

IMPROVING MASS FLOW RATES IN FREE CONVECTIVE DRYERS

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ABSTRACT

This paper presents the first results of specific experiments, conducted to design a low-cost solar dryer for small (less than 500 kgs) to medium (about 1000 kgs) scale rice farming operations. Data characterising weather conditions, and the operation and performance of the dryer configurations investigated, under no-load and load conditions are presented. Mass flow rates of drying air can be improved by: i. adequate sizing of chimney diameter and cabinet insulation; ii. proper design of the heated airflow path leading to a better output (dried grains per unit time) per unit of glazing area; and iii. replacing purchased imported elements of the dryer with comparatively inexpensive but superior locally available materials.

INTRODUCTION

The spiralling cost of imported fuel and materials, the development and use of such dryers has become very unattractive. This paper reports the development of a solar crop dryer which is both free of the disadvantages of the traditional sun drying method and conservative in use of energy and materials. As a result of investigations reported here, two prototypes were designed. The performance of these prototypes on a no-load and load bases are compared with controls.

EXPERIMENTAL APPARATUS

The solar crop dryer used for experimentation is shown schematically, in Figure 1. It consists of a solar collector, drying cabinet, and chimney. The air heater is constructed from galvanised steel sheet metal 0.16 cm thick, plywood, 1.2 cm thick and glazing 0.3 cm thick. The sheet metal, painted black, acts as the absorber plate. It is enclosed in a wooden frame heavily insulated with glasswool of 10 cm thickness. The air gap between the absorber plate and glass cover is 4 cm.

Air enters the collector, which is inclined at 20° to the horizontal, through the inlet at the lower end. Heated air from the collector flows into the drying cabinet through a heavily lagged throat.

The drying cabinet, made of plywood, has an area of 90 x 90 cm² and height of 70 cm. Up to three wooden racks inside it can carry sliding trays with wire mesh bases for loading the crops. All the cabinet panels are insulated with 7.5 cm thick bags filled with dry sawdust. There is a chimney of adjustable height and diameter.

Figure 1 shows the location of the copper-constantan thermocouples inside the dryer system. These are connected to a data acquisition system (deploying a temperature indicator, model 31671 Thermo electric) to monitor the temperatures. Temperature readings are correct to $\pm 0.5^{\circ}\text{C}$.

The flow rate (m³/s) through the dryer is monitored using an access port (Figure 1) located midway along the length of the chimney. This post is closed between

readings with a cork. The probe of the anemometer, TA 400 by Air Flow, measures the flowrate in a cross-section coplanar with the thermocouple location T⁷.

The solar radiation on the plane of the collector is measured using a solarimeter (solar 118, Enercorp). Humidity is measured by dry and wet bulb readings of a sling psychrometer. A wind anemometer measured wind speeds in the vicinity of the dryers under test.

EXPERIMENTAL PROCEDURES

Experiment I

Two similar dryers prototypes PI and PII were subjected to the same weather conditions to study the effect the changes in chimney diameter on the mass flow rate. PI with chimney diameter 15 cm was the control and PII, positioned in parallel to PI, was fitted with a different chimney diameter for each test.

Experiment II

Two dryers (PI and PII) identical except that PI was not insulated were subjected to the same insolation levels.

Experiment III

Two dryers PI and PII (Figure 2) were exposed to the same weather conditions for data acquisition. PI carried a tray of useable volume 87 cm x 56 cm x 12 cm mounted 22.5 cm from the cabinet floor. PII carried a similar tray of useable volume 77 cm x 55 cm x 12 cm having an air-flow slot of cross-sectional area 5 cm x 37 cm.

Experiment IV

On-load data measurements for two dryers PI and PII, each with a tray, were compared with two control, C1 and C2, air drying methods under the same insolation levels. The tray in PI and PII was loaded with rice to a height of 6 cm. Control, C1, was a rice bed on the ground contained by a wooden frame to an area and height equivalent to that of the bed in PI. Control, C2, had the same quantity of rice, as in C1, spread thinly on the ground as in the traditional method.

Freshly cut rice was weighed and equal quantities placed in the dryers, PI, PII, C1 and C2. Initial samples were then taken for moisture content tests. Temperatures were recorded and samples of rice were taken from the dryers during the drying period at regular intervals of 30 minutes. The samples used for the moisture content determination were taken after mixing the rice in the dryers.

Each sample of rice was weighed and then placed in an oven, maintained at 110°C, for 24 hours. The weight of the dried rice was recorded and the moisture content on a dry basis established.

During all the experiments the insolation (I in W/m², in the plane of the collector) the temperatures, and the air flow rate (m/s) at the measurement port 7 were recorded at 30 minute intervals. The wind speeds in the vicinity of the dryers were also monitored regularly.

RESULTS AND DISCUSSION

The effect of diameter of chimney on mass flow rates in dryers under no-load

The exhaust air flow rates (m/s) from the dryers were measured using the measurement port located at 7, Figure 1. These readings were transformed into corresponding mass flow rates under the following assumptions:

- a. The density of the air at 7 is a function of temperature and pressure at that position.
- b. Pressure at 7 is approximately equal to the ambient pressure, the length of ducting from the outlet of chimney to that position being very short.
- c. The outlet air is dry, thus the density of the air could be obtained from published data in the ASHRAE Handbook 1981.
- d. The equation of continuity applies.

Typical values for the mass flow rates obtained for various diameters compared against the diameter of 15 cm (Control) for different days (meteorological conditions) are shown in Figure 3. The general trend is that mass flow rate increases with increasing chimney diameter. This is consistent with the reasoning behind the glazing of chimneys to promote gains and inhibit losses. As the losses continue to rise with increasing diameter, the mass flow rate would tend to a peak value where the chimney losses match the gains. After this point no further gains in the mass flow rate should be observed. In the prototype understudy this was achieved with a 24 cm diameter chimney.

Effect of added insulation on dryer mass flow rates

The insulated dryer (PII) had a superior mass flow rate profile, compared to that of PI (Figure 4). Insulation promotes the temperature difference between the hot column (heated airflow within the dryer) and the cold air column outside thus increasing the mass flow rate. The only limitation to its application would be costs and the thermal protection it offers the heated air output from collector without exposing the dryer mass flow rate to the transients of thermal mass and ambient meteorological conditions. Stable dryer operation is a design objective.

Effect of internal geometry of flow path on dryer mass flow rate

The different internal geometry did not result in significantly different mass flow rates when not loaded with rice. When loaded there was a major difference in air mass flow rate depending on the internal flow path geometry. (Figure 5).

For the flow through bed design (PI) the drying air from collector is passed through the entire mass, across the surface of individual grains. For the flow-under-and-over bed design (PII) only the bottom and top layers of the rice bed are exposed to drying air. Moisture transfer from grain between these two layers would occur as a result of vapour migration between solid grains as opposed to vapour release from grains to heated air in the flow through bed configuration. So the mode of vapour transfer and flow path is different for PI and PII.

While more detailed tests are required to confirm the efficiency of the two designs, it is, however possible to make certain broad generalisations from the results, Figure 6. Starting from the initial moisture content of the freshly harvested rice the ranking of the dryers is CII, CI, PI and PII in that order. At no insolation, eg overnight, the rice absorbs moisture. The changes in moisture content are not smooth but there is an overall decrease in the level of this parameter with time, in agreement with work already reported by Bassey (1982).

Significance of wind measurements

Meaningful readings of wind speed could not be obtained as any prevailing wind regime was very changeable - wind gusts of between 1-3 m/s only lasted for a few second and were few and far apart. Its effect is expected, however, to be twofold:

- a. promote improve flow rates when dryer is substantially aligned in its direction;
- b. encourage heat losses from the dryer. It is noted that the results of this wind effect can be uncomplementary.

CONCLUSIONS

1. The analysis of performance of dryers is quite complex. An averaging technique relating the average values of insolation, heated air mass flow rate, temperature etc. is needed as a simple tool to analyse the interacting variables relating the dryer system to its load (drying rice). This would "iron out" the problem of induced irregularities due to thermal mass (insulation) and ambient meteorological conditions.
2. It is unrealistic to compare the traditional method of drying rice on a virtually unlimited area to other methods deploying a limited area. When drying area becomes a premium and alternatives (with superior thermal properties) to imported purchased materials are available the capital cost involved in dryer design and construction can be drastically reduced to match open air drying on a limited area. The result presented suggested this where it is difficult to separate PI, PII and CI in terms of performance.
3. Three evidently cheap ways of improving drying air mass flow rates in free convective dryers can be identified:
 - a. Optimising chimney diameter - the results of Experiment I.
 - b. Added insulation by switching over to cheaper locally available materials with better properties eg mudbricks, clay bricks and mortar for construction of drying cabinet.
 - c. Reducing the resistance to drying air flow by redesigning flow path.

RECOMMENDATION

Research must be directed towards better and firmer control of dryer performance (drying air mass flow rate and temperature). The use of simple shutters to control the air inflows and exhaust should be explored.

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Bassey M W (1982) Potential use and performance of indirect free convective solar crop dryers in Sierra Leone. Final Report, IDRC Research Project No. 3-8-78-0113, Department of Mechanical Engineering, University of Sierra Leone.

FIGURE 1: Diagram of dryer showing general features and location of measurements

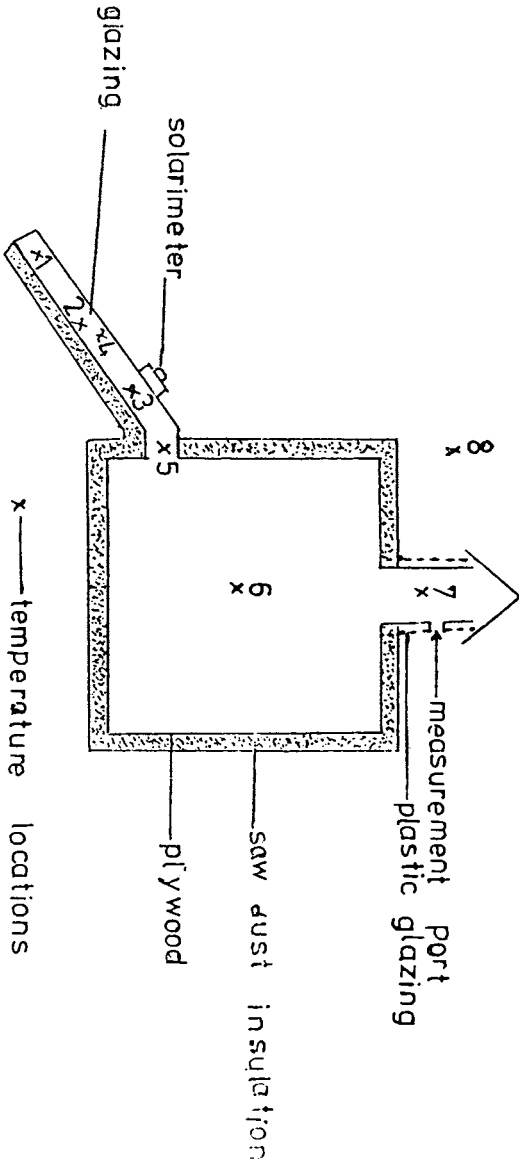


FIGURE 2: Diagram showing internal geometry of P I & P II under load

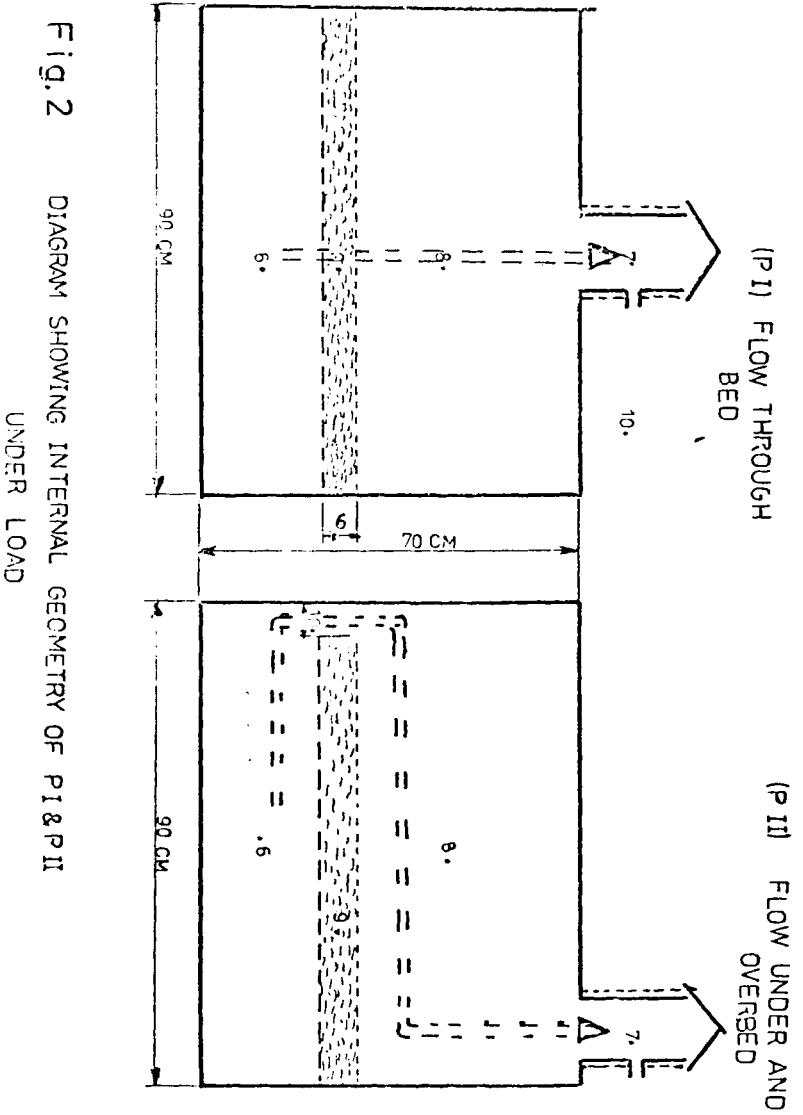


FIG. 2

DIAGRAM SHOWING INTERNAL GEOMETRY OF P I & P II UNDER LOAD

FIGURE 3: Effect of chimney diameter on mass flow rates through dryer under no-load

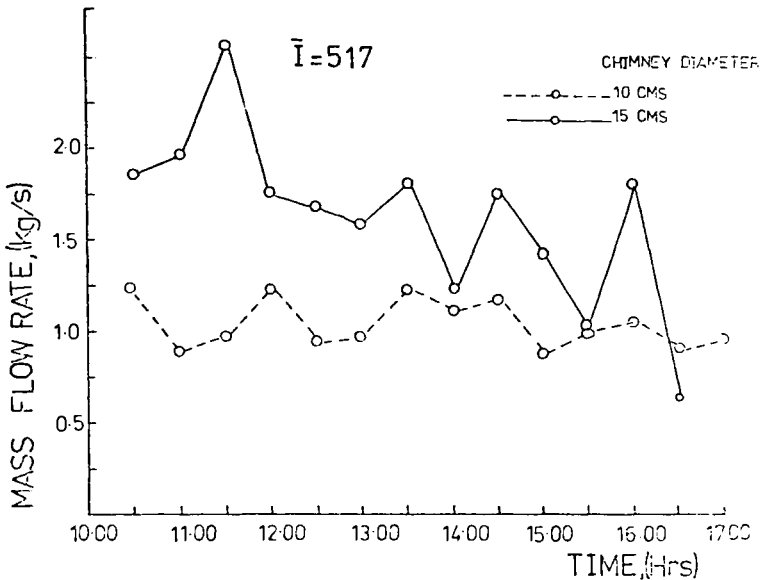
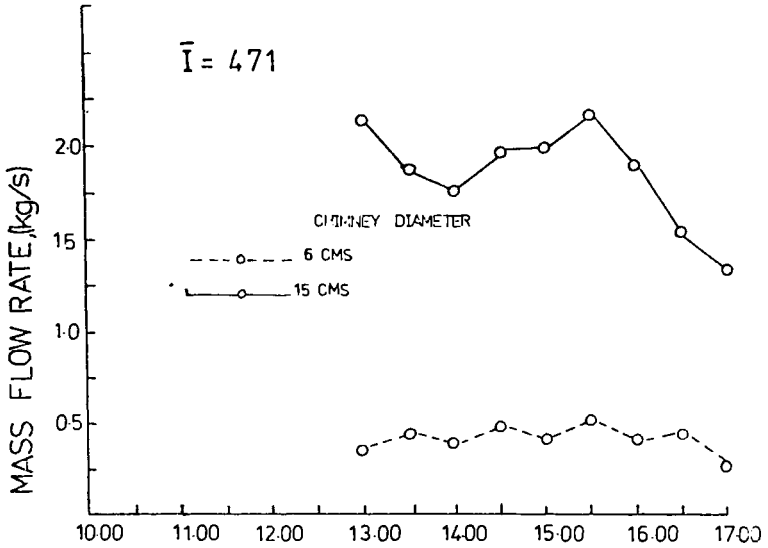


FIGURE 4: Effect of insulating dryer cabinet on mass flow rates for no-load condition

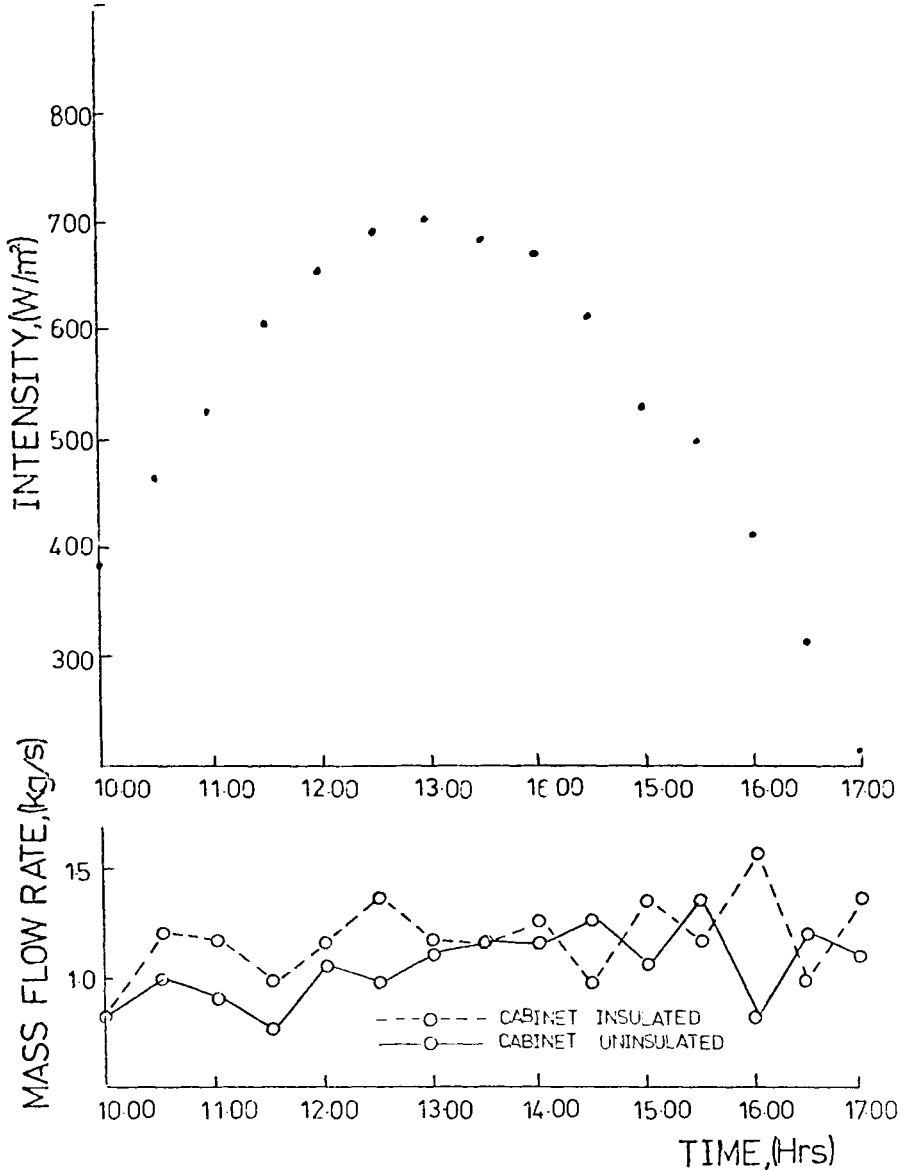


FIGURE 5: Comparison of mass flow rates for flow "through-bed" versus "flow-over-and-under bed" for loaded condition

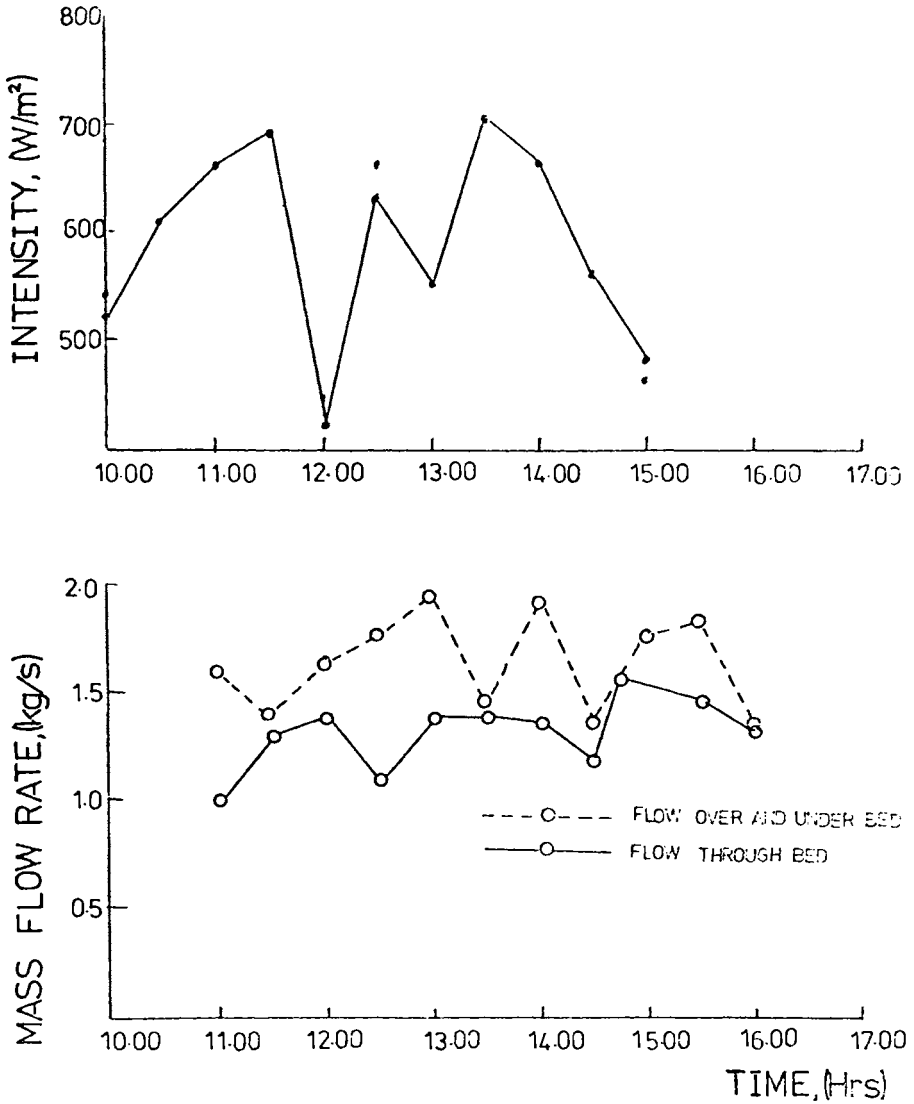


FIGURE 6: Drying curves for various conditions using rice

