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Thermal performance of a solar box cooker with outer reflectors: Numerical study and experimental investigation

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ABSTRACT

A design of a box-type solar cooker was modeled and tested in the region of Sfax-Tunisia. This solar cooker was designed to allow reaching relatively high temperatures during days with low solar radiation owing to four outer reflectors. A mathematical model, which is based on thermal balances, was developed and implemented in a Matlab program to predict the thermal performances of the solar cooker. Several tests were effectuated in order to validate the robustness of the mathematical model and to determine the thermal performance of the solar cooker. The obtained results showed an acceptable matching between the experimental temperature values and the computed temperature values with a maximum error inferior to 4%. It was also proven that the use of four outer reflectors improved the optical efficiency of the solar cooker. Indeed, the first figure of merit passed from 0.07 to 0.14 and the maximum temperature of the absorber plate passed from 81.3 °C to 133.6 °C. The sensible loading test revealed that the calculated second figures of merit for different water loads were in the range of 0.34–0.39. Finally, two real cooking process were carried out where 72 min and 107 min were required to fully cook rice and beans respectively.

1. Introduction

The ruin of the environment is a sufficient reason for humanity to reconsider the means by which it ensures its comfort. The excessive emission of greenhouse gases, that not only contribute to global warming but also to the pollution of the globe, is considered to be the direct cause of several anomalies affecting every living species on earth (Ashmore, 2017). Faced with this awful situation, human communities have decided to take initiatives and to encourage developing new technologies that are not based on polluting processes (Houghton et al., 2001).

Cooking is among the most affected fields by this policy where several attempts have been made to replace traditional cooking means by other low-cost and low-emission technologies. Electric ovens may have locally low emissions, however this advantage collides when considering electricity as a secondary energy. Indeed, according to the U.S department of energy DOE, electricity production is accompanied with greater gas emissions than that accompanying burning LPG (DOE, 2010).

All these facts managed to renew the interest of scientists in solar energy exploitation and allowed solar cookers to thrive and occupy the focus of many researches (Schwarzer and da Silva, 2008; Yettou et al., 2014; Beaumont et al., 1997; Geddam et al., 2015). Yet, this technology, despite of the great issues it gives, have also its limitation such as a relatively long cooking time compared to electric or biomass stoves, especially during days with low solar radiation (Saxena et al., 2011).

To overcome these weaknesses several works have been carried outduring the last few years and have resulted in a variety of technologies. In Rao and Subramanyam (2003), the influence of equipping the cooking vessel with lugs was studied and revealed that the improvement has reduced the boiling time compared with that obtained when using a conventional cooking vessel. Adding an annular central cavity, such as in Rao and Subramanyam (2005), has also shown a good impact since this change increases the heat transfer surface between the food to be cooked and the cooker. Another way to increase the heat transfer surface was proposed in Harmim et al. (2008) and which consists on using a finned cooking vessel. These technologies have resulted in decreasing the boiling time which is a good fact however constructing such complicated devices would be a burden on the cost of the cooking vessel.

On the other hand, some researchers have focused their studies on

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Nomenclature

$\dot{Q}_{ab}$	absorbed heat rate [W]
$\dot{Q}_{acc}$	accumulated heat rate [W]
$\dot{Q}_{cv}$	convective heat rate [W]
$\dot{Q}_r$	radiation heat rate [W]
C_p	specific heat [J kg^{-1} K^{-1}]
e	thickness [m]
h_{cv}	convection heat transfer coefficient [W m^{-2} K^{-1}]
h_r	radiation heat transfer coefficient [W m^{-2} K^{-1}]
I	global solar radiation [W m^{-2}]
L	length of solar cooker [m]
m	mass [kg]
Nu	Nusselt's number
Ra	Rayleigh's number
S	surface [m^2]
T	temperature [K]
U	overall heat transfer coefficient [W m^{-2} K^{-1}]
V	wind speed [m s^{-1}]

Greek symbols

α	absorption coefficient
λ	thermal conductivity [W m^{-1} K^{-1}]
τ	transmission coefficient

Subscripts

air	air gap
amb	ambient
back	back of the solar cooker
base	solar collector base
face	face of the solar cooker
G1	first glass
G2	second glass
ins	insulation
p	absorber plate
ref	reflectors
rockwool	Rockwool cladding
s	sky
wall	solar cookers walls
wood	wood box

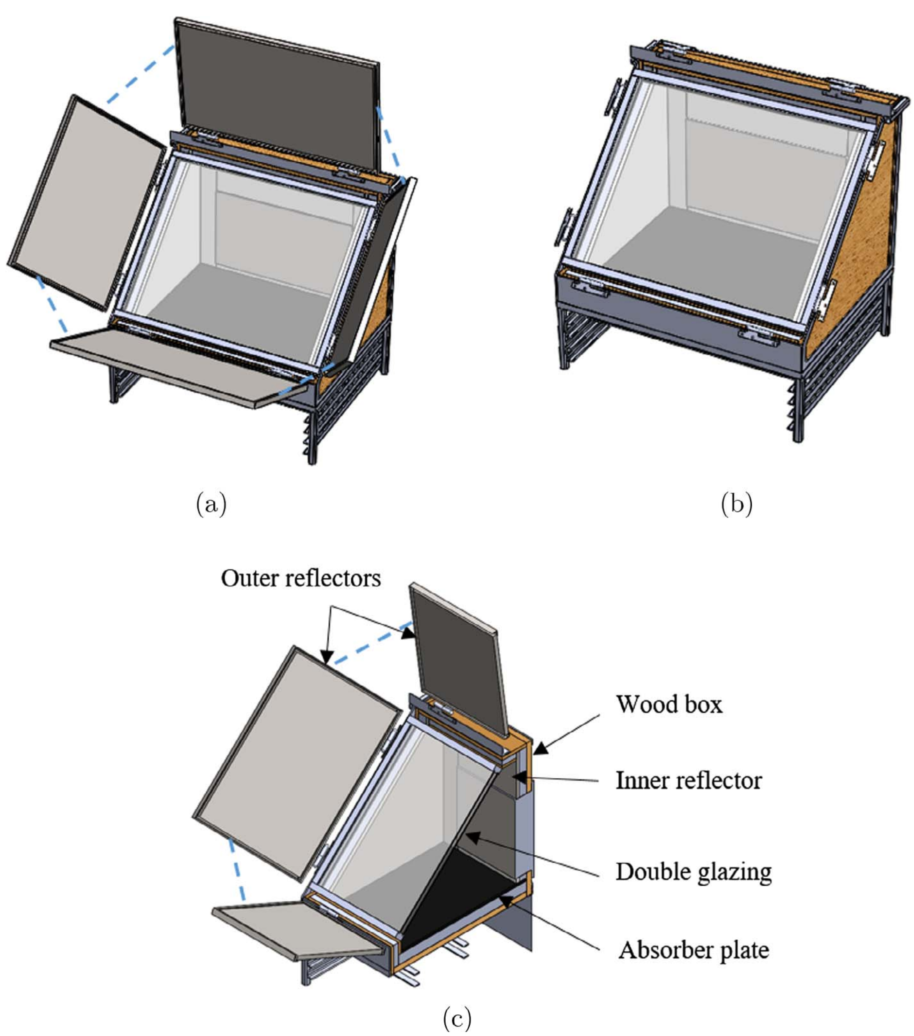

Fig. 1. Three dimensional sketch of the solar cooker box-type: (a) solar cooker with outer reflectors, (b) solar cooker without outer reflectors, (c) cut view of the solar cooker.

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