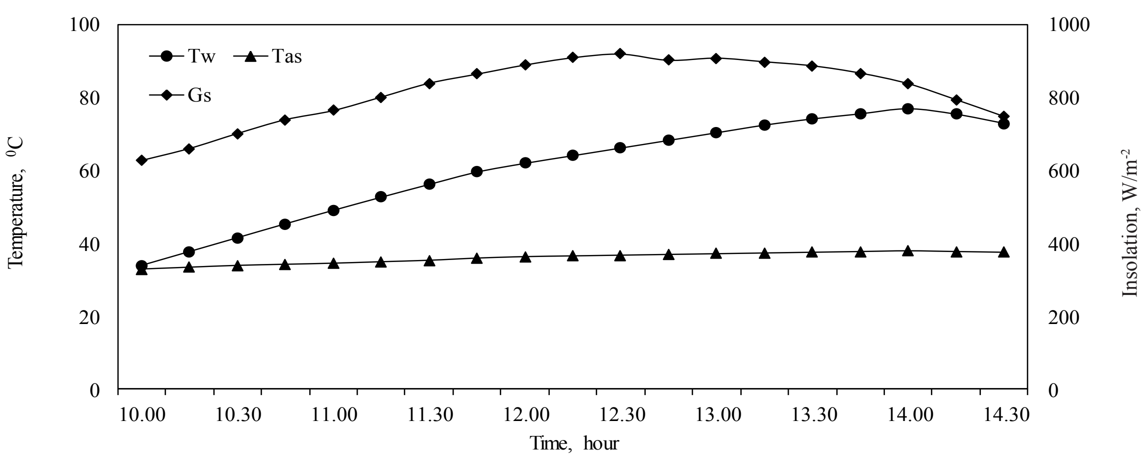


**Fig. 4: Water heat-up test of animal feed solar cooker for $F_2$**

which was within the recommended standard value in the range of 0.254-0.490 (Mullick *et al.,* 1987). The value of $F_2$ within the range of standard value indicated good thermal performance of the animal feed solar cooker. A high value of $F_2$ indicate good heat exchange efficiency factor F′with number of pots, and low heat capacity of the cooker interiors and vessels compared to the full load of water (Lahkar and Samdarshi, 2010). It was found that $F_2$ increased with load, and this occured because of an improvement in heat capacity ratio CR with increase in mass of water in the pots (Mullick *et al.,* 1996).

## Cooking Power

Cooking power experiment was conducted based on international standard procedure on April 25, 2016. Experiment was conducted for the load of 4.0 kg of water. Animal feed solar cooker was exposed to the sun at 10.00 hour to 14.00 hour, and initial temperature of water, final temperature of water, ambient temperature and solar insolation were recorded at 10-min intervals, Table 3. Eq. (8), (9), and (10) were used to calculate P, $P_s$, and $T_d$ for each interval. Standard cooking power ($P_s$) was plotted against the difference between water temperature and ambient temperature ($T_d$) as shown in Fig. 5.

A linear regression of the plotted points was used to find the relationship between the cooking power and the temperature difference in terms of intercept, W, and the slope, (W.°C$^{-1}$). The cooking regression equation is

$$P_s = 69.78 - 1.114 T_d \qquad ...(12)$$

The coefficient of determination ($R^2$) or proportions

**Table 3. Cooking power estimation**

| Time interval, hh: mm | $T_1$, °C | $T_2$, °C | Difference, $T_2 - T_1$ | P, W | $G_s$, W.m$^{-2}$ | $P_s$, W | $T_a$, °C | $T_w$, °C | $T_d$, °C |
|---|---|---|---|---|---|---|---|---|---|
| 10.00 | 31.4 | 33.8 | 2.4 | 67.0 | 620.0 | 75.6 | 33.0 | 33.8 | 0.8 |
| 10.10 | 33.8 | 36.1 | 2.3 | 64.2 | 635.0 | 70.8 | 33.1 | 36.1 | 3.0 |
| 10.20 | 36.1 | 38.3 | 2.2 | 61.4 | 649.0 | 66.2 | 33.3 | 38.3 | 5.0 |
| 10.30 | 38.3 | 40.4 | 2.1 | 58.6 | 666.0 | 61.6 | 33.5 | 40.4 | 6.9 |
| 10.40 | 40.4 | 42.4 | 2.0 | 55.8 | 681.0 | 57.4 | 33.8 | 42.4 | 8.6 |
| 10.50 | 42.4 | 44.4 | 2.0 | 55.8 | 696.0 | 56.1 | 34.2 | 44.4 | 10.2 |
| 11.00 | 44.4 | 46.5 | 2.1 | 58.6 | 720.0 | 57.0 | 34.6 | 46.5 | 11.9 |
| 11.10 | 46.5 | 48.5 | 2.0 | 55.8 | 740.0 | 52.8 | 34.8 | 48.5 | 13.7 |
| 11.20 | 48.5 | 50.5 | 2.0 | 55.8 | 759.0 | 51.5 | 35.1 | 50.5 | 15.4 |
| 11.30 | 50.5 | 52.4 | 1.9 | 53.0 | 780.0 | 47.6 | 35.4 | 52.4 | 17.0 |
| 11.40 | 52.4 | 54.3 | 1.9 | 53.0 | 799.0 | 46.5 | 35.8 | 54.3 | 18.5 |
| 11.50 | 54.3 | 56.1 | 1.8 | 50.2 | 815.0 | 43.1 | 36 | 56.1 | 20.1 |
| 12.00 | 56.1 | 57.9 | 1.8 | 50.2 | 826.0 | 42.6 | 36.4 | 57.9 | 21.5 |
| 12.10 | 57.9 | 59.7 | 1.8 | 50.2 | 835.0 | 42.1 | 36.5 | 59.7 | 23.2 |
| 12.20 | 59.7 | 61.5 | 1.8 | 50.2 | 844.0 | 41.7 | 36.6 | 61.5 | 24.9 |
| 12.30 | 61.5 | 63.2 | 1.7 | 47.4 | 854.0 | 38.9 | 36.8 | 63.2 | 26.4 |
| 12.40 | 63.2 | 64.9 | 1.7 | 47.4 | 863.0 | 38.5 | 37 | 64.9 | 27.9 |
| 12.50 | 64.9 | 66.6 | 1.7 | 47.4 | 872.0 | 38.1 | 37.1 | 66.6 | 29.5 |
| 13.00 | 66.6 | 68.3 | 1.7 | 47.4 | 882.0 | 37.7 | 37.2 | 68.3 | 31.1 |
| 13.10 | 68.3 | 69.9 | 1.6 | 44.7 | 890.0 | 35.1 | 37.3 | 69.9 | 32.6 |
| 13.20 | 69.9 | 71.5 | 1.6 | 44.7 | 897.0 | 34.8 | 37.5 | 71.5 | 34.0 |
| 13.30 | 71.5 | 73.0 | 1.5 | 41.9 | 905.0 | 32.4 | 37.6 | 73.0 | 35.4 |
| 13.40 | 73.0 | 74.4 | 1.4 | 39.1 | 912.0 | 30.0 | 37.8 | 74.4 | 36.6 |
| 13.50 | 74.4 | 75.7 | 1.3 | 36.3 | 919.0 | 27.6 | 37.9 | 75.7 | 37.8 |
| 14.00 | 75.7 | 77.0 | 1.3 | 36.3 | 926.0 | 27.4 | 38.0 | 77.0 | 39.0 |

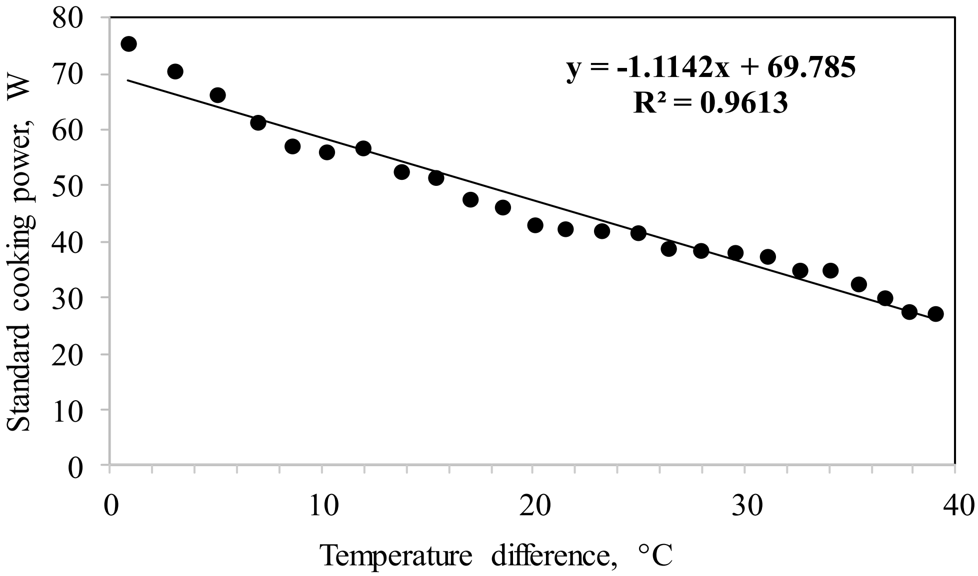


**Fig. 5: Standard cooking power variations with temperature difference**

of variation in cooking power was 0.961, satisfying the ASAE International test standards to be better than 0.75 (Funk, 2000). The initial cooking power was found to be 69.78 W, and within the range of the ASAE International test procedure. The standardized cooking power ($P_s$) was calculated using the regression equation to be 27.40 W, which was high in comparison to the other systems (Folaranmi, 2013; Elamin and Abdala, 2015). The loss coefficient from the slope of the regression line was found to be 1.114 °C.$W^{-1}$. High initial cooking power and low heat loss coefficient revealed that the multilayer insulation was efficient and inexpensive for solar thermal appliances (Mahavar *et al.* 2012).

Figure 5 shows that as the temperature difference increased, the standard cooking power decreased. The behaviour might be due to the increase in cooking temperature not equalizing with the decrease in the cooking mass, and thus it is preferable to use solar cooker for adequate cooking mass quantity to get a high merit (Folaranmi, 2013; Hermelinda and Mauricio, 2014).

The maximum stagnation temperature was 112 °C. The efficiency of the cooker was determined by using 16.0 kg of cold water in three cooking utensils. The initial temperature of cold water was 34 °C, and the final temperature of hot water was 77 °C. The efficiency of the solar cooker was calculated using the Eq. (11), and was 26.4 per cent. Thermal efficiency of solar cooker depends upon factors like solar radiation, mass of loaded water, time taken to boil the water, control of the reflector, etc.

The animal feed solar cooker demonstrated good performance and highest efficiency at the maximum load of 16 kg of water, indicating better heat retention ability of the cooker as compared with some other designs found in the literature (Nahar, 1990; Nahar, 1994; Currin *et al.*, 1994; Nahar, *et al.* 1996a).

The animal feed solar cooker thus seems a promising option for energy conservation, and it also helps to reduce the $CO_2$ emission as compared to 100% biomass usage. The estimated annual saving is about 1000 kg of $CO_2$, fuel wood, LPG and kerosene. The technology also helps in reduction of drudgery of farm workers. The users would also have economic advantage through 30-40% savings of fuels. Such cooking operation is done mostly by women, and as they contribute significantly in the farm operations, they can save time for taking care of their family or other agricultural operations (Panwar *et al.,* 2013).

## CONCLUSIONS

The improved animal feed solar cooker had an aperture area of 1.21 $m^2$ with length: breath ratio of 3:1, thereby eliminating the tracking requirements. The experimental results showed that First Figure of Merit ($F_1$), Second Figure of Merit ($F_2$) and standardized cooking power ($P_s$) were 0.089 $m^2.°C.W^{-1}$, 0.288 $J.W^{-1}.°C^{-1}$ and 27.40 W, respectively, which indicated that the developed cooker was suitable for boiling about 8-10 kg of animal feed once a day. The thermal efficiency of the solar cooker was 26.4 %.

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