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Angular optimization of dual booster mirror solar cookers – Tracking free experiments with three different aspect ratios

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Abstract

An experimental investigation supported by numerical simulations to determine the performance parameters of dual booster mirror box type soar cookers having three different length to width ratios, has been carried out in this paper. In addition, the most optimal tilt angles for each of the two booster mirrors, for each day of the year, have been determined for tracking free operation. The numerical investigation has been carried out for a 25° latitude location for all days of the year to determine the best power collection capability of a dual booster mirror solar cooker during 6 h of the most desirable cooking period, ranging from 3 h before to 3 h after the solar noon. Three solar cookers selected for this investigation have length to width ratios of 1.33, 2.66 and 3.99, respectively. Tracking free experiments are conducted for three days to compare the simultaneous performance of each cooker with proportionate water load. Finally, the analysis of the experimental results has been carried out, including the determination of the first and second figures of merit, cooking power, exergy efficiency and the quality factor, in each case. Results indicate that tracking free performance of fully loaded box type solar cookers with two booster mirrors inclined at appropriate angles, becomes optimal with an aspect ratio of 2.66.

Keywords: Solar cookers; Box type solar cookers; Tracking free solar cookers; Aspect ratio of solar cookers

1. Introduction

Modern solar cookers have been studied since the 1950's to provide an alternate to one of the most fuel consuming activity on Earth. In the developing countries, this activity accounts to over one third of the total primary fuel consumption (Muthusivagami et al., 2010; Farooqui, 2014a,b). Box type solar cookers utilizing the green house effect to acquire the cooking temperatures are so far the most popular type, due mainly to their simplicity and lower costs. However, they suffer from a main disadvantage that they require frequent solar tracking in two dimensions. Typically, the box type solar cooker utilizes a horizontal double glazed top surface made out of transparent glass. Food is placed in the box below this surface, under airtight conditions. A booster mirror, mounted as the lid of the box, reflects the sun rays into the box. This has to be frequently angularly adjusted as the sun changes its elevation on the sky. The box as a whole also has to be rotated frequently in the east to west direction as the sun changes its azimuth. This movement is more inconvenient, especially when the cooker is loaded. This dual axis tracking requirement has become the major impediment in the large scale adoption of these cookers (Farooqui, 2013a).

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Nomenclature

B-1	booster mirror – 1
B-2	booster mirror – 2
β	angle of B-1 with the horizon
β_{opt}	optimal inclination angle of B-1
θ	angle of B-2 with the horizon
θ_{opt}	optimal inclination angle of B-2
α	instantaneous solar altitude angle
α_{max}	altitude angle at solar noon
α_{min}	altitude angle at 9:00 and 15:00 h
θ_Z	zenith angle of the sun
φ	latitude of the test location
ω	hour angle
δ	solar declination angle
t_s	local solar time in hours
W	width of the solar cooker
L	length of the solar cooker
W_1	projection length of the reflected light from B-1onto the horizontal surface
W_2	projection length of the reflected light from B-2 onto the horizontal surface
N	number of day of the year
M	mass of water during experiment
C	heat capacity of water
A	aperture area of the cooker
I	solar radiation intensity on horizontal surface and top glazing
I'	radiation intensity perpendicular to the sun
I''_1	radiation intensity perpendicular to B-1
I''_2	radiation intensity perpendicular to B-2
I'''_1	radiation intensity on top glazing after reflection from B-1
I'''_2	radiation intensity on top glazing after reflection from B-2
I_o	extraterrestrial solar radiation intensity normal to the sun
I_{oh}	extraterrestrial solar radiation intensity on a surface tangent to earth
I_{sc}	solar constant
AM	air mass
F_1	first figure of merit
F_2	second figure of merit
T_s	surface temperature of the sun
T_{ps}	plate stagnation temperature
T_a	ambient temperature
T_w	water temperature
T_{av}	average ambient temperature during experiment
δT	difference between water and ambient temperature
ΔT_w	difference of water temperature between two readings
H_s	solar insolation on the horizontal surface
H_{av}	average horizontal radiation during experiment
τ	time interval (larger) between two readings
Δt	time interval (smaller) between two readings
T_{wi}	initial water temperature at the start of an interval
T_{wf}	final water temperature at the end of an interval
E_{Xi}	exergy input to the system
E_{xo}	exergy absorbed by the system
E_{Xloss}	exergy loss by the system
Ψ	exergy efficiency

The various box type solar cooker designs have been extensively investigated and modified continuously since 1980s by a number of authors (Dang, 1985; Vishaya et al., 1985; Tiwari and Yadav, 1986; Pande and Thanvi, 1987; Nahar, 1990; Nahar, 1992, 2001; Binark and Turkmen, 1996; Bari, 2000; Narasimha Rao and Subramanyam, 2000; Algifri and Al-Towaie, 2001; Tiwari, 2002; Purohit and Negi, 2003; Negi and Purohit, 2005; Mirdha and Dhariwal, 2008; Kumar, 2008). More recently, good reviews on solar cookers with and without thermal storage have been presented (Lahkar and Samdarshi, 2010; Muthusivagami et al., 2010; Panwara et al., 2012), and a single family solar cooker has been studied by Mahavar et al. (2012). Other types of cookers have also been presented by various authors (Farooqui, 2013a,b, 2014a,b, 2015).

In this paper, a numerical and experimental investigation has been carried out with a focus to eliminate the need for frequent solar tracking, by using two booster mirrors. A mechanism has been suggested and applied using computer simulations for 25° latitude test location for determining the optimal angle of inclination of each booster mirror, for cooking during 9:00–15:00 h solar time, for each day of the year. This permits a tracking free operation for 6 h. Further, the study has experimentally investigated the impact of using cookers with three different length to width ratios to eliminate the need to track along the azimuth direction. The experimental results are analyzed in each case for determining the first and second figures of merit, cooking power, exergy efficiencies and the quality factor to determine the most optimum aspect ratio of the cooker.

2. The dual booster mirror solar cooker

Solar radiation enters the solar cooker both directly and indirectly. Indirect incidence of light is attained through the booster mirror attached to the solar cooker as its lid. In the