Energy Convers. Mgmt Vol. 28, No. 3, pp. 265–269, 1988
Printed in Great Britain.

0196-8904/88 $3.00 + 0.00

MIRROR BOOSTERS FOR SOLAR COOKERS—I

A. V. NARASIMHA RAO,[1] T. L. SITHARAMA RAO[1] and S. SUBRAMANYAM[2]

[1]Mechanical Engineering Department, Regional Engineering College, Warangal-506 004 and [2]Civil Engineering Department, Kakatiya Institute of Technology and Science, Warangal-506 010, India

(*Received 10 February 1987; received for publication 22 January 1988*)

Abstract—An analysis of the effects of providing a single adjustable mirror booster, hinged on a box type solar cooker, is made. The mirror is hinged on one side and points toward the south. The total energy falling on the cooker aperture is calculated for a latitude of 18°N (Warangal City) and for five different declinations of the sun (five different days in a year). The effects of mirror adjustment are analysed under three categories to determine the energy boost. The calculations clearly demonstrate the choice among intermittent adjustment, continuous adjustment and fixed orientation of the mirror. Only beam radiation is considered in the calculations.

Box type solar cooker Mirror booster Horizontal aperture Fixed mode Intermittent tracking

NOMENCLATURE

A_e = Effective area (m^2)
E_I = Direct energy flux incident on aperture (W/m^2)
E_R = Reflected energy flux incident on aperture (W/m^2)
G = Intensity of solar radiation (W/m^2)
G_{sc} = Solar constant (W/m^2)

Greek letters

α = Altitude
β = Mirror angle
γ = Azimuth
δ = Declination
ϕ = Latitude
ω = Hour angle

Subscripts

b = Beam component
m = Mirror
n = Normal surface
o = Horizontal surface
r = Reflected ray
s = Sun

INTRODUCTION

Solar cookers and ovens are widely used in India. A thorough understanding of energy collection with booster mirror(s) is essential for evolving better designs of solar cookers. The fact that the increase in stagnation temperature and reduction in cooking time can be achieved by using booster mirrors has been well recognized. More uniform rate of energy collection throughout the day can also be obtained. The above mentioned effects ultimately result in better performance of the cookers and collection of more energy for a marginal increase in investment.

Tabor [1, 2] and McDaniels *et al.* [3] studied the effect of mirror boosters on solar energy devices. Meinel and Meinel [4] have discussed, in detail, the optics of mirror boosters and also described the different types of mirror booster systems demonstrated by various investigators. Aman Dang [5] did an optical and thermal analysis of a solar cooker augmented with a planar reflector using PCM as storage. Tiwari and Yadav [6] demonstrated a novel solar cooker with lid at the bottom of the oven. They found that the performance of a conventional box type cooker improved due to an appreciable reduction in preheating time. A complete analysis of energy accretion is not made so far. Much analytical work remains to be done to understand the pattern of energy collection by a solar cooker.

In the present work, the energy collection pattern in a box type solar cooker with a mirror booster hinged on one edge is studied under different conditions. Hottel's model of atmospheric transmittance [7] is adopted in computations of energy incident on the cooker aperture. The change in declination within a day is ignored.

The instantaneous values of energy flux received by the cooker at different times of the day and total energy collected per day are computed. The following cases are considered:

(a) Cooker without booster mirror.

(b) Cooker with booster mirror in fixed orientation.

(c) Cooker with booster mirror; both being given four intermittent adjustments in a day.

(d) Cooker with booster mirror; continuous tracking of sun for maximizing performance of both cooker and mirror.

METHODS OF ORIENTATION

In the present computation, a box type solar cooker with horizontal aperture is selected, as it is the universal mode of use at present. The cooker is with its adjacent edges along north–south and east–west directions. A mirror of the same size as the aperture

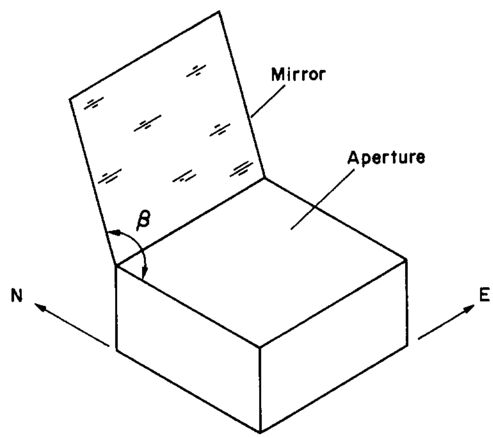

Fig. 1. Cooker and aperture.

is hinged on the northern edge of the cooker. The mirror is arranged to face south. This arrangement is shown in Fig. 1. The instantaneous values of energy flux and total energy incident on the cooker aperture per day are computed for four different cases.

Case (1). The cooker is kept in a fixed orientation such that the azimuth of one edge of the cooker is equal to the azimuth of the sun at noon. No booster mirror is used.

Case (2). The cooker is provided with a mirror which is hinged to the northern edge of the box. The azimuth of the cooker aperture, the mirror and the sun are adjusted to be the same at solar noon. The mirror angle is also set to reflect all the rays of the sun impinging on it into the aperture as shown in Fig. 2.

Case (3). The cooker azimuth and mirror angles are adjusted twice in the morning and twice in the afternoon. The orientation of cooker and mirror are decided on the following basis. Let the orientation changes be assumed to be made at m_1 and m_2 hours. The energy collection during the interval $(m_2 - m_1)$ is maximized by choosing suitable orientations for the cooker and mirror. The changes in azimuth and altitude of the sun are considered as linear during this short interval. For this case, the maximum collection of energy occurs when the cooker and mirror are adjusted to full utilization at $\frac{1}{2}(m_1 + m_2)$ hours.

In the present study, the mirror and cooker are adjusted to the sun's elevation and azimuth at 11 a.m. for the entire interval between 10 and 12 noon. Similar values are used for other intervals, such as 8–10 a.m., 12–2 p.m. and 2–4 p.m.

Case (4). In this case, the cooker orientation is varied throughout the day such that the azimuth of the cooker coincides with the azimuth of the sun. The mirror angle is also varied throughout the day to satisfy the conditions stated earlier.

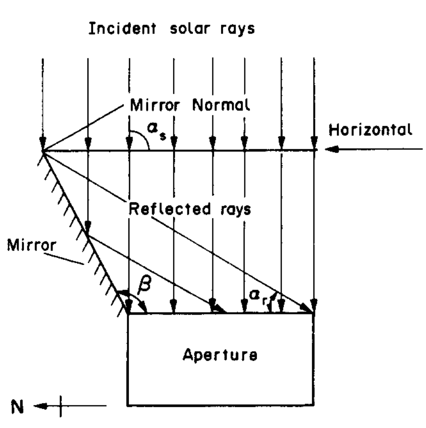

Fig. 2. Cooker—meredian section.

METHOD OF COMPUTATION

In the present computation, the variation of declination within a day is ignored. This ensures symmetry of the day about solar noon. The altitude and azimuth of the sun for a given declination and hour angle are found by solving the spherical triangle shown in Fig. 3. The solution is obtained [8] for locations in latitude of 18° only. It can be readily shown that the mirror angle to reflect all the rays into the cooker aperture at any altitude of the sun is

$$\beta = 60 + \frac{2}{3}\alpha_s. \qquad (1)$$

The azimuth of the reflected beam is found, using the equation

$$\gamma_r = 180 + |\gamma_m - \gamma_s|. \qquad (2)$$

Altitude of the reflected beam is found by the equation

$$\alpha_r = \alpha_s - 2\beta + 180°. \qquad (3)$$

Considering Hottel's model of atmospheric transmittance [7], the beam radiation falling on a surface kept normal to the sun at Warangal (latitude = 18°N, longitude = 79.5°E and altitude = 275 m above MSL) is

$$G_{bn} = G_{sc}\left\{0.14648 + 0.72425 \exp\left[\frac{-0.36855}{\sin(\alpha_s)}\right]\right\}. \qquad (4)$$

The intensity of beam radiation on a horizontal surface is

$$G_{bo} = G_{bn} \times \sin\alpha_s. \qquad (5)$$

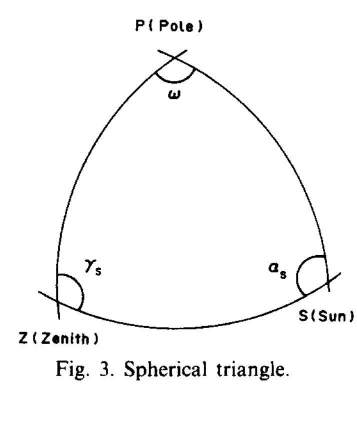

Fig. 3. Spherical triangle.

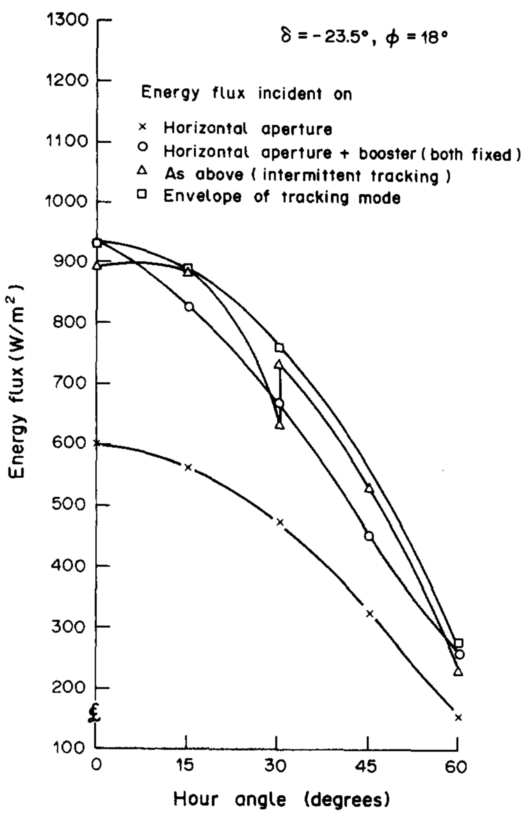

Fig. 4. Energy flux vs hour angle.

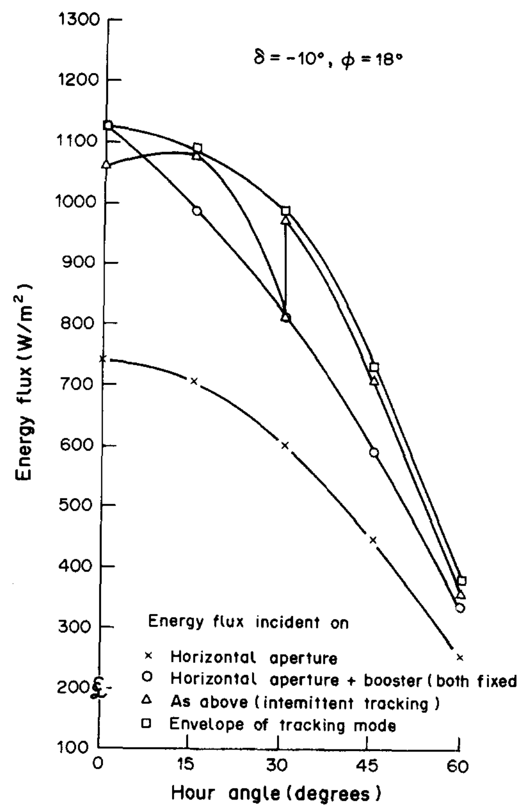

Fig. 5. Energy flux vs hour angle.

The average value of transmittance and reflectance of glass are chosen as 0.8 (very conservatively) within the range of the sun's altitude from 8 a.m. to 12 noon. The energy collection/m^2 of aperture are due to the solar radiation incident directly on the aperture

$$E_1 = G_{bo} \times 0.80 \times 1. \tag{6}$$

The energy reflected by the mirror into the aperture is given by

$$E_R = E_1 \times A_e \times 0.80 \times \sin \alpha_\pi. \tag{7}$$

The effective area, A_e, is computed for each case, considering the azimuth of the aperture and the azimuth of the reflected ray. These calculations are carried out for Warangal for five specific days having declinations of $-23.5°$, $-10°$, $0°$, $10°$ and $+23.5°$ for all four cases described previously. Only direct radiation is considered.

RESULTS AND DISCUSSIONS

The instantaneous values of energy flux vs hour angle for five typical days having declination of $-23.5°$, $-10°$, $0°$, $+10°$ and $23.5°$ and for each of the cases are shown in Figs 4–8. The curve for a continuous change in azimuth of aperture and mirror angle, of case (4), is obtained by the envelope of the maxima of the curve obtained in case (3) for all the days. The values are shown only for the morning. It is to be noted that the change of declination within

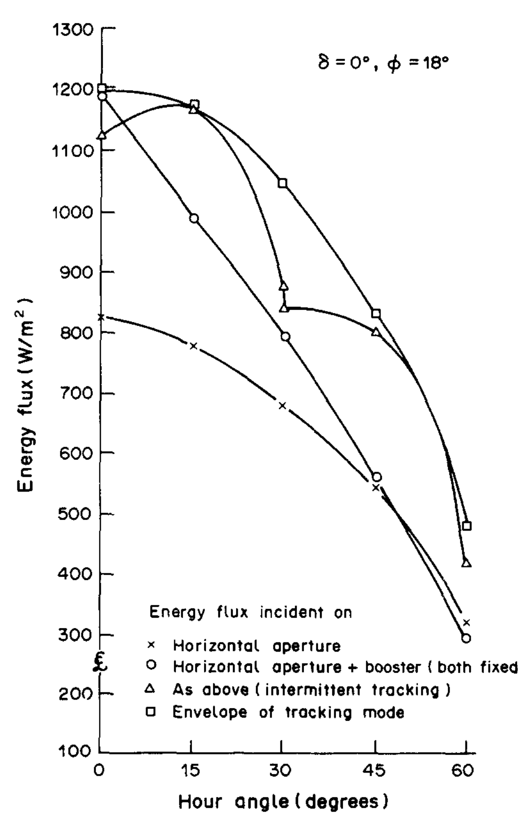

Fig. 6. Energy flux vs hour angle.

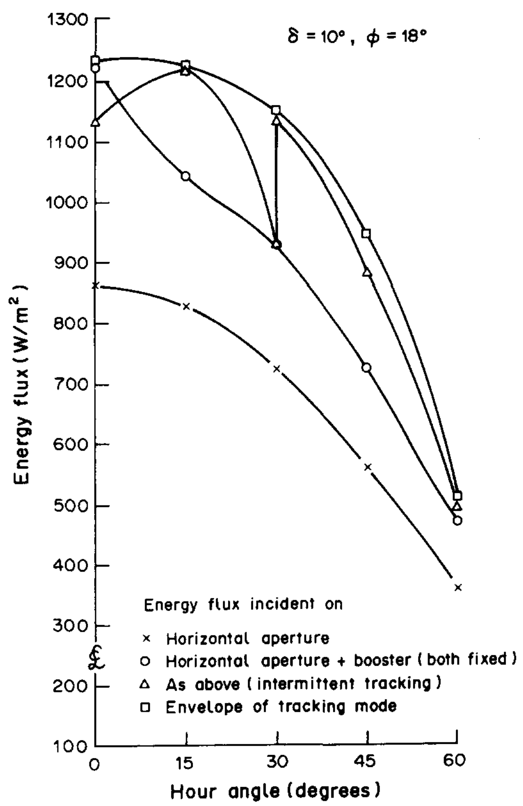

Fig. 7. Energy flux vs hour angle.

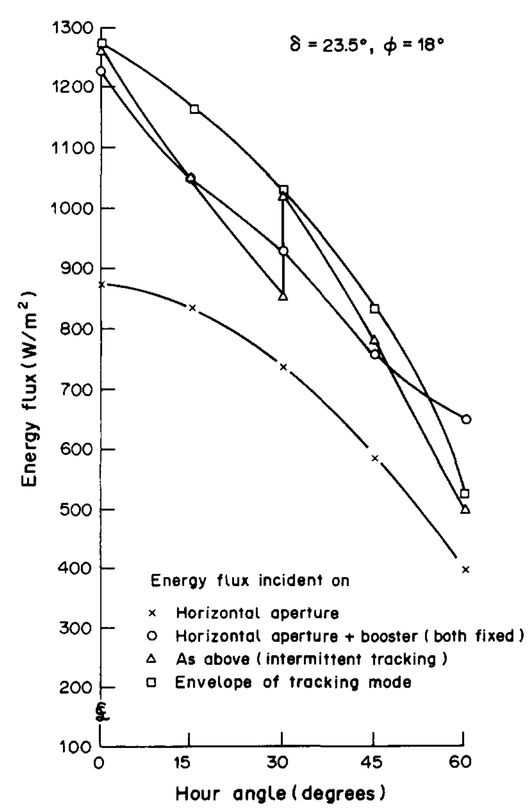

Fig. 8. Energy flux vs hour angle.

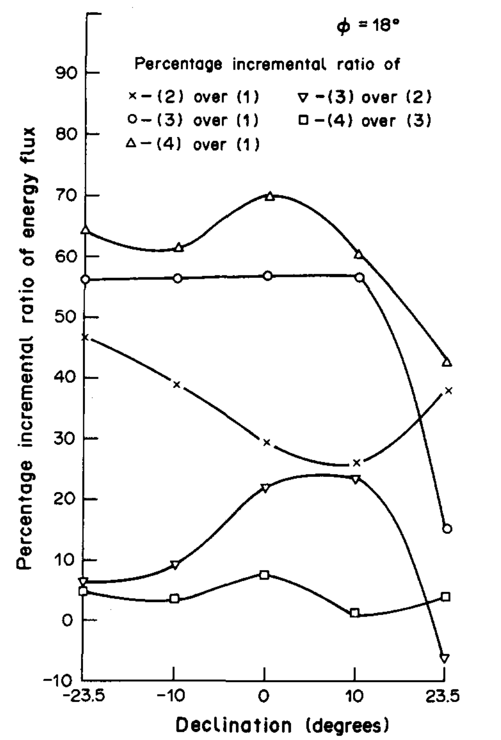

Fig. 9. Percentage incremental ratio of energy flux vs declination.

a day is ignored, thereby assuring symmetry of the day about the zero hour angle. In all the above figures, it is observed that there is significant improvement in the values of energy flux from 9 a.m. to 12 noon by having a single booster mirror. During the period when the declination is around $-23.5°$ (Fig. 4), it is seen that there is not a substantial gain in energy flux throughout the day in case (4) over case (3). Throughout the year, except on equinoctial days, a significant jump in the energy flux is noticed at 10° clock in case (3). This is due to the orientation change at that hour. During the period when the declination is 0–10° as seen in Fig. 6 and Fig. 7, i.e. around 15 March–21 April and 21 August–21 September a large deficit in energy flux is noticed for case (3) when compared to case (4) at about 10 a.m. and 2 p.m. This is due to the rapid change in the sun's altitude during these time intervals. The sun is near prime meridian. This trend indicates that it is possible to enhance the energy collection by effecting adjustments at 10 and 11 a.m. for maximum collection at those hours, instead of only one adjustment at 10 a.m. for maximum collection at 11 a.m.

The percentage increase in the instantaneous values of energy flux at different times of the day are computed for the different cases. Comparisons of case (1) with case (2), case (3) and case (4) have been made. These values are shown in Fig. 9. The percentage incremental ratio of energy flux of case (2) over case (1), as seen in Fig. 9, is a minimum on the day having declination of $+10°$. This ratio for case

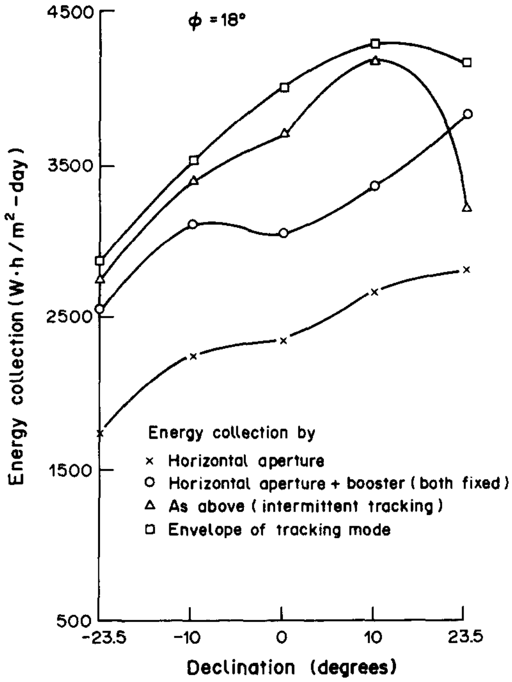

Fig. 10. Energy collection per day vs declination.

(3) over case (1) is fairly constant at around 56% during the period when the declination change is between −23.5 and 10° and then dropped to about 15% during the period when the change in declination is between +10 and +23.5°. The same ratio for case (4) over case (1) is a maximum of about 70%, during equinoxes and is a minimum of about 43% during summer solstice. The ratio for case (3) over case (2) is a maximum of about 24% for the days when the declination is +10°. It decreased sharply from the maximum value during the period when the declination change is between 10 and 23.5°. However, near summer solstice, this value is negative, indicating that there is a decrease in the ratio.

The total energy collected by the aperture is the sum of the incident energy and energy reflected on to it by the mirror. The total energy collected per day is obtained from the integration of energy flux vs time. These values for the four different cases for five typical days are shown in Fig. 10. There is a significant improvement in the total energy collection/day in all the three cases over case (1). During the period when declination changes from −23.5 to 10°, there is only a marginal increase in these values for case (4) over case (3). However, there is a considerable increase in these values during summer solstice. During the period near summer solstice, the daily energy collection is much better in the fixed mode over the intermittent tracking mode.

CONCLUSIONS

The geometrics of mirror boosters offer a rich field of study. Such studies are of considerable economic significance in upgrading many solar energy devices.

The following conclusions are drawn from the present study.

(1) It has been found that, by intermittent adjustment and continuous adjustment of the booster mirror (with the mirror angle at the optimum value), the total energy collection is improved at all hours of the day. When the insolation values are low, the improvement in energy collection is much larger, thereby reducing the variance in energy collection during the day.

(2) Further, there is a very significant improvement in total energy collection per year for a given aperture area with a single booster mirror.

(3) Only a marginal increase in energy collection/day is noticed in the continuous tracking mode over the intermittent adjustment mode during the entire year except during summer solstice.

Acknowledgement—The authors wish to express their sincere thanks to Professor K. Koteswara Rao, Principal, Regional Engineering College, Warangal, for providing the facilities to carry out this work.

REFERENCES

1. H. Tabor, *Sol. Energy* **2,** Nos. 3/4, 27 (1958).
2. H. Tabor, Solar Energy Conference, Boston, Massachusetts, 21–23 March (1966).
3. D. K. McDaniels *et al. Sol. Energy* **17,** 277 (1977).
4. A. B. Meinel and M. P. Meinel, *Applied Solar Energy—An Introduction.* Addison-Wesley, Reading, Mass. (1977).
5. Aman Dang, *Energy Convers. Mgmt* **25,** 255 (1985).
6. G. N. Tiwari and Y. P. Yadav, *Energy Convers. Mgmt* **26,** 41 (1986).
7. H. C. Hottel, *Sol. Energy* **18,** 129 (1976).
8. C. I. Palmer, C. W. Leigh and S. H. Kimball, *Plane and Spherical Trigonometry.* McGraw-Hill, New York (1950).