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# THE PERFORMANCE OF A COCOA BEAN SOLAR FERMENTING/DRYING SYSTEM FOR SMALL FARMERS

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**ABSTRACT.** Common methods used by farmers to ferment small lots of wet cocoa beans are the heap and basket methods. However the quality of dried beans produced after such fermentation is variable as small bean masses are unable to attain and maintain the normal temperatures of 46-50°C as obtained during large, commercial fermentations. For fermenting small quantities of cocoa beans Mc Donald (1936) and later De Witt (1954) proposed a solar fermentary/frame, essentially a solar cabinet, in which hot, solar heated air is used to heat the beans held in wooden, sweat boxes or to reduce heat losses from such boxes. Quesnel and Lopez (1975) later recommended the use of insulated, styrotex boxes for fermenting small lots.

These methods are brought together in this study, as a solar, cabinet fermentor/dryer 1.58 m (width) x 0.90 m (height) x 1.15 m (depth) with a 10° to the horizontal sloping glass cover was constructed and tested both for fermenting approximately 20 kg batches of cocoa beans placed in styrotex or wooden sweat boxes, and later for drying the beans on three drying trays placed in the cabinet. Normal fermentation temperatures were achieved over 7 and 8 day runs, while beans dried to the desired 6-7% moisture content over 6 and 9 day drying runs. Excellent quality dried beans (plantation grade) were obtained in this fermentation and drying system.

## INTRODUCTION AND LITERATURE REVIEW

The seeds from freshly opened, ripe cocoa pods are enveloped in a white, mucilaginous pulp having a slightly acid flavour and a fairly high content of fermentable sugars. Through fermentation and subsequent drying of such seeds, commercial cocoa beans with an optimum moisture content of 6-8% are obtained. It is known that with proper fermentation the astringent and bitter taste of the beans is improved and the purple internal colour of the raw beans changes towards a brown or cinnamon colour. Fine, aromatic odour characteristics are also developed and when dried beans are cut open, large inter spaces are seen with a fissured appearance, with the beans having a good "break" (De Verteuil, 1933). In Trinidad, fermentation is carried out on the large estates in sweat boxes which can have dimensions 1.2 m x 1.2 m x 0.9 m, holding as much as 1000 kg of wet beans with fermentation lasting 6-8 days, and with the beans being turned every other day (Cocoa Research Unit, 1987). The temperature of the bean mass in the sweat boxes is a key indicator of the progress of fermentation. In a normal, commercial fermentation in Trinidad, it was reported (Haworth, 1952) that the beans mass temperature rose from 33.3°C to 48.8°C in just over two days, dropping to 44.5°C by the third day. After turning, the temperature quickly rose to 50.0°C dropping to 48.3°C by the fifth day. After turning again, temperatures were not so high, with beans cooling to 46.1°C by the seventh day. The temperature range of 46 - 50°C results in fermented cocoa beans of good quality.

The fermentation of small batches of cocoa beans, as required by small farmers and often practised in covered baskets or heaps, poses special problems. In order to obtain uniformity of fermentation, a sufficient weight of beans is needed to develop the exothermic heat necessary to bring about the death of the embryo. With significant cooling of the bean mass and dehydration of the beans occurring in small lots, the temperature of the bean mass does not rise to the desired level, and incomplete fermentation with inferior product quality obtains (Palma, 1951). McDonald (1936) and De Witt (1954) explored the concept of a "Solar fermentary" for fermenting small quantities of cocoa beans. This consists of a thermally insulated, sloping glass-topped box or cabinet, wooden sided and painted black. In this cabinet are placed small wooden fermentation boxes of 0.3 x 0.3 x 0.3 (m), each provided with lids and drainage holes at the bottom for the sweatings. Solar radiation is trapped within the cabinet, with daytime temperatures of 35°C-65°C obtained in the cabinet and around the fermentation boxes. This heat is used to warm the beans and/or reduce heat losses from the fermenting boxes. McDonald (1936) noted that small quantities of beans (18 kg) fermented in this manner for 11-13 days showed maximum temperatures of 49°C-51°C, whereas boxes outside of the cabinet (ambient conditions) attained maximum temperatures of 42°C-44°C. Well fermented cocoa beans were obtained from the fermentary.

It appears that this solar assisted method of fermentation was confined to experimental rather than practical use. Quesnel and Lopez (1975) proposed the use of small, commercial styrotex sweat boxes for fermenting small batches (10 kg-20 kg) of cocoa beans. They noted that in the styrotex fermentor, temperatures may be slightly lower than obtained in good, large scale commercial fermentations, but were nevertheless satisfactory. In more recent times, solar drying of agricultural produce has become popular, and the natural convention, solar cabinet dryer, as described by Lawand (1967) has essentially the same features and principle of operation as the solar fermentary, previously described. While drying of cocoa beans to 6-7 % moisture after fermentation is practised either by sun drying (7-10 days) or artificial, heated air drying (1-2 days), there is a widely held view that slowly dried beans are of better quality and are more aromatic, as during slow drying certain beneficial reactions which occur during fermentation continue, especially oxidation of the tannins, improvement in colour and aroma. (De Verteuil, 1933; Palma, 1951).

The objective of this work was therefore to design, fabricate and test Mc Donald's solar fermentary principle, but to use the fermentary also as a solar, cabinet dryer.

## MATERIALS AND METHODS

**The solar cabinet fermenter/dryer:** A solar, cabinet fermentary/dryer (Figure 1) modified from the version of De Witt (1954) was built and tested. A wooden frame, made from 5 cm x 5 cm pitchpine was cladded on all four sides with 1.875 cm plywood. Sliding gates were placed at the bottom, front end and the top, rear side of the cabinet to allow for air movement by natural convection. The top of the cabinet consisted of two hinged, wooden-framed glass doors, and was sloped at 10° to the horizontal to maximise the collection of solar radiation. The bottom of the cabinet consisted of a corrugated, galvanize absorber. Two wooden planks were fixed edgewise along the bottom of the cabinet, and 25 cm above the absorber to support the sweat boxes and later the drying trays.

**The sweat boxes and drying trays:** Three sweat boxes were used in this study, two styrotex boxes of dimensions given in Figure 2, and as described by Quesnel and Lopez (1975) and a wooden, 2.5 cm thick box made of white pine wood. Holes of 1 cm diameter and 2.5 cm apart were drilled at the bottom of all boxes. Each box had close fitting lids, with a 0.8 mm hole drilled at the centre of each lid for the insertion of a thermocouple wire. All boxes were painted, flat black on the exterior. Three drying trays, 30 cm wide x 90 cm long x 10 cm deep, wooden sided and having 0.62 cm square wire-meshed base for supporting the layer of beans to be dried, were also fabricated.

## PROCEDURE

Cocoa pods were obtained from a large estate in Biche, Trinidad and were cracked and gutted so that 16 kg of beans could be placed in each of the three sweat boxes to be fermented. Boxes were ¾ full. One wooden and one styrotex sweat box were placed inside the cabinet, while the other styrotex box was placed under ambient conditions. Plastic trays were placed under each box in the cabinet to collect the "sweatings". The beans were allowed to ferment over a 7-day period and this was followed by solar, cabinet drying over a 6-day period. At 2-day intervals, beans in the boxes were aerated by turning them out into trays, manually mixing them and then returning them to the sweat boxes. After fermentation, the beans from each box were placed in one of the three drying trays for solar drying, and this was allowed to continue for eight days. Beans on the drying trays were manually turned three times a day. During fermentation all vents were closed, while during drying vents were half-opened. This was the first run. The trials were repeated a second time (second run), with 21.3 kg fresh beans per sweat box. Boxes were filled. Fermentation occurred over an 8-day period followed by solar drying over nine days.

## MEASUREMENTS

The temperatures at the centre of each sweat box, cabinet temperature and ambient temperature were measured at one hour intervals (through thermocouples) each day between 8:00 a.m. and 5:00 p.m., and at 12:00 midnight. Solar radiation and relative humidity were also measured. From daily samples of beans taken from the boxes, % moisture content, % weight loss, % volume change, colour of pulp and cotyledon, shape of beans and appearance of cotyledons were obtained. During drying, the moisture content of the beans were determined, daily at 8:00 a.m., 12:00 noon and 5:00 p.m. At the end of the fermentation and drying run, a cut test was performed (Cocoa, Chocolate and Confectionery Alliance, 1984) in order to determine the % purple, % partly purple and % brown beans. Samples from each box were also sent to the Cocoa and Coffee Industry Board of Trinidad and Tobago, for commercial grading.

## RESULTS AND DISCUSSION

**Fermentation temperatures:** The most useful index of the progress of the fermentation of the cocoa beans is the temperature attained in the bean mass. As stated earlier, in good commercial fermentations, temperatures of 46°C-50° are attained in about three days and this may be maintained for several days longer. Figure 3 shows the temperature profiles of the bean masses in the three boxes, for the duration of the fermentation process and for the two runs. Fermentation began at noon on the first day, and the beans were turned at 9:00 a.m. on the third day (45 hours) and 10:00 a.m. on the fifth day (94 hours) for the first run. The second run began at 3:00 p.m. of the first day and the beans were turned at 5:00 p.m. on the third (50 hours) and fifth (98 hours) days. Turning together with the diurnal changes in ambient temperature may be attributed to the cyclic nature of the temperature profiles of Figure 3.

The results indicate a steady rise in temperature of the bean masses within the first two days of fermentation, except for the temperature drops resulting from opening and turning of the beans. During this period the temperatures in the boxes were of the order: wooden box (WB-in) > styrotex box (SB-in) > styrotex box (SB-out) for run 1 and styrotex box (out) > wooden box (in) > wooden box (in) for run 2. Temperatures were 48.4°C (WB-in), 45.2°C (SB-in), 44.8°C (SB-out), at 49hours in run 1 and 43.9°C (SB-out), 41.3°C (WB-in), and 38.8°C (SB-in), at 50 hours in run 2. Maximum temperatures were 50.9°C (SB-out), 51.0°C (SB-in), and 48.4°C (WB-in), after 53 hours, 52 hours and 49 hours respectively in run 1and 51.6°C (SB-out), 51.8°C (SB-in), and 51.7°C (WB-in) after 65 hours, 146 hours and 122 hours respectively in run 2.

TABLE 1. *Weight and moisture loss during the fermentation of cocoa beans in boxes in and out of the Solar, Cabinet fermenter*

| *FERMENTATION TIME (h)* | *FERMENTATION BOX TYPE* | | | | | |
|---|---|---|---|---|---|---|
| | *STYROTEX IN* | | *STYROTEX OUT* | | *WOODEN IN* | |
| | Moisture Content (%) | Weight Loss (%) | Moisture Content (%) | Weight Loss (%) | Moisture Content (%) | Weight Loss (%) |
| 0 | 54.4 | 0.0 | 54.4 | 0.0 | 54.4 | 0.0 |
| 24 | 54.2 | 12.8 | 54.4 | 13.9 | 50.6 | 15.5 |
| 48 | 53.6 | 19.6 | 54.1 | 23.3 | 51.7 | 16.7 |
| 72 | 51.8 | 23.5 | 50.4 | 19.2 | 51.2 | 18.7 |
| 96 | 71.7 | 17.3 | 50.1 | 20.5 | 45.7 | 25.8 |
| 120 | 50.2 | 14.6 | 47.2 | 18.5 | 45.3 | 26.2 |
| 144 | 51.1 | 18.4 | 47.0 | 29.1 | 41.9 | 35.4 |

Ambient and cabinet temperatures for runs 1 and 2 are shown in Figure 4. Average cabinet temperatures within the first 48 hours were 38.2°C and 35.5°C for runs 1 and 2 respectively, while for the remaining period of the fermentation they were 41.5°C and 39.2°C. Ambient temperature averaged 29.2°C and 28.8°C in runs 1 and 2 respectively. These were not ideal conditions for solar assisted fermentation as cloudy, overcast and even rainy conditions predominated. Moisture condensation on the inside of the glass cover necessitated opening the vents for some period during run 2, a run in which both the ambient and cabinet temperatures were lower. Despite this however, mean fermentation box temperatures for the duration of the fermentation and after the first 2 days (in the first 2 days the temperatures rose as earlier described) were 45.4°C(SB-in), 46.1°C(SB-out) and 38.2°C(WB-in) in run 1 and 44.4°C (SB-in), 45.7°C (SB-out) and 45.4°C (WB-in) in run 2. All these temperature statistics, except for the wooden box in run 1,and after the first two days of fermentation, indicate that fermentation temperatures were good and as expected in a normal, commercial fermentation of large quantities. The temperature in the wooden box of run 1 dropped after 48 hours, as the wooden lid warped, resulting in both heat and moisture loss from this box. In run 2, the wooden lid was replaced by a plywood lid which did not warp. Table 1 shows changes in moisture content and weight loss of the beans, during fermentation. Chatt (1953) noted that during the fermentation process, the beans including adhering pulp lose about 25% of their weight. A further loss of 40% is incurred in drying. Table 1 shows that the greatest weight loss occurred in the wooden box in run 1 and correspondingly the moisture content was lowest. Reduction of water loss due to moisture evaporation is absolutely necessary to maintain good box temperatures as this reduces the conversion of sensible heat to latent heat, which can cause cooling of the boxes.

The temperatures within the fermentation boxes will be functions of the internal heat generation rate, heat gains or losses from the boxes due to conduction and convection from/to the surroundings and thus depend principally upon the construction material used with styrotex being a good insulating material, as well as the ambient conditions such as temperature, wind speed and radiation levels. Because conditions were variable, as expected in solar field experiments, it is difficult to draw specific comparative conclusions on the thermal performance of the boxes. This needs to be done under controlled, experimental conditions. However the results do confirm the good thermal performance of the styrotex boxes, either in or out of the fermentor as reported by Quesnel and Lopez, (1975). On the other hand, the wooden sweat boxes would benefit from being placed in the solar cabinet fermenter, as the rate of heat gain by the beans in the first 2 days of fermentation would be greater in such boxes, pushing the box temperatures up at a faster rate, compared to those in the styrotex boxes, as the results in run 1 probably indicate. In the daytime, the hot air surrounding such wooden boxes would also reduce heat losses when box temperatures of 45°C-50°C have been achieved. Mc Donald (1936) reported that when 18.2 kg of cocoa beans were fermented in 30 x 30 x 30 cm wooden sweat boxes, when such boxes were inside the solar cabinet fermenter mean box temperature was 43.3°C (47.2°C-40.0°C range), while for boxes outside the fermentor or under ambient conditions, mean temperature was 39.4°C (40.5°C-38.8°C range).

**Drying:** The drying curves for the solar cabinet drying of the fermented beans are shown in Figure 5, for both runs. The moisture content - time curve obtained in run 1 was quite typical of crop drying in a natural convention, solar cabinet dryer, and the moisture content of the beans fell to the desired level of 6-7% after the 6$^{th}$ day of drying. No differences in drying behaviour could be detected between prior fermentation method. In the second run, the quantity of beans/drying tray increased by 32% and the drying curves show a much slower rate of initial drying. In natural convection solar drying systems, tray overpacking can adversely affect drying behaviour. This appeared to have occurred in this run. The final 6-7% moisture content was therefore not achieved until 9 days of drying.

From the perspective of the solar cabinet fermenter being used as a solar cabinet dryer; the cabinet performed quite well, particularly in run 1 with a tray loading of approximately 3.96 kg wetbeans/tray.

**Bean quality:** At the beginning of fermentation, the beans could be described as having a white/off white pulp, cotyledons which were rich, bright purple and seed coats which were white with brown streaks. Such beans were flat and dense. At the end of the fermentation and for both runs, the cotyledons showed a dark band on the edges with light purple centres while the seed coat was light brown. The seeds were very plump with the cotyledons having fissures which gave a grainy appearance. These were signs of good fermentation.

When the dried, brown, crisp, cocoa beans with fissured cotyledons were commercially graded by the Cocoa and Coffee Industry Board of Trinidad and Tobago (CCIB) the grades achieved are given in Table 2.

TABLE 2. *Grades of cocoa beans obtained after fermentation and drying in the solar cabinet fermenter/dryer*

*Run 1*

| | |
|---|---|
| Cocoa beans from SB-out | Plantation grade<br>cutting good<br>8% moisture content, well dried |
| Cocoa beans from SB-in | Plantation grade<br>cutting good<br>8% moisture content, well dried |
| Cocoa beans from WB-in | 50% classed as Estate grade<br>not fully fermented<br>8% moisture content, well dried |

*Run 2*

| | |
|---|---|
| Cocoa beans from SB-out | Plantation grade<br>cutting good<br>8% moisture content, well dried |
| Cocoa beans from SB-in | Plantation grade<br>cutting good<br>8% moisture content, well dried |
| Cocoa beans from WB-in | plantation grade<br>cutting good<br>8% moisture, well dried |

Plantation grade cocoa is defined by the CCIB as "Well fermented, thoroughly dry, clean cocoa, free from commercial defects. These defects include mouldy, insect infected or germinated beans". Cocoa beans from the wooden box in run 1 suffered from insufficient fermentation, because of problems with the cover of the box and lower than normal temperatures. This did not occur in the second run, where all the beans were graded as plantation.

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Figure 1. Isometric Of Solar Cabinet Fermenter / Dryer

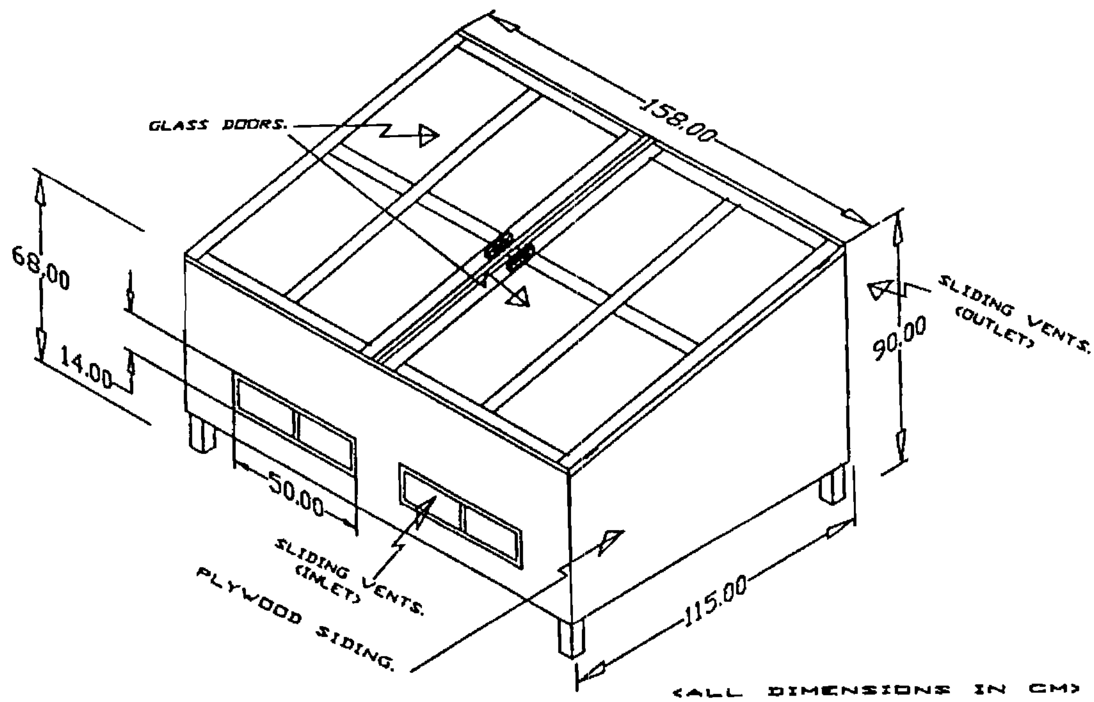
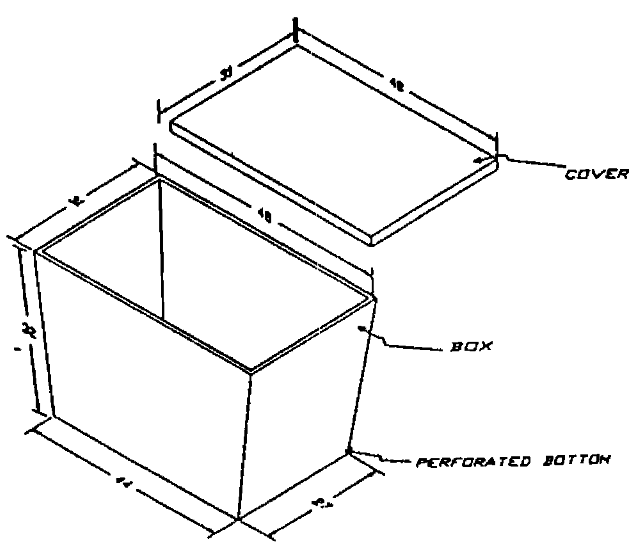



Figure 2. Isometric Of Fermentation Boxes.



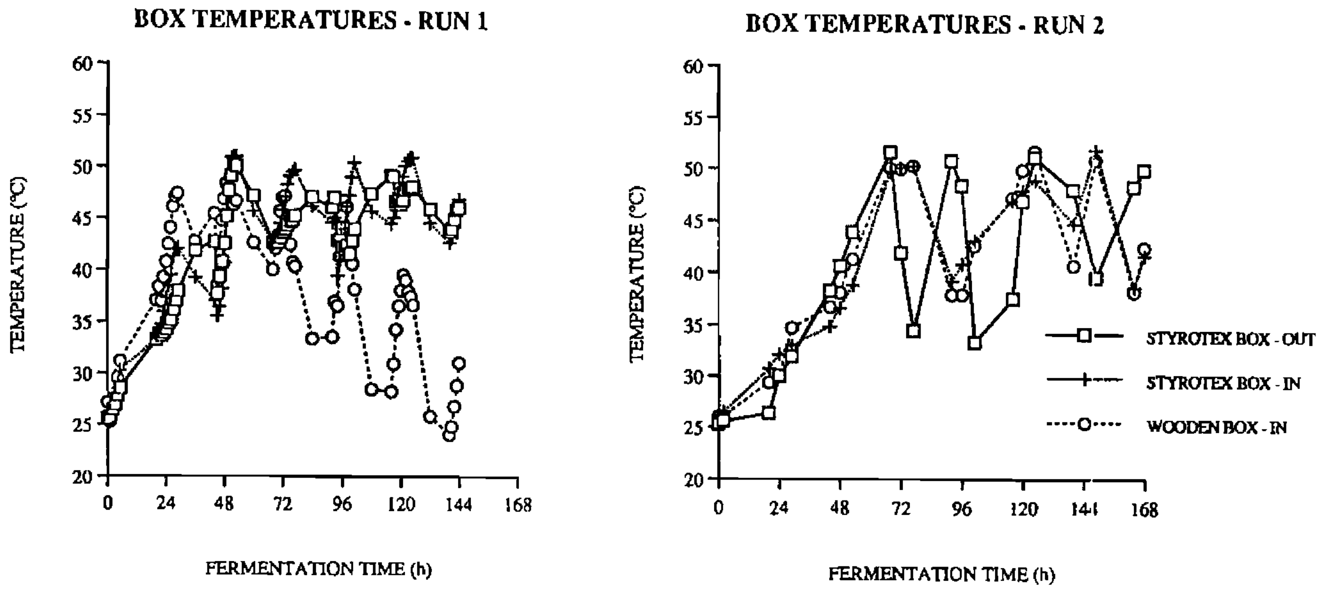



FIGURE 3

TEMPERATURE PROFILES OF BEAN MASSES DURING FERMENTATION

*AMBIENT AND CABINET TEMPERATURES*

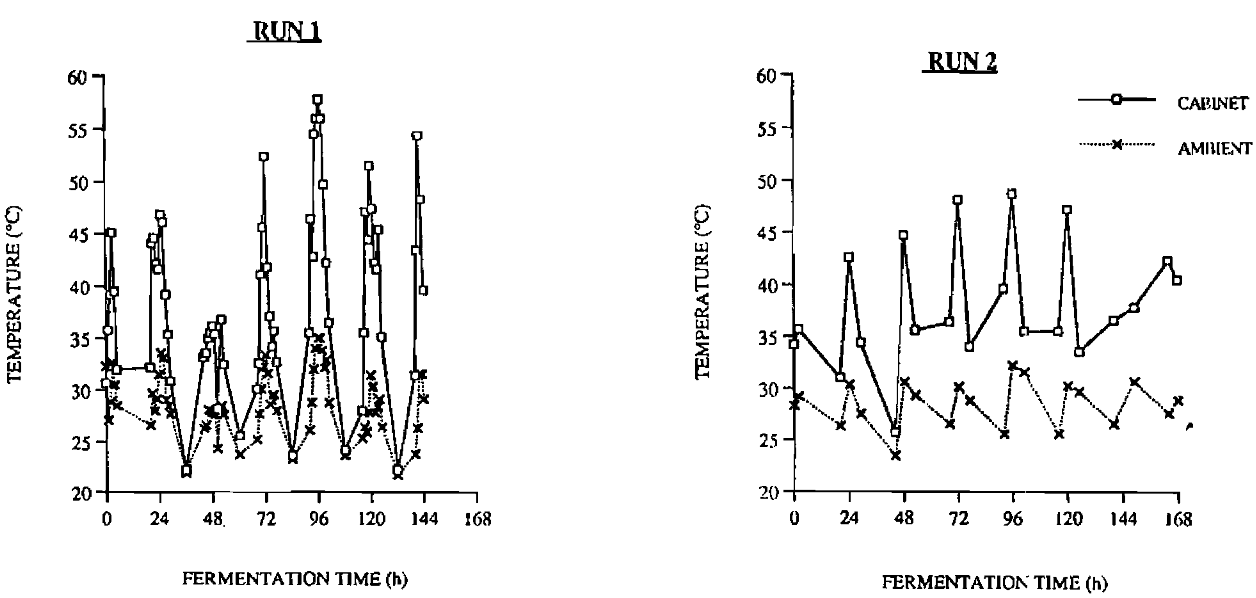



FIGURE 4

AMBIENT AND SOLAR CABINET TEMPERATURES

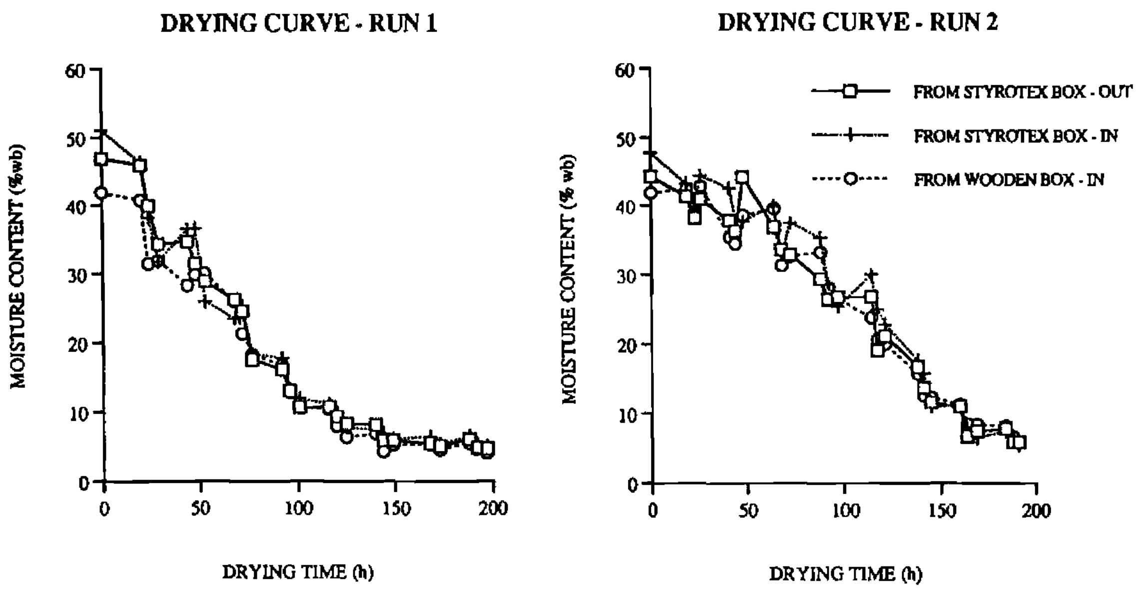



FIGURE 5

DRYING CURVES FOR SOLAR CABINET DRYING OF BEANS