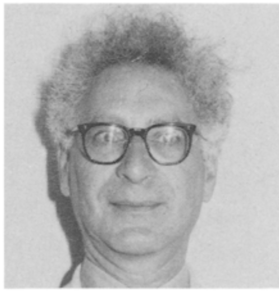

Production of Palm Oil from Fruit

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ABSTRACT

Palm oil is obtained from the fruit flesh of *Elaeas guineensis*. Whole bunches of ripe fruit are harvested and brought to the oil mill. Processing involves sterilization, mechanical removal of fruit from the bunch, and mechanical breakdown of the fruit structure followed by expression of the oil in a screw press. Oil mixed with water and fruit debris is purified in settling tanks and centrifuges, dried and stored. Oil yield represents 22% of the fresh fruit bunch and kernels a further 5%. The solid wastes are the empty fruit bunch, the press fiber and the nut shells. Empty bunches are incinerated, while fiber and shell are used to fire the mill boilers. The liquid effluents are mixed and usually treated by anaerobic/aerobic fermentation until fit for discharge. Various treatment systems are described. Quality control in the oil mill concentrates on (a) minimizing deterioration of the oil by hydrolysis and by oxidation, and (b) optimizing oil yield by frequent measurements of oil losses.

There are today 168 oil mills, processing nearly 3 million tons of oil in Malaysia. The production of palm oil is divided into 2 main stages: (a) harvesting of fruit and transport to oil mill; and (b) production of crude palm oil and palm kernels in the oil mill.

Harvesting of Fruit

The oil palm produces bunches of ripe fruit throughout the year, although there are peak and trough periods. Each bunch weighing 10-20 kg contains more than 1,500 fruits, and they do not all ripen together. However, most of the oil is synthesized in the last two weeks, and a correct judgment of ripeness is essential to ensure good yield. Overripeness leads to biodeterioration and poor quality oil and lower mill efficiency. Optimum ripeness is judged according to the proportion of loose fruit—at about 10%. The palm frond beneath the bunch is cut off, then the bunch itself is cut. With young palms an axe is used. With the older, taller palms, a sharp hooked knife on a bamboo pole is required. The bunches and loose fruit are picked up manually and loaded into transport.

The commonest form of transport is by lorry. However, on the older estates in flat coastal areas, rails have been laid. This enables loading to be done into metal cages suitable for the first mill process. There is considerable reduction in handling and bruising of fruit with this method.

Oil Mill Process

A flow sheet for the mill process is given in Figure 1.

Loading sterilizer cages. Lorries are driven up a ramp and the fruit tipped into a chute. Rail cages are loaded beneath the chute, 2½ tons in each, and pushed into horizontal cylindrical pressure vessels.

Sterilizing. The fresh fruit bunches (FFB) are cooked at 40lb/sq. in. pressure. It is necessary to expel all the air from the sterilizer vessels and this is usually done by bringing up to pressure, and releasing pressure twice. On the third occasion, pressure is maintained for 20-30 min. Pressure is released rapidly, resulting in a beneficial drying effect on the fruit. Automatic systems for controlling sterilizer cycle are available. A typical cycle is illustrated in Figure 2 (1).

The objectives of sterilization are: inactivation of enzymes, loosening of fruit on the bunch, softening of fruit,

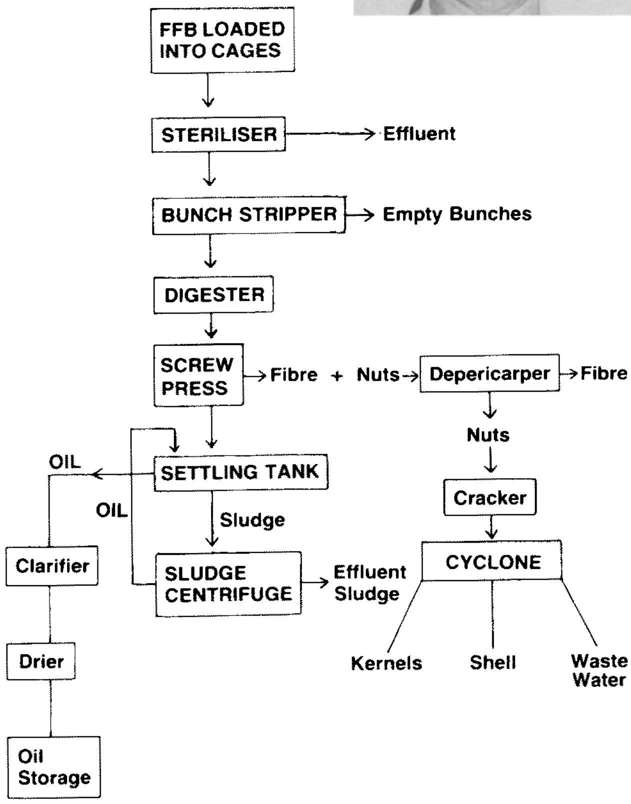

FIG. 1. Oil mill process flow sheet.

conditioning of nuts, and coagulation of proteins. The total time of the process is 80-90 min, including loading and unloading.

Bunch stripping. After removal from the sterilizer, the cages are hoisted in turn and emptied into the feed hopper of the bunch stripper. This consists of a horizontal rotating drum in which each bunch is lifted and dropped several times to shake out the fruit.

Digester and press. The loose fruit is elevated to a vertical cylindrical vessel, steam-jacketed and fitted with beater arms. The vessel is kept filled. The action of the arms breaks up the fruit, especially the oil-containing cells. The temperature is kept at 90-95 C. The digester is linked by means of a screw feed conveyor to a continuous single- or double-screw press. The back-pressure within the press is adjusted by means of a cone to obtain maximum oil expulsion with minimal breakage of nuts. The press squeezes out liquid consisting of 53% oil, 7% finely divided solids and 40% aqueous phase and a press cake containing fruit fiber and nuts.

Vibrating screen. The mixed liquid phase flows through a 20 and a 40 mesh vibrating screen to a settling tank where it may be diluted with hot water. Fiber, shell and some solids removed by the screen are recycled to the digester.

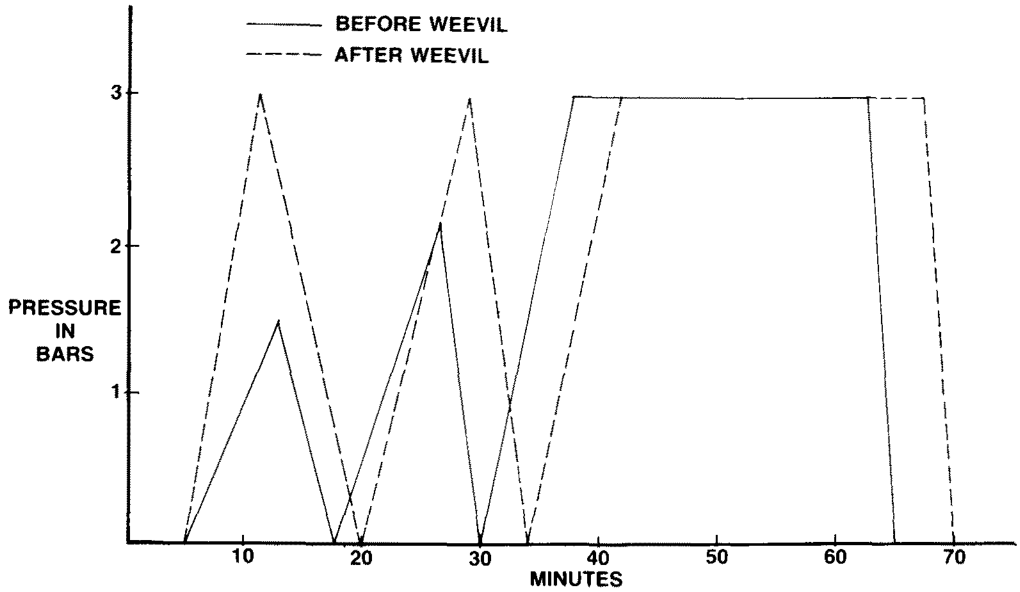

FIG. 2. Typical sterilizer cycles.

Oil clarification and purification. During a 2-hr residence period in the settling tank, a fairly clean oil and a sludge layer separate. Dirt and moisture are removed from the oil layer in a hermetically sealed purifying centrifuge and the oil is dried in a vacuum drier operating at ca. 50 mm pressure to 0.10-0.15% moisture before storage.

The sludge layer may be passed through a small desanding cyclone before going to a sludge centrifuge. The recovered oil from this stage is returned to the settling tank and the remaining sludge to the waste treatment system.

Recovery of palm kernels. A large part of the space in an oil mill is taken up by the kernel processing, because large air separation and drying systems are used.

Depericarper. The cake from the screw press passes down a conveyor, specially designed to break up the cake and to dry it somewhat. In other designs, the mixture is first treated in a horizontal drum before pneumatic separation. The broken-up cake, nuts and fiber are fed into a moving air column which blows most of the fiber away. The nuts drop into a polishing drum, which frees the rest of the fibers, so that they can also be removed in air stream.

Nut cracking. Before the nuts are cracked, they are stored in a silo, where their moisture content is reduced, typically from 16% to ca. 11%, by a stream of heated air. Alternatively, drying may be done by heating in an autoclave and rapidly releasing the pressure.

The nuts are cracked in a centrifugal nut cracker, mostly of the self-grading type. The nuts drop onto a rotor and are hurled outwards against a cracking ring where they break on impact. It is at this point that correct conditioning of the nuts is important. It ensures that the shell is brittle enough to crack, and that the kernel has dried enough to detach from the shell.

The mixture of kernels and shell fragments is separated first in a pneumatic column and then in a hydrocyclone. Finally, the kernels are dried in a silo with hot air to below 8% moisture, and bagged for despatch.

Palm kernels are processed into oil and meal in conventional pressing and solvent extraction processes usually sited in separate factories.

The capacity of most oil mills ranges from 20 to 80 tons/hr. Sizes of equipment are appropriately related to the expected proportions of the various product and byproduct streams. At the time of writing, a series of operational problems have arisen resulting from the introduction and proliferation during 1981 of the weevil *Elaedobus kamerunicus*. The purpose of this introduction from West Africa was to improve fertilization of the flowering bunch, and avoid the cost of manual pollination which is sometimes required. As a result, there has been an increase in fruitlets per bunch, an increase in bunch weight and a higher proportion of kernels. A higher yield of oil is obtained, but the following consequences are being experienced:

- Bunch ripeness is less uniform because there are more fruits on the inside of the bunch and the correct ripeness for harvesting is more difficult to determine.
- Sterilization is more difficult, so that the sterilizer treatment has had to be increased (see Fig. 2).
- In consequence, the steam supply is less adequate.
- More fruits remain in the empty bunches so that they have to be recycled.
- The higher proportion of kernels to mesocarp makes press operation more difficult.
- The equipment for processing kernels is insufficient.

In due course, the necessary engineering adjustments will be made. The practical effect, in terms of yield can be seen from Table I. There is a higher oil yield and a much higher proportion of kernels.

Treatment of Oil Mill Wastes

One hundred tons of fresh fruit bunches produce 20-24 tons of palm oil and about 3.6 tons of palm kernels. The remaining material emerges at various stages of the oil mill process as byproduct giving rise to problems of disposal. The solid wastes in various forms have been successfully used in animal feeds as the recommendations (2) in Table II show. They are based on considerations of chemical composition and digestibility in feeding trials. These uses have not yet been applied beyond the experimental stage.

Empty Fruit Bunch

The most usual practice is to burn the bunches in an incin-

TABLE I

Yield of Oil Mill Products

		Ref. (1)	Ref. (16)	Ref. (7)	K.H. Lim[a]
Bunch components	Empty bunch	24	29	22	35
	Evaporation and water	10	–	12	–
	Fruit	66	71	66	65
Fruit components	Nuts	12	12	10	18
	Mesocarp	54	59	56	47
Nut components	Wet shell	7	6.5	5	9
	Kernel	5	5.5	5	9
Mesocarp components	Nonoil solids	9	11	12	4.7
	Water	20	26	22	18.8
	Oil	25	22	22	23.5

[a]Preliminary results "post weevil" (private communication, 1982).

TABLE II

Optimal Rate of Inclusion of Oil Mill Waste in Feeds

Feeds	Inclusion rate in diet (%)			
	Pigs	Poultry	Cattle/buffalo	Goat/sheep
Palm oil sludge solids (POSS)	10-20	10-15	15-30	10-20
Fermented sludge	20-30	20-30	–	–
Palm press fiber	–	–	10-20	10-15

erator and use the residual ash as a fertilizer. Being rich in potash, it is particularly valued on acidic peat soils. Burning is now being discouraged because of environmental pollution. An alternative (3) is to return the bunches to the land as a mulch beneath the palms, where they help to retain moisture and eventually rot down and yield the mineral components. However, considerable transport costs are involved. It has also been shown experimentally that empty bunches can be used in paper making, but this has not been commercialized to date.

Fiber

The fiber from the screw press contains about 7% oil on a dry weight basis. Solvent extraction of this oil is not economical. Current practice is to use the fiber as fuel for the mill boilers. As a result, the oil mill is able to generate its own electricity and is usually more than self-supporting in energy terms.

Shell

A part of the shell is used as fuel in the boilers, mixed with fiber. Shell is also useful as hard core on the estate roads. An estate may have 200 miles of internal roadways requiring maintenance, especially during periods of heavy rain fall. Shell is suitable for the manufacture of activated charcoal, and has been used for this purpose to a limited extent.

Liquid Effluent

Three steps in the process produce significant amounts of liquid effluent. Table III gives a typical quantitative picture.

As it leaves the plant, this product is innocuous vegetable material which has just been sterilized. It is being successfully used direct as a cattle feed at one site, but this is not widely practiced.

In the early growth stage of the industry, much of the waste was discharged to rivers, but Pollution Control Legislation now requires that the waste be treated to defined standards before it is discharged.

A number of different treatment systems have been installed, varying in sophistication, capital cost and efficiency. The main processes are:

- *Ponding.* The most common system is a ponding system which is cheap to instal when suitable and sufficient land area is available. Sixteen acres are required for a 20-ton FFB/hr process. A number of ponds are connected in series. After removal of surface oil, the effluent is placed in an acidification pond for 2-3 days. It is then treated in an anaerobic pond with a hydraulic retention time of 30-80 days. The digested liquor is treated in facultative ponds for about 20 days before discharge.
- *Tank digestion and mechanical aeration.* In this system, a considerable degree of control is exerted over the process (4). (a) Effluent is cooled somewhat and then placed in an open acidification pond, where it is seeded with some liquor from the (subsequent) anaerobic stage. Organic components are converted to volatile fatty acids in 1-2 days. (b) The effluent is transferred to tanks for the mesophilic anaerobic phase of digestion, care being taken to maintain the tank contents above pH 6.8, so that the methanogenic bacteria are active. After a hydraulic retention time of 20 days, the effluent is transferred to an open lagoon where it is vigorously agitated to provide oxy-

TABLE III

Composition of Oil Mill Effluents

	Sterilizer		Oil clarifiers		Hydrocyclone		Mixed	
Volume/ton oil produced	0.9		1.5		0.1		2.5	
Oil (%)	0.4	4.3	0.75	5.25	0.03	0.11	0.6	4.5
Dissolved solids (%)	3.4		2.2		0.01		2.1	
Suspended solids (%)	0.5		2.3		0.07		1.8	
pH	5.0		4.5		–		4.7	

genation and mixing. A 20-day retention time is sufficient to produce an effluent fit for discharge according to the present Department of Environment requirements. The methane generated in the anaerobic phase can be recovered and utilized.

- *Tank digestion and facultative ponds.* The effluent is treated by mesophilic anaerobic digestion in a stirred tank with a retention time of 20 days, methane being recovered and utilized. Subsequently, the digested liquor is held in ponds for facultative digestion and finally disposed of on land.
- *Decanter and ponds.* The oil/water/solids phase from the screw press is passed direct to a decanter/centrifuge instead of the settling tank (5), where 90% of the suspended solids and 20% of the dissolved solids are removed in a slurry containing 17% nonoil solids.

The crude oil from the decanter is passed to the settling tank. The oil layer is processed in the conventional way. The sludge layer is treated in a sludge centrifuge. The slurries separated from the decanter and from the sludge centrifuge are dried together in a rotary drier utilizing the waste heat from the boiler flue gases.

The dried sludge representing 75% of the usual effluent load is used as a fertilizer or as a component of animal feed. Its nutrient contents are 1.87% nitrogen, 0.46% phosphorus, 2.35% potassium, 0.99% magnesium and 0.67% calcium. The other liquid effluents, from the sterilizer and the hydrocyclone, are treated in anaerobic ponds. Together they represent only 25% of the original effluent load.

Typical results illustrating the performance of the 4 processes described above are given in Table IV (6). The last 2 columns of the table give the current and future standards required by the Department of the Environment.

- *Land application.* Extensive experiments have shown that direct application of the effluent to land is feasible, and when carried out in a systematic and controlled manner provides fertilizer without causing pollution of surface waters (7,8). It is necessary to apply the effluent to a limited area, defined by earth bunds, on a regular basis. Pipeline and pump systems have to be installed and the system is only feasible on flat land. At present, permission for land application has to be obtained from the Department of the Environment.

A number of unsolved problems require further research. These include disposal of the settled solids from ponding systems, and efficient removal of dissolved solids and nitrogen from the effluent. A thermophilic digestion system, if adequately controlled, would reduce retention times.

Quality Aspects of the Mill Operation

The importance of good harvesting routines in relation to development of free fatty acids has often been stressed. It has generally been thought that the rapid glyceride hydrolysis observed in overripe or bruised fruit was due to endogenous lipases. Recent work, however (9), has demonstrated the absence of lipase activity in fresh palm fruit. On the other hand, Toombs (private communication) has found yeast cells in the fruit with numbers in proportion to the free fatty acid content. The supposition is that the hydrolysis is caused by transient yeast lipases. If this hypothesis can be proved, a way may be found to prevent infection by the yeasts in the field. Hydrolysis during the mill process is prevented by rapid sterilization on arrival and by good housekeeping of the plant.

The second aspect of quality is the reduction of oxidation of the oil during the process. Oxidation of crude palm oil, particularly in the presence of iron, causes difficulty in the refining process. The oil mill is therefore designed to avoid excessive contact between the oil and air during the process. Vessels are covered where possible and sealed centrifuges are used (10).

Since the plant is mainly constructed of mild steel, contamination with iron is inevitable. Bek-Nielsen (11) has shown that attrition of the digester and press contributes the equivalent of 56 ppm or more of iron calculated on oil, to the material being processed. However, two alternative procedures have been adopted for minimizing this contamination: the wearing parts of the digester and the screwpress and the crude oil pipe work are constructed of stainless steel; and residual particulate iron is removed from the crude oil stream after the centrifuge by means of magnetic traps (12).

The effectiveness of these procedures is shown in Table V which shows results of samples drawn from three oil mills for iron content before and after filtration. Samples were subsequently stored at 55 C in the laboratory. The table shows quality analyses after storage (13). It will be noted that the sample from the "Normal" mill, with the higher iron content deteriorated much more rapidly. It is also of interest that iron went into solution during storage.

Oil having a residual moisture content of 0.2-0.3% develops peroxides more slowly during storage than oil with lower moisture content (14), as shown in Table VI. However, since these higher moisture levels promote hydrolysis, a compromise is usually achieved by drying to ca. 0.15% moisture.

Considerable emphasis is placed on monitoring oil yield in the mill. Owing to the variability in oil content among bunches of fruit, it is not possible to measure the amount of oil in the incoming supplies. Control is therefore achieved by measuring the oil output and the oil content of each waste stream on a regular basis (15). Deviations in any one

TABLE IV

Summary of Analysis of Effluent Discharge Samples from Various Treatment Systems (17) and DOE Standards for 1983 (18)

		Treatment system				DOE Standard	
Parameter[a]	Raw effluent	Ponding	Tank digestion and mechanical aeration	Tank digestion and facultative ponds	Decanter and ponds	Up to 1/7/82	Up to 1/1/84
BOD_3[b]	25000	360	120	610	270	500	250
Suspended solid	19020	610	1060	4680	670	400	400
Oil and grease	8370	40	30	130	15	50	50
Ammoniacal nitrogen	35	120	3	180	120	10	150[c]
Total nitrogen	770	190	100	520	165	50	300[c]
pH	4.1	7.7	8.1	7.3	8.0	5.0-9.0	5.0-9.0

[a]All except pH in mg/L.
[b]Biochemical oxygen demand incubated at 30 C for 3 days.
[c]Requirements modified as a result of experience.

TABLE V

Effect of Iron on Quality of Crude Palm Oil

Storage period (days)	Temperature (C)	Mill	FE ppm		β-Carotene (ppm)	Total tocopherols (ppm)	Totox value	SCOPA Bleach test red color 5¼" cell
			Unfiltered	Filtered				
0	–	Normal	6.2	3.6	501	503	20.6	–
		SS	2.2	1.1	582	501	9.3	1.1
		Magnetic trap	2.2	1.5	533	469	4.3	0.9
20	55	Normal	1.5	5.3	321	211	61.8	4.2
		SS	2.4	2.4	533	383	41.7	2.5
		Magnetic trap	2.3	1.6	475	508	27.5	1.9
30	55	Normal	6.3	4.9	215	116	69.6	5.0
		SS	2.4	2.5	453	309	61.8	3.1
		Magnetic trap	2.4	1.9	385	319	60.2	3.0

TABLE VI

Peroxide Value Increase (meq/kg)

	Days at storage at 40 C					Days at storage at 50 C				
Moisture	15	30	45	60	Increase/day	15	30	45	60	Increase/day
0-0.10%	4.6	9.2	12.3	17.9	0.298	11.4	17.0	21.7	25	0.416
0.10-0.15%	2.2	5.0	8.1	11.4	0.190	6.1	13.5	20.2	23.3	0.388
0.15-0.20%	1.0	1.5	2.7	4.7	0.078	4.6	10.9	18.4	23.5	0.391
0.20-0.30%	1.1	1.6	2.2	2.8	0.046	5.3	11.8	15.6	18.7	0.311
Above 0.30%	0.6	1.1	1.7	2.8	0.046	4.2	11.0	19.0	–	0.422

source of loss are then investigated. Oil losses occur in the sterilizer condensate, on the bunch stalk, in the press fiber, on the surface of the nuts, and in the waste water from the clarifier centrifuges.

In each case, oil content is determined on a suitable representative sample taken at half-hourly or hourly intervals throughout production. By adding yield and all the measured oil losses, a calculated oil content of the FFB can be obtained. Hence an extraction efficiency can be calculated. This is usually in the range 92-93%. In order to obtain a more complete material balance, some mills have recently been measuring the input rate of fruitlets after they are stripped from the bunch, and analyzing samples for oil content.

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