DRYING OF ROBUSTA COFFEE IN UGANDA USING SOLAR HEATED AIR

Wilfred R Odogola*, Sam Oinya** and Uringi Okello***
* Agricultural Engineer, (Research and Development), National Research Council, PO Box 6884, Kampala
** Post-harvest Scientist, National Research Council of Uganda.
*** Biochemist (Quality Controller), Coffee Marketing Board of Uganda.

ABSTRACT

This paper discusses the use of low-temperature solar heated air for drying coffee berries. In comparison to open-sun drying, this method affords higher drying temperatures which considerably reduces the length of the drying period. Test results, using a tray type dryer are presented. A natural-convection chimney aided batch type solar dryer, is proposed for the typical rural setting.

INTRODUCTION

Coffee has been the most important cash-crop since 1955, of late contributing well over 95% of the foreign exchange earnings of the country. Harvesting of the crop is spread throughout the year with harvest peaks in November-December and January-February for Robusta and Arabica respectively, the two main coffee varieties grown in the country.

The peak harvests generally coincide with months of frequent rainfall and thus of inclement weather conditions. This very often makes it difficult for the farmer to harvest, handle and safely dry the large volume of the readily perishable crop ("kiboko") from the normally high moisture level of up to 65-68% (wb), down to the safe-storage moisture level of 12% (wb). In addition to climatic problems, common to the Robusta growing areas in E Africa, labour during this period is scarce, being thinly divided between numerous other agricultural, farm and household operations.

This explains why a large portion of the "kiboko" delivered by individual farmers to the processing factories usually has a moisture content as high as 13 to 15% (wb) (Cowie 1963) and during years of bumper harvest, up to 16% moisture. Thus further drying is necessary at factories. Provision of a cheap, simple and reliable artificial drying technology at the grass-root level, would relieve the cooperative unions and the Coffee Marketing Board (CMB) from the task of re-drying the fairly high moisture crop received.

CURRENT PROCESSING AND DRYING PRACTICES

Wet processing

Coffee is normally either wet- or dry-processed. Processing by the wet method starts by selectively harvesting the crop in the "red-ripe" stage (60-65% moisture wb) and preliminary grading of berries by sorting and "floating" in water. Good red-ripe healthy berries are subsequently pulped, fermented, washed and drained before drying. Compared to dry-processed crop, pulped and washed coffee is generally credited for its cleaner flavour, delicacy and fineness, and for freedom from undesirable elements. However, wet-processing requires capital equipment and clean water in quantities normally beyond the reach of a small scale farmer. In Uganda wet-processing has, therefore, until recently, been mainly confined to the Arabica crop at estates.

Dry-processing

Robusta, representing 90% of the total coffee crop in the country, is an exclusively small holders' crop. Harvesting, particularly during the peak period, is still largely indiscriminate: involving mere stripping or "milking" of the bearing branches. The heterogenous mixture of coffee berries, with a moisture range of 30-65% (wb) is then traditionally dry-processed in the cherry by the individual producers themselves, quite often without any sorting.

During the late 1960s, considerable attention and encouragement was given to wet-processing of the Robusta crop in the country (Anon 1964; Krug, 1968) in an effort to improve its marketing power and quality. These efforts were, however, abandoned due to the economic situation prevailing in the country during the 1970s.

More than half of the coffee bulk worldwide, both wet- and dry-processed, is still dried in the open sun (Haarer 1962). This process involves spreading the crop thinly on firm bare ground, on mats/sacks simply laid on the ground, or at best, on a cement surface or special raised wire-bottomed wooden trays.

Although the process appears cheap, it calls for large areas of drying space and is extremely labour intensive and slow. Drying, according to Cowie (1963), can take anything from 3 to 5 weeks to complete, depending on climatic conditions, the method of drying and the care taken. Often with poor handling, the crop is exposed to contamination which taints the flavour. It is also difficult to inhibit the growth of molds and microorganisms. The "mustiness" caused is the most serious taint of dry-processed Robusta coffee in Uganda and has in recent years been responsible for depreciation of the coffee export from the country.

Mechanical dryers

When fossil and wood fuels were cheap and plentiful, mechanical dryers using these fuels gained acceptance in the coffee industry in Uganda, for direct or indirect heating of air for drying (Sivetz 1963; Ghosh 1966). At present day costs of these fuels, coupled with their scarcity and because of the impracticability of employing electrical dryers in rural areas where coffee is produced, it is essential to seek alternative energy sources for drying coffee (and other perishable agricultural crops).

This paper discusses the applicability of solar heated air to the drying of Robusta coffee in Uganda. Literature reviews (Allan 1965; Anon 1980, 1982) indicate that solar energy offers major potential as an improved and cheap method of crop drying, particularly in less developed countries of the tropics with abundant solar radiation - a cost-free source of energy.

DESCRIPTION OF APPARATUS AND INSTRUMENTATION USED

Experimental test rig

The experiments reported here were carried out during the 1983-84 coffee season, using an indirect tray solar dryer, designed and constructed at Kabanyolo University Farm, near Kampala. The test rig (Figure 1) consisted of a four-legged, box-like, wooden drying bin housing four independently movable wire-bottomed trays for the crop. The roof was of iron and a tall chimney aided air flow through the system. The drying trays were served by two flat-plate solar collectors positioned symmetrically along the East-West trajection, such that the sun rises on one side, passes almost vertically over both collectors, and sets on the other side. This arrangement is only suitable for locations very close to the equator.

Each of the collectors consisted of a blackened corrugated iron sheet (absorber) suspended between a corrugated sheet of clear fibre glass (heat trap) to the top, and a 50mm thick coffee-husk insulation sandwiched between two plywood sheets to the bottom

The solar dryer is simple both to manufacture and to operate, and the main construction materials can be obtained locally. The one major component not locally available is the axial flow fan. Consequently, this is the most expensive single unit of the system. Basic dryer parameters and technical data are given below:

Basic dryer parameters

1.	Solar dryer system	
	- total length x width x height	6.4 x 3.66 x 3.85m
2.	Solar collectors (two)	
	- aperture area: 2(2 x 2.275)	9.1 m^2
	- optimum tilt angle	15°
	- predicted mean power rating	7.5 kwh/day m^2
	- predicted mean efficiency	50%
3.	Drying trays (four)	
	- length x width x depth	1.16 x 1.04 x 0.25m
	- max. volume: 4 x 0.3	1.2 m^3
4.	Axial flow fan/electric motor	recommended/available
	- volumetric flow rate	950-1000 m^3/hr; (405) m^3/hr
	- static pressure	0.5-0.75" H_2O
	- power rating	0.75-1.0 kw; (0.25) kw

Operation principle

During operation, low temperature ambient air was forced, by means of an axial flow fan driven by a fractional horse-power electric motor, through a wooden T-junction air ducting unit. The air was then forced through the collectors where it was solar heated before going through the crop in the bin. Each of the collectors was optimally tilted for maximum collection of solar radiated energy particularly during the peak harvesting/drying period.

Instrumentation

To assess the performance of the solar dryer system throughout an experimental day, as the sun elevation and azimuth vary and weather conditions change, frequent and continuous observations of relevant meteorological states and temperatures of the working fluid and of the drying crop were made.

Table 1 gives ten-year mean values of the various meteorological elements for Kabanyolo University Farm. The dryer design was based on these data. Other important factors in the design were: crop type, chemical composition, and size of operation; harvest season, quantities handled, etc.

EXPERIMENTAL PROCEDURE AND METHOD

Coffee used in this experiment was indiscriminately picked by farm workers. Prior to each test run, therefore, the heterogeneous mixture of berries was roughly sorted into two main moisture groups, ie 30-55% and 55-65% moisture (wb). The latter batch was used in these studies.

A 180-200 kg sample of berries was cleaned of all extraneous material and divided into four equal sub-lots for drying in the four wire-bottomed trays. A similar sample was uniformly spread, single layer, on a cemented drying floor (barbecue) to sun-dry as a "control".

Each day's test run normally lasted from 8.00 or 9.00 hours to 17.00 or 18.00 hours, depending on weather conditions. During test runs, various readings were taken either hourly or automatically recorded in graph or table form through instantaneous prints. The major parameters recorded, including details of locations and instrumentation employed, are summarised in Table 2. The fan was turned off whenever it started raining. At the end of a test day, trays were unsealed and the coffee in each tray thoroughly stirred prior to sampling for moisture level determination using a standard oven method described in Sivetz et al. (1963).

RESULTS AND DISCUSSION

Working fluid temperature variations

Changes in temperatures of air within the dryer, the crop and ambient air are shown in Figure 2 and 3 for a typical sunny day. Figure 2 represents findings for a typical day during which a fan was employed. The ambient air temperature and at various locations in the dryer system, were very similar. That of the crop bulk in the bin, on the other hand, was slightly higher than the rest indicating that the batch, after the previous day's run, does not totally cool down to the ambient air conditions at night.

As the solar radiation gradually intensifies during the day air temperatures in all parts of the system rise, reaching their peak at approximately 13.00 hours. Thereafter, the temperatures dropped almost symmetrically. The maximum difference in temperature between the ambient and the air inside the collector, ranged from 15° to 20°C, while that between the ambient air and the crop ranged from 8° to 12°C. The latter greatly depended on the drying stage: being lowest when the crop was wettest (effects of self evaporative cooling by the crop), and vice versa.

Whenever the fan was not employed (due to power failure, for instance), air temperatures inside the collector increased to nearly 80°C for a typical ambient air temperature of 25°C. At the same time, the crop temperature rose only slightly above the ambient. This suggests that without the fan very little of the solar heated air passes through the crop. The drying rate, consequently, was reduced more than two-fold, as compared to not using the fan.

Collector performance

Table 3 summarises the performance of the collector during a typical sunny day. In determining the efficiency of the collector, hourly ambient air temperature and mean hourly temperature rises inside the collector were used. With hourly solar radiation values known, the total theoretical energy collected by a collector of known aperture area, was evaluated hour by hour. The flow rate of the fan was taken to be approximately 95% of the fan flow rating: the difference accounting for air leakages through cracks and joints in the system. Collector efficiency was then determined, according to Mrema (1982), as the ratio of extracted energy to incident solar energy, per unit of collector.

For a typical sunny day, during the period of peak harvest, the collector was found to have an efficiency ranging from 10% at the start of the day, to 34% at peak performance; the mean being 25%. Further, the temperature rise and relative humidity were well within the required limits for a single glazed flat plate collector. On an overcast and cloudy or rainy day, the average collector efficiency was reduced to a mean of less than 10% and the changes in temperature and relative humidity were not as satisfactory as might be desired. However, the drying rate was still better than for open sun-drying. The efficiency-time relationships are shown in Figure 4.

Moisture removal pattern during drying

Coffee well picked and dried in cherry, has an initial moisture level of 60-65%, as compared to the 50-54% moisture (wb) obtained in coffee pulped, fermented, washed and drained. When properly dried, the final moisture of the parchment, in both cases, should be 12% (wb). This reduction of moisture under conditions which will not harm the inherent qualities of the coffee is achieved by artificial or sun drying. Figure 5 shows the aviation of moisture of the robusta crop, dried in cherry.

During the initial drying stage, wet coffee readily looses moisture to the drying air. The process proceeds at a more or less uniform rate until the moisture level of 25-20% (wb) when the process gradually slows down towards the 12% moisture level. The gradual slowing down of water-rate loss occurs as the slimy, sticky mucilage that covers the seed, also starts drying; being much more impermeable to moisture the drier the coffee becomes.

For the test runs carried out during the 1983/84 coffee season, the period taken for the 180-200 kg batches to dry ranged from between nine days to sixteen days, each of approximately 8 hours of drying.

Coffee quality: its relationship to drying

Coffee is a commodity which suffers from world over-production. Naturally, therefore, buyers can afford to be very selective and coffee offered for sale must be attractive with liquoring attributes positive enough to readily win consumer acceptability.

Drying of the crop is among the most important factors contributing to quality. Too slow a drying rate, with poor handling, causes mustiness and provides opportunities for a number of off-flavours. Drying the crop too fast and at temperatures higher than 60°C, results in case-hardening, bleaching of the berries to chalky-white, and browning of the roast, with consequent loss of aroma. Failure to dry the crop to correct moisture levels, a process typical for traditionally dried robusta crop, breeds numerous handling and storage problems, resulting in very rapid deterioration of what would even have been regarded an excellent coffee product.

In Uganda an individual farmer handles the crop from the farm up to the point of hulling, either by a co-operative union or a licensed private processor, who then sells the crop to the Coffee Marketing Board (CMB) of Uganda. At the board, the coffee is tested for: moisture level, "defective" counts and size grades. Figure 6 gives the mean percentages of the robusta coffee received by the CMB (1979-1984) together with respective percentage-moisture levels. It is noted that less than 20% of the crop brought to the board actually satisfies the 12% moisture requirement by the board. More than 55% is received with moisture ranging between 13-16%, with mean moisture levels higher than 13%, prevailing during periods of peak harvests.

In a bid to combat this problem, the board imposes a monetary penalty on all coffee received at excess moisture, as follows: 7,000 Sh/ton; 10,000 Sh/ton; 17,000 Sh/ton and 22,000 Sh/ton respectively, for moisture levels of 12-13%; 13-14%; 14-15%; and 15-16% (wb). This practice has not been able to avert the problem particularly during peak harvest.

Grading coffee based on screen size

Table 5 shows the percentage weight of an average farm coffee produced from each screen size after the processing has been completed in the CMB. From the table, it is noted that Uganda's robusta crop is good, with the advantage that 25% is classed as "grade A" quality, and only 7% being graded as triage.

TABLE 5: Grading through screening

Grade		Screen size in 64th of an inch	Percentage production
1	A	17 and above	25
2	B	15 and 16	27
3	C	12, 13 and 14	21
Triage	Z	Below 12	7

Grading based "defective" counts

Based on defective counts, Appendix 1 shows the grading of coffee received by the CMB during the 1983-1984 coffee season; the defectives being dominated by those due to poor drying. It is noted that nearly all the coffee brought to the board falls within the "fairly average quality" (FAQ) classification. This stresses the importance of producers and owners of coffee co-operative unions, improving their methods of processing, particularly harvesting, handling, drying and storage of the crop.

Liquoring quality

Poor drying has negative effects on the liquoring quality of coffee. This is normally detected by smell and taste, and together with other coffee attributes, determine the price to be paid to thelocal marketing agents. After these have been paid their monetary dues, efforts are made by the board to improve the liquoring quality through "bulking", ie mixing various grades of coffee to obtain uniform appearance and cup taste to orient the crop for a particular market.

CONCLUSIONS

As previously stated, weather conditions and drying space can make sun-drying of coffee wet- or dry-processed, impractical. To ensure high produce quality under these circumstances, farmers and estate owners will have to consider some form of artificial drying. The use of solar energy for coffee drying promises a feasible answer towards improvement in quality.

Uganda robusta is naturally good with advantage that approximately one quarter of the crop consists of bold beans retained by screen 17. The coffee when well dried and standard-roasted also affords a brilliant uniform roast, with rich heavy body - basic characteristics of good cup quality. It is therefore, up to the grower and processor to ensure that these natural quality attributes of Uganda robusta are amplified, and that by improved processing methods, particularly drying, the crop is afforded all the chances for better competition in the now discriminate and congested world coffee market.

ACKNOWLEDGEMENT

The UK Overseas Development Administration through CSC, and the Uganda Government through the NRC, provided all the financial and material support for the experimental work; while the Faculty of Agriculture, Makerere University, provided the test site and facilities for the work.

BIBLIOGRAPHY

Allan L P, Drying of coffee with solar heated air, Solar Energy Vol IX, No 4, 1965.

Anon, Agricultural production programme 1964, Min. of Agric. Uganda Gov. Printers, Entebbe.

Anon, Caribbean Alternative Energy Programme. Report of the Workshop on Solar Crop Drying; CSC (80) AEP-10 Barbados, 21-23 July 1980. Commonwealth Secretariat.

Anon, African Energy Programme; Report of a Workshop on Solar Crop Drying; Nairobi, Kenya 11-13 Oct., 1982 Commonwealth Secretariat CSC (82) AEP-10.

Cowie J T, Robusta Coffee. A guide to better processing in Uganda. Min of Agriculture, 1963.

Ghosh B N, A review of the mechanisation problems of coffee processing in East Africa, Kenya Coffee, No. 35, pp 245-254, 1966.

Ghosh B N, Airflow characteristics of parchment coffee beans, J. Agric. Eng. Research, No 45, 11; pp 233-237, 1966.

Haarer A E, Modern Coffee Production. Leonard Hill Ltd., London, 1962.

Krug C A, World Coffee Survey. FAO, Rome, 1968.

Mrema G C, Development of standard test methods for evaluating the performance of solar crop dryers. Paper presented at the Workshop on Solar Crop Drying. Nairobi 11-13th Oct, 1982.

Odogola W et al. Solar drying of agricultural produce in Uganda under the AE-Programme: Progress and Potentials. Paper presented at the AEP Review meeting. Harare, 15-20th October 1964.

TABLE 1: Ten year mean values for meteorological parameters at Kabanyolo University Farm

Meteorological parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Whole Year
Solar Radiation (Langleys/day)	416	401	416	400	384	364	347	367	400	410	395	402	397
Sunshine hours (daily)	7.3	6.6	6.3	5.8	6.2	6.3	6.0	5.9	5.9	5.8	5.9	6.6	6.2
Maximum Temp (°C)	28	28	27	26	26	26	26	26	27	27	26	27	27
Minimum Temp (°C)	16	16	17	17	17	16	15	15	16	16	16	16	16
Daily Mean Temp (°C)	22	22	22	22	22	21	21	21	21	21	22	21	21
Relative Humidity (% at 0900)	88	89	90	92	91	91	92	92	90	89	90	89	90
Relative Humidity (% at 1500)	58	61	66	72	72	68	66	66	65	68	69	64	66
Precipitation (mm)	65	77	138	197	128	74	56	77	104	130	177	99	1322
Pot: Evapotr (mm) Penham	145	130	143	129	124	114	116	121	137	134	125	135	1553
Wind speed (m/s)	1.2	1.3	1.3	1.3	1.2	1.2	1.1	1.2	1.2	1.2	1.1	1.1	1.2

TABLE 2: Summary of major parameters recorded with respective locations and instrumentation

	Parameter and location	Instruments used	Remarks
1.	Temperature - of inlet ambient air (db & wb) - of ex-collector air (db & wb) - of centre of drying crop (db)	J-type copper/constantan thermocouple junction (wet-thermocouple provided with a thin wetted cotton wick)	Readings every minute printed in graphic form by a 6 point recording pontentiometer
2.	Insolation level in the plane of collector	Dome shaped solarometer with volt-time solar integrator, "Mark V"	Readings remote-record-printed as integrated hourly values (W/m^2 hr)
3.	Moisture content of drying crop	Gallen Kamp Oven, 250°C	Oven method recommended for coffee as in Sivetz (1963)
4.	Static air pressure (laterally across collector)	A 15° inclined manometer and pitot tube	Manometer probes linked 15-20 cm from collector inlet and exit
5.	Relative humidity - of ambient air - of air leaving bin	A polymeter	Suspended under a well ventilated shade nearby, and at bin air exit
6.	General weather conditions - wind speed and direction - rain and cloud cover - others of interest		Reading from the farm Meteorological station, located approx 400m away

TABLE 3: Collector performance during a typical sunny day: November 1983

Hour	Hourly Temp ^{o}C	Mean hourly Temp rise ^{o}C	Hourly R H (%)	Hourly Rad (KW/M^2)	Integrated rad (Kwh)	Energy gain (kwh)	Collection efficiency %
8 - 9	19	1.5	85	0.225	2.05	0.21	10.25
9 - 10	22	7.5	78	0.530	4.82	1.03	21.37
10 - 11	25	14.5	66	0.813	7.40	2.00	27.06
11 - 12	26.5	21.0	57	0.972	8.85	2.89	32.66
12 - 13	28.5	22.0	53	0.978	8.90	3.03	34.04
13 - 14	27	13.0	55	0.686	6.24	1.79	28.69
14 - 15	27.5	14.0	56	0.716	6.52	1.93	29.60
15 - 16	24	7.0	61	0.477	4.34	0.96	22.12
16 - 17	22	3.0	69	0.238	2.17	0.41	18.89
TOTAL	–	–	–	**5.635**	**51.29**	**14.25**	-
MEAN	**24.6**	**11.5**	**64.4**	**0.626**	**5.70**	**1.58**	**24.95**

Remarks: Flow rate: 405 x 95% = 384.75 m^3/hr = 492.48 Kg/hr = 0.1375 Kw/hr.

Clear day throughout with light NE - Wind; Maximum/Min ambient temperature respectively: 28.5^{o}C/19 ^{o}C.

FIGURE 1: Tray solar drier

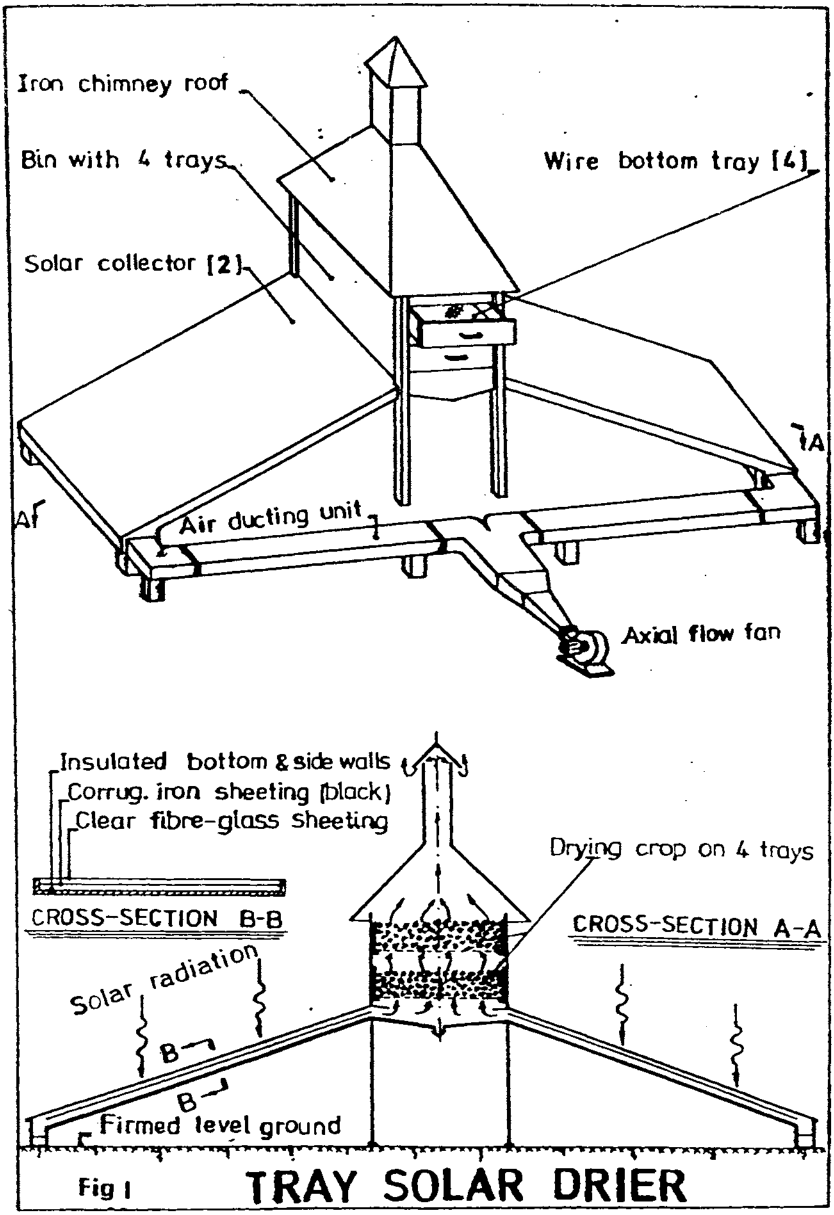

FIGURE 2: Variation of temperature with time of day (fan employed)

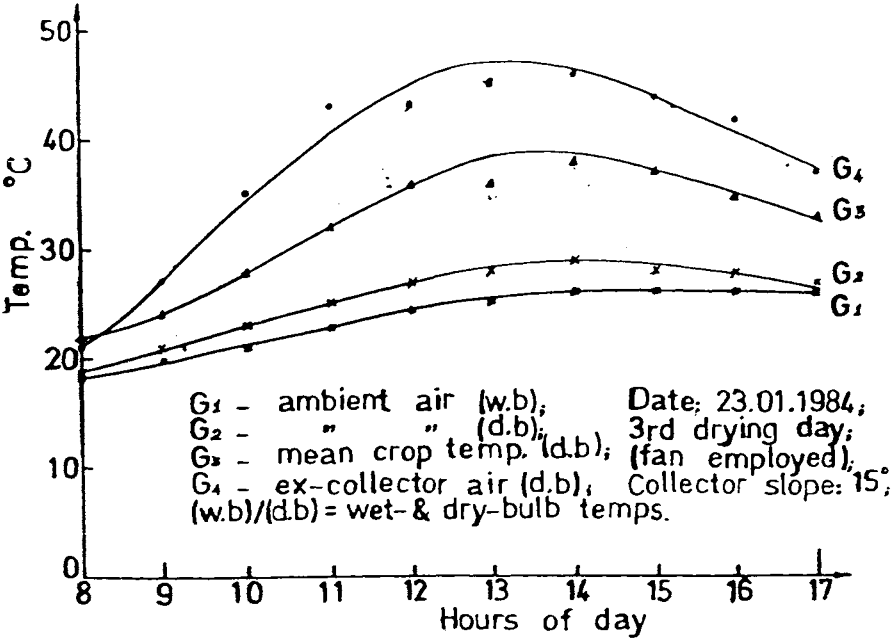

FIGURE 3: Variation of temperature with time of day (fan not employed)

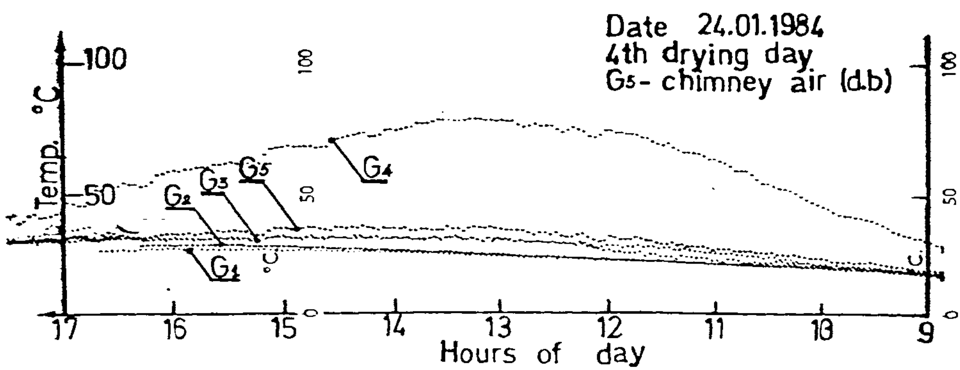

FIGURE 4: Efficiency-time relationship

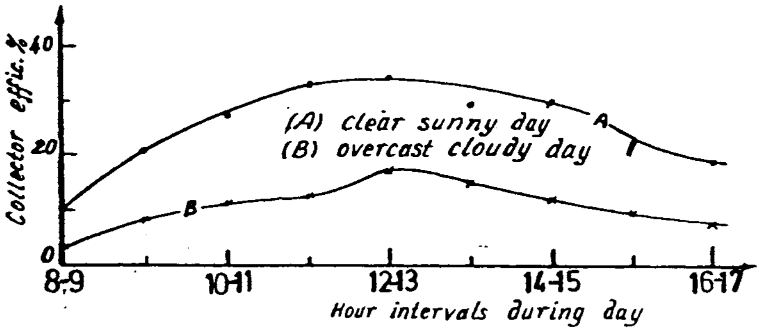

FIGURE 5: Moisture loss pattern