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Prediction and experimental verification of performance of box type solar cooker – Part I. Cooking vessel with central cylindrical cavity

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Abstract

The performance of conventional box type solar cookers can be improved by better designs of cooking vessels with proper understanding of the heat flow to the material to be cooked. An attempt has been made in this article to arrive at a mathematical model to understand the heat flow process to the cooking vessel and thereby to the food material. The mathematical model considers a double glazed hot box type solar cooker loaded with two different types of vessels, kept either on the floor of the cooker or on lugs. The performance of the cooking vessel with a central cylindrical cavity is compared with that of a conventional cylindrical cooking vessel. It is found from the experiments and modeling that the cooking vessel with a central cylindrical cavity on lugs results in a higher temperature of the thermic fluid than that of a conventional vessel on the floor or on lugs. The average improvement of performance of the vessel with a central cylindrical cavity kept on lugs is found to be 5.9% and 2.4% more than that of a conventional cylindrical vessel on the floor and on lugs, respectively.

Keywords: Box type solar cooker; Conventional cylindrical vessel; Vessel with central cylindrical cavity; Thermic fluid; Intermittent azimuthal tracking

1. Introduction

Some efforts on using solar energy for cooking were reported in the history of solar energy [1]. These efforts were quenched by the advent of cheap and very convenient petroleum fuels in the early twentieth century. A renaissance of solar cookers started in 1950. Since then, several investigators have studied various aspects of solar cooking. The studies on solar cookers can be broadly classified into the following categories: (a) design, fabrication and testing of new types of solar cookers, (b) methods of boosting the solar energy on the cooker aperture using booster mirrors, (c) energy storage types of cookers, for use indoors and also during off sunshine periods, (d) tests on different types of cooking vessels and (e) modeling and simulation techniques.

Telkes [2] has designed, fabricated and tested some excellent models of solar cookers incorporating features such as mirror boosters, inclined aperture and side loading. Tabor [3] has developed a solar cooker that can deliver 400–500 W of solar energy. Tiwari and Yadav [4] have fabricated and tested a bottom loaded solar cooker for reducing heat loss due to escape of the hot air when the top lid is opened for unloading and reloading the conventional box type solar cooker. Grupp et al. [5] have fabricated an advanced box type solar cooker in which they fixed the cooking vessel in good thermal contact with a conductive absorber plate. Mohamed Ali [6] designed and fabricated a cooker with sloping top cover, adding significantly to the thermal performance. Hussain [7] developed a cooker with auxiliary heating for making use of the solar cooker through out the year. Emad Amer [8] designed a novel solar cooker in which the absorber is exposed to solar radiation from the top and bottom faces.

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Nomenclature

A	area (m^2)
G	insolation (W/m^2)
M	heat capacity (J/K)
Q	heat transfer (W)
T	temperature (K)
t	time (s)

Subscripts

1	conventional cylindrical vessel on floor/on lugs
2	vessel with central cylindrical cavity on lugs
a	air inside cooker
amb	ambient air
av	air inside vessel
g_1	lower glass cover
g_2	upper glass cover
ins	insulation
p	absorber plate
sp	side plate
spr	side plate projected area
v	cooking vessel
vc	vessel cover
w	thermic fluid inside vessel
ws	wetted surface

Narasimha Rao et al. [9–12] made extensive analysis of the energy contribution of differently oriented mirror boosters in various tracking modes on a horizontal aperture. Nahar [13,14] designed, fabricated and tested a solar cooker with used engine oil as storage material, so that cooking can be performed even in the late evening. He had also observed that a cooker with transparent insulation material (TIM) is more efficient than the ordinary cooker without TIM. Klemens and Vieira Da Silva [15] developed a solar cooking system, with or without heat storage, facilitating indoor and night cooking. Buddhi [16] has designed and developed a solar cooker with commercial grade acetanilide as storage material. Sharma et al. [17] have designed and studied a simple cylindrical PCM heat storage unit for cooking during off sunshine periods.

Gaur [18] studied the performance of a cooker with a modified utensil with a concave shaped lid. Narasimha Rao et al. [19,20] demonstrated experimentally that a cooking vessel kept on supports (lugs) and also a cylindrical cooking vessel with central annular cavity performs much better when compared to a conventional cylindrical vessel on the floor of the cooker. The present work compares, both experimentally and theoretically, the performance of a cylindrical vessel with central annular cavity on lugs with that of a conventional cylindrical vessel on the floor of the cooker or on lugs.

A few investigators have developed techniques for simulating the performance of a box type solar cooker. Garg et al. [21] developed a mathematical model for studying the transient behaviour of a single glazed box type solar cooker. Later, Aman Dang [22] presented an analytical model of a box type solar cooker assisted by a single booster mirror using a phase change material (PCM) as storage system. Further, Thulasidas et al. [23,24] modeled a box type solar cooker with a reflector and loaded with one, two or four vessels and studied the effects of base plate thickness, cooker size etc. Binark and Turkmen [25] presented a mathematical model for the solar box cooker. They made a thermal analysis for a cooker with four pots loaded with water and compared their results with experimental results. El-Sebaii [26] presented a simple mathematical model for a box type solar cooker with outer–inner reflectors. Raji Reddy et al. [27,28] presented mathematical models in which heat transfer analysis of a conventional vessel on lugs is compared with that of a conventional vessel on the floor of the cooker and also compared the performance of the vessel with central cylindrical cavity on lugs with the conventional vessel on the floor of the cooker. In the above models, the estimated solar insolation values are supplied as input whereas in the present model, observed values of insolation and ambient temperature are used.

Mullick et al. [29] outlined a test procedure for the solar box cooker. Funk [30] presented the international standard testing procedure for evaluation of solar cookers. Subodh Kumar [31,32] conducted several indoor and outdoor experiments on a solar cooker to develop a correlation to estimate the top heat loss coefficient. He had also presented a simple test procedure to obtain two figures of merit, F_1 and F_2, of a solar cooker.

2. Present study

It is obvious from the literature review that not much attention has been paid to the design of the cooking vessel used in a solar cooker. In the present study, it is proposed to examine the following aspects:

(1) Improvements to heat penetration through the cooking vessel and into the food material to be cooked.
(2) Modifications to the cooking vessels to enhance heat flow to the foodstuff.
(3) Development of good mathematical models for studying the above phenomenon theoretically.
(4) Validation of the theoretical models developed with the observations made in different cases.

The above aspects are discussed in parts. The first part deals with a detailed theoretical and experimental study of the performance boost obtained by a cooking vessel with a central cylindrical cavity on lugs when compared to a conventional cylindrical vessel on lugs during Test 1 and a conventional cylindrical vessel on the floor of the cooker during Test 2. In Test 1, both the conventional cylindrical vessel and the vessel with a central cylindrical cavity are kept on mild steel lugs to lift them above the floor of the cooker. In Test 2, the conventional cylindrical vessel is kept on the floor of the cooker, i.e. on the absorber plate whereas another vessel with a central cylindrical cavity is placed on mild steel lugs. The thermic fluid is heat transfer oil whose boiling point is around 250 °C. This oil is used in place of water to avoid errors in measuring the temperature due to evaporation of water around 95 °C.

3. Description of the solar cooker

Figs. 1 and 2 show schematics of a box type solar cooker with cooking vessels during Test 1 and Test 2, respectively. The cooker consists of a trapezoidal aluminum tray (35 cm × 35 cm at bottom, 49 cm × 49 cm at top and 10 cm height) made of 1 mm thick sheet. In Test 1, the conventional cylindrical vessel (ϕ 20 cm) and another vessel (ϕ 20 cm) with central cylindrical cavity (ϕ 6 cm) are kept on lugs. In Test 2, the conventional vessel is kept on the floor, and another vessel with a central cylindrical cavity is placed on lugs. The details of the conventional cylindrical vessel and the vessel with a central cylindrical cavity are depicted in Figs. 3 and 4, respectively. Each of the vessels was loaded with a fixed mass of thermic fluid (1 l). The sides and bottom of the tray are encased in a box made of sheet metal. The gap between the tray and the casing is filled with glass wool to provide thermal insulation. The tray is provided with a movable double glass cover, hinged to one side of the casing at the top. A plane glass mirror, encased in a sheet metal shell, is fitted to serve as a reflector. This serves as a cover for the double glass glazing when the cooker is not in use. The cooking vessels are cylindrical in shape and have a flat base. The vessels are provided with tight fitting flat covers. The tray and outsides of the vessels are painted with dull black paint.

4. Mathematical model

A box type solar cooker with one conventional vessel on the floor or on lugs and another vessel with a central cylindrical cavity on lugs are considered. The various heat transfer processes are illustrated in Fig. 5. In earlier models, the cooking vessel and its contents are taken as a single element, and also, the air inside the cooking vessel, i.e. between the contents of the vessel and the lid has not been considered, which plays an important role in transferring heat from the vessel cover to the contents of the vessel. Its presence makes a difference in the prediction of the temperature of the contents of the vessel. Therefore, these elements are taken separately in the present model to come closer to reality.

This is a transient model that evaluates the temperature of the elements of the cooker for every second and is fed as

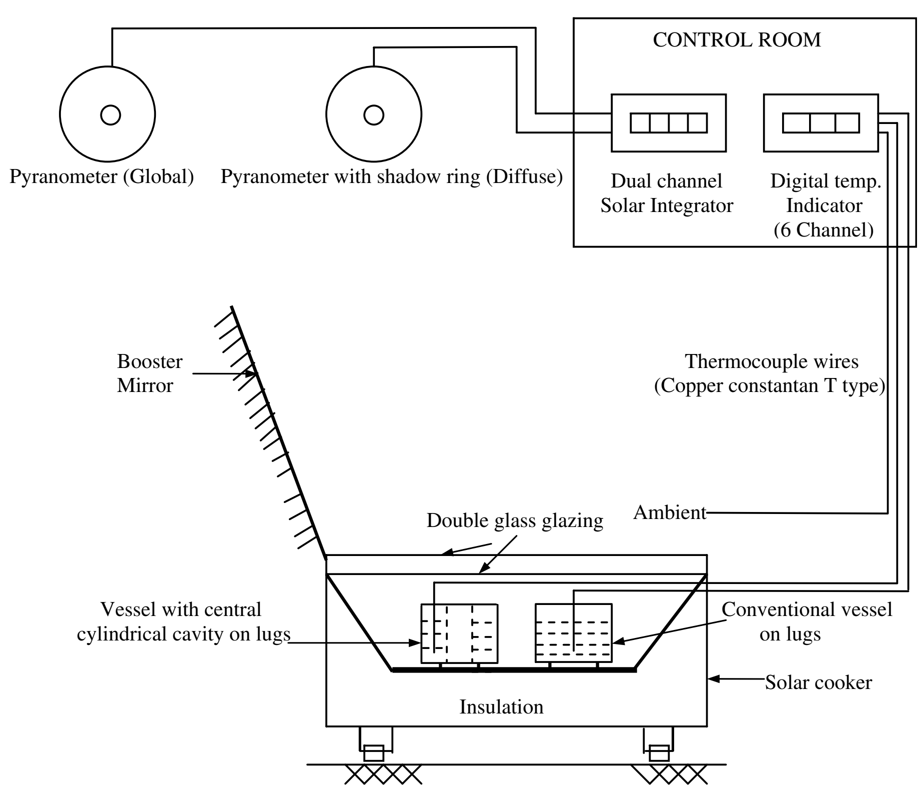

Fig. 1. Schematic of a box type solar cooker with central cylindrical cavity vessel and conventional cylindrical vessel both on lugs (Test 1).

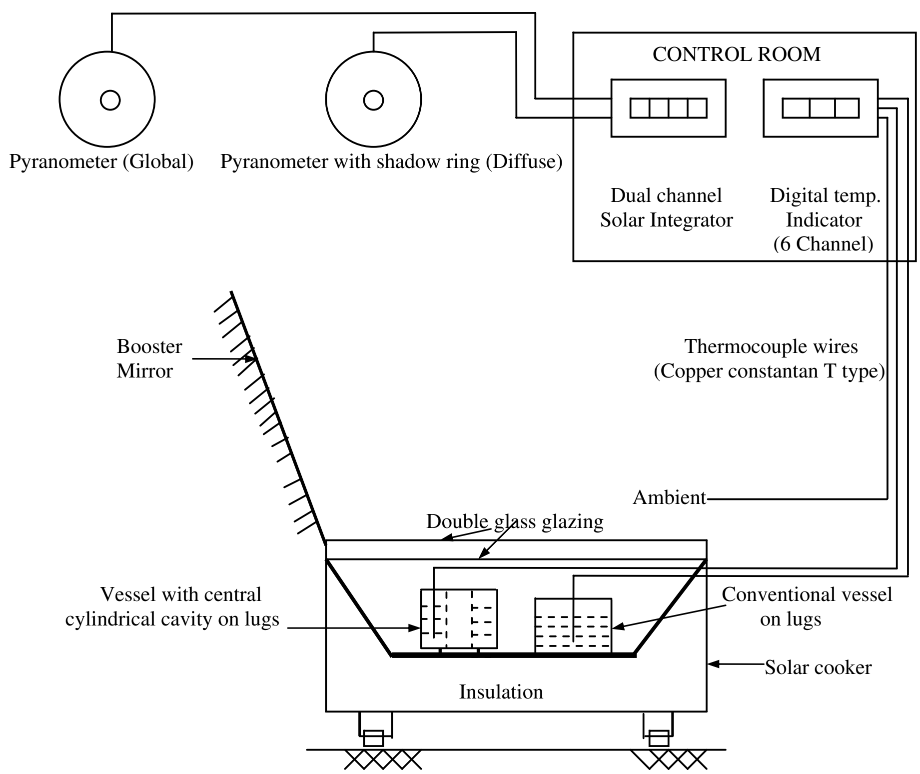

Fig. 2. Schematic of a box type solar cooker with central cylindrical cavity vessel on lugs and conventional cylindrical vessel on floor of the cooker (Test 2).

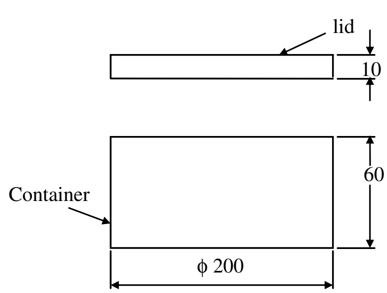

Fig. 3. Lid and container of a conventional cylindrical cooking vessel.

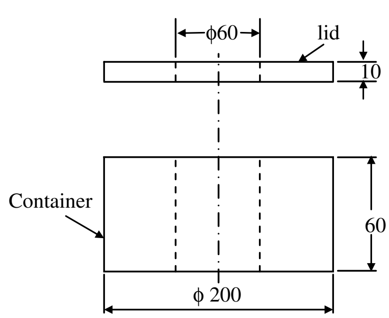

Fig. 4. Lid and container of a cooking vessel with central cylindrical cavity.

input to the next iteration. In previous models, the cooker cavity is taken as a rectangular one with the total insolation falling only on an absorber plate and the vessel cover, whereas in our present model, the cooker interior is in the shape of a trapezoid. Hence, some insolation also falls on the side plate. The various heat transfer processes are identified, and energy balance equations are obtained for the nine elements of the cooker, such as the absorber plate, side plate, vessel cover, air inside the cooker, glass covers, air inside the vessel, the vessel and its contents. The variation of the temperatures of the elements of the cooker with time can be found by solving these energy balance equations using a computer program written in MATLAB. The following assumptions are made:

1. There is no radiative heat transfer between the sidewalls of the cooker and the vessel cover.
2. Solar radiation is incident only on the absorber plate, side plate and the vessel cover.
3. The heat transfer coefficients are fixed and taken as constants.
4. Heat conduction between the absorber plate and the side plates and also between the vessel cover and the vessel side is negligible.
5. Heat loss due to air exchange between the cooker and the ambient is negligible.

4.1. Mechanism of heat flow in a cooking vessel

4.1.1. Conventional cylindrical vessel on floor/on lugs

The cooking vessel has three boundaries; (i) the bottom of the vessel, (ii) the sides of the vessel and (iii) the air layer above it. When the vessel is on the floor,

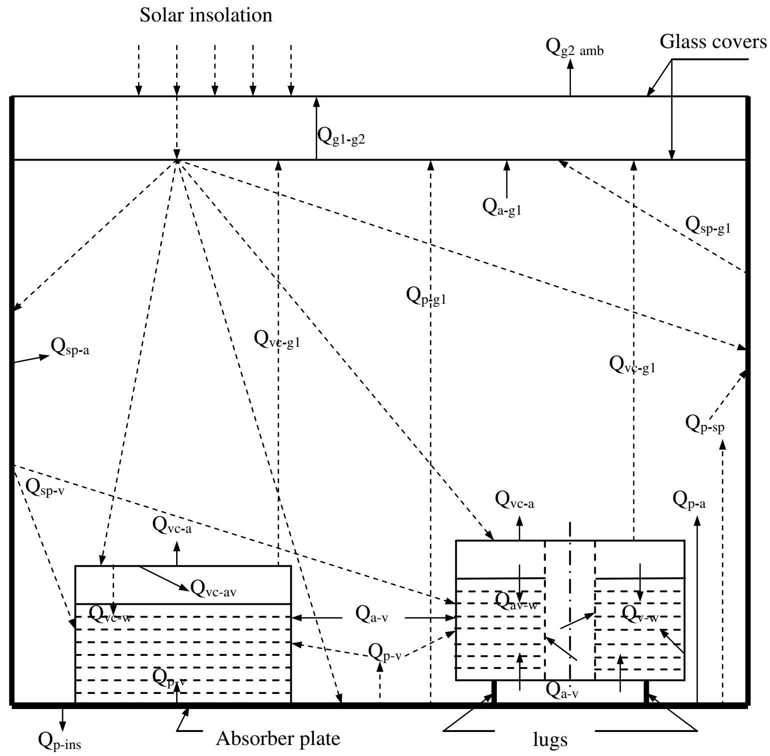

Fig. 5. A schematic indicating various modes of heat transfer in a box type solar cooker containing a cylindrical vessel on the floor of the cooker and another vessel with central cylindrical cavity on lugs.

heat transfer takes place by means of conduction from the absorber plate to the vessel bottom and vice versa. The heat flow from the sides of the vessel takes place by convection in both directions, i.e. inwards and outwards. When the net flow is inwards, the thermic fluid gains heat and its temperature rises, whereas the thermic fluid loses heat and cools if the net heat flow is outward. When the heat flows are equal, then equilibrium is established and the equilibrium temperature is maintained. The lid of the vessel intercepts the maximum energy. However, this is not effectively transferred to the thermic fluid as there is an air gap between the lid and the thermic fluid, which allows only convection between the lid and the working medium. A vessel being kept flush with the floor of the cooker prevents circulation of hot air. By keeping the vessel on lugs, i.e. lifting the vessel above the floor of the cooker, hot air in the cooker is allowed to circulate in the space between the bottom of the vessel and the plate, resulting in an increase in heat transfer to the contents of the vessel. Hence, the temperature of the contents of the vessel will be more than that of the vessel on the floor.

4.1.2. Vessel with central cylindrical cavity on lugs

A cooking vessel with a central cylindrical cavity kept on lugs provides hot air circulation freely through the central cylindrical cavity of the vessel. The central cylindrical cavity reduces the heat flow path length and facilitates better transfer of heat to the thermic fluid kept in the vessel from both the radial directions, i.e. from inside the vessel and from outside the vessel. The enhanced area of heat transfer and the improved circulation of the hot air through the central cylindrical hole reduce the cooking time.

4.2. Heat balance equations

Upper glass cover

$$M_{\mathrm{g2}}\frac{\mathrm{d}T_{\mathrm{g2}}}{\mathrm{d}t} = G_{\mathrm{g2}} + Q_{\mathrm{g1-g2}} - Q_{\mathrm{g2-amb}} \tag{1}$$

Lower glass cover

$$M_{\mathrm{g1}}\frac{\mathrm{d}T_{\mathrm{g1}}}{\mathrm{d}t} = G_{\mathrm{g1}} + Q_{\mathrm{a-g1}} - Q_{\mathrm{g1-g2}} + Q_{\mathrm{p-g1}} + Q_{\mathrm{vc1-g1}} + Q_{\mathrm{vc2-g1}} + Q_{\mathrm{sp-g1}} \tag{2}$$

Air inside the cooker

$$M_{\mathrm{a}}\frac{\mathrm{d}T_{\mathrm{a}}}{\mathrm{d}t} = Q_{\mathrm{p-a}} + Q_{\mathrm{vc1-a}} + Q_{\mathrm{vc2-a}} + Q_{\mathrm{sp-a}} - Q_{\mathrm{a-g1}} - Q_{\mathrm{a-v1}} - Q_{\mathrm{a-v2}} \tag{3}$$

Absorber plate

$$M_{\mathrm{p}}\frac{\mathrm{d}T_{\mathrm{p}}}{\mathrm{d}t} = G_{\mathrm{p}} - Q_{\mathrm{p-a}} - Q_{\mathrm{p-v1}} - Q_{\mathrm{p-v2}} - Q_{\mathrm{p-g1}} - Q_{\mathrm{p-sp}} - Q_{\mathrm{p-ins}} \tag{4}$$

Vessel cover 1

$$M_{vc1}\frac{dT_{vc1}}{dt} = G_{vc1} - Q_{vc1-g1} - Q_{vc1-a} - Q_{vc1-w1} - Q_{vc1-av1} \quad (5)$$

Vessel cover 2

$$M_{vc2}\frac{dT_{vc2}}{dt} = G_{vc2} - Q_{vc2-g1} - Q_{vc2-a} - Q_{vc2-w2} - Q_{vc2-av2} \quad (6)$$

Side plate

$$M_{sp}\frac{dT_{sp}}{dt} = G_{sp} + Q_{p-sp} - Q_{sp-a} - Q_{sp-g1} - Q_{sp-v1} - Q_{sp-v2} - Q_{sp-ins} \quad (7)$$

Vessel 1

$$M_{v1}\frac{dT_{v1}}{dt} = Q_{p-v1} + Q_{a-v1} + Q_{sp-v1} - Q_{v1-w1} - Q_{v1-av1} \quad (8)$$

Vessel 2

$$M_{v2}\frac{dT_{v2}}{dt} = Q_{p-v2} + Q_{a-v2} + Q_{sp-v2} - Q_{v2-w2} - Q_{v2-av2} \quad (9)$$

Air inside vessel 1

$$M_{av1}\frac{dT_{av1}}{dt} = Q_{vc1-av1} + Q_{v1-av1} - Q_{av1-w1} \quad (10)$$

Air inside vessel 2

$$M_{av2}\frac{dT_{av2}}{dt} = Q_{vc2-av2} + Q_{v2-av2} - Q_{av2-w2} \quad (11)$$

Contents of vessel 1

$$M_{w1}\frac{dT_{w1}}{dt} = Q_{av1-w1} + Q_{v1-w1} + Q_{vc1-w1} \quad (12)$$

Contents of vessel 2

$$M_{w2}\frac{dT_{w2}}{dt} = Q_{av2-w2} + Q_{v2-w2} + Q_{vc2-w2} \quad (13)$$

5. Experiment

The temperature of the thermic fluid in each of the vessels and the ambient temperatures were recorded at preset intervals of time using a digital temperature indicator (range; 0–300 °C, accuracy; ±0.25%, resolution; 1 °C). Thermic fluid temperatures were measured by a copper-constantan thermocouple whose hot junction is fixed inside the vessel through a small hole in the lid. The tip of the thermocouple is placed 10 mm above the base of the vessel. The solar cooker is not opened during the course of the tests. The cooker is tracked once every 30 min in order to collect the maximum amount of insolation. The tracking is done by rotating the cooker azimuthally in such a way that the azimuth of the mirror normal and the sun are equal, and the reflected rays from the mirror illuminate the entire cooker aperture and aperture alone. The global and diffuse components of insolation were also recorded with the help of pyranometers (range; 0–1400 W/m^2, accuracy; ±0.5%, response time; 5 s) and a dual channel solar integrator (range; 0–2000 W/m^2, accuracy; ±0.2%, resolution; 1 W/m^2).

The experiments are conducted for several days at the Solar Energy Laboratory of the National Institute of Technology, Warangal (latitude 18°N, longitude 79.5°E and elevation 275 m above sea level), India.

6. Results and discussion

This model takes care of every component of the cooker, like the presence of air between the lid and the vessel cover, vessel and its contents. The energy balance equations (1)–(13) are solved by using a computer program written in MATLAB. This program is executed for every second as the time interval, whereas the temperatures are recorded for every half hour. The variation of ambient temperature is considered in the modeling. The various heat transfer coefficients are fixed and taken as constants. The various parameters of the cooker used in modeling are tabulated in Table 1. This model takes care of the shape of the vessel and orientation when both simultaneously exist in the cooker interior. The insolation data at Warangal on the days when the experiments were conducted, i.e. on the 10th and 13th November 2005 are depicted in Figs. 6 and 7, respectively. It is evident from the insolation records that the sky is very clear during the above days.

Fig. 8 depicts the temperature time history of the thermic fluid in the conventional cylindrical vessel on lugs and that of the thermic fluid in the vessel with the central cylindrical cavity on lugs. Second degree polynomial fits of the above data are also shown in the same figure. It is evident from the figure that the vessel with the central cylindrical cavity is performing better than the conventional vessel when both the vessels are on lugs. It is also observed that the maximum temperature of the thermic fluid in the conventional cylindrical vessel on lugs occurred at 13.75 h, and the same temperature could be attained in the case of the vessel with the central cylindrical cavity nearly half an hour earlier. This is because the surface area

Table 1
Heat capacity and area of various elements of the box type solar cooker

Heat capacity	(J/K)	Area	m^2
M_p	297.43	A_g	0.25
M_{sp}	443.72	A_{sp}	0.1826
M_a	21.01	A_{spr}	0.1276
M_{g1}	1638	A_p	0.1224
M_{g2}	1638	A_{vc1}	0.02836
M_{w1}	1699	A_{vc2}	0.02597
M_{w2}	1699	A_{v1}	0.0449
M_{vc1}	76.30	A_{v2}	0.05
M_{vc2}	69.43	A_{ws1}	0.0273
M_{av1}	1.07	A_{ws2}	0.0296
M_{av2}	0.87	A_{av1}	0.0276
M_{v1}	167.86	A_{av2}	0.0204
M_{v2}	188.47		

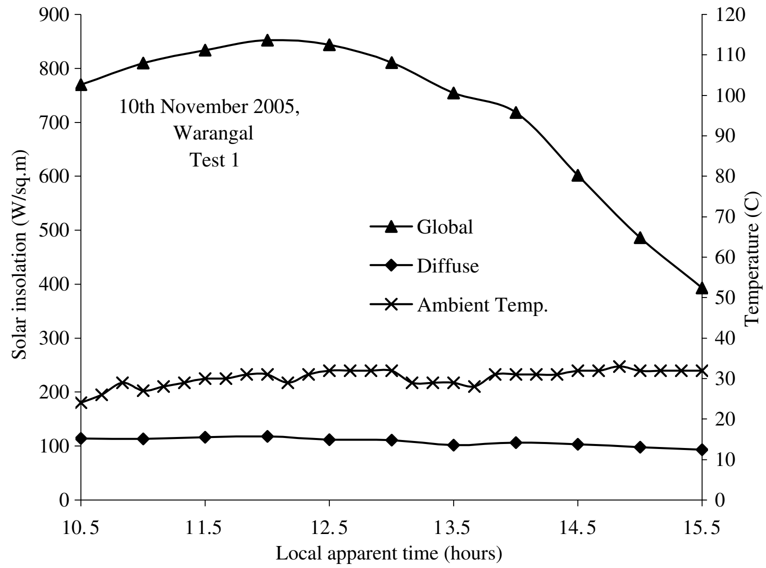

Fig. 6. Measured solar insolation and ambient temperature on 10th November 2005 at Warangal (latitude 18°N, longitude 79.5°E and elevation 275 m above mean sea level).

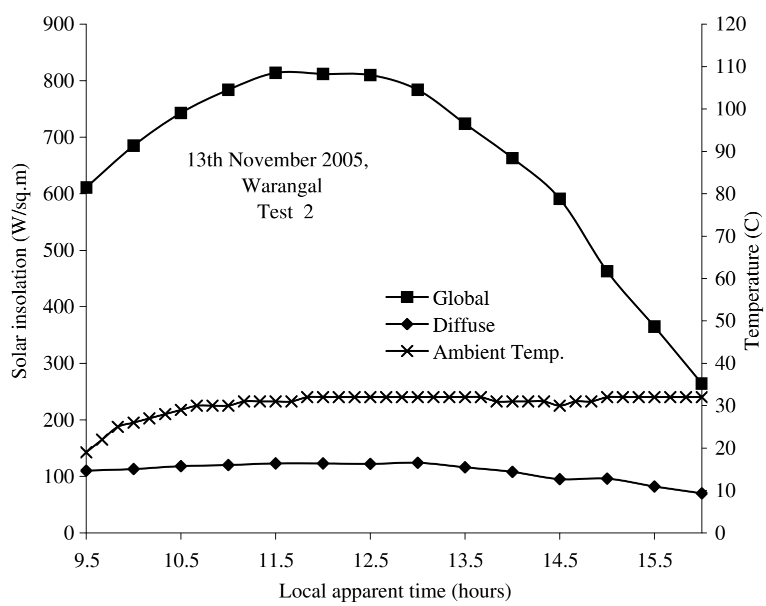

Fig. 7. Measured solar insolation and ambient temperature on 13th November 2005 at Warangal (latitude 18°N, longitude 79.5°E and elevation 275 m above mean sea level).

for heat flow is more in the case of the vessel with the central cylindrical cavity.

Fig. 9 illustrates the temperature time history of the thermic fluid contained in the conventional vessel on the floor and that of the vessel with the central cylindrical cavity on lugs. It also depicts the second degree polynomial fits of the experimental values in each case. It is readily seen that the temperature of the thermic fluid is more in the vessel with the central cylindrical cavity all through the day. The difference is quite substantial between 11.5 and 15.5 h. The maximum temperature boost is around 10 °C at 13.5 h. The maximum temperature of the thermic fluid in the conventional cylindrical vessel on the floor occurred at 13.5 h and is found to be 110 °C. However, the same temperature could be attained in the case of the vessel with the central cylindrical cavity nearly 1 h earlier. It is a clear indication that the cooking would be faster in the cooking vessel with the central cylindrical cavity.

Fig. 10 shows the predicted and observed values of the temperature of the thermic fluid in a conventional cylindrical vessel on lugs. A second degree polynomial fit of the experimental data is also shown in the above figure. It has been found that the difference between the observed and the predicted values of temperature is more during the first half of the test, i.e. up to 13 h, and it is much less during the period 13–15.5 h. Fig. 11 illustrates the variation

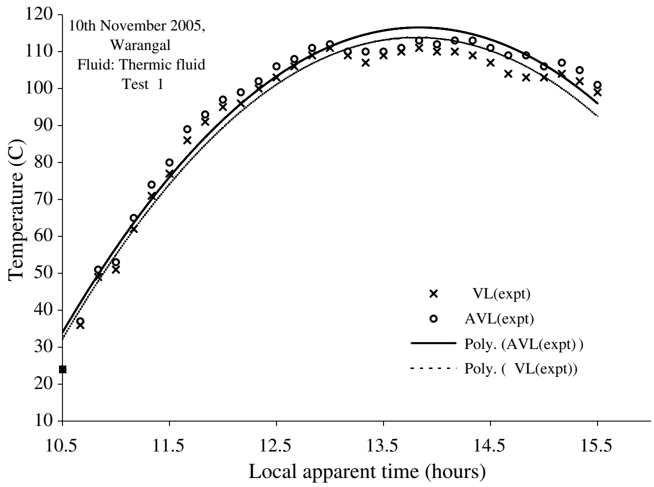

Fig. 8. Variation of temperature of thermic fluid contained in conventional vessel kept on mild steel lugs (VL) compared to that of thermic fluid in vessel with central cylindrical cavity on mild steel lugs (AVL). The experiments were conducted on 10th November 2005 at Warangal (latitude 18°N, longitude 79.5°E and elevation 275 m above mean sea level).

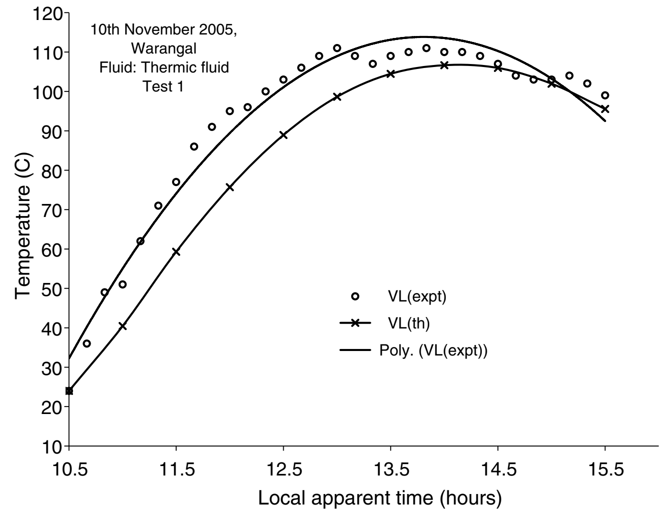

Fig. 10. The predicted and observed values of temperature of the thermic fluid contained in a conventional cylindrical vessel kept on mild steel lugs (VL). The experiments were conducted on 10th November 2005 at Warangal (latitude 18°N, longitude 79.5°E and elevation 275 m above mean sea level).

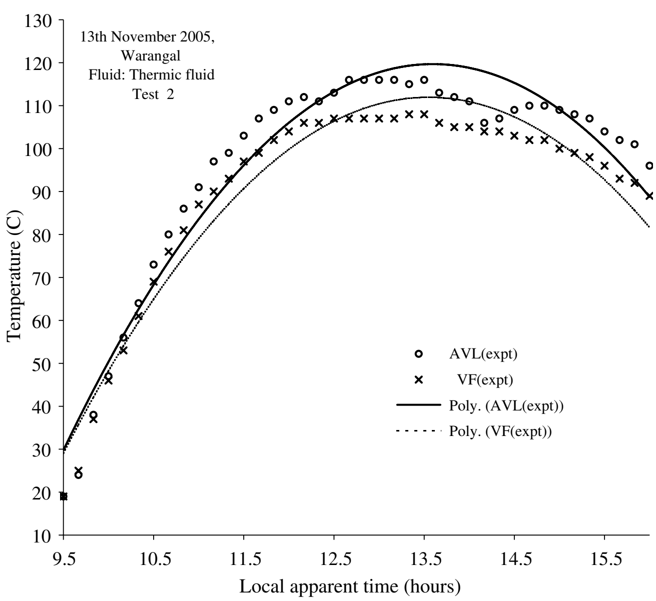

Fig. 9. Variation of temperature of thermic fluid in cylindrical vessel kept on floor (VF) compared to that of thermic fluid in vessel with central cylindrical cavity on mild steel lugs (AVL). The experiments were conducted on 13th November 2005 at Warangal (latitude 18°N, longitude 79.5°E and elevation 275 m above mean sea level).

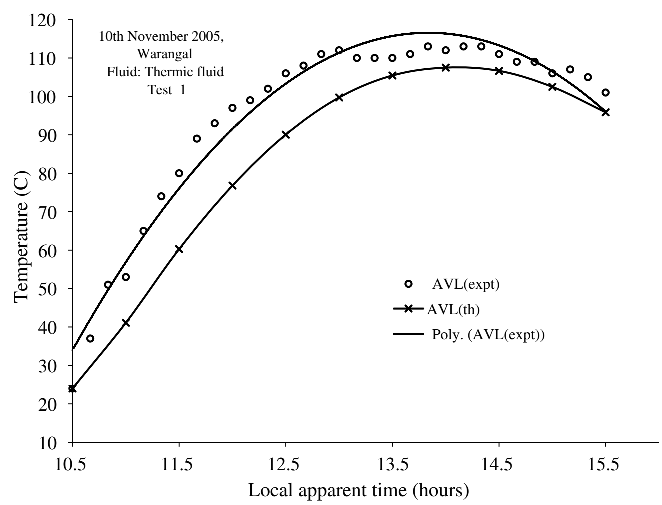

Fig. 11. The predicted and observed values of temperature of the thermic fluid contained in central cylindrical cavity vessel kept on mild steel lugs (AVL). The experiments were conducted on 10th November 2005 at Warangal (latitude 18°N, longitude 79.5°E and elevation 275 m above mean sea level).

of the observed and predicted values of the temperature with time of the thermic fluid in a vessel with the central cylindrical cavity on lugs. A second degree polynomial fit of the observed data is also shown in the same figure. The model is predicting lower values of temperature compared to the observed values, but the temperature difference is gradually decreasing as the day progresses and converges around 15.5 h. It is also seen that there is a close agreement between the predicted and experimental values during the period between 13 and 15.5 h.

Fig. 12 illustrates the observed and predicted temperature time history of the thermic fluid in a conventional cylindrical vessel on the floor. A second degree polynomial fit of the experimental data is also presented in the above figure. The predicted values of temperature appear to be lower when compared to the observed values even in this case. The predicted and observed values are very close during the period between 12.5 and 15.5 h. Fig. 13 depicts the observed and predicted values of the temperature of the thermic fluid in a vessel with the central cylindrical cavity on lugs. A second degree polynomial fit of the experimental data is also shown in the above figure. The model is pre-

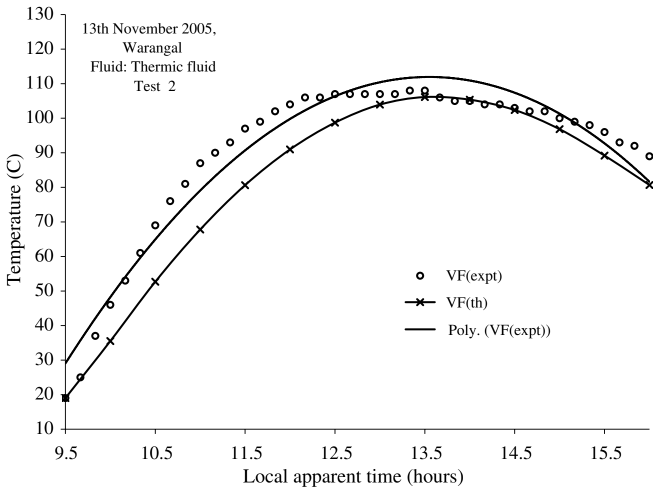

Fig. 12. The predicted and observed values of temperature of the thermic fluid contained in conventional cylindrical vessel kept on floor of the cooker (VF). The experiments were conducted on 13th November 2005 at Warangal (latitude 18°N, longitude 79.5°E and elevation 275 m above mean sea level).

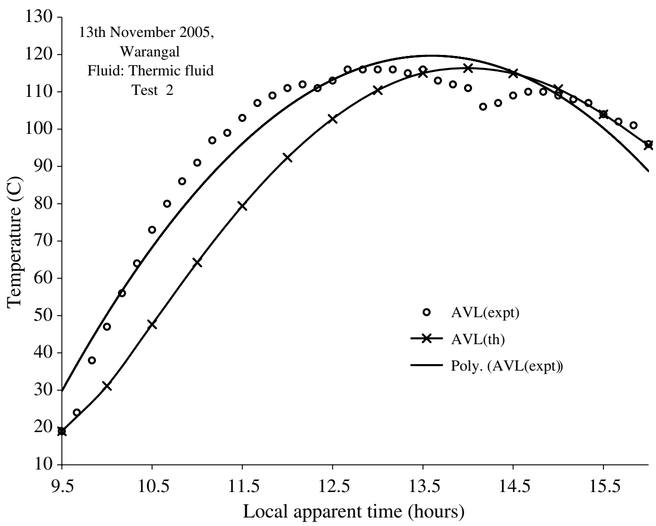

Fig. 13. The predicted and observed values of temperature of the thermic fluid contained in central cylindrical cavity vessel kept on mild steel lugs (AVL). The experiments were conducted on 13th November 2005 at Warangal (latitude 18°N, longitude 79.5°E and elevation 275 m above mean sea level).

dicting lower values of temperature up to 12.5 h, and thereafter, there is very close agreement between the experimental and predicted values till 15.5 h.

It is observed from the experiments (see Figs. 8 and 9) that the vessel with the central cylindrical cavity performed better than the conventional cylindrical vessel on the floor or on lugs. The average improvement of the performance of the central cylindrical cavity vessel is found to be 5.9% and 2.4% more than that of the conventional cylindrical vessel on the floor and on lugs, respectively. On the whole, the model is predicting lower values of temperature compared to the observed values, but the temperature difference is gradually decreasing as the day progresses and converges around 15.5 h. It is seen that the predicted and observed values are very close during the period between 12.5 and 15.5 h. The cooking vessel with the cylindrical cavity provides more surface area and, hence, makes the heat transfer more effective. It is a clear indication that the food is cooked faster in a vessel with the cylindrical cavity on lugs than that in a conventional vessel on the floor or on lugs. The cooking in the cylindrical cavity vessel has to be a homogeneous one as the length of heat flow is less when compared to that of the conventional vessel.

7. Conclusions

A cylindrical vessel with a central cylindrical cavity on lugs performs better than the conventional cylindrical vessel. This has been observed through the results of modeling and experiments as well. Hence, the cylindrical vessel with a central cylindrical cavity is recommended for use in solar box type cookers.

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