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Instrumentation error analysis of a box-type solar cooker

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ABSTRACT

In order to certify the performance of a box-type solar cooker, thermal performance is evaluated in terms of two figures of merit viz. F_1 and F_2 (IS 13429:2000). The acceptable criterion to make the solar cooker eligible for ISI mark is that the value of F_1 should not be less than 0.12, and that of F_2 should be greater than 0.40. Further, the solar cooker is classified as *Grade A* if the value of F_1 is determined to be 0.12 or higher; otherwise, the solar cooker is classified as *Grade B*. Determination of F_1 and F_2 comprises measurements of the temperature of cooking tray, water temperature and ambient air, solar irradiance, and other associated parameters. The effect of accuracy obtained in these measurements assumes significance in the perspective of grading of solar cookers.

In the present work, an attempt has been made to analyze the effect of instrumentation on F_1 and F_2, which is normally employed for testing and standardization of solar cookers. The analysis is supported by a large number of outdoor tests conducted on a box type solar cooker under stagnation as well as load test conditions. It is observed that the variation of absolute value of error in F_1 and F_2 could be in the range of 0.002–0.003 and 0.015–0.033, respectively. This corresponds to errors of the order of 2.5–3.0% in the evaluation of F_1 and 5.0–6.0% in F_2.

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1. Introduction

Solar thermal energy devices hold a large potential for use in a variety of applications in developing countries [1,2]. Many of the devices such as solar water heaters, solar cookers, solar dryers have been commercialized in different parts of the world [2–7]. In India, solar water heating systems and box-type solar cookers are commercialized solar thermal technologies. There are more than 100 manufacturers of flat plate collector (FPC) based solar water heating systems, 40 for evacuated-tube collector (ETC) based solar water heating systems and more than 40 of box-type solar cookers in the country [8] approved by Bureau of Indian Standards (i.e. *ISI marked*). In the past two decades, the Government of India has made considerable efforts to promote the development and dissemination of box-type solar cookers in the country [8,9]. However, the number of box-type solar cookers reportedly disseminated in India till January 2007 is merely 0.625 million; which is far below from their respective potential [10]. Fig. 1 presents the cumulative installations of box-type solar cookers in India [8]. A variety of reasons are attributed to the current low levels of dissemination of box-type solar cookers in India as against their respective estimated potentials. Several of these attributes could, one way or the other, be related to the current status of development of the technology, its appropriateness and dissemination strategies adopted for their diffusion and deployment [11]. Some other barriers include relatively high start-up costs, socio-cultural acceptance and a lack of continued support subsequent to introduction of box-type solar cookers [12,13].

Interest has been renewed in the design, development and testing of various types of solar cookers like box type [14–17], concentrator type [18–20] and oven type [21,22] around the globe in which the box type solar cookers have so far been disseminated at the mass level in India [7,8,10,23,24]. For the purpose of quality control, maintenance, performance characterization and enhancement of solar energy devices and systems, thermal performance testing is critically important [25–28]. Thermal performance of solar thermal devices critically depend upon the testing and environmental conditions [29–32] viz. available solar radiation intensity on the aperture of solar cooker, ambient air temperature, prevailing wind speed, diffused fraction in total solar irradiance, etc. In order to have a sustained growth of the solar energy technologies it is essential to have a proper mechanism for characterizing the performance of these devices and systems under various climatic and operating conditions. Therefore, it is critically important to adopt and implement test procedures and methodologies for producing performance characteristic parameters, which could provide an equitable basis for comparison of performances of the products offered to the end user.

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Nomenclature

$\overline{T_a}$	average ambient temperature in load test (°C) in between the water temperature raises from T_{w1} to T_{w2}
$\overline{H}$	average solar radiation in F_2 test (W/m^2) in between the water temperature raises from T_{w1} to T_{w2}
A	aperture area of the solar cooker (m^2)
C_w	specific heat of water (J/kg °C)
F_1	first figure of merit of box-type solar cooker
F_2	second figure of merit of box-type solar cooker
H_s	total solar radiation at stagnation condition (W/m^2)
M_w	mass of the water (kg)
T_{as}	ambient temperature at steady state condition (°C)
T_{ps}	cooker tray temperature at steady state condition (°C)
T_{w1}	initial water temperature (°C)
T_{w2}	final water temperature (°C)
$w_{(A)}$	accuracy in measurement of aperture area
$w_{(Cw)}$	accuracy in measurement of specific heat of water
$w_{(F2A)}$	absolute error in F_2 due to measurement of mass of aperture area
$w_{(F2CW)}$	absolute error in F_2 due to measurement of specific heat
$w_{(F2F1)}$	absolute error in F_2 due to evaluation of F_1
$w_{(F2H)}$	absolute error in F_2 due to measurement of average total solar radiation
$w_{(F2MW)}$	absolute error in F_2 due to measurement of mass of water and pots
$w_{(F2Ta)}$	absolute error in F_2 due to measurement of average ambient temperature
$w_{(F2Tw1)}$	absolute error in F_2 due to measurement of initial water temperature
$w_{(F2Tw2)}$	absolute error in F_2 due to measurement of final water temperature
$w_{(F2\tau)}$	absolute error in F_2 due to measurement of cooking time
$w_{(H)}$	accuracy in measurement of average solar radiation
$w_{(Hs)}$	accuracy in measurement of total solar radiation
$w_{(Mw)}$	accuracy in measurement of mass of water
$w_{(Ta)}$	accuracy in measurement of average ambient temperature
$w_{(Tas)}$	accuracy in measurement of ambient temperature
$w_{(Tps)}$	accuracy in measurement of cooker tray temperature
$w_{(Tw1)}$	accuracy in measurement of initial water temperature
$w_{(Tw1)}$	accuracy in measurement of final water temperature
$w_{(\tau)}$	accuracy in measurement of cooking time
W_{F1}	absolute accuracy in first figure of merit
$w_{F1(Hs)}$	absolute error in F_1 due to measurement of solar radiation
$w_{F1(Tas)}$	absolute error in F_1 due to measurement of ambient temperature
$w_{F1(Tps)}$	absolute error in F_1 due to measurement of cooker tray temperature
W_{F2}	attainable accuracy in second figure of merit
τ	time interval (s)
ΔF_1	overall error in the determination of F_1
ΔF_2	overall error in the determination of F_2

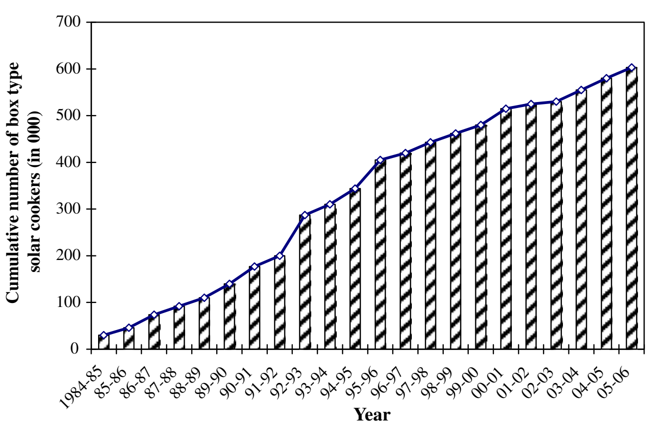

Fig. 1. Cumulative installations of box-type solar cookers in India.

The need to evaluate a solar cooker and compare different designs calls for testing procedures and performance parameters which represent their respective thermal performance [25]. Vaishya et al. [33] proposed a test procedure for thermal performance evaluation of a box-type solar cooker. On the basis of outdoor experiments, the maximum attainable temperature i.e. stagnation temperature in empty cooker has been used to estimate the overall heat loss coefficient of the cooker from the energy balance equation. It was observed that the ratio of the intensity of the total solar radiation on a horizontal surface to the temperature difference between the absorber plate and the ambient at stagnation condition remains constant throughout the year and thus can be used as a test parameter. As a part of developing test procedures for evaluation of thermal performances of solar cookers, Shrestha [34] carried out stagnation temperature studies under indoor simulation conditions.

Mullick et al. [35] proposed a test method to evaluate two thermal performance parameters i.e. F_1 and F_2, which were called first and second figures of merit. The first figure of merit, F_1, can be determined from an energy balance equation for the horizontally placed empty box-type solar cooker at stagnation test condition. The second figure of merit, F_2, can be obtained from the sensible heating of water in cooking pots up to 100 °C. Funk [36] developed the international standard testing procedure for evaluation of all types of solar cookers and in that context calculated standard cooking power that can be used for the comparison of performance of different types of solar cookers. On the basis of the test method proposed by Mullick et al. [35], Indian test standard IS13429 [37] was developed for evaluation and certification of the thermal performance of box-type solar cooker in India in which the thermal performance is evaluated in terms of two figures of merit viz. F_1 and F_2 for the purpose of the certification of the performance of box-type solar cookers (IS 13429:2000). A specific criterion is mentioned in IS 13429:2000 that to make the solar cooker eligible for ISI mark that the value of F_1 should not be less than 0.11, and that of F_2 should be greater than 0.40. If the value of F_1 is more that 0.12 the cooker is classified as *Grade A* otherwise; the cooker is classified as *Grade B* [37]. For the determination of F_1 and F_2 measurements of the associated parameters with stagnation and load tests viz. temperatures of cooking tray, water temperature and ambient air, solar irradiance, dimensions of the absorber and cooking utensils etc. is required. The accuracies of the measuring instruments significantly make effect in the perspective of grading of solar cookers. It is in this context, an attempt has been made to analyze the effect of instrumentation on these figures of merit in this study, which is normally employed for testing of solar cookers on the values of F_1 and F_2 based on large number of outdoor tests conducted on a box-type solar cooker under stagnation as well as load test conditions as per IS 13429:2000.

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