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Abstract

A pilot scale through circulation drier using solar heated air has been developed for drying cassava chips. The design of the drier system, which includes a bottom ventilated drying bin, centrifugal fan and solar collector is described. In the evaluation trials the variables studied were drier loading (37.5 - 150.0 kg/m^2), airflow (11-18 $m^3/min.\ m^2$) and varying air conditions in the range 24-28°C and 62-72% RH. Design parameters for drier scale-up are presented.

Introduction

The great potential that exists in tropical Latin American countries for using dry cassava as a source of carbohydrate in animal feed concentrates (Pachico, 1980; Gómez, 1982) has led to the need to develop efficient methods of drying that are technically and economically suited to the production and cost structures prevailing in the region. Natural drying on concrete floors is the method most commonly employed for drying cassava for animal feed purposes and during the 1970s research was carried out by various workers aimed at improving natural drying techniques, both on concrete floors (Thanh, 1979) and in vertical and inclined trays (Roa, 1974; Best, 1978). The results of these studies has led to a greater understanding of the effect that factors such as chip geometry, loading density and ambient conditions have on the rate of drying.

Despite the improvements in drying efficiency achieved through these studies and the advantages that natural drying offers over artificial drying in terms of relatively low capital and operating costs, it is a method that remains totally dependent on the weather. Consequently, natural drying is not practical in areas with high year round relative humidity and, in regions with marked wet seasons, the periods in which natural drying is possible are restricted. In cases such as these, the use of forced air, through circulation driers, operating with ambient or heated air, or a combination of both, could provide an economically feasible alternative to the fully artificial, continuous drying plants whose scale and costs of operation are such that their use in Latin America has seldom met with success (Crown, 1981; Freivalds, 1982).

A number of laboratory studies have been carried out to determine the optimum parameters — bed depth, air temperature and velocity — for drying cassava chips in through circulation driers. Chirife and Cachero (1970) found that for bed depths upto 120 mm, the drying time is not increased at airflow rates above 5000 kg/h.m^2 and scorching of the chips occurs above 84°C. They determined that no constant drying rate exists and concluded that internal water movement is the controlling mechanism from the beginning of the drying process, findings which have subsequently been confirmed by Webb and Gill (1974); Akhtar (1978) and Igbeka (1982).

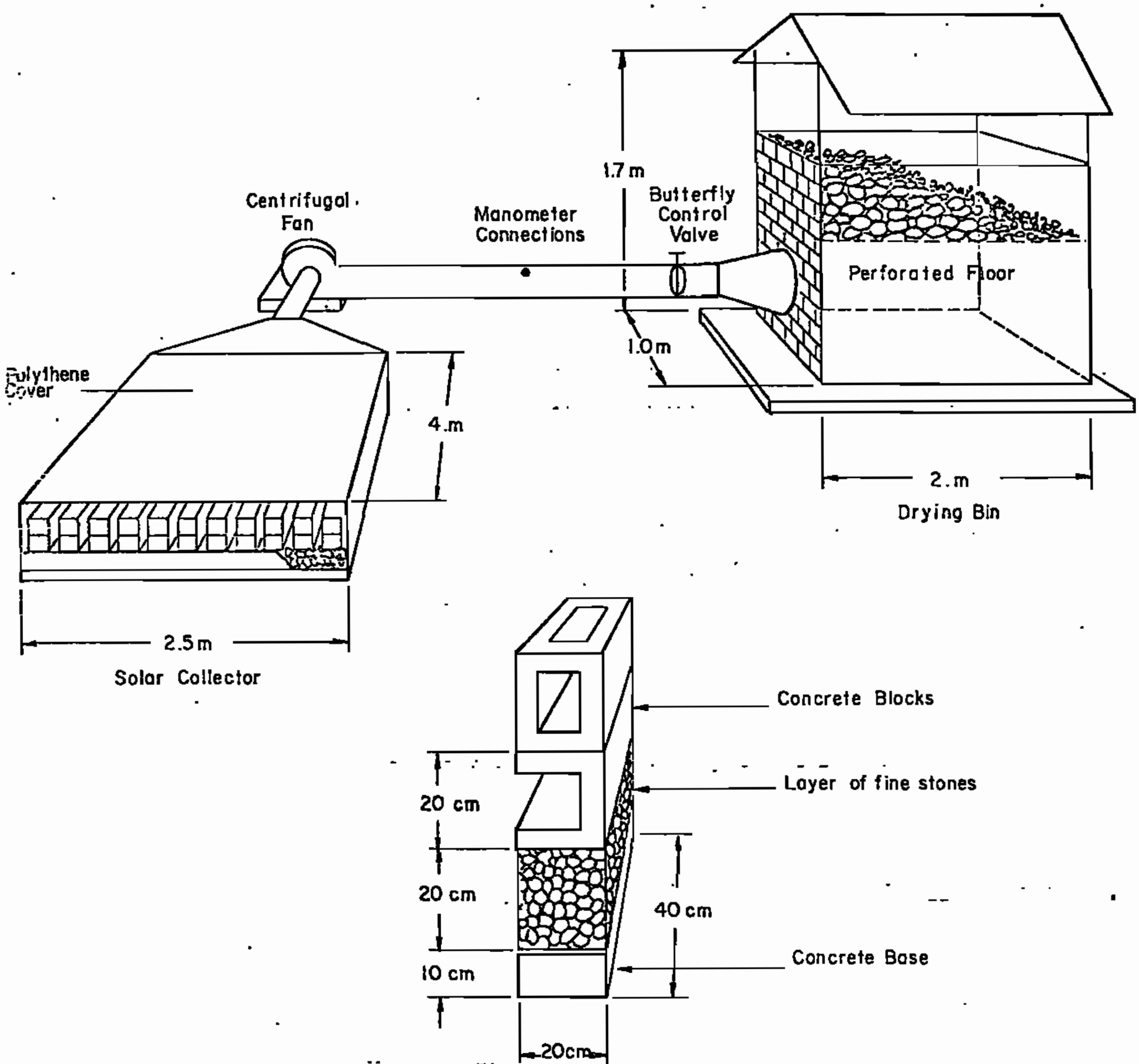
On a larger scale, Rossi and Roa (1980) and Ospina (1980) carried out trials in a 15 m^2 drier, coupled to a 100 m^2 solar collector. They used mathematical models for cassava drying and deterioration to determine minimum airflow rates under varying air temperature and relative humidity conditions. For bed depths of 300 mm, the minimum airflow rates varied between 47.5 and 102.5 m^3/min per ton of fresh cassava, for temperatures in the range 40 to 20°C, corresponding to relative humidities in the range 25 to 55%.

The present paper reports some preliminary results of a joint project between the Centro Internacional de Agricultura Tropical, CIAT and the Universidad del Valle, Cali, Colombia, whose principal objective is to develop and evaluate a forced air through circulation cassava drier for use by farmers' associations on the Atlantic Coast of Colombia (Ospina et al., manuscript in preparation). The complete evaluation will include a technical and economic comparison of ambient, solar heated and fuel fired air systems: results of trials of the solar heated air system only are presented here.

Drying system

The drying system that has been constructed at CIAT is an adapted version of the system developed at the Centro Nacional de Treinamento em Armazenagem, CENTREINAR, Brazil (Sinicio and Roa, 1980) and consists of a solar collector, a centrifugal fan and a drying bin (Figure 1). The centrifugal fan draws air through the solar collector and passes it through a 305 mm diameter duct into the plenum chamber of the drying bin.

The solar collector, with an area of 10 m^2, is constructed on a concrete base and is made up of 200 mm layer of fine stones on which are placed concrete



DETAIL OF INTERNAL SOLAR COLLECTOR CONSTRUCTION

Figure 1. Through circulation cassava drying system with solar collector

blocks, arranged longitudinally along the collector. The concrete blocks, of 200 mm square section and 400 mm long, are designed in such a way that their cavities may be oriented to maximize solar radiation absorption. The stones and blocks are painted matt black. Above the blocks, a polythene cover is supported by chicken wire and the lateral brick walls of the collector. CIAT's proximity to the equator has made it unnecessary to incline the collector.

The centrifugal fan has forward curved blades and is driven by a 1.5 hp electric motor at 600 rpm. The air flow can be varied between 0 and 38 m^3/min by adjusting a butterfly valve placed before the plenum chamber. The air flow is measured using a pitot tube connected to an inclined manometer.

The drying bin, whose dimensions are 1.0 m x 2.0 m x 1.7 m high, is constructed of brick with a concrete floor. At a height of 600 mm above the floor and supported by wooden cross beams, a galvanized steel sheet with 3% opening (3 mm diameter holes) is placed. Onto this perforated floor, which has an area of 2 m^2, are loaded the cassava chips to be dried. The drying bin is protected from the rain by a corrugated sheet roof raised 800 mm above the walls.

Thermohydrographs are used to monitor ambient temperature and relative humidity and air conditions in the plenum chamber. Solar radiation is measured using an integrating pyranometer.

Procedure

The cassava variety used in the trials was HMC 1, harvested from 12 through to 15 months. The whole cassava roots were washed in a concrete tank before chipping in a Thai type chipping machine (Thanh, et al., 1979). The cassava chips were sampled for fresh moisture content and then loaded into the drier.

The change in moisture content of the cassava chips during drying was determined by weighing three 200 mm diameter sampling cylinders placed in the drying bed. At the end of the drying period a further sample of dry cassava was taken for moisture determination. On both fresh and dry samples, moisture content measurements were carried out by drying to constant weight in an oven at 60°C. During drying the cassava was turned at 0800, 1200 and 1600 hours to prevent deterioration of the upper layers of chips, and the fan was operated continuously day and night.

To date three sets of trials have been undertaken as part of the evaluation of the drying system. The objectives of each set of trials were as follows:

1st set : To determine optimum drier loading

2nd set : To determine optimum airflow rate

3rd set : To determine the optimum time of starting drying

Results and discussion

In the analysis of the results the parameter used to compare trials is the rate of loss of moisture, in kg of water per hour per square metre of drying floor. This parameter, which is a function of the initial moisture content of the chips, the airflow rate and the temperature and relative humidity of the drying air, gives an indication of drying efficiency.

The results of the first set of five trials, in which the loading rate was varied from 37.5 to 150.0 kg of fresh cassava chips per square metre of drying floor are presented in Table 1. The drying time increases with increasing loading, however the rate of loss of moisture is highest at 2.04 kg/h.m^2 for a loading of 150 kg/m^2, followed by 1.90 kg/h.m^2 for a loading of 75 kg/m^2.

Table 1. Determination of optimum drier loading

Trial	Drier loading kg/m^2 [a]	Initial moisture content % dry basis	Time of starting drying h	Mean airflow rate $m^3/min.m^2$ [b]	Maximum pressure drop ins w.g.	Conditions of drying air T°C	%RH	Drying time h [c]	Rate of loss of moisture $kg/h.m^2$ [d]
1.1	37.5	184	1400	13.4	0.25	25	67	22	1.10
1.2	75.0	173	1400	12.0	0.24	28	59	25	1.90
1.3	100.0	178	1400	10.6	0.27	28	63	43	1.49
1.4	125.0	178	1400	11.2	0.27	27	66	45	1.78
1.5	150.0	212	1400	11.0	0.28	28	63	50	2.04

[a] Drier loading in kg of fresh chips per square metre of drying floor.

[b] Mean airflow rate over the drying period in cubic metres per minute per square metre of drying floor.

[c] Drying time in continuous hours from the time of starting.

[d] Rate of loss of moisture in kg per hour per square metre of drying floor.

At the 150 kg/m^2 loading, discolouration of the cassava chips ocurred after 36 hours and a faint malodor was observed. It was therefore felt that this loading was too high to produce dry cassava of an acceptable quality. On the other hand, the 75.0 kg/m^2 loading gave a drying time of 25 hours which, taking into account practical plant operating conditions, is too long for a one day per batch system. In the circumstances it was decided to opt for the loading of 125 kg/m^2 which, drying in 45 hours, would fit into a two day per batch operation.

In the second set of trials, the airflow rate was varied between 11 and 18 m^3 per minute per square metre of drying floor, at a constant drier loading of 125 kg/m^2, Table 2. The rate of loss of moisture for the two extreme conditions of airflow rate were the same at 1.82 kg/h.m^2. However, at the 18.3 m^3/min.m^2 airflow rate the relative humidity of the drying air was six points higher, which suggests that the higher airflow rate will be necessary to allow for the worst drying air conditions encountered.

Finally, a set of four trials was carried out in which drying was started at 0800, 1100, 1400 and 1700 hours, Table 3. The results clearly indicate that, in terms of drying time and rate of loss of moisture, it is advantageous to initiate drying in the later hours of the afternoon. Starting at 1700 hours makes best use of the night hours, when the relative humidity of the air is high, to remove moisture from the fresh cassava chips and then, on the second day of drying, the hotest hours are available to terminate the process.

As a means of comparing experimental results between trials, Table 4 brings together the data for four trials in which a loading of 125 kg/m^2 was used and the time of starting drying was 1400 hours. Comparing trials 1.4 and 2.4, in which airflow rate and drying air conditions were similar, it can be seen that

Table 2. Determination of optimum airflow rate

Trial	Drier loading kg/m^{2a}	Initial moisture content % dry basis	Time of starting drying h	Mean airflow rate m^3/min.m^{2b}	Maximum pressure drop ins w.g.	Conditions of drying air T°C	%RH	Drying time h^c	Rate of loss of moisture kg/h.m^{2d}
2.1	125.0	230	1400	18.3	0.31	24	71	48	1.82
2.2	125.0	190	1400	15.7	0.31	25	71	49	1.67
2.3	125.0	228	1400	12.5	0.23	27	62	71[e]	1.22
2.4	125.0	249	1400	11.3	0.29	26	65	49	1.82

a, b, c y d As in Table 1.

e In this trial drying was interrupted for 18 hours because of rain.

Table 3. Determination of the optimum time of starting drying

Trial	Drier loading kg/m2[a]	Initial moisture content % dry basis	Time of starting drying h	Mean airflow rate $m^3/min.m^2$ [b]	Maximum pressure drop ins w.g.	Conditions of drying air T°C	%RH	Drying time h[c]	Rate of loss of moisture kg/h.m2[d]
3.1	125.0	203	0800	15.6	0.32	25	72	54	1.55
3.2	125.0	209	1100	17.0	0.33	26	69	49	1.73
3.3	125.0	227	1400	17.3	0.30	26	67	47	1.85
3.4	125.0	214	1700	16.0	0.29	26	67	46	1.85

a, b, c y d As in Table 1.

Table 4. Effect of initial moisture content and airflow rate on drying time[a]

Trial	Initial moisture content % dry basis	Mean airflow rate $m^3/min.m^2$	Conditions of drying air T°C	 %RH	Drying time h	Rate of loss of moisture $kg/h.m^2$
1.4	178	11.2	27	66	45	1.78
2.4	249	11.3	26	65	49	1.82
3.3	227	17.3	26	67	47	1.85
2.1	230	18.3	24	71	48	1.82

[a] Drier loading, 125 kg/m^2; time of starting, 1400 hours.

the higher initial moisture content of the chips in trial 2.4 increased drying time by 4 hours. The considerable change that occurred in dry matter content of the fresh chips,which decreased from 36.0 to 28.7%,can be attributed to a change in climatic conditions. Roots for trial 1.4 were harvested during the dry season, whereas roots for trial 2.4 were harvested after the rains had begun. The rains stimulated growth, causing the breakdown of root starch to sugars and their transport to the aerial parts of the plant. This is a phenomenon that should be taken into account in planning root supply to a processing plant, as changes in dry matter content could effect the profitability of the process; the decrease in dry cassava yield per ton of fresh roots can be as great as 20%.

The effect of a high airflow rate on drying time and rate of loss of moisture can be appreciated by comparing trials 2.4, 3.3 and 2.1. The higher airflows in trials 3.3 and 2.1 were sufficient to reduce drying time and maintain rate of loss of moisture even though the relative humidity of the drying air was higher in these two trials.

An important parameter for selecting an appropriate fan for the drying system is the pressure drop through the drying bed; this never exceeded 0.33 inches water gauge. It was observed during the drying trials that the pressure drop decreased during drying as the resistance to airflow was reduced, presumably because the chips, on losing moisture, lost their tendency to adhere to one another. There was also a noticeable shrinking of the drying bed, for a drier loading of 125 kg/m^2, the thickness of the layer of cassava chips decreased from approximately 250 mm to 180 mm.

The detailed evaluation of the solar collector has not been concluded. However, during the period of these trials the collector gave average increases in air temperature of between 1 and 3°C, corresponding to reductions of between 4.4 and 9.6% in relative humidity. It has yet to be determined whether the additional cost of the solar collector is justified in terms of increased drier loading, as compared with drying using ambient air alone.

Future work and conclusions

These preliminary results have indicated that basically two areas require further investigation. Firstly, a comparison of one and two day drying needs to be undertaken, as the former may be more convenient in terms of root supply to the processing plant and will definitely produce dry cassava of a higher visual quality. It had been hoped to evaluate the quality of the dried product by measuring the condensed tannin content, whose production during drying could account for the brown discolouration observed. Unfortunately the high tannin content of the periderm (bark) interfered with the results. Secondly, in order to make better use of the drying capacity of the air, which after a certain drying period leaves the drying bed unsaturated, a double bed bin or a two bin reversible airflow system will be tested.

Although it is evident that further development work still needs to be carried out, the results obtained from these trials have shown that at a drier loading of 125 kg/m^2 and an airflow rate of 18 m^3/min.m^2, it is possible to dry cassava chips in two days, using solar heated air at average temperatures ranging between 24 and 28°C and relative humidities in the range 62 to 72%. This is equivalent to a requirement of 8 square metres of drying floor and 146 cubic metres per minute of airflow for each ton of cassava chips to be dried.

References

Akhtar, J. Drying of cassava with heated air. Asian Institute of Technology. AIT Thesis No. AE-78-5. 1978. 47p.

Best, R. Cassava processing for animal feed. In Cassava harvesting and processing: Proceedings of a Workshop held at CIAT, Cali, Colombia. 24-28 April 1978. Ottawa IDRC-114e, 1978. 12-20.

Chirife, J. and Cachero, R.A. Through-circulation drying of tapioca root. Journal of Food Science. 35, 1970.364-368.

Crown, F. White elephant tales: Venezuela's cassava processing plants. Agribusiness Worldwide. Dec. 1980/Jan. 1981. 24-29.

Freivalds, J. Farm fiction: the feasibility studies for cassava production and processing in Espiritu Santo, Brasil. Agribusiness Worldwide. 3(6), 1982. 10-13.

Ospina, B., Best, R. and Gómez, G. Natural drying of cassava for animal feed - the establishment of small scale agroindustries on the Atlantic Coast of Colombia. Paper to be presented at the 6th Symposium of the International Society of Tropical Root Crops. Lima, Peru. February 21-26. 1983.

Ospina, V.E. Quantifição da deterioração de mandioca durante a secagem em barcaça por convecção forçada de ar aquecido com coletor solar. Tesis de Maestría, Universidade Estadual de Campinas, Faculdade de Engenharia dé Alimentos e Agricola. 1980. 100 p.

Pachico, D. Prospects for the feeds concentrates industry in Latin America: Market potential for Colombia. Centro Internacional de Agricultura Tropical, CIAT, Cali, Colombia. Internal Document. March 1980. 24p.

Roa, G. Natural drying of cassava. Ph.D. Thesis. Department of Agricultural Engineering. Michigan State University. 1974. 234 p.

Rossi, S.J. y Roa, G. Secagem e armazenamento de produtos agropecuários com uso de energia solar e ar natural. Secretaria da Industria, Comercio, Ciencia e Tecnología. Academia de Ciencias do Estado de Sao Paulo. Publicación ACIESP No.22. 1980. 295 p.

Sinicio, R. and Roa, G. Secador Rural de Café, Cacau, Mandioca e outros produtos agropecuários com uso de energia solar. Centro Nacional de Treinamento em Armazenagem, CENTREINAR, Viçosa-Brasil. Serie Centreinar No.1. 1980. 22 p.

Thanh, N.C., Muttamara, S., Lohani, B.N., Rao, B.V.P.C. and Burintratikul. Optimization of drying and pelleting techniques for tapioca roots. International Development Research Centre - Asian Institute of Technology. Final Report No. III. Bangkok, Thailand. 1979. 119 p.

Webb, B.H. and Gill, K.S. Artificial heat drying of tapioca chips. Malaysia Agric. Res. 3.1974. 67-76.