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Review

Figures of merit and their relevance in the context of a standard testing and performance comparison methods for solar box – Cookers

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ABSTRACT

Solar cookers, in particular solar box cookers, are becoming more popular and widespread. New ideas, manufacturing techniques and higher performance designs are being proposed. As usual, a good testing standard is an important tool for the market and for cooker acceptance from the users. In the past, testing procedures and figures of merit have been proposed [1–5] for cooker characterization. These have several limitations that can be eliminated with a deeper analysis of solar box cooker optical a thermal behavior. This paper proposes a revision of these procedures yielding more meaningful and useful Figures of Merit. This work can be a first step towards a future and more precise testing standard. This revision is formulated keeping an important characteristic of the existing proposals: simple and available instrumentation allowing these tests to be carried anywhere in the World, with a minimum of investment and/or lab conditions.

1. Introduction

In Mullick et al. (1987, 1996) the authors proposed a way towards the testing of solar cookers and extracted from the testing results two figures of merit, F_1 and F_2, to help in the comparison of different cookers performance.

F_1 is a figure of merit related with the fact that for proper cooking, the cooker must provide temperatures above the boiling point of water and F_2 is related to the way the cooker handles the sensible heating of the load. Other important definitions for cooker characterization and comparison are power delivered, cooker efficiency, etc. (Funk, 1999; Funk, 1998).

These figures of merit have become a part of the standard for testing of Box Cookers, proposed by BIS. These definitions should take into account that there are many different box type cooker geometries, with and without performance augmenting reflecting lids.

However, in BIS, the proposed standard demands that all augmenting mirrors be covered by a black cloth during testing and thus, in fact, the tests are carried out over the box only! Their usefulness is thus very limited and the proposed application of the resulting F_1 and F_2 for the calculation of a parameter like time to reach boiling is rather meaningless, since the cooker will normally operate with its augmenting mirrors and that time will certainly be shorter. Even the text of the standard acknowledges that. In fact, the authors in Mullick et al. (1987) were well aware (and even comment about it) that their definition was set as if augmenting mirrors did not exist.

Later, other authors in De Castell et al. (1999) discussed and extended the ideas of the first proposals for these figures of merit in an attempt at refining/correcting at least some of the shortcomings of the first definitions, by recognizing the presence of augmenting mirrors and different possible geometries, with and without concentration. However, their proposal does still not take fully advantage of a more accurate way for taking into account the cooker's characteristics.

In any case, the present situation is disturbing since not only researchers are using different definitions but also these are not really as precise as they could be. That hinders their application either to fully characterize any box cooker (Geddam et al., 2014), predict boiling time, determine optimal cooking loads (Mahavar et al., 2015), determine heat loss and optical efficiency (as for instance in Mullick et al. (1991)).

This paper proposes new definitions for F_1 and F_2 which go a step further from the proposals in De Castell et al. (1999), by taking into account the optical behavior of the lid augmenting mirror without requiring irradiation measurements other than on the horizontal plane.

In fact, a true merit of the very first proposals (Mullick et al., 1987; Mullick et al., 1996; BIS) is that only simple measurements are required for the characterization being sought, in contrast with a possible list of more demanding ones, which would perhaps better characterize each individual box-cooker, but might be quite difficult to transform into a procedure to be used everywhere in the same way and with good but

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Nomenclature

Acronyms

BIS	Bureau of Indian Standards
CPC	Compound Parabolic Concentrator

Greek symbols

δ	solar declination
η_0	optical efficiency
Θ	zenith angle
λ	local latitude
ρ	mirror reflectivity
τ	time between T_{w1} and T_{w2}
τ_0	water boiling time
τ_{0new}	new water boil time
ω_t	solar time angle

Roman symbols

A_c	horizontal transparent cover area
A_n	normal area to incoming beam irradiation
A_p	plate area
A_H	projected area by the lid on the horizontal plane of the cover
F_1	figure of merit 1
F_{1new}	new figure of merit 1
F_2	figure of merit 2
F_{2new}	new figure of merit 2
I_c	collected solar irradiance
I_h	solar irradiance on horizontal plane
$(MC)_w$	product between mass of water and specific heat capacity of water
$(MC)'_w$	product between mass of water and specific heat capacity of all system (water, pot and cooker interiors)
P	power
T_{air}	ambient temperature
T_p	absorber (plate) temperature
T_{ps}	absorber (plate) temperature at stagnation
T_{w1}	initial water temperature
T_{w2}	final water temperature
U_L	heat loss coefficient

not expensive instrumentation.

A future standard will certainly benefit from these more precise definitions but must still be very careful at defining testing conditions that will resolve ambiguities in the results as consequence, for instance, of the time of the year of the testing, the load to be used, the extent and use of pre-heating, etc. This discussion is not the objective of this paper.

This paper derives and proposes adjustments to the definitions of the existing figures of merit, with the goal of contributing to a future standard testing procedure and performance comparison method for solar box – cookers.

2. Basic definitions

2.1. The problem

Consider a box cooker, just as the one in Fig. 1.

The work described in Mullick et al. (1987) proposes two figures of merit, F_1 and F_2. For the sake of the discussion that follows, a brief derivation of these figures of merit is presented just as made in Mullick et al. (1987).

Considering A_c as the horizontal transparent cover area and I_h as the irradiance on the horizontal plane (in this case coincident with the irradiance on the horizontal transparent cover to the cooker).

F_1 is obtained from a thermal performance equation describing the empty cooker's performance, by stating that the power being delivered by the cooker (the reflecting lid, if it exists, is considered to be covered by a black cloth) is as in Eq. (1)

$$P = A_c \times I_h \times \eta_0 - A_c \times U_L \times (T_p - T_{air}) \quad (1)$$

where

U_L represents the cooker heat loss factor referred to the cover area A_c;
η_0 the optical efficiency of the cooker;
T_p the absorber (plate) temperature of the empty cooker and T_{air} the ambient temperature.

At stagnation T_p becomes T_{ps} (maximum absorber temperature) and the power to be extracted is zero. Hence

$$A_c \times I_h \times \eta_0 = A_c \times U_L \times (T_{ps} - T_{air}) \quad (2)$$

And F_1 appears defined as

$$F_1 = \frac{\eta_0}{U_L} = \frac{(T_{ps} - T_{air})}{I_h} \quad (3)$$

The problem with this definition is that the cover area (A_c) may not characterize the cooker by itself: usually there may be an augmenting lid (see Fig. 1), intercepting solar irradiation and changing the cooker's performance; an infinite variety of cookers could correspond to the same cover area (A_c). Besides, the cover may not be horizontal (see Fig. 2) and such a definition does not even take into account that specificity.

The other Figure of Merit, F_2, arises in the context of loading the cooker with a certain quantity of food (represented by a certain quantity of water for the sake of the testing) and measuring the heating time associated with it.

Let $(MC)_w$ be the mass times the specific heat of the water being heated by the cooker; τ is the time, in seconds, it takes the water (standing for a cooking load) to go from T_{w1} to T_{w2} and again T_{air} is the average ambient temperature during testing.

The equations leading into the definition of F_2 are the following:

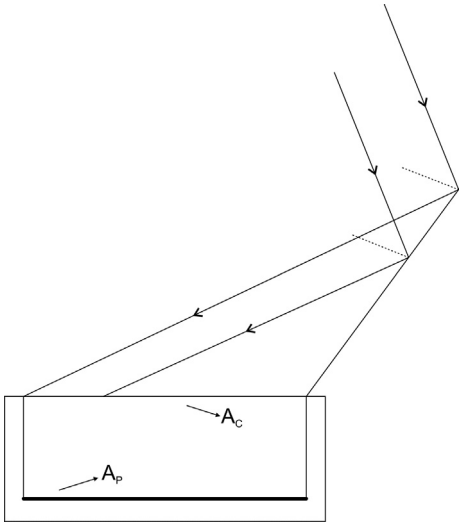

Fig. 1. A typical box cooker with a horizontal transparent cover and an augmenting lid.