Simulation of solar drying of copra[1]

Mataia Tavale G. Maiava[2]

Drying of copra in a short time is a great problem in the islands of the South Pacific. With a view to determine the appropriate type of dryer three experiments were conducted in the simulation of solar drying of copra using a simple passive direct solar cabinet dryer.

In the first experiment, the operating characteristics, namely, air flow rate, temperature, humidity, driving pressure and heat losses of the dryer with one square-metre drying area to dry 16 kg of extracted coconut meat were investigated. A good quality of copra was obtained as characterised by its off-white colour appearance and the final moisture content.

The second experiment was conducted to determine the relationship between two variables, viz, air flow rate and power input without using the coconut meat in the drying chamber over a range of power input levels of 150 watts to 900 watts.

In the third experiment, the same relationship between the two variables using coconut meat was determined. This experiment indicated a decrease of 20% in the overall average volume of air flow rate through the dryer as compared with experiment No.2.

Introduction

Coconut is a traditional valuable food crop in the islands of the South Pacific. It plays a dominant role in the lifestyle of the people providing one of the main components of the daily diet as well as drinks, copra and copra products for export, timber for houses, leaves for thatching, string and materials for handicrafts.

Oceania, which comprises of the islands of the South Pacific, is one of the two (the other is Asia) world's largest coconut producing regions which both account for more than 90% of the world's total production (Thampan, 1982).

To cite a few examples, the total volume and value of copra and copra products of Western Samoa's leading exports for the year 1986 accounted for 22,001 metric tonnes and WS$8,249.000 respectively, or about 66% by value of the total leading exports (Western Samoa Dept. of Economic Development, 1987).

In Tuvalu, 87% of all outer island households obtained cash income from copra production during the 1979 census (Tuvalu Ministry of Finance, 1983) Copra production and income to cutters for the year 1983 accounted for 233.45 metric tonnes and A$47,022, respectively (Op.cit.). Coconut production remains a high priority in Tuvalu.

Copra is the leading major income earning commodity in Tonga (Vaka, 1983). The estimated potential copra production, based on the national average of 0.5 metric tonne per acre per annum, is 25,400 metric tonnes (Op.cit.).

Open air sun drying is a traditional method of preserving coconuts and other food-stuffs in the region. Sun drying in this context, denotes the spreading of the food crop on a suitable surface, hanging it from eaves of buildings, trees and suchlike. Although this technique requires little capital or expertise and one that can give a product of acceptable quality in a reliable climate, sun drying, however, has many limitations.

These limitations include: intermittent and irregular moisture loss, low drying rate thus increasing the risk of spoilage during the drying process. The final moisture content of the dried product can be high, because of low air temperature and high relative humidity, which can result in spoilage during subsequent storage.

Possible contamination occurs by dust, airborne fungi and by insect infestation. During the time of drying, the crop is liable to theft or damage from bird droppings, rats, wandering pigs and other animals and even humans.

There is also a need for labour to be on hand to move the crop under cover in the event of rain and also to scare away would-be predators. The direct exposure to sunlight or more precisely to ultra-violet radiation, can greatly reduce the level of nutrients

1. This paper is an extract from the author's Master's thesis on the "Development of Solar Crop Drying for Western Samoa".

2. Formerly Lecturer and Head, Agricultural Engineering, School of Agriculture, University of the South Pacific.

such as vitamins in the dried product (Brenndorfer *et al.*, 1985).

Solar drying differs from sun drying in that a structure, often of very simple construction, for example, a simple passive direct solar cabinet dryer, is used to enhance the effect of the insolation. In many cases solar drying is a sensible alternative to sun drying for the farmer in the region and particularly when it supplements or replaces artificial drying.

Compared with sun drying, solar dryers can generate higher air temperatures and consequential lower relative humidities which are both conducive to improved drying rates and lower final moisture contents of the dried crops. As a result the risk of spoilage is reduced both during the actual process and in subsequent storage. The higher temperatures attainable are also a deterrent to insect and microbial infestation.

Additionally, protection against dust, insects and animals is controlled by drying in a solar dryer. All of these factors contribute to an improved and more consistent product of better quality. Solar dryers can also be relatively waterproof, minimizing the requirement for labour to be on hand in case of rain, or to move the crop under cover at the end of the day.

The specific objective of the experiments was to investigate various parameters in the simulation of solar drying of copra using a simple passive direct solar cabinet dryer.

Materials and methods

Drying cabinets and instruments

A simple passive direct solar cabinet dryer was used in the experiments under laboratory conditions. It was constructed with cheap timber and a single glass sheet used as the inclined (about 26°) top transparent cover. The dryer consisted of two perforated metal trays with a combined effective drying area of two square metres. The top tray was used to place the extracted coconut meat for experiments No. 1 and No 3 whilst the bottom tray was used as a baffle to achieve an even air flow. Only the base of the dryer was insulated using glass wool material. The interior of the combined collector/drying chamber was painted black to increase heat absorption. Two chimneys, each measuring 125 cm long and 7 cm in diameter, were installed on each side of the dryer to increase draught. An opening was provided at the back to place and remove the drying trays.

The designed electric power required as the heat source consisted of three thermotube heaters, each with a capacity of 240 watts; a combined power of 720 watts. These were installed at the front of the dryer with an opening area of 0.06 m^2 at the bottom for the airstream. The set-up of the dryer for experiments No.1 and No.3 is illustrated in Figure 1. For experiment No. 2, the set-up was the same as in experiment No. 3 but without using the coconut meat. A total of 80 nuts were used in the experiments with a weight of 32 kg of fresh extracted coconut meat. In the first experiment, 16 kg. of extracted coconut meat was used. The rest was used in the third experiment. Coconut meat was extracted manually using a laboratory-made metal device similar to a small blunt knife commonly used by Samoan coconut producer. The extracted coconut meat was evenly spread on the top tray about 40 mm thick prior to the drying operation.

Instruments and equipment used for measuring various parameters included the : Variac, which accurately supplied the amount of power required, electronic meter, which operated in conjunction with the Variac in recording the exact power supplied by the latter; thermal anemometer, a thermistor operated type, which measured air flow and temperature at various locations of the drying chamber and the airstream; thermometer-hygrometer, which measured wet and dry bulb temperatures to determine percentage humidity; miniature net radiometer, which measured the net influx of shortwave radiation mainly from the surface of the glass cover; automatic multimeter which automatically recorded radiation reading from the net radiometer; beam balance, which weighed samples of coconut meat before and after drying at different stages during the drying operation to determine the amount of moisture (wet basis) removed; electric oven, which dried six samples of the extracted fresh coconut meat to determine the initial moisture (dry basis) content; selector unit temperature recorder and thermocouples, which recorded temperature at various locations of the glass cover and the outlets of the chimneys.

Initial Moisture Content Determination of Copra

Six samples of the extracted fresh coconut meat were dried in the oven at 102°C for 24 hours and the average initial moisture content expressed in percentage dry weight basis (d.b.), was determined (Thampan, 1982).

The initial moisture content of the fresh coconut meat obtained was 46% (d.b.), and this was reduced to the recommended safe storage final moisture content of 4% (w.b.) (Purseglove, 1977; Thampan, 1982, Kochhar, 1986).

Experiment No. 1

Maximum power input, as the heat source required for drying 16 kg of extracted coconut meat on a one

Table 1. Simulation of solar drying of Copra under ambient conditions in the first experiment.[3]

Date	Drying time (Hours)	Average air temperature (°C)	Average air flow (m^3/sec.)
15.5.1989	1250	19	0.19
	1350	20	0.23
	1450	20	0.23
	1550	21	0.22
	1650	21	0.20
16.5.1989	0900	16	0.19
	1000	18	0.22
	1100	20	0.22
	1200	22	0.23
	1300	22	0.23
	1400	22	0.22
	1500	22	0.22
	1600	22	0.22
	1700	22	0.24
17.5.1989	0930	19	0.20
	1030	19	0.32
	1130	20	0.33
	1230	20	0.34
	1330	21	0.36
	1430	21	0.36
	1530	22	0.35

3. Room air humidity was between 65% and 68% during the simulation process

[3]Room air humidity was between 65% and 68% during the simulation process.

Table 2 a. Simulation of solar drying of Copra under drying conditions in the first experiment.

Date	Drying Time (Hours)	D. Chamber Air Flow [a] (m^3/ses.)	Temp [b] (^{0}C)	Moisture Removed[c] (% w.b.)	Relative Humidity (%)	Outlet Temp [d] (^{o}C)
15.5. 1989	1350	0.28	40		74	31
	1450	0.30	42	3	68	35
	1550	0.31	43		66	35
	1650	0.28	39	3	58	38
16.5.1989	1000	0.28	38		55	30
	1100	0.30	42	8	48	28
	1200	0.32	44		46	28
	1300	0.32	43	5	40	30
	1400	0.26	37		38	27
	1500	0.25	34	5	42	26
	1600	0.26	35		40	26
	1700	0.25	35	4	39	27
17.5.1989	1030	0.24	33		39	28
	1130	0.28	37	10	30	28
	1230	0.32	42		30	31
	1330	0.31	42	2	26	29
	1430	0.35	43		26	29
	1530	0.32	45	2	24	28

a, b, c, d indicate average values

Table 2 b. Simulation of solar drying of Copra under drying conditions in the first experiment

Date	Drying Time (Hours)	Radiation on Glass Cover (watts/m^2)	Temperature of inside surface of glass cover [a] (^{o}C)
15.5.1989	1350	19.23	29
	1450	40.38	32
	1550	32.69	32
	1650	50.00	35
16.5.1989	1000	40.38	31
	1100	59.61	34
	1200	57.69	34
	1300	61.54	37
	1400	42.31	33
	1500	44.23	33
	1600	36.54	31
	1700	42.31	33
17.5.1989	1030	32.69	30
	1130	65.38	34
	1230	71.15	36
	1330	71.15	38
	1430	73.07	39
	1530	73.07	40

a. Average temperature difference between inside and outside surfaces was 3.5^{0}C square-metre area of the top tray, was maintained constant at 900 watts. The heated air flow was directed at the bottom of the whole layer of coconut meat through the bottom tray in the drying chamber. The bottom tray was used as a baffle to achieve an even air flow.

The following parameters were monitored every hour during the drying operation:

Ambient temperature and ambient air flow - Three readings of each parameter were measured at the airstream and the average was calculated.

Drying temperature and air flow rate - nine and twelve readings of each parameter were measured at the top and the bottom of the whole layer of coconut meat, respectively, and the average was calculated.

Ambient relative humidity and the relative humidity in the drying chamber;

Radiation on the glass cover; Temperature of the inside surface of the glass cover; Outlet temperature of the chimneys.

The amount of percentage moisture (w.b.) removed at different stages of the drying operation was determined every two hours from the four samples monitored at different locations in the drying chamber.

Calculations were done on the following parameters: heat losses, mainly the radiation loss on the glass cover; volume of air flow rate through the dryer; driving pressure across the bed of coconut meat and the constant.

Appropriate insulation materials to use in a solar dryer include woodshavings, sawdust, dried grass or tree leaves, coconut fibre etc., which are cheap and readily available in the region. Also any openings around the dryer for possible heat loss, except the outlet air passage(s) from the dryer, were sealed off using a sealing compound.

An empirical test (Purseglove, 1972; Thampan, 1982) was carried out with samples of copra after the drying operation to further determine the final moisture content. The empirical test for moisture content determination is explained as follows:

Copra with a moisture content of 3% to 7% should be brittle and break easily. A small piece of copra is lighted with a match. If it burns readily, the moisture content is less than 7%. If the flame occasionally splutters it is 7% to 10%. Above a 10 % moisture content the copra burns with difficulty. At high moisture content copra will not burn at all.

This test may be quite useful for a coconut producer in the region to determine the final moisture content of copra, because it is very simple and very easy to carry out.

Experiment No. 2

This experiment was conducted to determine the relationship between two variables, viz, ambient air flow rate and power input without using the coconut meat in the drying chamber over a range of power input levels of 150 watts as starting power and a maximum of 900 watts.

Three readings of ambient air flow rate through the dryer were measured at one-hour intervals and the average was taken.

Change to power input through the dryer was monitored at hourly intervals.

Other parameters measured at one-hour intervals included ambient temperature, relative humidity and temperature in the drying chamber.

(iv) Experiment No. 3

The third experiment was conducted to determine the relationship between the two variables viz. ambient air flow rate and power input as indicated in the second experiment with coconut meat.

Similar procedure was followed in monitoring the variables as in the second experiment.

Results and discussion

The simulation of solar drying of copra in the first experiment took 18 hours to complete. This consisted of 4 hours in the first day, 8 hours in the second day and 6 hours in the third day. The air flow through the dryer appeared to be fairly stable in the first and second day but in the third day a slight increase was noted (Table 1 and Fig. 2). The increase could be attributed to the reduction in the relative humidity of the air in the drying chamber, thus more moisture has been removed from the coconut meat. The calculated average volume of air flow rate through the dryer was 0.02 m^3/sec.

Room or ambient air temperature during the simulation process remained somewhat stable and the average temperature was about 20°C (Table I and Fig. 5).

The calculated driving pressure across the bed of coconut meat was 0.93 Pascal. Since the dryer was operated on a natural convection process, the driving pressure across the coconut meat in this context was solely due to the density difference between the hot air inside the dryer and the ambient air. As volume of air flow rate was proportional to the driving pressure the constant was determined to be about 0.02.

Table 3. The relation between the air flow rate and the power input through the dryer [illegible] coconut meat in the second experiment

Date	Time of Day (Hours)	Average Air Flow Rate (m^3/sec.)	Power Input (watts)
22.5.1989	1410	0.05	150
	1510	0.08	200
	1610	0.11	250
	1710	0.10	300
	1810	0.14	350
23.5.1989	1000	0.13	400
	1100	0.15	450
	1200	0.16	500
	1300	0.20	600
	1400	0.20	650
	1500	0.23	700
	1600	0.26	800
	1700	0.27	850
	1800	0.29	900

Table 4. The relation between the air flow rate and the power input through the dryer [illegible] meat in the third experiment

Date	Time of Day (Hours)	Average Air Flow Rate (m^3/sec.)	Power Input (watts)
24.5.1989	1310	0.03	150
	1410	0.03	200
	1510	0.05	250
	1610	0.08	300
	1710	0.10	350
	1810	0.11	400
25.5.1989	1000	0.10	450
	1100	0.14	500
	1200	0.16	600
	1300	0.17	650
	1400	0.20	700
	1500	0.19	750
	1600	0.23	800
	1700	0.24	850
	1800	0.25	900

The relative humidity in the drying chamber after one hour of drying was 74% and upon completion of the drying operation this was reduced to 24% (Table 2a and Fig. 6). Ambient or room air humidity during the simulation process was between 65% and 68%.

The temperature of the top and the bottom of the whole layer of coconut meat was 40°C and 44°C, respectively, and the average difference was found to be 4^0C or 9%. The drying rate curve for copra (Fig. 3) illustrates the information on the drying mechanism rather than the drying curve (Fig.4) (Brenndorfer *et al.*, 1985). The drying curve (Fig. 4) for copra is a plot of moisture content (% w.b.) against drying time, whereas the drying rate curve is a plot of the rate of drying, that is, the change in moisture content with time, against the moisture content (% w.b.).

In the initial stages of drying the rate of moisture movement from the interior of the coconut meat to the surface was sufficiently high to maintain the surface in a completely wetted condition. Moisture movement is known to be dependent on diffusion and capillary flow (Xiaoren, 1989).

The temperature, moisture content (or moisture gradients) and the physical dimensions of the coconut meat were the most important factors affecting the rate of moisture movement (Brenndorfer *et al.*, 1985). The internal structure and composition of the coconut meat were also of importance.

At point A in Figure 3 the drying rate of the coconut meat started to decrease tending to zero, hence, the falling rate period is shown as part AB. In this context the rate of drying decreased with decrease in moisture content but increased with decrease in the coconut meat size.

The calculated total heat loss from the dryer was 204 watts, from which the radiation loss alone (mainly on the glass cover) accounted for about 72 watts; the rest by convention and conduction. After one hour of operation, the temperature of the inside surface of the glass cover and radiation on the glass cover were measured to be 29°C and 19 W/m^2, respectively. But upon the completion of the drying operation the measurements were 40°C and 73 Wm^{-2}, respectively (Table 2 b). Average temperature obtained between the inside and the outside surface of the glass cover during the simulation process was 3.5°C.

A major factor attributed to the high heat loss could be lack of insulation in the dryer. This was not insulated except only at the base. Improvements to reduce heat loss could be made by insulating the sides in addition to the insulated base.

Upon completion of the simulation process, copra shrinkage was around 41% and waste of about 1% of the original weight of the coconut meat. Waste included handling and fallen pieces of copra through the drying tray. The final moisture content of the copra was 4% (w.b.). A good quality copra characterised by its final moisture content and off-white colour appearance was obtained.

An empirical test (Purseglove, 1972; Thampan, 1982) was carried out with samples of copra to further determine the final moisture content. It was noted that samples of copra burnt readily. These results, therefore, indicated that the final moisture content of the copra was less than 7%.

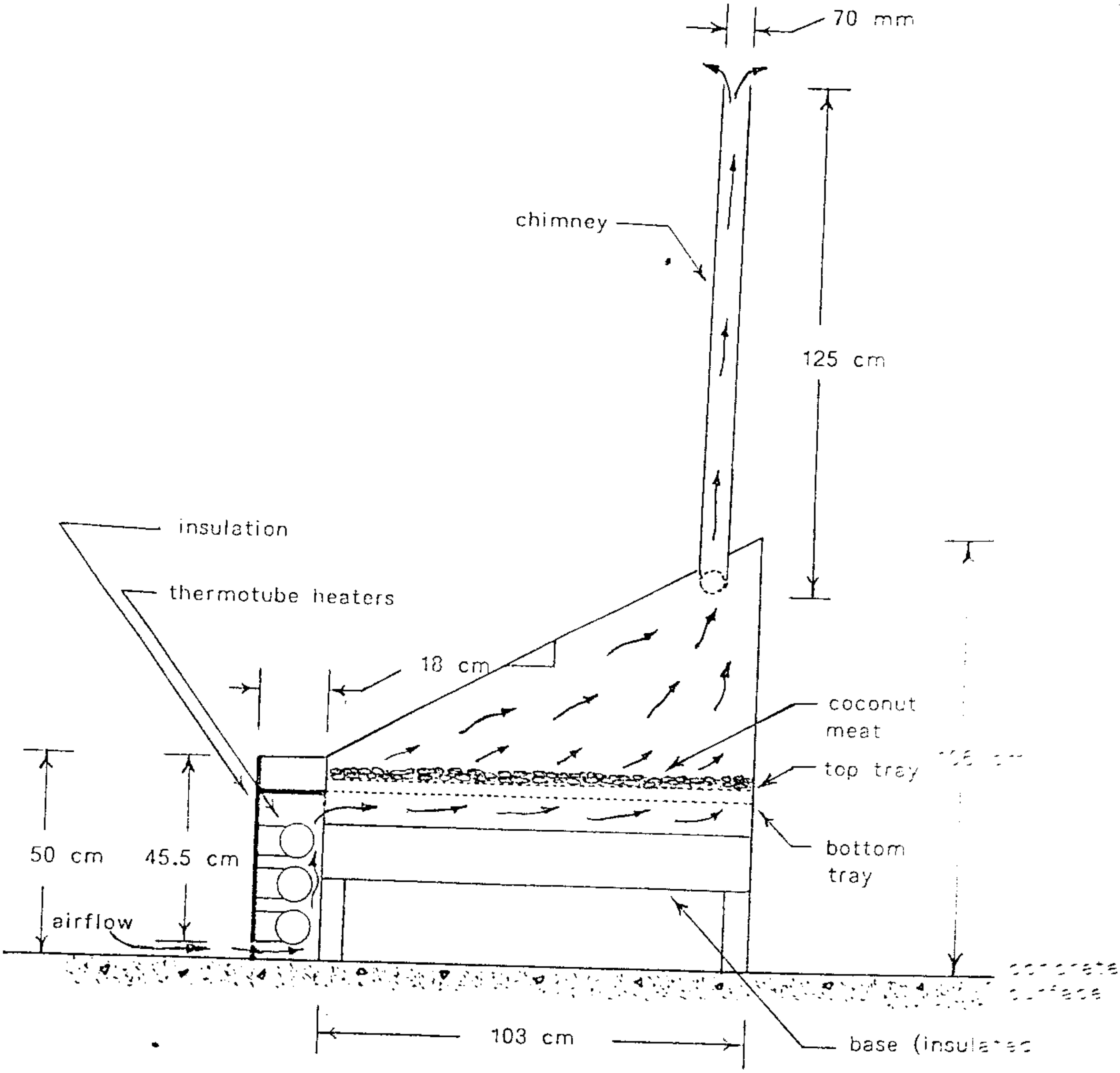
In the second experiment without using the coconut meat ambient air flow rate and power input indicated a gradual increase in the former variable in response to an increase in the latter variable (Table 3 and Fig. 7). In this context, warm air rose with an increase in the temperature inside the dryer by natural convection and passed through the drying tray and out of the dryer via the chimneys. This created a partial vacuum and fresh air was drawn up through the airstream entrance at the front of the dryer (Fig. 1). As a result, there was a continuous flow of air through the dryer.

The calculated average volume of air flow rate through the dryer was 0.01 m^3/sec for a two-day investigation or a total of 14 hours. The relative humidity in the drying chamber varied from 55% to 17% with an average of about 33%. Average ambient or room temperature was 23°C, indicating that the days were quite warm. An average temperature of 40°C was noted in the drying chamber at different power input levels.

Experiment No. 3 with the coconut meat drying showed a slight decrease in air flow through the dryer as expected (Table 4 and Fig. 7). The calculated average volume of air flow rate was 0.008 m^3/sec as compared to 0.01 m^3/sec in the second experiment, indicating a decrease of 20%. The relative humidity in the drying chamber varied from 80% to 24% with an average of about 43% for a two-day invesitgation or a total of 15 hours. In comparison with the average 33% relative humidity in experiment No.2, it is an increase of 10%.

Conclusions

The use of a simple passive direct solar cabinet dryer in the simulation of solar drying of copra greatly reduced the moisture content of copra from 46% (d.b.) to its recommended safe storage final moisture content of 4% (w.b.). This process produced good quality copra as characterised by its final moisture content and its off-white colour appearance. The solar dryer generated high air temperature and consequential lower relative humidity which were both conducive to an improved drying rate and a lower final moisture content of the copra.



A cross-section of a direct solar cabinet dryer.

Scale: 1 cm = 15 cm

Figure 1 (a): Simulation of solar drying of copra with hot air flowing under in the first experiment.

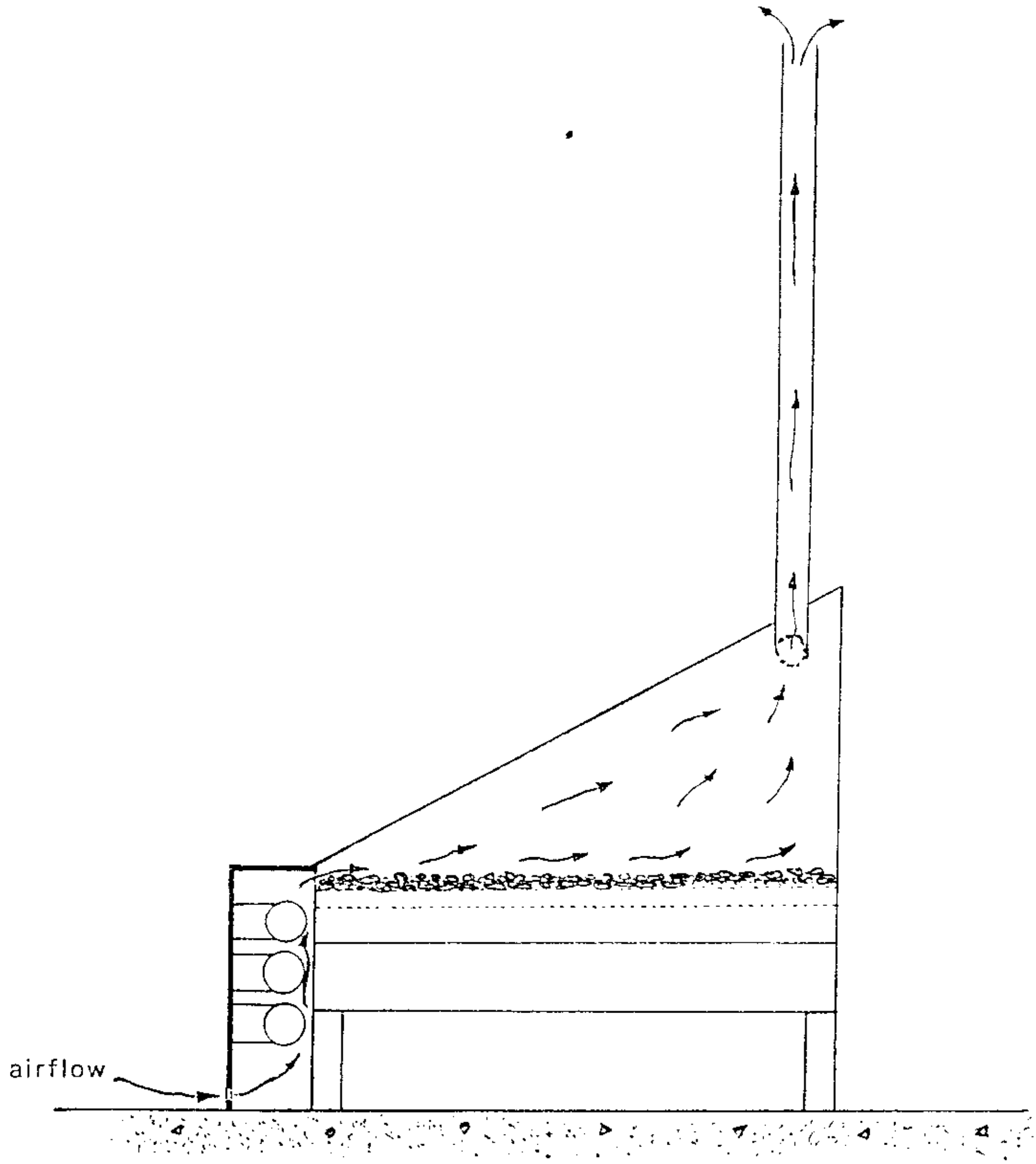


Figure 1 (b): Simulation of solar drying of copra with hot air flowing over crop in the third experiment.

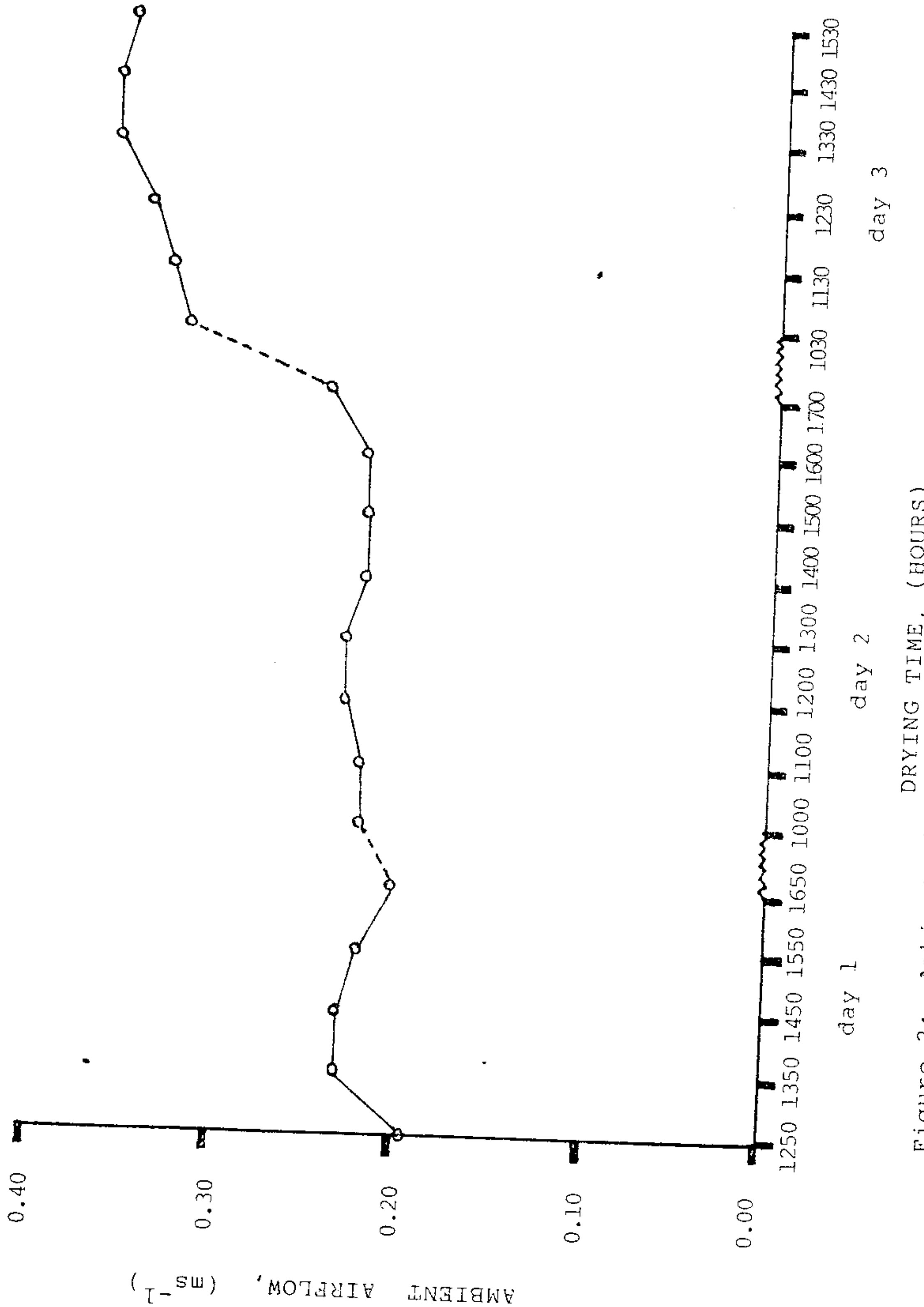


Figure 2: Ambient Air Flow Curve for Copra Drying.

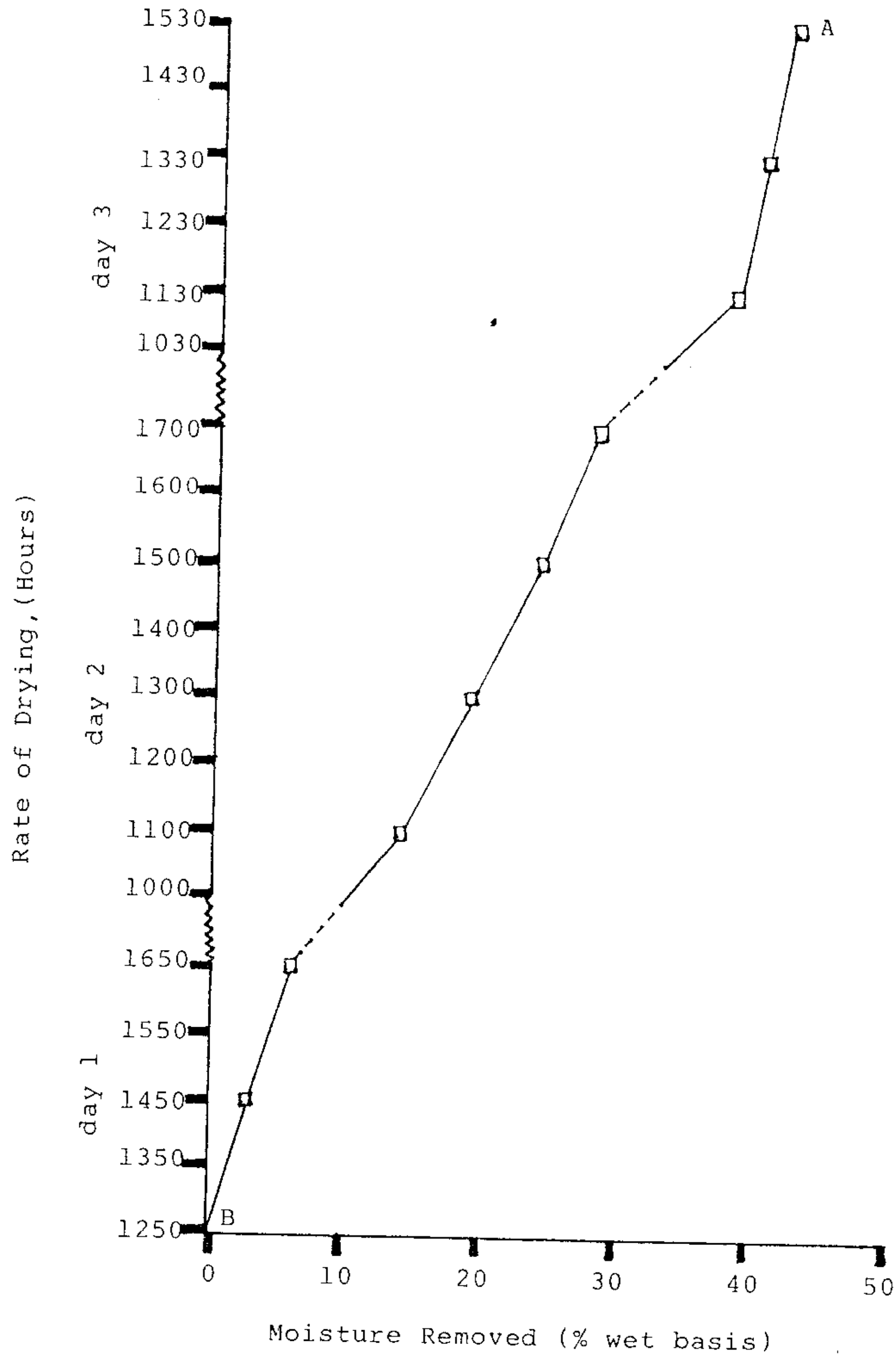


Figure 3: Drying Rate Curve for Copra.

Note: Dotted line indicates power shut-off at the end of the day.

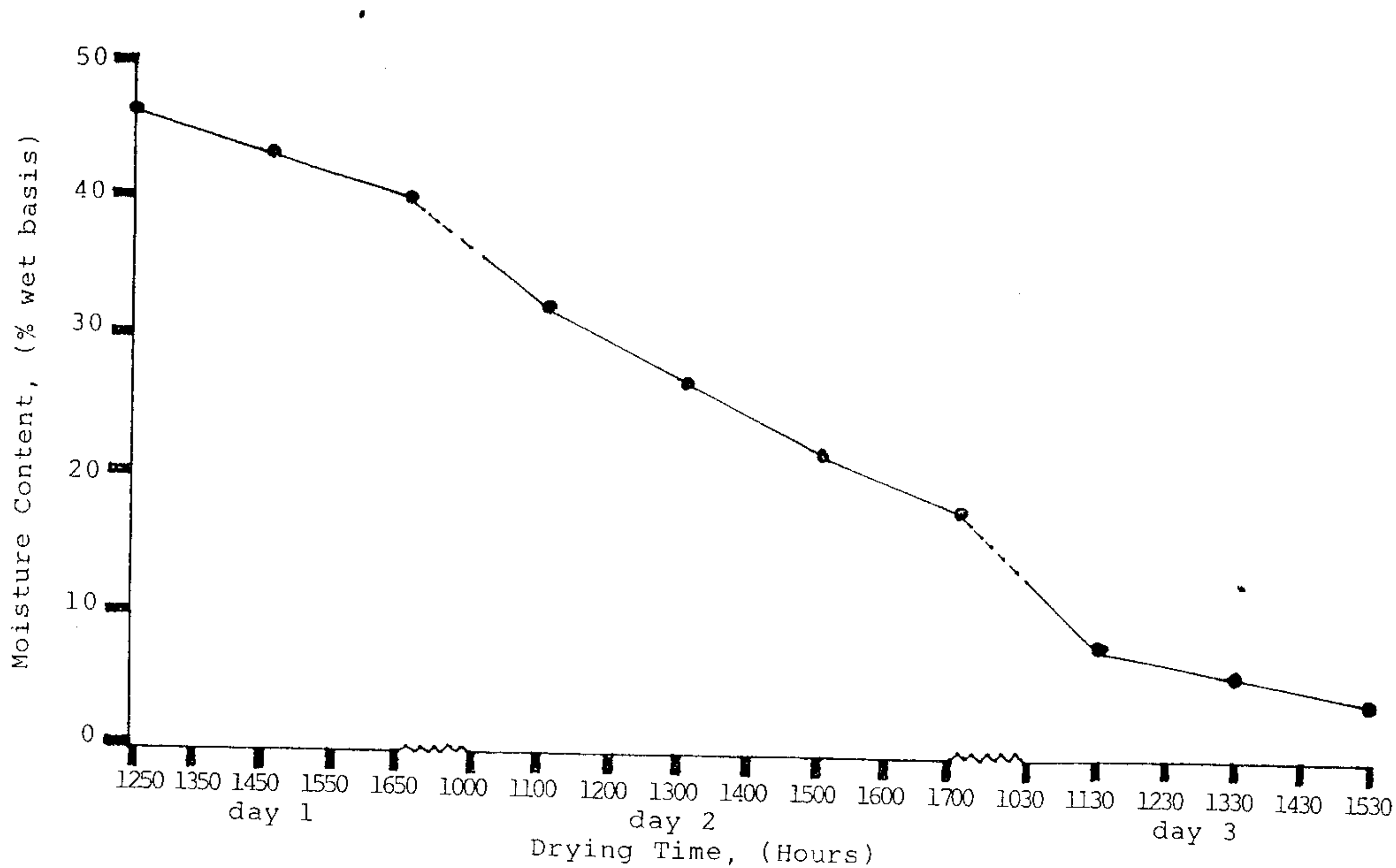


Figure 4: Drying Curve for Copra.

<u>Noted</u>: Dotted line indicates power shut-off at the end of the day.

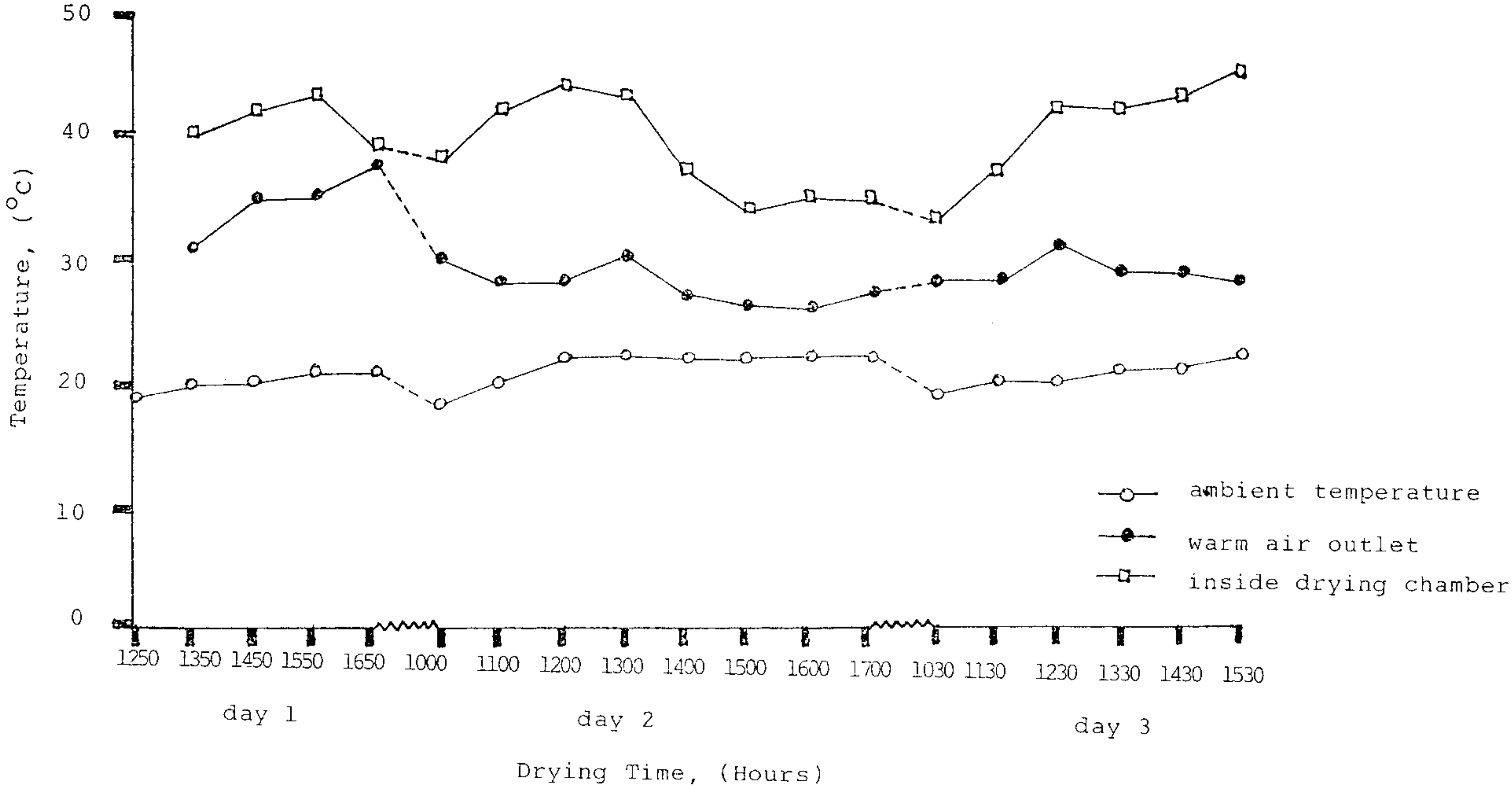


Figure 5: Temperature Reading Curves for Copra.

Note: Dotted line indicates power shut-off at the end of the day.

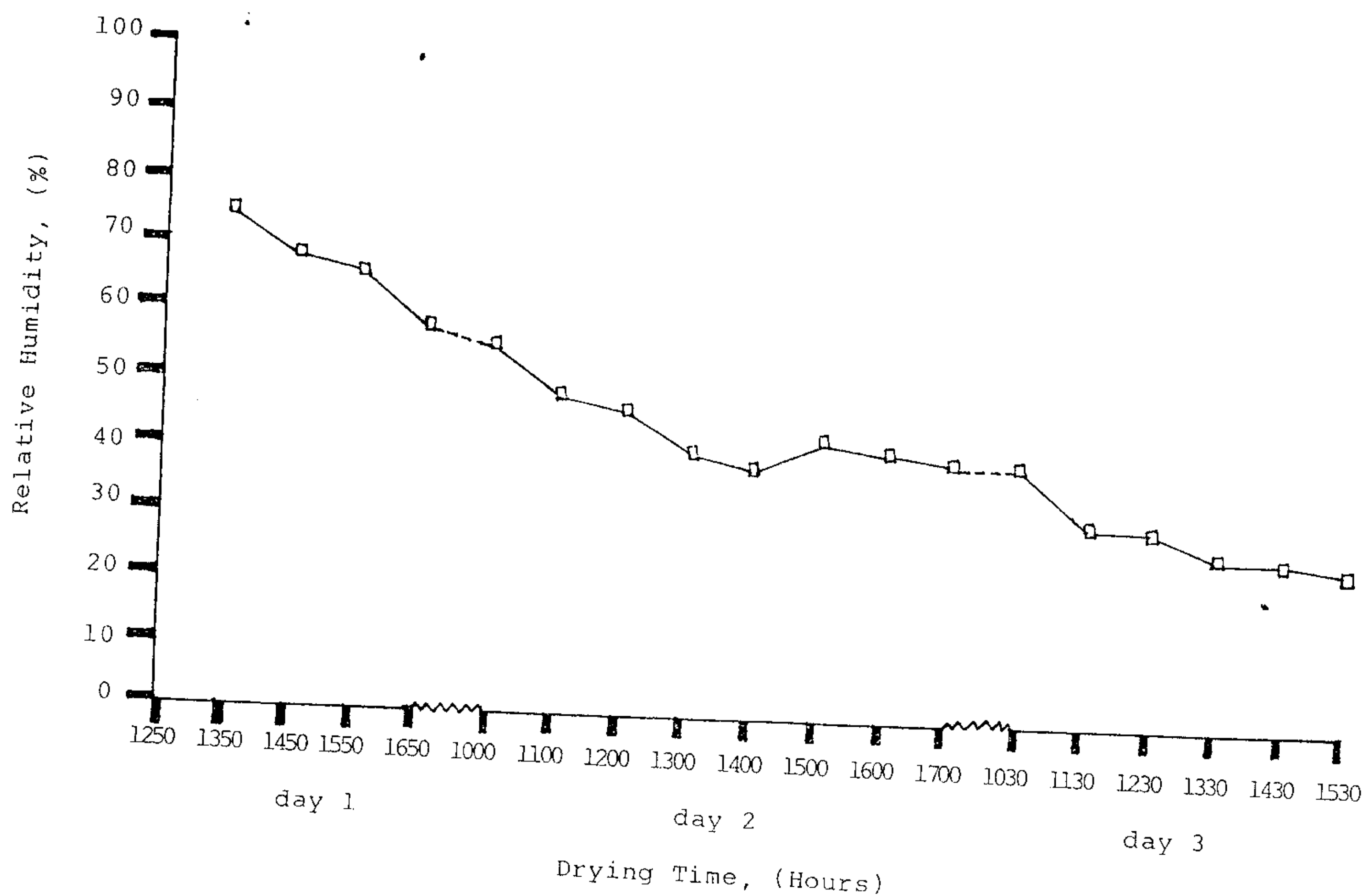


Figure 6: Drying Relative Humidity Curve for Copra.

Note: Dotted line indicates power shut-off at the end of the day.

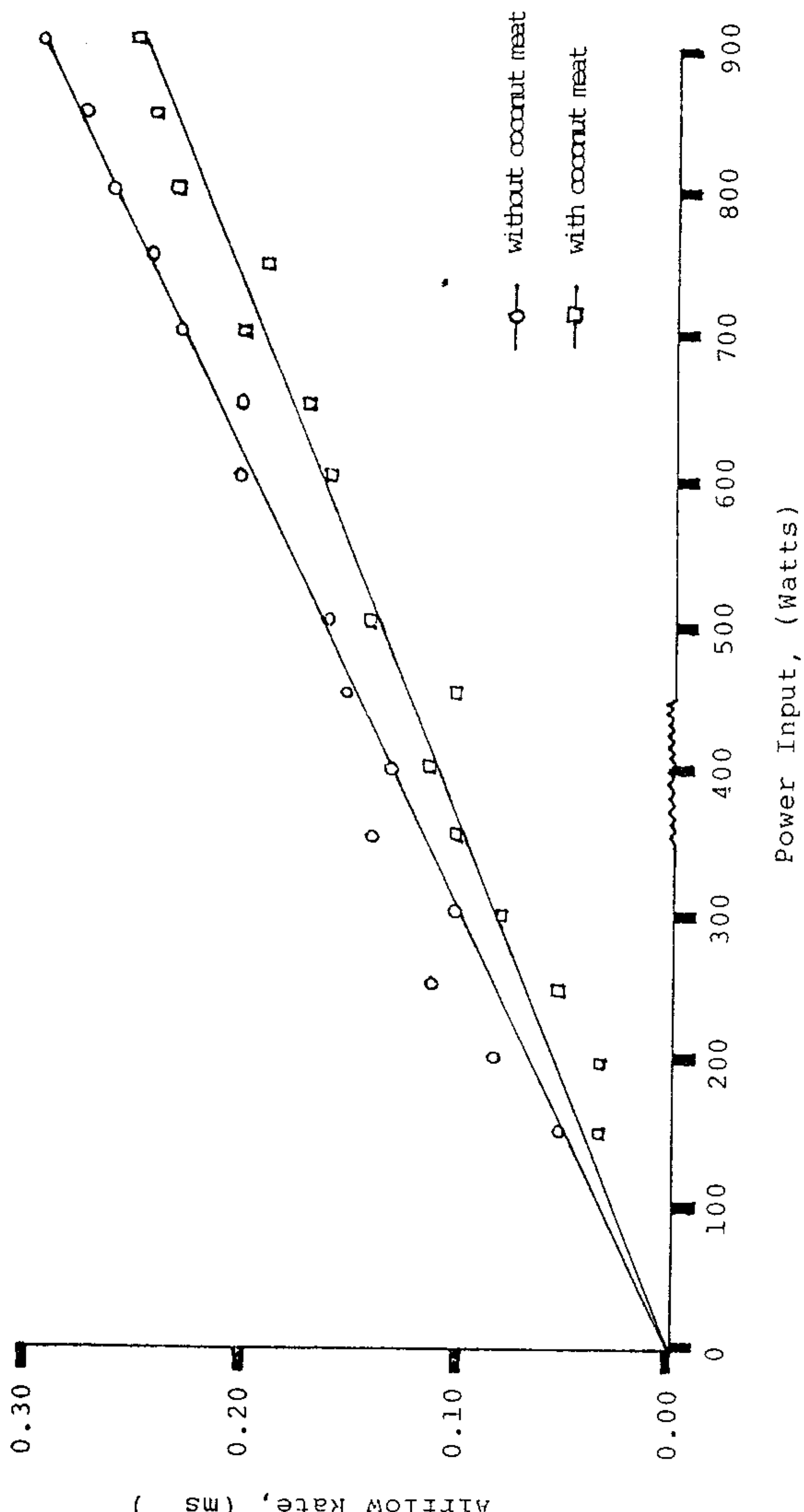


Figure 7: Power Input versus Air Flow Rate.

Solar drying of copra and other crops is a sensible alternative to sun drying in the region particularly when it supplements or replaces artificial drying for crop and food preservation.

The results obtained from this investigation indicated that about 8 metric tonnes of copra per annum could be obtained by solar drying using a simple passive direct solar cabinet dryer.

Generally, passive solar dryers which employ natural convection should be a suitable choice in the Region at a village level than active types because of the added costs involved in the latter in terms of the source of motive power required and maintenance and repair.

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