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Comparative Analysis of SK-14 and PRINCE-15 Solar Concentrators

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Abstract - SK-14 solar concentrator is a widely used and popular domestic solar cooker in parabolic dish cooker category. If the bowl of solar concentrator is fabricated then concentrators become bulky and transportability is a problem. If the bowl is not fabricated and only reflector sheets are stitched together with screws and bolts then transportability improves but bowl is weak and gets damaged even with high wind or strike of a ball or a stone. Author$_1$ developed a new geometry of solar concentrators with square or rectangular shape and PRINCE-15 is one such concentrator which matches aperture area of SK-14. This new design permits framed bowl structure with excellent transportability. A comparative testing was done with these two solar concentrators of same aperture area but different geometries. Standard test protocols were used and both the concentrators were tested simultaneously so as to nullify the effect of wind and any error because of radiation measurement. Results show that PRINCE-15 not only has better transportability but also higher efficiency.

Keywords: Solar energy, SK-14, PRINCE-15, solar concentrator.

Nomenclature

A_a Aperture area
A_f Area of focus.
C Geometrical concentration ratio,
C_{pw} Specific heat of water
$F'_{\eta o}$ optical efficiency factor
F'_{UL} heat loss factor
F_1 First figure of merit
F_2 Second figure of merit
η_b Efficiency of solar oven with beam radiation %
I_g Total solar radiation, watts/sqm
Id Diffused solar radiation, watts/sqm
I_b Solar beam radiation, watts/sqm
M_w mass of water
T_{stag} Stagnation temperature °C
Ta Ambient temperature °C
Tw_1 Start temperature of water °C
T_{w2} End temperature of water °C
ζ Time sec.

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I. INTRODUCTION

Solar Cooker is a device that uses only sunlight to cook food and pasteurize water. Solar cooker can be used along with other cooking devices to save cost, fuel and the time spent in gathering fuel wood.Solar cooking enables individual families to do without commercially sold fuel and help save money. [1] SK 14, is a solar concentrator developed by Dr. Ing. Dieter Siefert. Solar EG, a German charitable organisation along with many other companies manufactures and sells SK-14 solar concentrator primarily as a domestic solar dish cooker. It has a diameter of 1400 mm and a performance of up to 700 Watts [2]. Conventionally SK-14 solar concentrator is manufactured in fabricated version with bowl made of rings and radial arms of steel wires. Such fabricated bowls are strong and last longer. However transporting such big fabricated bowl is a big task. For this reason few companies like EG solar have come up with bowls stitched with screws and bolts and all reflector sheets are joined together to form bowl shape. This improves transportability to great extent, but the bowl is weaker and high wind or strike of a ball or stone can damage the bowl easily. Assembling these design of solar cookers also requires reasonable skill. For this reason author$_1$ invented a new geometry of solar dish concentrator which uses square or rectangular dishes with point focus [3]. This geometry has fabricated bowl that can be transported in a box. Bowl being fabricated is strong enough to stand good wind and rough handling. This design is easy to assemble and available as DIY (Do It Yourself) kit. Apart from saving in reflector area higher efficiency is also noted.

II. SK-14 AND PRINCE-15 SOLAR CONCENTRATORS

SK-14 parabolic concentrator is commonly used as a family size solar cooker that can cook for up to 10 people. This is a circular dish of 1400 mm diameter and has a reflecting surface in the form of a parabolic dish, which concentrates the solar rays at a focal point at which the black coated cooking pot is placed. Numbers of reflector sheets vary from 24 to 36 in different designs manufactured by different manufacturers. Polished, anodized hardened aluminum sheets are used as reflectors. [4]. The net power of the concentrator is approximately 600 watts in good sunshine. Stagnation temperatures of 300°C can be achieved. Heat delivered to the pot is proportionate to the aperture area. Two liters of water, on a sunny day, takes about 15 minutes to boil. Almost every types of cooking such as boiling, frying, baking can be done in this cooker. Due to its deeply curved parabolic reflectors, the focal point lies inside the dish. Tracking the cooker every 20 minutes is required. [1] Efforts have been made to popularise these cookers through north-south cooperation through NGOs [5] and training rural women for cooking as well as for livelihood generation. [6]

PRINCE-15 parabolic concentrator: PRINCE-15 is a concentrator with square or rectangular dish shape. This shape permits use of same sized strips of steel to make bowl. This makes the bowl sturdy. As the members of the dish have same geometric shape interchangeability of support members is possible. This geometry permits the cooker design in DIY (Do It Yourself) kit and even novice people can assemble the cooker. Focal length of this design is kept at 400 mm as compared to 280 mm of SK-14. Size of the concentrator used during test was 1.35 m X 1.1 m. Other features like aperture area, tracking mechanism, framed structure are similar as that of SK-14.

III. EXPERIMENTAL SETUP

To have a comparative study of these two solar concentrators SK-14 and PRINCE-15 a simultaneous testing was planned. Simultaneous testing eliminated the possibility of errors because of difference in wind speed, ambient temperature and variation in solar radiation. Mild steel plates were used for stagnation temperature test and thermocouples are connected to the mild steel plate. Similarly water was used for heat duty test and temperatures were recorded continuously. Test duration was fixed at 25 minutes to keep the water peak temperature below 90^0C. This limit was decided during the trial itself. Solar radiation is measured using Apogee solar sensors for total and diffused radiation. All thermocouples and solar sensor were connected to Sunpro data logger with provision for 16 inputs. During experimentation tracking was done every 10 minutes. Fig. 1 shows photograph of the test carried out simultaneously on the two concentrators.

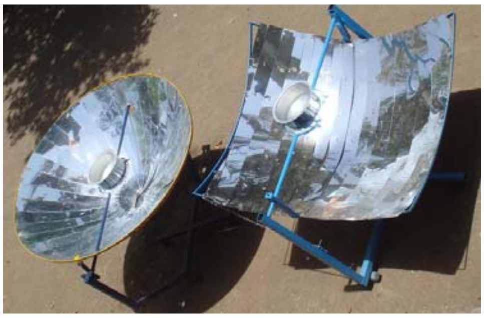

Fig. 1 Photograph showing test set up

IV. TEST PROCEDURE

For paraboloidal solar concentrators Mullick et al (1991) had proposed a testing procedure. Two parameters – optical efficiency factor ($F'\eta_o$) and the heat loss factor ($F'U_L$) were defined for evaluating performance of dish concentrators. The optical efficiency factor gives the theoretical upper limit of the overall efficiency of concentrator [8]. Paul A. Funk defined two figures of merits, F1 and F2 as operating parameters. Test method of Paul A. Funk was generally followed [9] with simplification suggested by Funk, Mullick S.C. et al, and Subodh Kumar, are adopted [9,10]. In current application mild steel plate was used for calculations of F1 and water as a medium for calculations of F2. Different mediums were used as peak temperature of the concentrator exceeds 100^0C and hence steel plate was used for recording stagnant temperature and calculating F1. For all calculation purpose value of beam radiation, Ib, is used as solar concentrators work on the principle of beam radiation, Ib, and not the global radiation, Ig. Similar adoption of using beam radiation in place of global radiation was adopted by authors for evaluating a Scheffler concentrator based oven [11]. Both the concentrators were tested at school of energy studies, University of Pune, which is an approved test center by Government of India. SK-14 was tested in year 2005 and PRINCE-15 in year 2010. [12,13]. These tests also report higher efficiency for PRINCE-15 solar concentrator as compared to SK-14, but these tests were carried out at different time in different weather conditions. Effort herewith is to test both the concentrators simultaneously to eliminate effect of weather parameters like variation in solar radiation and wind velocity. These trials were conducted during the period of 28th Feb. 2010 to 21st March 2010.

V. OBSERVATIONS

Measurements were recorded using data logger for stagnation temperature, ambient temperature, solar radiations and water temperatures. For heat duty measurement, temperature of water was kept below 90^0C to avoid error that can creep in because of evaporation of water. Table I, shows sample set of observations and calculations for calculation of first figure of merit F1 and Table II, shows set of observations for calculating second figure of merit F2, overall efficiency of the system η_b with reference to beam radiation Ib.

TABLE I
FIRST FIGURE OF MERIT F1

Parameter	SK-14	PRINCE-15
Stagnation temperature Tstag	289	310
Ambient temperature Ta	28	28
Solar Beam Radiation Ib	660	660
First figure of merit F1 (calculated)	0.395	0.427

TABLE II
SECOND FIGURE OF MERIT F2

Parameter	SK-14	PRINCE-15
Mass of water in kgs Mw	4.5	4.5
Avg. Beam radiation Ib	695	695
Ambient temperature Ta	28	28
Start temp. of water Tw_1	28	28
End temp. of water T_{W2}	81	87
Time Interval ζ in seconds	1500	1500
Mass of water in kgs Mw	**4.5**	**4.5**

VI CALCULATIONS AND RESULTS

First figure of merit F1 is calculated by using formula

$$F_1 = \frac{T_{stag} - T_a}{I_g} \tag{1}$$

Calculated values of F_1 are shown in table 1. As stagnation temperature of PRINCE-15 is higher, F_1 value is reported to be 0.427 as against 0.395 of SK-14.

Second figure of merit F_2 is calculated using following formulae [9, 10].

$$F_2 = \frac{F_1(Mw \times Cpw)}{A\zeta} l_n \left[\frac{1 - \frac{1}{F_1}\left(\frac{Tw_1 - Ta}{Ib}\right)}{1 - \frac{1}{F_1}\left(\frac{Tw_2 - Ta}{Ib}\right)} \right] \tag{2}$$

Heat duty was calculated using formula

$$HeatDuty = Mw \times C_{pw} \times \frac{Tw_2 - Tw_1}{\zeta} \tag{3}$$

Overall System efficiency with beam radiation,

$$\eta_b = \frac{HeatDuty}{\frac{I_b \cdot A_p}{1000}} \tag{4}$$

Test results are tabulated in the result Table III. Test results show that the second figure of merit and also heat duty increases in PRINCE-15 as compared to SK-14. It also shows overall improvement of around 7% in thermal efficiency.

TABLE 3
TEST RESULTS

Parameter	SK-14	PRINCE-15
First figure of merit F_1	0.376	0.406
Second figure of merit F_2	0.6539	0.7222
Avg. Heat duty in W thermal	923	1017
System efficiency η_b in %	59.04	65.06

VII CONCLUSIONS

Interesting results were obtained by comparing two solar concentrators with same aperture area, same material for reflectors but different geometries. SK-14 is conventional circular dish concentrator while PRINCE-15 is a rectangular dish concentrator. Readings were taken simultaneously on both units to avoid any variation because of wind velocity and variation in solar radiation. PRINCE-15 proved to be improved concentrators on account of heat duty and efficiency as well. Probable reasons for improvement are more accurate construction of paraboloid is possible in PRINCE-15 and higher focal length which results in better concentration ratio.

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