Cocoa Drying with the Lister Moisture Extraction Unit.

K. NEWTON.

Agronomist-in-Charge, Lowlands Agricultural Experiment Station, Keravat.

Description of the Moisture Extraction Unit.

BASICALLY this drying unit consists of a high efficiency axial flow fan directly coupled through a centrifugal clutch to a Lister heavy duty HA4, 40 h.p. air-cooled diesel engine fitted with electric starting, and operating at a maximum speed of 1800 r.p.m. In front of the fan blades and within the fan housing, a series of eight metal vanes are fitted to assist in the reduction of turbulence in air driven into the plenum chamber by the fan. This fan produces a very high volume of air (rated at 38,000 c.f.m. free flow) which is warmed solely by heat produced from the engine. The entire engine assembly is covered by a fibreglass hood or canopy, one end of which fits around the fan housing while the opposite end remains open to allow intake of air. In this way all air passing through the fan must pass through the enclosed space around the engine and exhaust system. Utilization of heat produced by the engine is improved by the action of a small single stage axial flow fan fitted to one side of the engine, which forces cooling air around the cylinders. Additional heat is also obtained from the long exhaust system, consisting of a flexible pipe leading from the manifold to a large exhaust silencer, thence to a long exhaust pipe leading from the silencer out through the fibreglass canopy. Exhaust gases are emitted well above the level of the engine so that contamination of air drawn in by the fan is avoided.

A valuable additional feature of the engine is the provision for a power take-off at the end opposite to the fan, which can be fitted with a generating unit, water pump or other equipment. The whole assembly is mounted on a solidly-constructed trailer chassis enabling it to be transported readily from one location to another.

Principle of Drying.

Much of the hot air drying of cocoa beans in Papua and New Guinea is based on platform drying of fermented beans using temperatures of 120 degrees F. to 170 degrees F. and air volumes of 3,000-12,000 c.f.m. Under these conditions batches of 2-2½ tons dry bean equivalent can be dried in shallow layers in two to three days. However, it has been demonstrated with grain crops that large quantities can be dried over longer periods provided that a large volume of slightly warmed air at adequate pressure is available. The design of the moisture extraction unit incorporates this latter principle of drying, so that it increases the drying capacity of large volumes of air at ambient temperature by raising the temperature a few degrees and forcing it through the material to be dried.

Performance data for the unit, as submitted by the manufacturers, are presented in Table I and Figure 1. These show the relationship between air volume and temperature rise above ambient for *total* water gauge pressures of 1 inch to 7 inches at the fan, and also the relative humidity differential between air at ambient temperature and warmed air.

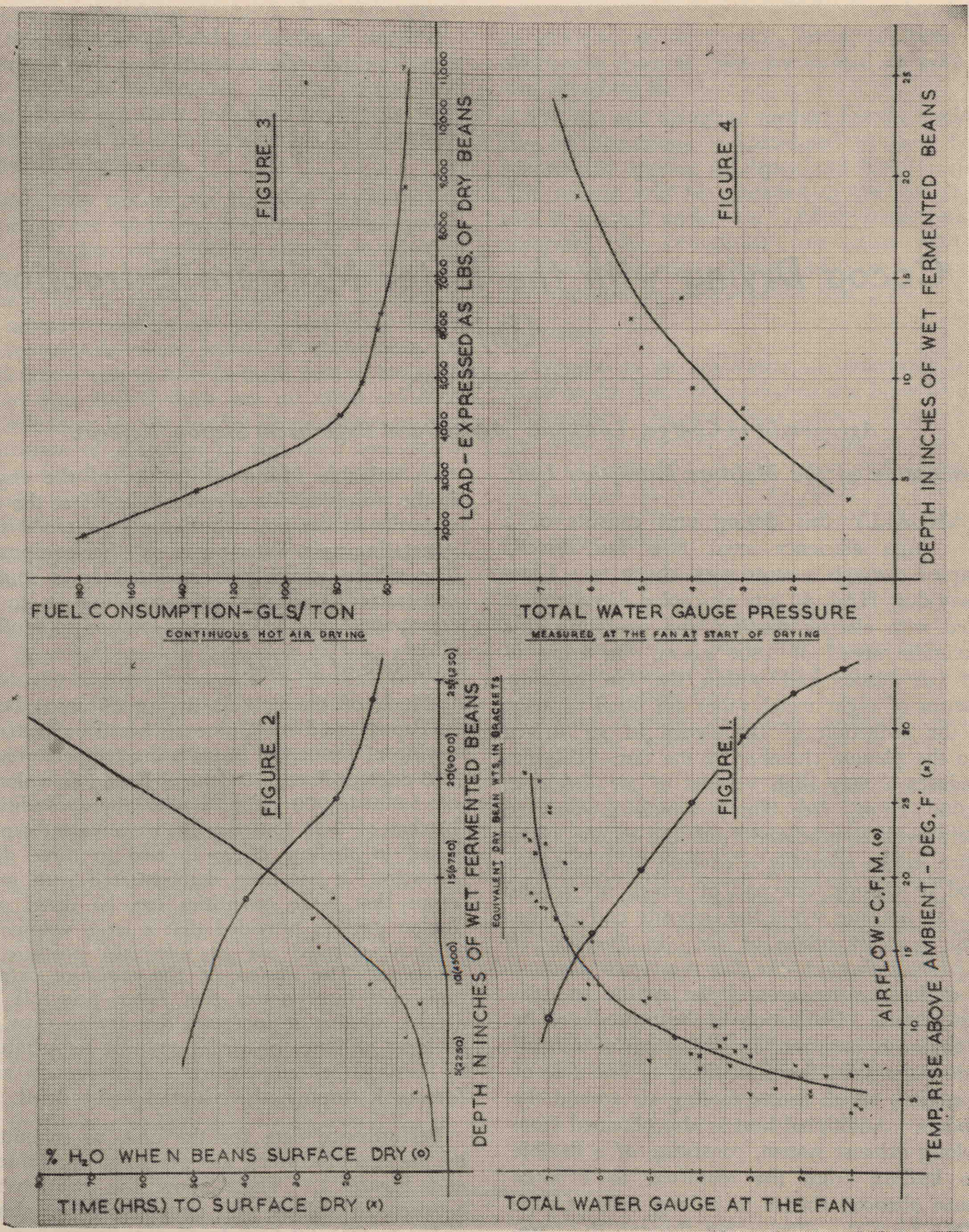
FIGURE 3
LOAD - EXPRESSED AS LBS. OF DRY BEANS
FUEL CONSUMPTION - GLS/TON
CONTINUOUS HOT AIR DRYING
FIGURE 4
DEPTH IN INCHES OF WET FERMENTED BEANS
TOTAL WATER GAUGE PRESSURE
MEASURED AT THE FAN AT START OF DRYING
FIGURE 2
DEPTH IN INCHES OF WET FERMENTED BEANS
EQUIVALENT DRY BEAN WTS IN BRACKETS
% H_2O WHEN BEANS SURFACE DRY (o)
TIME (HRS.) TO SURFACE DRY (x)
FIGURE 1
AIRFLOW - C.F.M. (o)
TEMP. RISE ABOVE AMBIENT - DEG. F° (x)
TOTAL WATER GAUGE AT THE FAN

(a) Nil Blanking Pieces.

Table I.

Performance Data for Lister Moisture Extraction Unit.

Total W. G. (inches)	Air Flow (C. F. M.)	Temp. Rise (Degrees F.)	Relative Humidity Differential. (per cent.)
1	34,000	6.0	15
2	32,300	6.8	17
3	29,400	7.2	18
4	25,000	7.75	19.4
5	20,500	8.5	21.2
6	16,200	12.0	30
7	10,200	20.0	50
(*b*) Two Lower Blanking Pieces.			
1	32,300	6.0	
2	28,500	7.0	
3	25,000	8.0	
4	22,000	7.75	
(*c*) Two Upper and One Lower Blanking Pieces.			
1	19,000	5.0	
2	17,000	6.0	
3	14,700	8.0	
4	11,700	9.0	
(*d*) Two Lower and One Upper Blanking Pieces.			
1	23,600	7.0	
2	22,000	7.5	
3	19,200	8.0	
4	17,600	9.0	
(*e*) Two Upper Blanking Pieces			
1	22,000	8.0	
2	20,300	9.0	
3	18,000	10.0	
4	16,200	10.8	
5	11,800	14.4	

From this table it is apparent that as the total water gauge pressure increases, either because of an increase in load or the utilization of blanking pieces over the fan to restrict airflow past the engine and through the fan, so the temperature rise above ambient increases, and the volume of air being delivered by the fan falls. The table also shows the effect that various combinations of blanking pieces have on these relationships.

Total Water Gauge.

The general lack of exact specification by manufacturers of drying equipment and cocoa growers necessitates clarification, exact description, and location of any water gauge measurements quoted for such processing machinery. In the case of this Moisture Extraction Unit all water gauge measurements referred to are *total* water gauge readings, i.e., "velocity" water gauge plus "static" water gauge. Velocity water gauge is defined as the height in inches of a column of water which can be supported by the pressure of air resultant from air speed or air velocity. Static water gauge is the height in inches of a column of water which can be supported by the pressure of air which is not produced by velocity but maintains velocity against resistance. Velocity, static, and total pressures can be readily measured by the use of a simple manometer. On this unit the manometer is located immediately in front of the fan, and therefore all water gauge readings are total water gauge readings at the fan. Consequently they are much higher than static water gauge readings would be beneath the dryer floor under the same conditions.

Blanking Pieces.

These are quadrants of strong masonite fitted with clips which allow them to be attached readily to the circular wire mesh guard on the inlet side of the fan. By using them it is possible to cover quarter circle sections of the fan and so reduce airflow as indicated in Table I.

Additional data made available by the manufacturers of the M.E.U. have been used in the compilation of Table II, which shows the drying capacities of air at given temperatures in accordance with the rated output of the dryer.

Drying Capacity of Lister Moisture Extraction Unit.

Table II.

Cwts. of water removed per 24 hours by volumes of air at the temperatures shown for four levels of relative humidity. Based on an ambient temperature of 70 degrees F. The calculations are based on the assumption that air is exhausted at a relative humidity of 94 per cent.

Air Vol. (C. F. M.)	Temp. Rise Above Ambient (degress F.)	Relative Humidity (per cent.)			
		60 per cent.	70 per cent.	80 per cent.	90 per cent.
10,200 c.f.m.	at 20°F.	45.6	40.8	36.5	32.4
16,200 c.f.m.	at 12°F.	54.3	45.4	38.6	32.6
20,500 c.f.m.	at 8.5°F.	58.4	48.0	38.1	30.8
29,400 c.f.m.	at 7.2°F.	79.4	63.2	49.4	38.5
34,000 c.f.m.	at 6.0°F.	86.7	68.0	51.7	38.8

The table illustrates that, theoretically, the machine should have a greater capacity to dry when operated at maximum air volume and minimum temperature rise, than when lower volumes at higher temperatures are used. However, this assumes that the drying air is exhausted at a relative humidity of 94 per cent., which is a difficult level to achieve with a large volume at low temperature unless the load is spread at a shallow depth over a large area. Assuming that an airflow through cocoa beans at 20 ft./minute allows the drying air to approach 94 per cent. r.h. when exhausted, then 34,000 c.f.m. would have to be pushed up through 1,700 square feet of floor space at a total water gauge of 1 in. at the fan (equivalent to a load of approximately 3-4 in. of wet fermented beans to achieve maximum drying efficiency. This system would possibly handle the equivalent of five tons of dry beans. However, as will be shown from the trial results, a three ton dry bean equivalent load can be dried on 216 square feet of floor, i.e., approximately $\frac{1}{8}$th of the area using less air at a higher temperature. Thus, the economics of dryer construction in terms of area must obviously be balanced against cost of drying for this type of machine.

Drying Systems.

Potentially the unit can be used to dry cocoa beans in two ways.

(*a*) Firstly, it can be applied to a platform type drying bed and used in much the same way as most sun/hot air platform dryers are used for complete drying *in situ,* i.e., a single load or batch of fermented beans is spread evenly over the area of the drying floor and dried out completely in two to four days without being moved.

(*b*) Secondly, because of the power the fan has to push out air at high pressures, it can be used to pre-dry or surface dry small batches of beans on a continuous output basis. Each batch, once it is pre-dried, is then transferred to a deep bin where final drying of beans up to eight feet in depth can theoretically be achieved. Results from the preliminary trials indicate that this depth could probably be handled by the unit. It is emphasized at this point that no local information is available on this system of drying and that the unit might prove to be most economic when used in this way. See Appendix.

Drying Trials—Complete Drying in situ. (*Method* (*a*) *above.*)

The first series of ten drying trials was designed to provide information on the capacity of the unit when used to dry completely a single load of beans *in situ.* Data recorded were fuel consumption per ton for complete hot air-drying, the maximum depth at which beans could be surface dried on a given floor area, and all associated data on water gauge readings, airflow, temperature rises, oil consumption, drying times, etc. Much of this information is summarized in Table IV, while more detailed information is available from individual trial reports.

For the trials, a temporary dryer was constructed with timber frame and plywood sides and an 18 ft. x 12 ft. floor of cocoa wire supported by 3 in. x 2 in. arc mesh. Depth of the air chamber beneath the floor was 48 in. (to eliminate cold spots), with the unit fitted into a fish tail duct which opened into one end of the air chamber. Fermented beans for drying were contained on the floor by a plywood lined wall 24 in. deep so that in effect the dryer consisted of an 18 ft. x 12 ft. x 24 in. deep bin with a cocoa wire/arc mesh floor and an 18 ft. x 12 ft. x 4 ft. deep air chamber below.

As the first two trials were carried out using a different system for blanking or baffling the fan from that used in the remaining eight trials, the results will be discussed accordingly. In the first and second trials, airflow was varied either by fitting the blanking pieces supplied by the manufacturers over the fan guard, or by reducing engine speed. By using one, two or three blanking pieces, air intake can be restricted and the c.f.m. output and temperature rise above ambient controlled to some extent. Unfortunately, as soon as the blanking pieces were fitted, total water gauge readings on the manometer located in front of the fan were affected to such an extent that they were meaningless and could not be used as a guide to the c.f.m. output of the machine, as indicated in *Table* I.

Consequently the baffling system was altered for the last eight trials by fitting on the dryer side or outlet side of the fan a sliding plywood door which could be moved across the front of the fan to restrict airflow. This not only gave excellent control of airflow with little interference to the water gauge, but also enabled output of the fan to be varied from 10,000-34,000 c.f.m. and temperatures from 6 degrees F. to 20 degrees F. rise above ambient, thus turning the unit into a far more versatile machine both for experimental purposes and as a dryer.

In the first trial, beans were dried mainly during the day and the machine turned off overnight. The object was to get some information on fuel consumption under these conditions although the final figure of 34.6 gals/ton represents drying to a level of 8.2 per cent. moisture only. When corrected for drying to six per cent. moisture, fuel consumption was estimated as 44.4 gals/ton. Tests during this trial also showed that variations in engine speed do not give any variation in air temperature, and that the reduction in c.f.m. output which results from a slower engine speed is balanced by the lower heat output from the engine, with the net result that air temperature remains about the same.

In the second trial, beans were dried continuously except for a break on the final night, and fuel consumption rose to 43.8 gals/ton (corrected to 55.1 gals/ton for 6 per cent. moisture). Continuous drying and a smaller load on the dryer were the main factors responsible for this rise.

Several combinations of blanking pieces were used with various engine speeds during the first and second trials and temperature rises for each particular combination recorded. However, as water gauge readings could not be simultaneously recorded because of the effect previously mentioned, the results are of no value for comparison with figures provided by the manufacturers. This information was not necessary for the subsequent trials, however, as the method of baffling was changed and improved.

As shown in Table IV, quantities of 4,693 lb. and 3,940 lb. of dry beans were dried in the first and second trials respectively at a reasonable cost in terms of fuel, oil and labour. Perhaps the most interesting feature was the ability of the machine to surface dry beans 8½ in. deep in a little more than five hours. The remaining eight trials provided the following information.

(1) *Temperature Rise Above Ambient.*

Throughout the series of ten trials, temperature readings at various water gauge pressures were continuously recorded. These results are summarized in Table III which shows the maximum and minimum temperature rise above ambient which was recorded for each of the water gauge readings. Table III is also graphically represented by Figure 1.

Temperature Rise above Ambient at Varied Water Gauge Pressures.

Table III.

Water Gauge (inches).	Minimum Temp. Rise. (Degrees F.)	Maximum Temp. Rise. (Degrees F.)	Makers' Rating.
7.3	22.8	27.0	....
7.2	18.9	22.5	....
7.1	18.4	21.6	....
7.0	18.0	26.4	20.0
6.9	18.0	22.2	....
6.8	24.3	24.6	....
6.7	17.1	17.1	....
6.5	15.9	21.0	....
6.3	11.7	19.2	....
6.2	12.6	16.9	....
6.0	12.6	15.6	12.0
5.1	11.6	11.6	....
5.0	7.5	11.7	8.5
4.5	9.0	9.0	....
4.2	8.0	8.0	....
4.0	7.0	7.8	7.75
3.7	9.9	9.9	....
3.6	8.5	8.5	....
3.5	9.0	9.0	....
3.4	7.2	7.2	....
3.3	8.2	8.2	....
3.1	8.4	8.4	....
3.0	5.2	7.8	7.2
2.5	5.7	5.7	....
2.1	7.2	7.2	....
2.0	6.3	6.3	6.8
1.8	5.1	5.4	....
1.5	6.5	6.5	....
1.0	4.0	6.6	6.0
0.9	4.5	4.5	....
0.8	4.2	4.2	....
0.7	7.2	7.2	....

Taking into consideration the fact that the above measurements were made under field conditions, there is reasonable agreement between the temperature readings recorded and those quoted by the manufacturers. Even so, in some cases wide variations were found between maximum and minimum rises above ambient for a given water gauge. Also, in some cases the range was at a higher level for a lower water gauge reading, e.g., 6.8 in. ; 24.3-24.6 degrees F., 7.2 in. ; 18.9-22.5 degrees F. Consequently it must be assumed that either the water gauge is affected to some degree by the fan blanking door or else the gauge does not give readings of great accuracy. Until this can be checked by fitting a

Table IV.

Summary of Results of Preliminary Trials with the Lister Moisture Extraction Unit.

	Trial 1.	Trial 2.	Trial 3.	Trial 4.	Trial 5.	Trial 6.	Trial 7.	Trial 8.	Trial 9.	Trial 10.	Means.
Vol. wet beans (cu. ft.)	195	155	352	273	440	170	205	245	80	120	
Av. wt./cu. ft. wet beans (lb.)	53¼	55	—	—	—	—	56	52.5	—	—	54.7
Total wt. wet beans (lb.)	10,384	8,525	—	—	—	—	11,480	12,862	—	—	
Av. wt./cu. ft. fermented beans (lb.)	47¼	47½	50¾	47	48½	51	48¾	50.4	—	—	48.96
Total wt. fermented beans (lb.)	9,214	7,363	17,775	12,842	23,522	8,670	9,994	12,348	—	—	
Moisture at end of fermentation (percentage)	51.7	52.2	56.8	55.6	55.7	55.6	55.1	—	—	—	
Type of drying and duration	Interupted : day only : 7 days	First 2 days continuous 3 days	Cont. 5 days	Cont. 4 days	Cont. 6 days	Cont. 3 days	Interrupted : day only : 6 days	Cont. 4 days	Cont. 4 days	Cont. 4 days	
Depth of beans in dryer (ins.)	10½	8½	19	14	24	9½	11½	13	4	6½-7	
Total water gauge at start of drying (ins.)	?	3.0	6.25	4.2	6.5	4.0	5.0	5.2	0.9	3.0	
Time to surface dry completely (hours)	Irrelevant	5½	66½	21	75-91	15	24	25	6¾	8¼	

Table IV.—*continued.*

Summary of Results of Preliminary Trials with the Lister Moisture Extraction Unit.

Time to surface dry to indicate depth (hours)	6"/14	8½"/5½	3"/7 10"/23	14"/21	9"/22 12"/27 16"/43	9½"/15	11½"/24	13"/25	4"/6¼	6½"/8¼	
Total drying time (hours)	69	60	120	94¾	139½	60½	91¾	88¼	89	99½	
Total fuel consumption (gals.)	72.5	77	198.5	167	239.5	104.5	151	141	145.5	163	
Av. fuel consumption (gals/hour)	Eng. speed varied : 1.05	Eng. speed varied : 1.28	Full speed 1.65	Full speed 1.76	Full speed 1.72	Full speed 1.73	Full speed 1.65	Full speed 1.60	Full speed 1.63	Full speed 1.64	
Engine Oil used (pints)	11	6	26	14	24	6	14	15	11	24	
Oil consumption/ton (pints)			6.7	5.3	4.8	3.2	6.4	5.4	13.5	19.7	
Fuel consumption/tons (gallons)	34.6	43.8	50.8	63.0	48.3	55.0	69.5	50.53	178.0	133.8	
Consumption/ton corrected to 6 per cent. moisture content	44.4	55.1	52.1	63.0	52.4	78.0	69.5	62.0	178.0	133.8	
Total man hours for turning	10	9	42	6	26	6	12	13	4	2¼	
Man/hours/ton	4.8	15.1	10.7	2.3	5.7	3	5.5	4.6	5	2	
Wt. dry beans (lb.)	4,693	3,940	8,750	5,945	11,109	4,255	4,877	6,250	1,830	2,730	
Dry beans/wet beans (percentage)	35.9	46.2	—	—	—	—	42.5	48.6	—	—	45.68
Dry beans/fermented beans (percentage)	50.9	53.5	49.2	46.3	47.2	49.1	48.8	50.6	—	—	49.00
Fermented beans/wet beans (percentage)	88.8	86.4	—	—	—	—	87.1	96.0			89.97
Wt. lb. dry beans/cu. ft. wet beans (lb.)	24.1	25.4	24.9	21.8	25.2	25.0	23.8	26.1	22.9	22.8	24.33

second water gauge to the machine, readings can only be taken as a reasonable but not accurate indication of operating temperatures and c.f.m. output.

An interesting feature of the relationship between temperature rise above ambient and total water gauge as shown in Figure 1, is the pattern between 1 in. total water gauge and 6 in. total water gauge (5 degrees rise to 13 degrees rise) , and 6 in. total water gauge and 7 in. total water gauge (13 degrees rise to 21 degrees rise. Because of this characteristic of the machine's performance it is obvious that only relatively low volumes of air are available at a 20-25 degrees F. rise above ambient.

(2) *C.f.m. Output.*

Detailed information on tests carried out to check the c.f.m. rating of the machine is given in the report on trial no. 3. Results indicate that when operating at a 7 in. total water gauge the unit pushes through approximately 5,000 c.f.m., which is about half the output quoted by the manufacturers. This figure should not be taken as exact, firstly because it is compiled from records which include some estimated measurements as well as accurate measurements of airflow through the beans, and secondly because of the possibility, as mentioned, that water gauge readings may not be accurate enough for this purpose. Reference to Table I will show that as water gauge readings increase from 3 in. to 4 in. to 5 in. to 6 in., rated c.f.m. output falls at the rate of 4,300—4,500 per inch. But the fall from 6-7 in. is 6,000 c.f.m. and the graph of total water gauge against c.f.m. output in Figure 1 shows that at 7½ in. the output could be in the vicinity of 5,000 c.f.m.

A check on c.f.m. output at lower pressures or water gauge readings was not possible with the airflow meter available. This records a maximum airflow of 27 ft. per minute which, though high enough to record airflow at 7 in. total water gauge is far too low to record the higher airflows which result when the machine is operating at lower pressure and hence higher c.f.m. output.

(3) *Load Capacity.*

In trial No. 3 wet fermented beans were loaded onto an 18 ft. x 12 ft. floor to a depth of 19 in. which, with the fan blanking door fully opened and no restriction of airflow, resulted in a total water gauge reading of 6¼ in. Obviously, therefore, a 19 in. depth of beans was not the maximum load which the machine could handle, as the rated maximum of 7 in. total water gauge was not reached. Subsequently in trial no. 5 wet fermented beans were loaded onto the floor to a depth of 24 in. (final dry weight of beans 11,109 lb.) and a total water gauge reading of 6½ in. was registered—see Figure 4. It would appear, therefore, that the floor could be loaded to an even greater depth although once again the accuracy of the water gauge comes into question. Suffice it to say that the machine is capable of drying the equivalent of 5 tons of dry beans loaded onto an 18ft. x 12 ft. floor, to a depth of 24 in. Whether this is the maximum physical capacity of the unit or whether it could take a slightly greater load is not, however, relevant because the initial drying rate is too slow to prevent beans from " going off " before they become surface dry. A graph illustrating the relationship between depth of beans and time for beans to become surface dry is shown in Figure 2. In trial no. 3, drying continued for 66 hours before the whole bean mass had become surface dry and before this stage was reached an unmistakeable " off " or " foul " odour had developed which would in all probability carry through to the final dried product. Again on trial no. 5 the whole bean mass did not become surface dry until somewhere between 75 and 91 hours after the commencement of drying and a " foul " odour had developed. The odour was quite obvious and one which experience has shown generally results in a foreign flavour in chocolate prepared from such beans. Presence of a foreign odour is also one of the grounds for rejection of cocoa beans as export standard cocoa and consequently must be avoided.

Therefore, the indications are that the load capacity for this unit is limited not by the maximum depth and volume of beans through which air can be forced (i.e., the physical capacity to dry) but by the maximum depth of beans which can be surface dried quickly enough to prevent the development of any foul or foreign odours, and therefore flavours, in the final product.

What then is the maximum load capacity of the unit when used to dry cocoa at depth on a small floor area ? An exact answer to this question is not possible because of the variation which occurs in the moisture content of fermented beans and the dependence of drying efficiency on relative humidity and ambient temperature. However, Figure 2 illustrates the relationship which has been established between load capacity and time to surface dry. From this it can be concluded that approximately three tons dry bean equivalent can be surface dried in approximately thirty hours. This is roughly the maximum time allowable if the development of foreign odours is to be avoided.

Furthermore, the graph of fuel consumption per ton of dry beans against load, illustrated in Figure 3, indicates that a three ton dry bean load results in a fuel consumption of approximately 60 gallons per ton for complete, continuous hot air drying.

From the foregoing remarks it is apparent that the load capacity of the Lister M.E.U. is limited by the low availability of heat from the engine and not by the quantity of air available, i.e., the performance of the fan. The argument is best illustrated by trial no. 5 in which it was shown that the fan was sufficiently powerful to push air through 24 in. of wet fermented beans (five tons dry bean equivalent) at an estimated 5,000 to 10,000 c.f.m. Taking floor area as 200 square feet, this amounts to an airflow of 25-50 feet per minute through the floor. Had this air been hotter there is no doubt that the beans could have been surface dried more quickly and therefore the load capacity increased. In fact one of the most essential requirements for any cocoa dryer is a heat reserve which enables beans to be safely surface dried within 24 hours or less if a daily intake of fermented beans is planned.

It is possible that the load capacity could be increased by improved design of the exhaust system so that more heat is made available. During the trials the final length of exhaust pipe was continually hot. Therefore improved design of the exhaust system could trap more of the heat from the exhaust gases.

Alternatively, load capacity could be increased by the incorporation of an oil burner and combustion chamber in the fish tail duct section between the fan and the dryer floor. This could be used in the initial phase of drying to provide more heat and therefore faster drying.

Another alternative which suggests itself is the utilization of a shorter fermentation period before drying commences. Although no definite information is available, it is possible that this would offset the expected occurrence of continued fermentation in the early stages of drying a deep mass of beans and thus counteract the development of foul and foreign odours. If this were achieved, load capacity could be safely increased.

Finally, on the basis of arguments put forward from the results in Table II, it may be possible to increase load capacity by using a large floor area with beans at a shallower depth. With this arrangement a given volume of beans may become surface dry in a shorter time than they would on a small area at a greater depth. It is intended that further trials will be conducted to investigate the validity of this argument.

(4) *Handling and Turning the Beans.*

When dried at the depths which were used in these trials, cocoa beans stick together and set in a fairly solid mass. The technique for handling this mass is to leave it undisturbed until surface drying has been completed through to the top layers. At this stage the mass is set, but the adhesion of one bean to the next is not strong and the whole mass can be broken up with paddles and by hand. Once this has been done beans will remain free for the rest of the drying period and if necessary can be easily turned and mixed with shovels to get more even drying.

(5) *Rate of Drying.*

In trial no. 3 the fan blanking door was closed across the fan to give a 7 in. water gauge reading and the minimum possible air flow, on the assumption that air moving slowly through the bean mass would take up and remove a greater amount of water than air moving quickly through the beans. In trials 4 and 5 the opposite effect was tested and a higher airflow rate at correspondingly low temperatures was initially used. Beans became surface dry in 21 hours in trial no. 4 and 75-91 hours in trial no. 5, and results indicate that the rate of drying and the time which beans took to become surface dry were more a function of depth of beans than of temperature/volume effects. In trials 3, 4 and 5 the moisture content of beans at the stage when they became surface dry was 20.2 per cent., 38.3 per cent. and 13 per cent. respectively, which when compared against bean depths (19 in., 14 in. and 24 in.) indicates that this moisture content was also a function of bean depth. Therefore as depth of beans increases, so the drying rate decreases, the time taken for beans to become surface dry increases, and the moisture content of beans when they do become surface dry, decreases.

(6) *Variation in Airflow through the Floor.*

Airflow readings taken during the trials with a Casella airflow meter indicated that the rate of flow through the floor varied from spot to spot for any given load of wet fermented beans, and that the variation was greatest at the beginning of drying and least when drying was almost completed. By recording several series of readings on a grid pattern over the whole floor area, it was evident that this variation in rate of airflow was due primarily to variation in depth of beans on the floor. High flow rates were closely correlated with shallow areas and flow rates could be readily lowered by adding an extra one inch layer of beans over any given area. Obviously, therefore, care must be taken to ensure that the drying floor is loaded evenly.

(7) *Cutting Tests and Flavour Assessments.*

At the commencement of each drying trial a sample of wet fermented beans was taken from the bean mass and spread out on a wooden platform for sun-drying. At the completion of each trial a second sample was taken from the hot air dried beans. Subsequently, sun dried and hot air dried samples from each trial were forwarded to the laboratories of Cadbury Fry Pascall Pty. Ltd., in Claremont, Tasmania, where the raw beans were subjected to a cutting test. Flavour assessments on tasting samples were prepared by a panel of four experienced tasters. The results from these tests indicated that :—

(*a*) There was a general trend for beans dried by the Lister moisture extraction unit to have a slightly lower percentage of under fermented beans than those dried by sun. In seven of the ten trials (1, 2, 3, 4, 6, 7 and 10) beans dried by hot air had a lower percentage of under-fermented beans than those dried in the sun. In two trials (5 and 8) there was no difference and in one trial (9) sun dried beans were slightly better than hot air dried beans.

(*b*) No significant trends were obvious with regard to chocolate flavour score. The average figure for sun dried beans was 9.9 and for hot air dried beans 9.7. In a few of the trials, significant differences were apparent but these could not be related to duration of drying, depth of beans, rate of airflow or any other factor.

(*c*) No relationship could be established between sun and hot air dried beans on the occurrence and level of acid and bitter flavours. However, there was a general trend for hot air dried beans to be more astringent than sun dried beans. The incidence of raisin and caramel flavours was at the same level in both sun and hot air dried samples but licorice flavours were significantly higher in sun dried beans.

Hammy, smoky and earthy flavours were reported more frequently in sun dried samples, foreign and foetid flavours to the same extent in both, while harsh flavours were reported only in hot air dried samples.

APPENDIX

The use of the Lister Moisture Extraction Unit with a tray/bin system for drying cocoa, as outlined by the manufacturers.

The Lister Moisture Extraction Unit with its large air volume and low temperature rise is well suited to the drying of cocoa. Because of the low temperature, no damage due to over-drying occurs, and with the absence of any heat exchanger the machine may be safely left to run unattended overnight. The machine is mobile and can be used to dry other crops such as maize or rice when not required for cocoa.

Because of its versatility the unit can be adapted to suit almost any fermentary and the drying trays and bins can be constructed out of local materials and built with local labour.

The system of tray/bin drying is done in two stages. The first stage incorporates a shallow tray or trays where the cocoa is loaded to a maximum depth of 18 inches and skin dried.

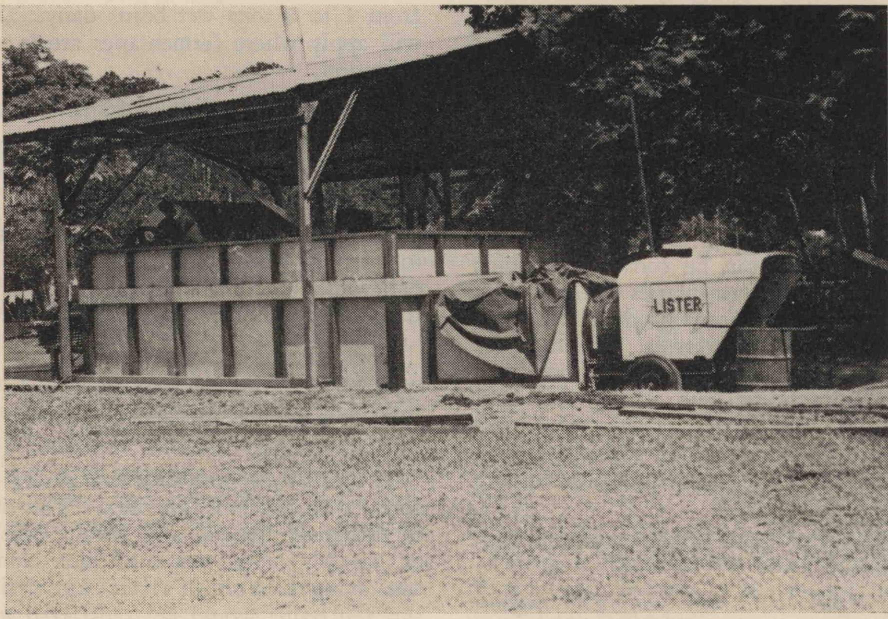

Plate I.—Lister Moisture Extraction Unit.

Plate II.—Spreading cocoa beans.

This is best done by adding layers of 3-6 inches at a time and after 12-24 hours the cocoa should have reached a stage when it will no longer stick together. In the second stage cocoa is transferred to a bin and bulked up to a depth of up to eight feet, where it will remain until dry; any beans that have tended to stick together during the skin drying stages will be separated during the transfer from tray to bin.

By varying the size and arrangement of the trays and bins units can be constructed which will be suitable for fermentaries with a daily output, or for those that only produce fermented beans at other regular intervals. Where cocoa is mainly harvested during the drier months, a system combining initial sun drying and final bulk drying can be evolved. This would cut down on the labour required for sun drying and also eliminate the need for large drying areas.

The operation of three simple systems is outlined below :—

1. *Two Units of one bin/two trays*—Capacity 4-16 tons wet beans/week. This sytem is designed to receive beans for four days a week at a rate of 4 tons of beans per day.

(*a*) Wet beans from the fermentary (about 50 per cent. moisture content) are loaded into trays (10 ft. x 9 in. x 4 in.), to a depth of up to 1 ft. This is best done by loading six inches, blowing for a short time using no baffles and full throttle, and then loading the remaining six inches.

(*b*) On the second day the air is cut off to each tray in turn, whilst the beans, which should now be past the stage when they will stick together, are transferred to the bins through the transfer doors. As soon as the floors of the bins are well covered blowing should commence. The trays are unloaded as above until the bins are full.

(*c*) Blowing through the bins will continue until the beans are dry and baffles may have to be fitted to the machine to obtain the necessary temperature rise in the final stages. The beans can be bagged off direct from the bins.

2. *Two Units of one tray/two bins*—Capacity from 1 to 8 tons wet beans daily. This system will apply where fermentaries are in continuous operation.

(*a*) Each tray 20 ft. x 10 ft. is loaded daily with up to 4 tons of wet beans to a depth of 1 ft. as described previously.

(*b*) The tray is sited adjacent to two bins and the output from the tray is transferred firstly to one bin, which when full is blown until it is dry, whilst the second bin is being filled. In this way continuous operation can be achieved.

The machine is capable of dealing with two such units (i.e., two trays and four bins) at a time, but obviously in the off peak season only one unit need be operated.

3. *Sun Drying and bulk bin drying*—Capacity from 1 to 16 tons per day. This installation is extremely flexible and would consist of six or possibly more ventilated bins alongside the sun-drying platforms. After skin drying in the sun the beans would be transferred to the bins filling each one in turn; using six bins and filling one each day should ensure that the first bin is dry before the last bin is filled.

In order to ensure that no deterioration of the cocoa takes place before leaving the plantation, cocoa could be stored in these bins and ventilated as the occasion demands. Sacking off would only take place immediately before the crop was despatched.

Summary.

Results from a series of ten drying trials with the Lister Moisture Extraction Unit indicate that it has the capacity to dry safely 14,500 lb. of wet fermented beans on an 18 ft. x 12 ft. floor at a depth of 15 in. to give three tons of good quality dry cocoa beans. This load can be handled by continuously drying for four full days at a cost of approximately 60 gallons of fuel and five pints of oil per ton of dry beans.

(Received November, 1963.)