DEVELOPMENT OF A MULTICROP SOLAR DRYER FOR SMALL HOLDERS

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ABSTRACT

This paper describes the development of a solar crop dryer which will meet most of the requirements of the small holder. Heat storage can also be incorporated if necessary. It is cheap and uses locally available materials. The dryer is designed to operate effectively throughout the year in changing climatic conditions and is suitable for drying a range of crops including unshelled maize, red chillis, rice, groundnuts, ginger, turmeric, onions, garlic and various fruits.

INTRODUCTION

The Government of Mauritius has set out production objectives for a number of crops in a policy of self-reliance (Table 1). All will need to be dried and stored. Some crops are only harvested at particular periods of the year, but the harvest times of all these crops is spread throughout the year (Table 1).

Large scale producers will normally use industrial drying processes. The 1200 small holders who will be called upon to contribute their share, will not be able to afford such processes. Most small holders farm only one fifth of a hectare and cultivate several crops. They are scattered widely accross the island, and it is uneconomical and impractical to send their produce to a central dryer. It is, however, feasible for small holders in a particular area to form cooperatives or associations.

Sun-drying is currently the only practical approach for small holders. But there are several drawbacks, including the inability to achieve the recommended maximum safe moisture content. For example, sun dried maize can only reach a minimum of 14% moisture and necessitates further artificial drying to 12% at the rate of MR 100 per tonne.

This paper therefore describes the development of a solar dryer suitable for the needs of small holders and which can be used to dry all these crops and utilised throughout the year in Mauritius.

DESIGN AND CONSTRUCTION OF AN EXPERIMENTAL PROTOTYPE DRYER

The design of the experimental prototype dryer was similar to the one developed by Exell (1980) for rice drying at the Asian Institute of Technology, Bangkok. However different materials were used. A sketch of the dryer is shown in Figure 1. The dryer was mounted on 200 mm concrete blocks, which in turn stood on a platform of concrete cement 50 mm thick. The platform and concrete blocks enclosed an insulating layer of air between the collector plate and ground.

The solar absorber was made of 22 gauge plain galvanised metal sheets coated with matt black painte. It had a collection area of 23 m^2. It was fixed and supported by a horizontal framework of mild steel bars. Sixteen clear window glass panes (1.2 m x 0.95 m x 4 mm) fitted to a mild steel structure inclined at an angle of approximately 20° from the horizontal formed the cover of the collector system. The joint between the window frame and glass panes was sealed with metal putty. The inlet vent (4.8 m x 0.1 m) was at the bottom of the collector.

The drying chamber housed four metal trays (1.2 m x 1.0 m x 0.3 m) with a bottom of fine galvanised wire mesh. The sides were made of a double layer of galvanised sheet metal and painted black. Two metal doors provided for the drying chamber were insulated with bitumen painted particle board. The chimney (0.2 m x 0.26 m and height 1 m) was made of sheet metal and painted black.

Initial drying tests were carried out by natural convection, but later the dryer incorporated a forced ventilating system provided by a centrifugal fan. The fan was powered by a 120 watt, 240V and 900 rpm motor capable of displacing 25 m^3 of air per minute. To obtain a uniform air flow over a solar collector two sheet metal baffles were installed inside a plenum of cross-sectional area, 0.025 m^2 (380 mm x 65 mm).

RESULTS AND DISCUSSIONS OF EXPERIMENTAL PROTOTYPE

Performance of solar collector

Design studies on various types of solar air heaters have been reported (Buelow, 1961; Close 1963; Whillier 1964; Bevil and Brandt 1968; and Niles et al. 1978). However, a simple method of calculating collector efficiency is to take the ratio of the net rate of useful heat energy collected per unit area to the amount of solar insolation:

$$\eta_c = \frac{Q_u}{AI}$$

where: η_c = collector efficiency; Q_u = useful heat collected, KJ hr^{-1}; A = area of collector absorber, m^2; and I = total insolation normal to the collector, KJ $hr^{-1}m^{-2}$.

By measuring the outlet collector temperature and ambient air inlet temperature, the useful heat output per unit area of collector is obtained from:

$$Q_u = GC_p\,(T_o - T_a)$$

where: G = mass flow rate of air per unit area of collector surface, kg hr^{-1} m^{-2}; C_p = specific heat of air, KJ kg^{-1} °C^{-1}; T_o = air temperature leaving collector °C; and T_a = ambient air temperature, °C.

Efficiency is therefore:

$$\eta_c = \frac{GC_p\,(T_o - T_a)}{I}$$

When empty the temperature rise of the drying chamber and absorber plate were respectively 35°C and 40°C, and the relative humidity was reduced by about 45% below that of ambient air. The average air velocity through the drying bed was 0.025 ms^{-1}. Calculated solar collector efficiency, using the above equation, showed that it varied from a minimum of 34% to a maximum of 40%.

Performance of dryer

Dryer operating by by natural convection

Several drying tests on batches of maize cobs and groundnuts weighing from 100 kg to 250 kg were carried out and the results showed a temperature rise of 30°C and a drying time averaging 6 days. The moisture content of both maize and groundnuts was reduced by 32% and 38% respectively to their required storage values of 12% and 9%.

Drying curves (A and B in Figure 2) show that after an initially high rate of drying, loss of moisture became progressively slower and then increased at the final stage of drying. A simple explanation of this drying pattern is that initially moisture at the surface of the grain was much easier to remove and as moisture from the interior of the grain moved to the surface the process became slower. During the final stage most of the moisture will have reached the surface where its removal was faster.

Drying rate is dependent upon both the rate of air flow over the grain and the temperature of the grain. Although high air temperatures were easily attained inside the drying chamber the air flow was relatively slow. This explains the rather long period needed to complete drying.

Dryer under forced ventilation

Drying tests carried on maize cobs indicated that under forced ventilation there was a temperature rise of 25°C and and the drying time was reduced at least 50%. Curve C if Figure 2 shows the drying pattern. For the first few hours the moisture content dropped by more than 7%, and this represented at least 50% of the moisture to be removed. For the next eight hours drying was partly affected by overcast periods and the moisture content was reduced by only 2%. In the final stage of drying seven hours were required to achieve the 12% moisture content.

The maize trials were carried out in summer. Trials on rice were also conducted in winter. The highest temperature rise recorded inside the dryer chamber was 20°C. Curve D in Figure 2 is the drying pattern for one of these trials. By the third day the moisture content had dropped from 30% to below the 14% required level.

System efficiency

The system efficiency can be calculated using the following formula

$$\eta_d \qquad \frac{WL}{I_s A}$$

where W = weight of moisture evaporated, kg; L = latent heat evaporation of water, KJ kg^{-1}; I_s = insolation on collector surface, KJ hr^{-1} m^{-2}; and A = Collector area, m^2.

The results obtained from the drying experiments showed that with the dryer operating on natural convection the system efficiency ranged from 7% to 14%. When forced convection was employed a higher value varying from 11% to 18% was obtained.

Economics

The construction cost of the prototype dryer was about MR 15,500 (valued at 1981) with maintenance costs of MR 200 per year. Maintenance includes cleaning of the glass panes, the interior of the drying chamber and the solar absorber to ensure maximum operating efficiency and repainting every four years.

Table 2 gives the annual operating cost calculated on the dryer operating for six months. It is assumed that the dryer would last for 15 years. A 10% charge for interest on capital investment is allowed to cover financing costs. The electrical energy required to power the fan is evaluated as 1 Kwh per day of operation at the rate of MR 1.40 per Kwh.

The cost of drying maize in an industrial fuel powered dryer is MR 50 per tonne for every per cent moisture content above 12%. If the average moisture content of crops sent for drying is 22%, then the charge is MR 500 per tonne. Table 3 is the cost benefit analysis for maize drying for different lengths of time of operation annually when an average of 4 days is taken to be the drying time for 400 kg of maize.

The investment cost could be covered from just over a year to about 4½ years depending on the period of utilisation of the dryer. In view of the relatively high investment cost, small holders may find it advantageous to join themselves in cooperatives or associations to benefit from such a dryer.

DEVELOPMENT OF AN IMPROVED PROTOTYPE

Slope of collector

It can be seen from Table 4 that the slope of the collector has to be varied constantly from -3° to 43° through the year in order to get the maximum insolation. For four summer months the optimum angle is around 1° and for the four winter months about 39°. Only 2 months, namely March and September, require the average angle of 20°.

Since a multicrop dryer will be used throughout the year and a fixed collector is always preferable, the best angle has to be selected. It must be noted that any inclination put on the collector will normally result in a taller and therefore less practical and economical upward flow dryer, unless some excavation is made and/or a sloping site is available. Also the taller the dryer, the more vulnerable it is to cyclones.

If the average angle of 20° is used on a 5 m long collector, the drying chamber will have to be raised 1.7 m above ground. And to be practical this dryer will need extra accessories like a platform and staircases. This would increase further the already higher cost of a taller dryer. At this angle there will be a decrease of 6% in insolation in both summer and winter ie during 8 months of the year. Any advantages associated with such an angle is therefore not apparent.

In winter the insolation is lowest, and in addition, the air temperature, humidity and cloud cover are at their least favourable. It is therefore most important to use the optimum slope of 39° during this period, especially if May through August are the major drying months. In this case, there will be a loss from optimum of 23% in the summer months, although the loss can be offset by the higher summer insolation and less severe climatic conditions. Such a collector slope will result in an extremely tall dryer with all its disadvantages. However a more practical and less expensive downward flow dryer (Figure 3) can be used.

A horizontal collector, on the other hand, offers the lowest cost and is most practical. Although on average it bears a reduction of 6% insolation throughout the year and 23% in winter, no reduction at all will occur in the four summer months. In any event, the decrease in insolation can be made up by increasing relatively the surface area of the horizontal collector. An enlarged collector to meet the requirements of the winter months will of course result in an over-design for all the other months. It must also be added that the glass cover, which is often parallel to the collector surface, will also cause some losses by reflection in winter. Therefore enlargement of the horizontal collector must also be considered to make up for the loss.

Thus, for a multicrop dryer to be used throughout the year, unless the site exceptionally lends itself to a sloping collector, an enlarged horizontal one should be preferred.

Optimisation of throughput

Most crops take several days to dry to the appropriate moisture content, even in the best conditions. This means that a dryer will normally remain loaded with the same product for a number of days until drying is over. This will make the drying process costly for a number of reasons.

Firstly, each day the crop harvested has to be loaded in a separate dryer or set of dryers; thus several units will be needed for one crop, as the number of units needed will be equal to the number of days of drying. Further, if the drying is shortened by favourable conditions, no advantage can be taken of it. But if conditions become unfavourable, the harvest schedule will be upset. Secondly, the dryer or set of dryers must be enough to hold the daily harvest. Anything bigger or smaller will not be suitable. Also it implies that once decided, the volume harvested itself cannot be increased.

The problem can be overcome if the normal pick-up efficiency of 30% can be improved to as close as possible to 100%. Such a high performance can be achieved with a tier of trays. The air leaving a normal dryer is still fairly dry and can be utilised again. This principle was used to develop the new dryer.

Each set of one or more trays in the tier should have a capacity to contain the whole daily harvest, and therefore the number of sets required will equal the number of drying days. Thus at any given time all the trays will be fully loaded. Where the capacity of the set can only contain a fraction of the daily harvest, the number of dryers must be increased accordingly.

The capacity of the set of trays in fact will be limited by the outgoing relative humidity of air which should not exceed the water activity. For some products, a relative humidity of almost 100% leaving the drying chamber can be tolerated. Once the moisture absorption isotherm is known, a simple laboratory experiment using the inlet air conditions can be performed to determine the optimum total bed thickness and therefore the individual tray thickness and its capacity.

Initially the fresh product is loaded in the last set of trays at the outlet of the drying chamber, and everyday following it will be moved one step forward to the inlet until the required number of drying days has been reached. Then the set of trays containing the adequately dried product is removed from the bottom of the tier (for an upward flow dryer), unloaded, refilled with fresh product and put back on the top and the whole cycle repeated. In these conditions, the daily throughput of the dryer or set of dryers will meet the demand of the daily harvest.

The number of trays in the tier can be increased or decreased depending on the drying conditions and the expected harvest.

Heat storage

As the ambient temperature falls at night, the relative humidity of the air increases. When it has reached the water activity level, absorption of moisture in the product will occur. However, if the dryer is kept airtight at night, only minimal absorption of moisture from the enclosed air will occur.

More important, microbial activity will start above certain water activities and thus spoil the product. For example above a water activity of 0.80 molds will start to grow. It may therefore be essential for certain products when drying takes more than a day, to maintain a relative humidity of the air below 80% by preventing the temperature to fall too much. This can be achieved by maintaining the dryer airtight after sunset and switching on a supplementary artificial heater. The heater, presenting a number of drawbacks, can be avoided altogether if a heat storage system can be incorporated in the dryer.

A collector surface , having a high thermal inertia, serves as a heat store but unfortunately only during short cloudy period. To be useful the heat must be stored below the drying chamber and in sufficient quantities to maintain the warmth of enclosed air throughout the night.

An assembly of blackened concrete units (Figure 4) will serve the purpose: concrete has a high thermal inertia. The units must be streamlined to minimise the rate of heat absorption and to decrease the pressure drop and therefore the need to use a more powerful fan.

The downward flow dryer (Figure 3) can also be adapted to provide a heat storage system. Since the storage material is under and therefore after the drying chamber, it is the waste heat which is utilised. Therefore, as opposed to the upward flow dryer, it is a high rate of heat absorption which is desired. For this purpose, properly arranged blackened basalt boulders offering minimal pressure drop can be used. The results obtained with a prototype are shown in Figure 5.

A suitable multicrop dryer

Figure 6 shows diagrammatically the features of a multiple crop dryer suitable for small holders. The glass covers are slightly inclined (1% gradient) to enable rainwater outside as well as condensation water inside to run off. Otherwise a glass cover parallel to the collector will result in a better heat transfer coefficient. The same steel framework and galvanised iron sheets can be used but the investment cost will be lower than that of the experimental prototype. Other cheaper substitute materials can be used to cut down the cost still more.

When crops like unshelled maize are to be dried only the two inclined trays are used. The cover of the drying chamber is first opened then the upper tray is removed and the bottom tray filled. Then the upper tray is replaced and filled in its turn. When drying is over the doors can be opened and the crops will immediately fall into the awaiting baskets. In certain cases, only the bottom tray need be used.

If crops like chillis or sliced fruit are to be dried, only the horizontal trays are used. In this case loading is done by opening doors of the drying chamber and sliding in the trays. These should fit exactly one on top of the other to ensure that air goes through the beds only.

For crops which can tolerate direct drying additional drying can be obtained from the glass cover of the drying chamber. Otherwise screening out with a piece of cardboard will be necessary.

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TABLE 1: Production objectives in the self-reliance policy and harvest times for key crops

Crop	Production objectives 1987 (Tonnes)								Harvest times				
				Summer					Winter				
		Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Maize	15,000	X	X	X					X	X	X		
Groundnuts	2500			X	X	X							
Garlic	450								X	X	X	X	
Turmeric	230	X	X	X	X	X	X	X	X	X	X	X	X
Ginger	2000			X	X	X	X	X	X	X	X	X	X
Onions	4300									X	X	X	X
Beans & Peas	1600									X	X	X	X
Rice	6000						X	X	X				
Coffee	80												
Chillies	225	X	X	X	X	X	X	X	X	X	X	X	X

(Source: White Paper on Agricultural Diversification, Government of Mauritius)

TABLE 2: Maintenance item

Maintenance item	Cost/year MR
Depreciation of dryer	687
Interest on capital investment	1550
Annual maintenance cost	206
Electricity for 6 months	252
Total annual cost	2695

TABLE 3: Cost benefit analysis of solar dryer

Period of utilisation (Months)	Annual operating cost (MR)	Returns (MR)	Profit (MR)	Payback period (Years)
4	2611	6000	3389	4.57
6	2695	9000	6305	2.46
12	2947	18,000	15,053	1.03

TABLE 4: Monthly variation of optimum slope angle (facing north)

Day of Month	Optimum Slope Angle
14 November	1
10 December	-3
17 January	-1
16 February	7
SUMMER AVERAGE	**1**
15 May	39
11 June	43
17 July	41
16 August	33
WINTER AVERAGE	**39**
16 March	18
15 April	29
15 September	22
15 October	10
AVERAGE	**20**

FIGURE 1a: An experimental prototype

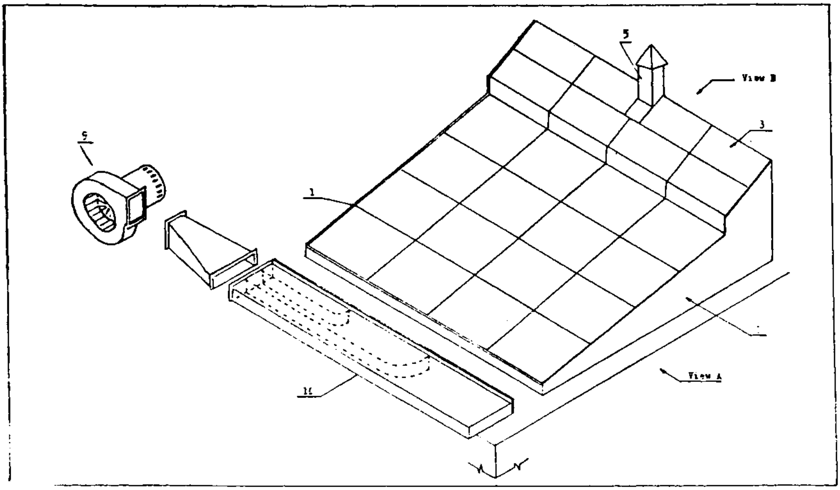
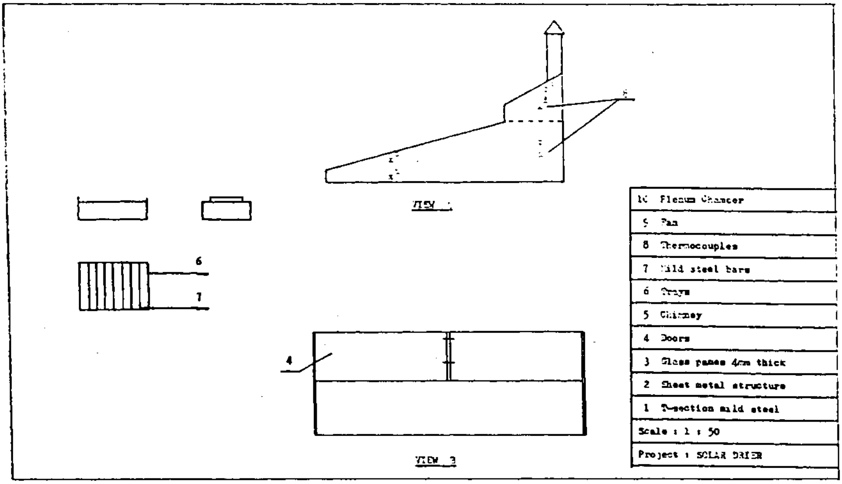


Figure 1b: An experimental prototype



Scale 1:50
1 T-section mild steel
2 Sheet metal structure
3 Glass panes 4 mm thick
4 Doors
5 Chimney
6 Trays
7 Mild steel bars
8 Thermocouples
9 Fan
10 Plenum chamber

FIGURE 2: Drying curves (A) and (B) for maize and ground nuts, both under natural convection; (C) and (D) for maize and rice, both under forced convection

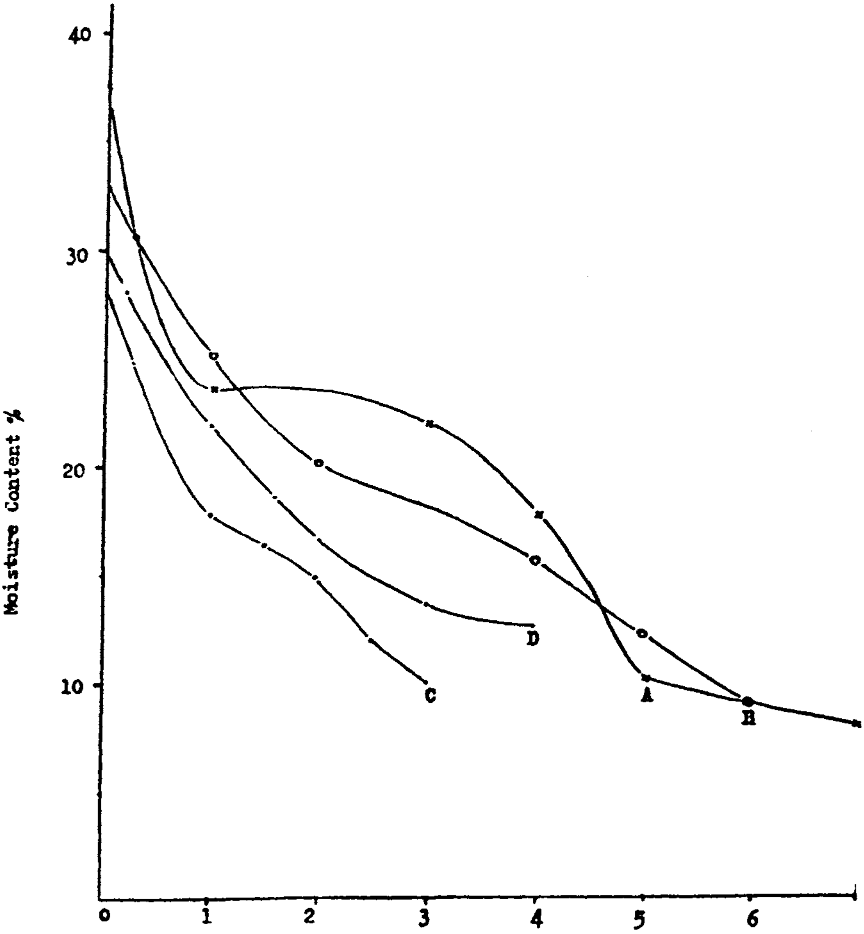


FIGURE 3: Downward flow dryer with heat storage

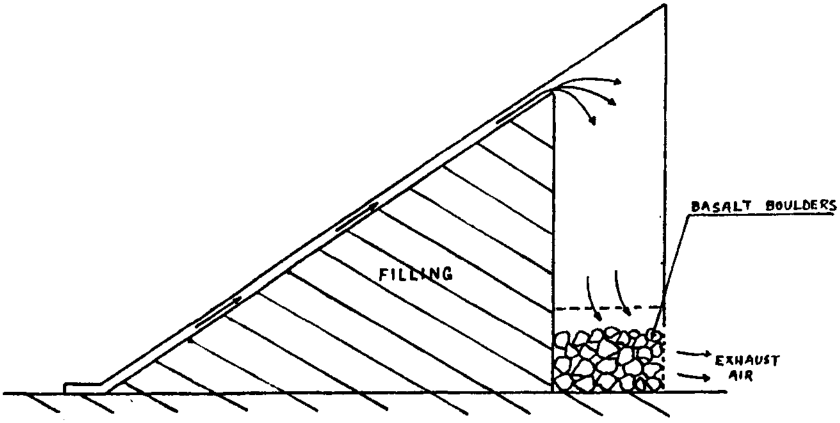


FIGURE 4: Upward flow dryer with heat storage

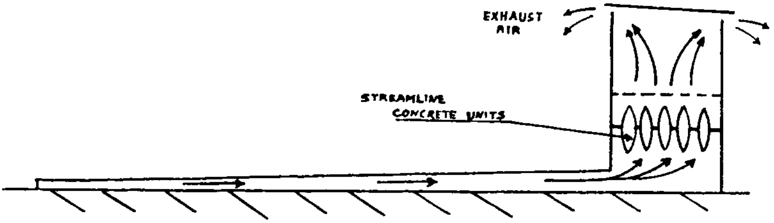


FIGURE 5a: Temperature with heat storage in downward flow dryer

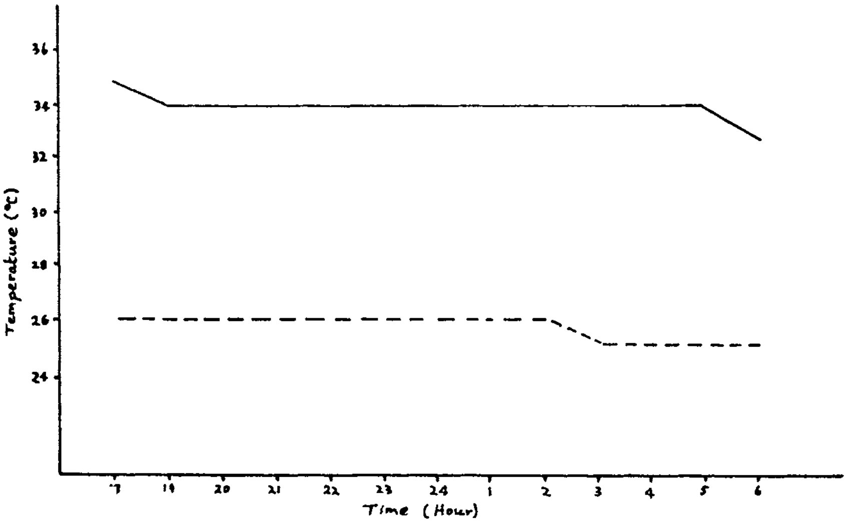


FIGURE 5b: Temperature without heat storage in downward flow dryer

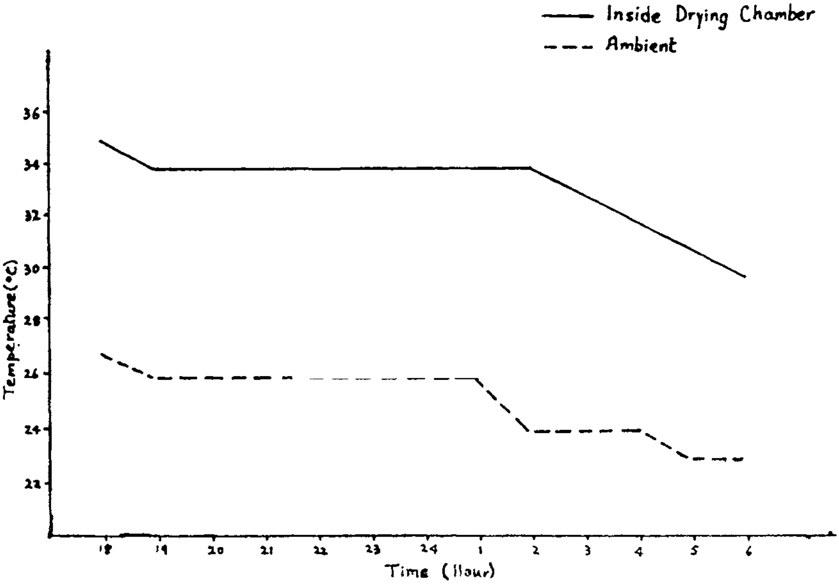


FIGURE 6a: A suitable multicrop dryer

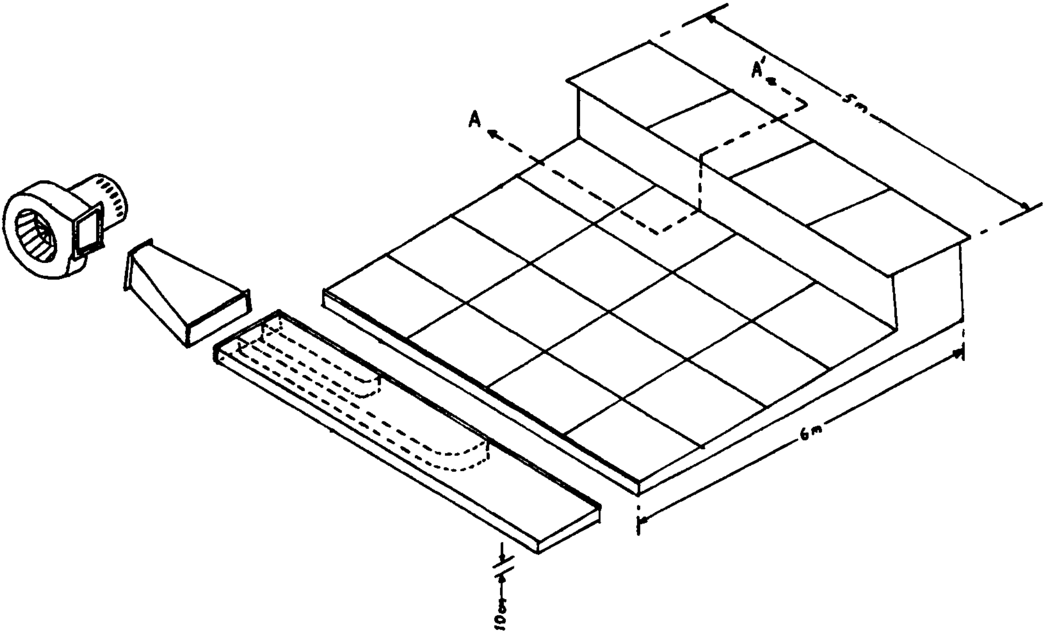


FIGURE 6b: Section AA' of multicrop dryer