INTERACTION BETWEEN TEMPERATURES, AIRFLOW AND CHIMNEY DESIGN IN INDIRECT FREE CONVECTIVE SOLAR DRYERS

Michael W Bassey
International Development Research Centre
B.P. 11007 CD Annexe, Dakar, Senegal

ABSTRACT

This paper presents the results of experiments using two indirect free convective solar dryers under no-load and loaded conditions using rice, under typical conditions existing in Sierra Leone. One of the dryers has a single passage in the air heater and the other a double passage air heater. Five different chimney configurations were used. The performance of the two dryers was compared in relation to mean daily chamber and chimney temperatures and mean daily solar radiation intensities. A short chimney (about 50cm) painted black and covered with transparent material was the most effective configuration. A single air passage heater appears to be more appropriate for use with free convective solar dryers.

INTRODUCTION

The use of solar dryers in rural areas of Africa has been severely restricted because of the low air flow rates existing in natural convection dryers. Owing to the low income of farmers and the absence of electricity, dryers for rural applications generally do not have a mechanical means, such as a fan, to circulate warm air through the crops.

Efforts to design a solar crop dryer which circulates air effectively through only free convection have proved disappointing. However, this can be achieved by systematic investigation of the operation of dryers under real life or simulated conditions. Although dryer designs have been discussed extensively (Brace Research Institute 1975; Exell 1980), there is apparently no published work which has studied the interaction between dryer design, ambient conditions and airflow.

Bassey (1982 a) has described the effect of various chimney designs on the temperatures obtained in an indirect solar dryer using an air heater with two air inlet channels. The study showed that it may not under all ambient conditions be useful to have tall chimneys on free-convective dryers. Furthermore, results indicated that the chimneys in these dryers should be designed so as to minimise heat losses from them.

This paper presents results of a study aimed at describing the complex response of indirect free-convective dryers to their environment. The performance of two dryer designs was assessed using five chimney configurations under various ambient conditions existing in Sierra Leone, under no-load and loaded conditions using rice.

EXPERIMENTAL APPARATUS

Solar dryer design

The general front and side views of the dryers are shown in Figures 1 and 2. They are identical except in the design of the air heater. Dryer 1 has a single air passage (4 cm high and 70 cm wide) between the absorber plate and the glass cover as shown in Figure 3. Dryer II (Figure 4) has two air passages (both 70 cm wide) separated by the absorber plate. The heights of the top and bottom passages are 4 and 2 cm respectively. The glass covers are approximately 90 cm by 90 cm in surface area and are attached to the solar collectors using wood putty.

The air heaters are connected to the drying chambers by means of a rectangular channel equal in cross sectional area to those of the air passages. Both dryers are mounted such that the air heaters are inclined facing south at an angle of about 20 degrees to the horizontal.

Chimney configurations

Five detachable chimneys of different configurations were used. All were made of 0.16 cm galvanised iron sheeting and each had an internal diameter of 15 cm. Their special features were:

(a) 38 cam high, unpainted;
(b) 38 cm high, painted black outside;
(c) 38 cm high, painted black outside, surrounded by transparent plastic;
(d) 180 cm high, painted black;
(e) 180 cm high, painted black outside, surrounded by transparent plastic.

The transparent cover acts as a solar collector. There is an air gap of 2 cm between the blackened outer wall and the plastic surround. Care was taken during construction to ensure that the plastic did not touch the chimney walls during operation.

Instrumentation

Temperatures were measured at several positions on the dryers, as shown in Figures 5 and 6, using copper constantan thermocouples connected to a ten-point thermo electric temperature indicator or a portable "Digimite" indicator, both accurate to 0.5°C.

Total solar radiation on a horizontal surface was measured using an Epply precision spectral pyranometer connected to an electronic integrator and printer. The output in units of Wh/m2 was recorded at 10 minute intervals. Wind speeds were monitored during the experiments using a hand held cup anenometer.

METHODS

Tests under no-load

The dryers were operated using different chimney configurations for the 8 hour period 0800-1600 hours. The temperatures at the locations shown in Figures 5 and 6, total solar radiation on a horizontal surface, wind conditions and other ambient conditions were measured at regular intervals. All experiments were repeated over several days, over a period of three years.

Tests under load using rice

Two sets of experiments were carried out with the dryers under load. In the first tests performance was compared when loaded with a rice bed 2.5, 5.0, 7.5 and 10 cm high. The rice was supported on a single tray in each dryer, situated above the inlet into the drying chamber. During these tests, a 38 cm, unpainted, chimney was used.

In further tests with similar bed depths as above, chimneys 38 and 180 cm high and painted black and covered with a transparent plastic cover were used in dryers I and II respectively.

The drying period for each bed of rice lasted several days to reduce the moisture content to the required value.

RESULTS AND DISCUSSION

Temperatures in dryers under no-load

Plate temperatures were the highest. These ranged from 80 to 100°C, depending on the solar radiation in dryer I. In dryer II, the temperatures at the top of the plate were generally lower than those of dryer I. There was a 40°C temperature difference between the two sides of the absorber plate for dryer II.

Temperatures in the drying chambers were less than 50% of the plate temperatures as a result of the low flow-rates through the air heaters.

Influence of solar radiation under no-load

During all experiments, total solar radiation was measured and recorded every 10 minutes from which solar radiation intensities were estimated. Mean values of intensity of solar radiation for a whole day were estimated by dividing the total energy for that day by the period of the test.

Figures 7 and 8 show the effect of mean intensity of radiation, on chamber temperature for various chimney configurations.

Chamber temperatures are generally higher for higher availability of solar radiation. However the chamber temperatures for lower mean radiation intensities are at times very close to or greater than temperatures for higher intensities (Figure 8c). This behaviour can be related to the variation of solar radiation during the experiments. Under cloudy conditions the chamber temperatures could be significantly lower.

In all cases temperature in the chamber was between 30 and 50°C. This indicates the potential usefulness of indirect free-convective solar dryers.

The variations of daily mean chamber temperature with mean solar radiation intensity for all the chimney configurations studied are shown in Figure 9. The scatter in the data results from the intermittency of the available solar energy due to cloud cover. It is possible to have the same mean solar intensity on two days although the mean temperatures for those days may be different.

Effect of type of chimney used under no-load

Chimney configuration affects the mean chamber temperature under no-load. In dryer I chamber temperature increased with a black chimney and increased further with a plastic cover. Increasing the height of the chimney decreases the temperature in the chamber. In dryer II chamber temperature decreased with a 38 cm chimney painted black and further decreased with the transparent cover in place. Increasing the height of the chimney tends to increase the chamber temperatures.

These results can be explained by the flows through the dryers as a result of the interaction of the chimney design, the air heater and the surroundings. In dryer I the chamber temperature is obtained as a result of ambient air being heated as it passes through the single channel heater. If the chimney is painted black, it is now heated by solar radiation causing a slightly higher flow rate through the air heater. As a result the chamber temperature is increased. If the blackened chimney is covered with a transparent cover, the heat losses from the chimney are minimised, resulting in higher temperatures inside it, this in turn causes higher buoyancy forces which increases the air flow. Increasing the height of the chimney tends to increase heat losses from it which in turn decreases the flow rates: the temperatures in the drying chambers are thus lowered.

In dryer II the effects of chimney configuration is reversed. This is a result of the increased flow rate causing a greater influx of cooler air introduced through the bottom channel.

Reasonable operating temperatures can be obtained in indirect free convective dryers. However, air flow rates can be very inadequate as a result of chimney design. Many solar dryers have tall and at times black chimneys which may in fact decrease airflow rates depending on the prevalent ambient conditions such as the incidence and duration of clouds, wind and fluctuations of ambient temperatures. For conditions existing in Sierra Leone, detailed examination of data has consistently supported this argument.

This problem of the adverse effect of chimney design and the above explanations are further reinforced by considering the relative magnitudes of chimney and chamber temperatures. Although temperatures in the chimney are usually higher than those in the drying chamber, under low solar radiation conditions this is not so (Figure 10). In dryer I with 38 cm unpainted chimney temperatures are generally lower and in dryer II with a 180 cm black chimney significantly lower during the whole day. Days for which the above type of results are typical had relatively low levels of solar radiation, frequent and prolonged cloud cover, and either low ambient temperatures (depending on the season) or windy conditions.

Temperatures in chimney and chamber under load

Rice at initial moisture contents ranging from 25% to 45% (dry basis), depending on the degree of soaking, was used during the on-load tests. Based on earlier discussions, the relative magnitudes of temperatures in the chimney and drying chamber give an indication of airflow through the dryer. Figure 11 shows chimney and chamber temperatures for two heights of the rice bed for dryer I. In both cases the solar radiation conditions were similar. With a rice bed 2.5 cm high, the chamber temperatures (below the rice bed) are higher than the chimney temperatures throughout most of the day. Early in the day, the chimney temperatures are higher. Results for the 7.5 cm rice bed are similar but the temperatures are relatively lower.

These data are consistent with the preceding discussions. Increase in the height of the rice bed should reduce the flow and for the single channel air heater this implies a drop in chamber temperature.

For prototype II (Figure 12) a reduction of airflow due to the deeper rice bed produces a higher temperature in the chamber (underneath the bed) than in the chimney. This is expected from results under no-load conditions and further emphasises the potential flow problems in free convective dryers. It is possible that these lower chimney temperatures, caused by the air being cooled by water from the crop, can substantially lower the flow rate. Adverse ambient conditions earlier discussed and poor chimney design can make such dryers very inefficient.

Under load, Figure 13 shows that for 5 and 10 cm deep rice beds, dryer I gives lower cabinet temperatures than dryer II although the former has higher plate temperatures.

Overall significance of results

The preceding discussion indicates that the flows through indirect free convective dryers are governed by many complex parameters. Some of these are: the chimney design, the air heater design, the ambient temperature, cloud cover, available solar radiation and wind conditions.

Results suggest that in the design of this type of dryer the single channel air heater may be adequate considering its relative performance to the double channel heater. The use of tall black or unpainted chimneys is unsuitable under atmospheric conditions where cloud cover, low solar radiation intensities and wind may exist. Under these conditions a 50 cm chimney painted black and covered with transparent plastic is recommended. However under clear sunny conditions, tall chimneys may prove to be more advantageous. Thus the overall design of free convective dryers are location specific.

Another important implication of the results is that during drying, the temperature in the dryer above the crops is substantially lower than that underneath. Thus in the design of these dryers there should be a revision of the usual assumption of constant densities in the dryer to take into account density changes throughout its height. (This has been treated elsewhere, Bassey (1982 b.) In order to do this, results such as those obtained in this study can be very useful.

In addition, experience gained during the course of the study suggests that an experimental study aimed at assessing the effects of all the relevant parameters is very tedious. Specific aspects need to be scrutinised in future experimental activities. In order to understand the response of the dryers to various conditions a next step should be the mathematical modelling of free convective dryers using realistic inputs such as those reported in this paper. Such a strategy could rapidly identify areas for further experimentation leading to better dryer designs.

CONCLUSIONS

The following main conclusions can be drawn from this paper:

(a) The interaction of various parameters makes the study of indirect free convective dryers very complex. It is however possible to quantify their overall performance by relating mean daily temperatures in the drying chamber to mean daily intensities of radiation.

(b) In general, the type of chimney used affects the flow of air through the dryer. For cloudy, low solar radiation conditions existing in many tropical areas, it is advisable to use short chimneys (about 50 cm high) painted black and with a transparent cover around it. Taller chimneys may suffer substantial heat loss.

(c) Air heaters with a single air passage are considered more appropriate for use on free convective solar dryers due to their simplicity in design and generally higher temperatures.

(d) Results presented can be used as a basis for carrying out analytical modelling studies with a view to improving dryer performance.

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FIGURE 1: General front view of dryers

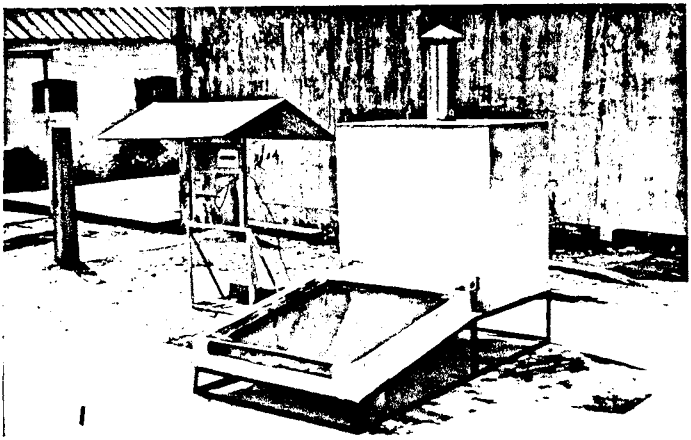

FIGURE 2: General side view of dryers

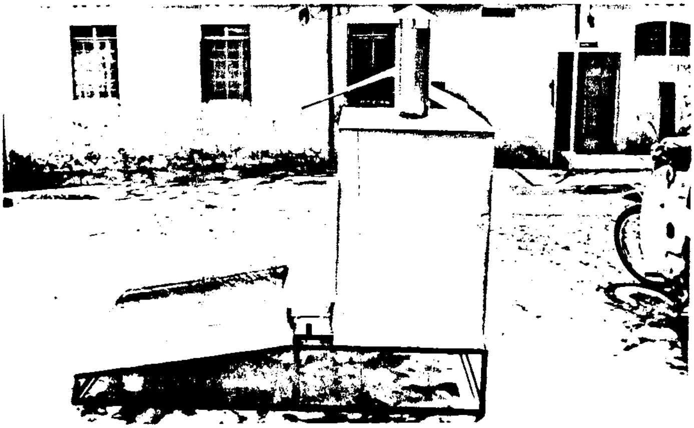

FIGURE 3: Cross-section of air heater for dryer I showing the single air passage

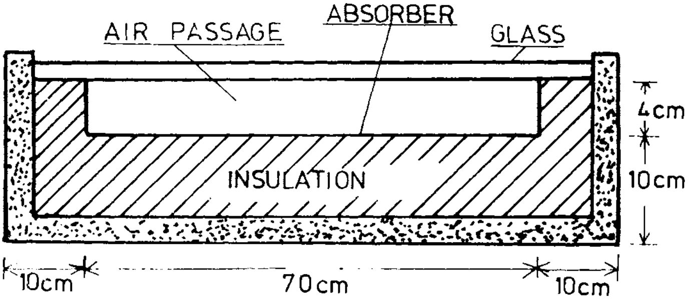

FIGURE 4: Cross-section of air heater for dryer II showing the double air passage

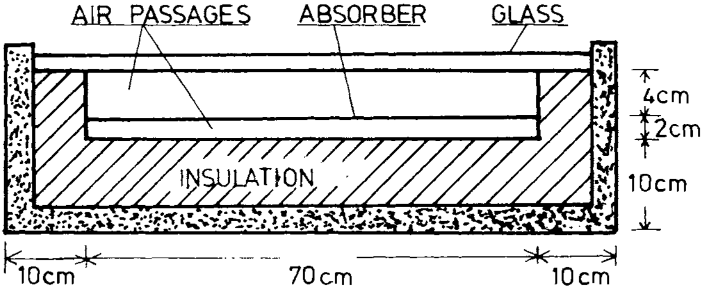

FIGURE 5: Diagram showing location of thermocouples in dryer I.

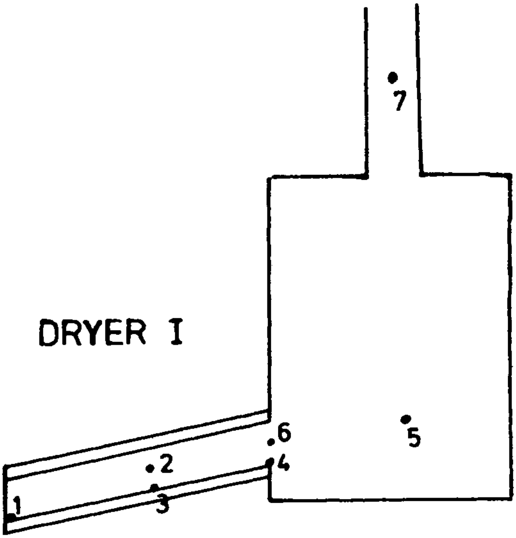

FIGURE 6: Diagram showing location of thermocouples in dryer II.

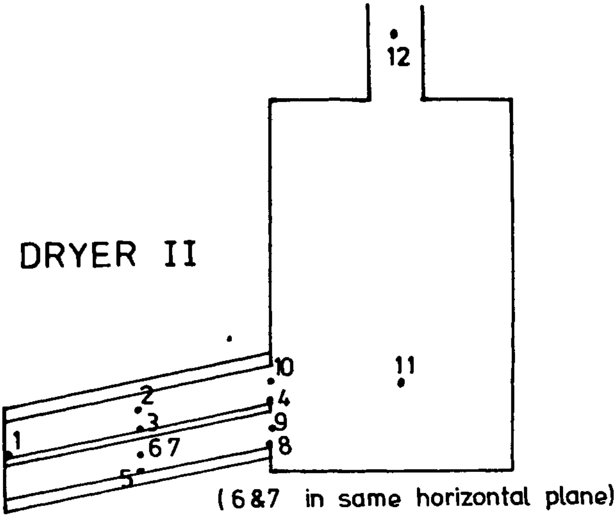

FIGURE 7: Effect of mean radiation intensity on chamber temperature for various chimney configurations, for dryer I.

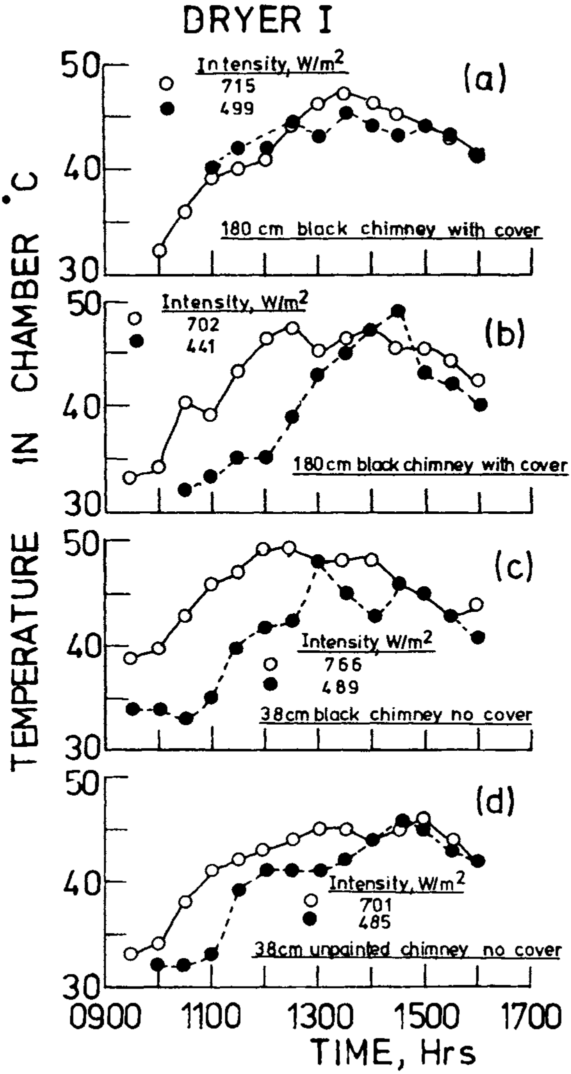

FIGURE 8: Effect of mean radiation intensity on chamber temperature for various chimney configurations, for dryer II.

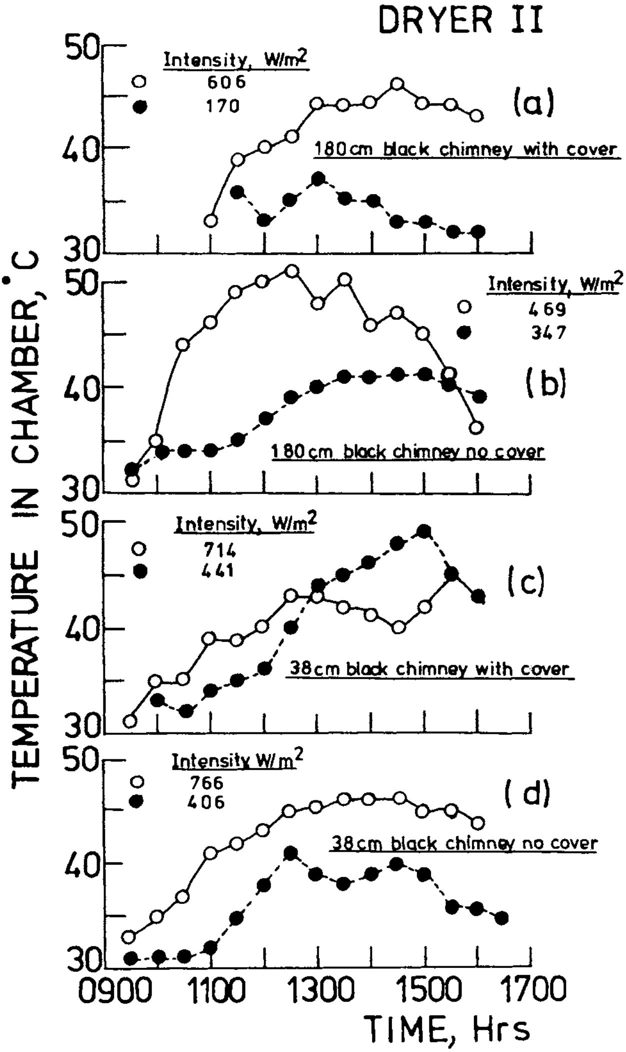

FIGURE 9: Effect of air heater design and mean solar radiation intensity on mean chamber temperatures under no load.

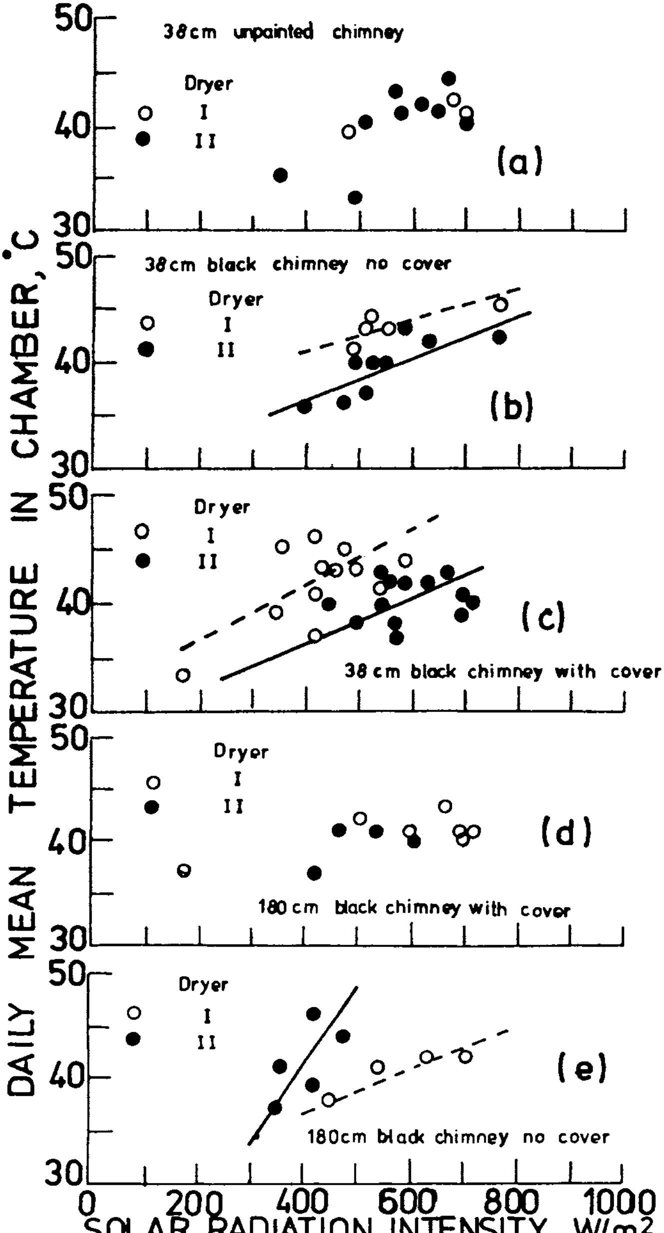

FIGURE 10: Comparison of temperatures in chimney and in drying chamber for dryers I and II, under no load conditions.

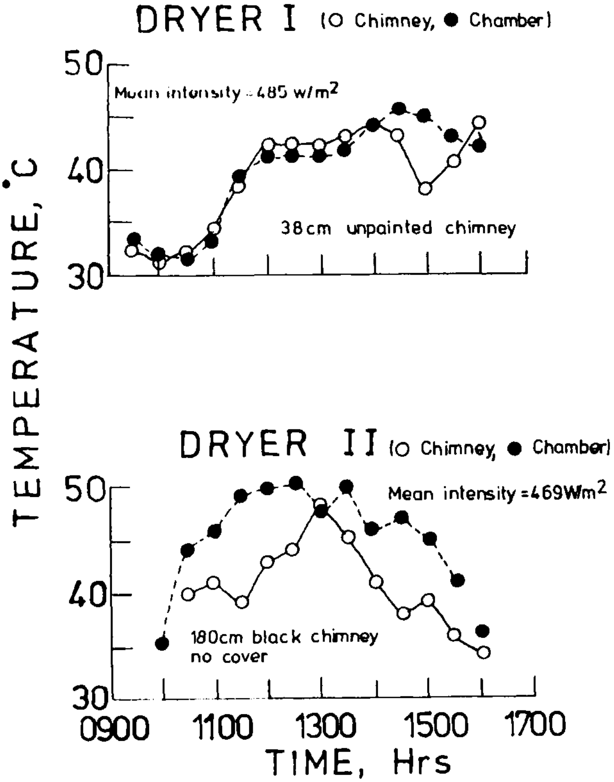

FIGURE 11: Temperatures in chimney and drying chamber during tests using rice, for dryer I.

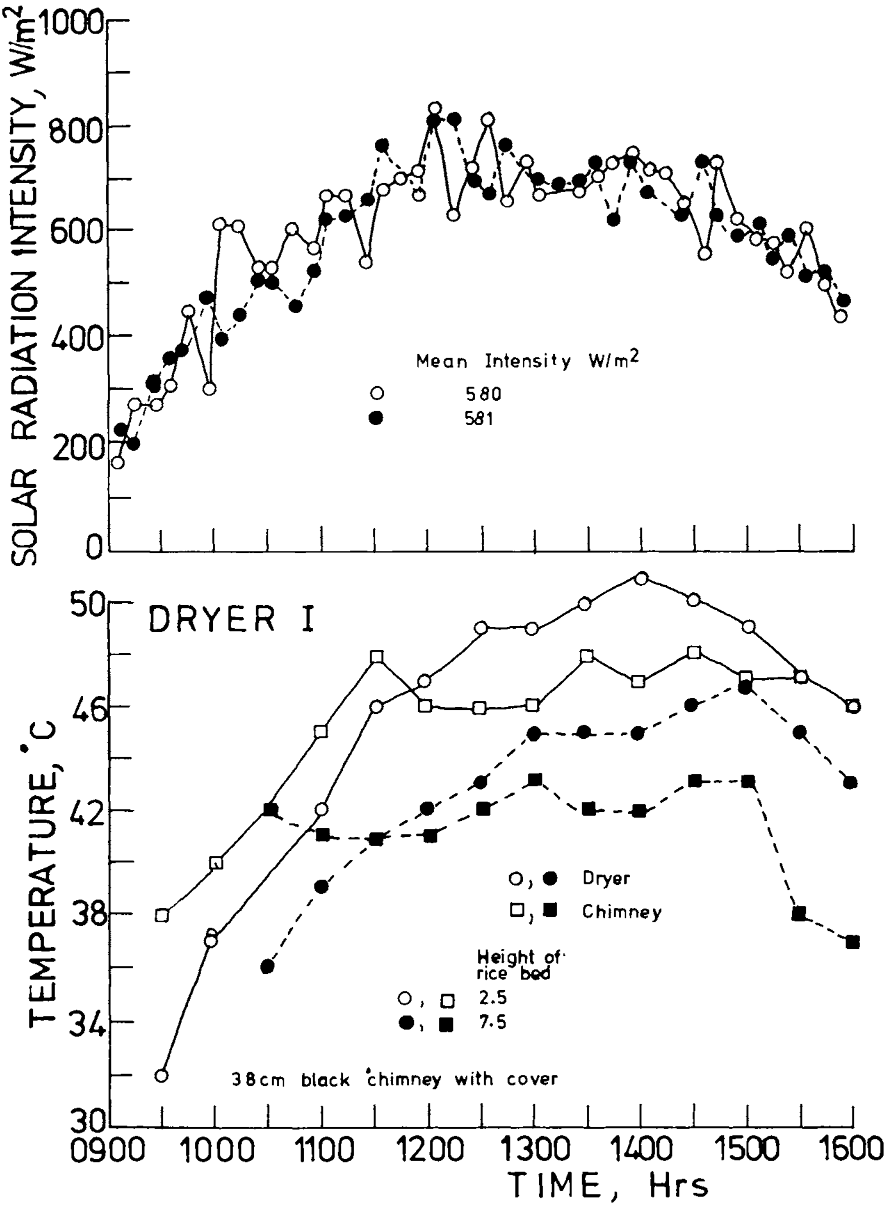

FIGURE 12: Temperatures in chimney and drying chamber during tests using rice for dryer II.

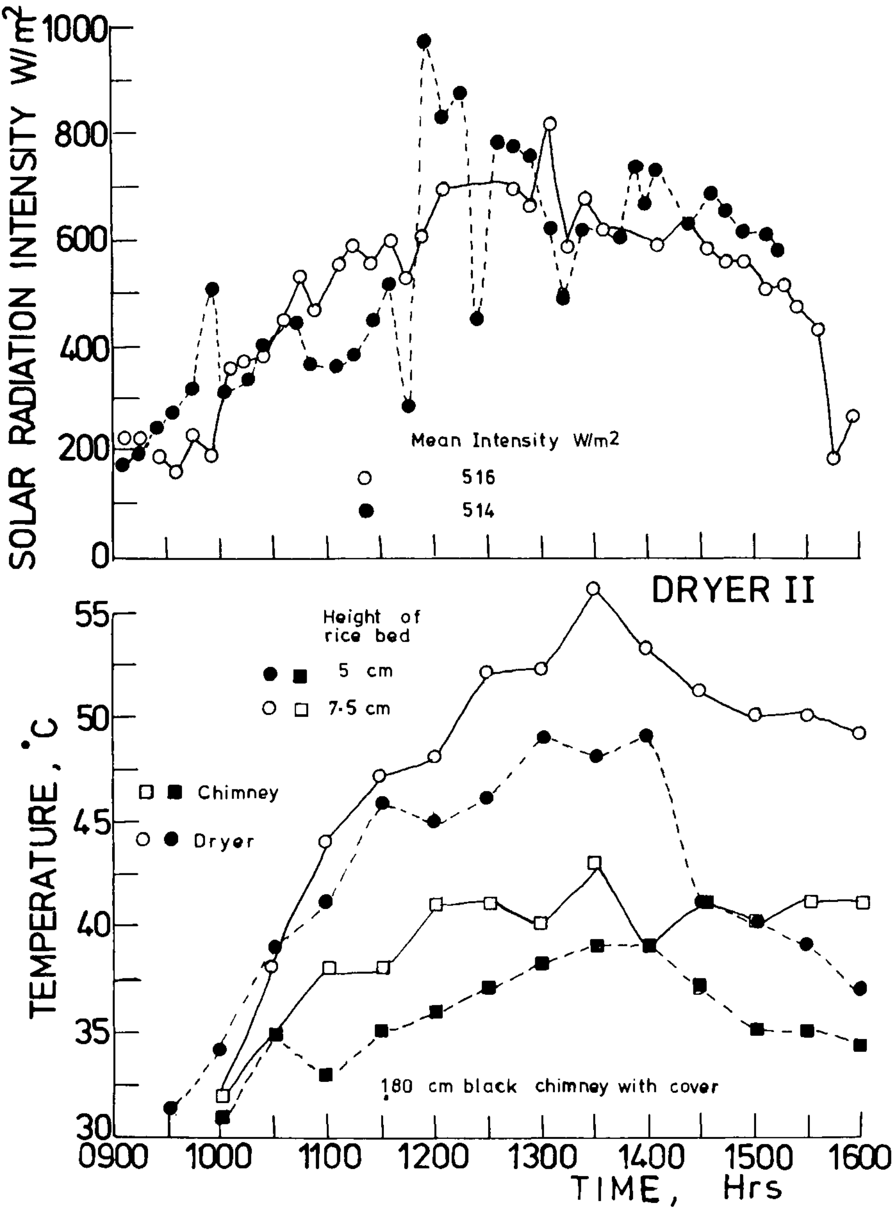

FIGURE 13: Effect of air heater design on chamber and absorber plate temperatures, under loaded conditions.