3. PALM OIL PROCESSING

3. 1 General processing description

Research and development work in many disciplines - biochemistry, chemical and mechanical engineering - and the establishment of plantations, which provided the opportunity for large-scale fully mechanised processing, resulted in the evolution of a sequence of processing steps designed to extract, from a harvested oil palm bunch, a high yield of a product of acceptable quality for the international edible oil trade. The oil winning process, in summary, involves the reception of fresh fruit bunches from the plantations, sterilizing and threshing of the bunches to free the palm fruit, mashing the fruit and pressing out the crude palm oil. The crude oil is further treated to purify and dry it for storage and export.

Large-scale plants, featuring all stages required to produce palm oil to international standards, are generally handling from 3 to 60 tonnes of FFB/hr. The large installations have mechanical handling systems (bucket and screw conveyers, pumps and pipelines) and operate continuously, depending on the availability of FFB. Boilers, fuelled by fibre and shell, produce superheated steam, used to generate electricity through turbine generators. The lower pressure steam from the turbine is used for heating purposes throughout the factory. Most processing operations are automatically controlled and routine sampling and analysis by process control laboratories ensure smooth, efficient operation. Although such large installations are capital intensive, extraction rates of 23 - 24 percent palm oil per bunch can be achieved from good quality Tenera.

Conversion of crude palm oil to refined oil involves removal of the products of hydrolysis and oxidation, colour and flavour. After refining, the oil may be separated (fractionated) into liquid and solid phases by thermo-mechanical means (controlled cooling, crystallization, and filtering), and the liquid fraction (olein) is used extensively as a liquid cooking oil in tropical climates, competing successfully with the more expensive groundnut, corn, and sunflower oils.

Extraction of oil from the palm kernels is generally separate from palm oil extraction, and will often be carried out in mills that process other oilseeds (such as groundnuts, rapeseed, cottonseed, shea nuts or copra). The stages in this process comprise grinding the kernels into small particles, heating (cooking), and extracting the oil using an oilseed expeller or petroleum-derived solvent. The oil then requires clarification in a filter press or by sedimentation. Extraction is a well-established industry, with large numbers of international manufacturers able to offer equipment that can process from 10 kg to several tonnes per hour.

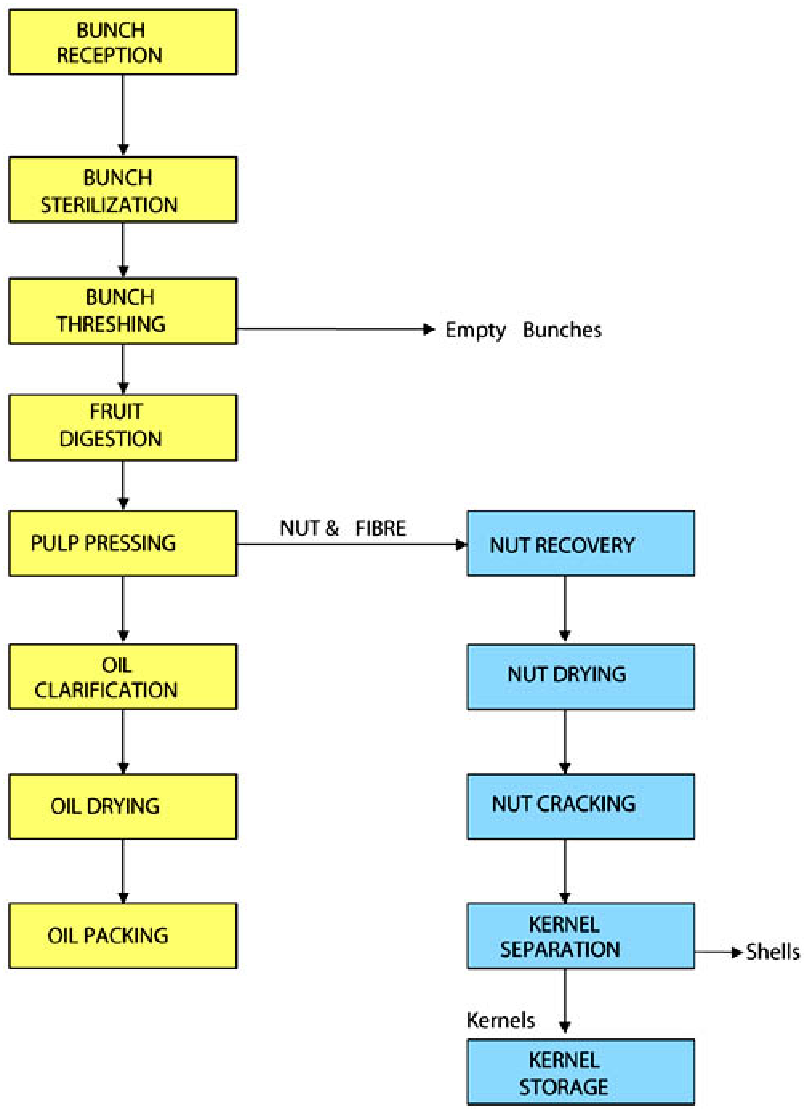
Alongside the development of these large-scale fully mechanised oil palm mills and their installation in plantations supplying the international edible oil refining industry, small-scale village and artisanal processing has continued in Africa. Ventures range in throughput from a few hundred kilograms up to 8 tonnes FFB per day and supply crude oil to the domestic market.

Efforts to mechanise and improve traditional manual procedures have been undertaken by research bodies, development agencies, and private sector engineering companies, but these activities have been piecemeal and uncoordinated. They have generally concentrated on removing the tedium and drudgery from the mashing or pounding stage (digestion), and improving the efficiency of oil extraction. Small mechanical, motorised digesters (mainly scaled-down but unheated versions of the large-scale units described above), have been developed in most oil palm cultivating African countries.

Palm oil processors of all sizes go through these unit operational stages. They differ in the level of mechanisation of each unit operation and the interconnecting materials transfer mechanisms that make the system batch or continuous. The scale of operations differs at the level of process and product quality control that may be achieved by the method of mechanisation adopted. The technical terms referred to in the diagram above will be described later.

The general flow diagram is as follows:

PALM OIL PROCESSING UNIT OPERATIONS



Harvesting technique and handling effects

In the early stages of fruit formation, the oil content of the fruit is very low. As the fruit approaches maturity the formation of oil increases rapidly to about 50 percent of mesocarp weigh. In a fresh ripe, un-bruised fruit the free fatty acid (FFA) content of the oil is below 0.3 percent. However, in the ripe fruit the exocarp becomes soft and is more easily attacked by lipolytic enzymes, especially at the base when the fruit becomes detached from the bunch. The enzymatic attack results in an increase in the FFA of the oil through hydrolysis. Research has shown that if the fruit is bruised, the FFA in the damaged part of the fruit increases rapidly to 60 percent in an hour. There is therefore great variation in the composition and quality within the bunch, depending on how much the bunch has been bruised.

Harvesting involves the cutting of the bunch from the tree and allowing it to fall to the ground by gravity. Fruits may be damaged in the process of pruning palm fronds to expose the bunch base to facilitate bunch cutting. As the bunch (weighing about 25 kg) falls to the ground the impact bruises the fruit. During loading and unloading of bunches into and out of transport containers there are further opportunities for the fruit to be bruised.

In Africa most bunches are conveyed to the processing site in baskets carried on the head. To dismount the load, the tendency is to dump contents of the basket onto the ground. This results in more bruises. Sometimes trucks and push carts, unable to set bunches down gently, convey the cargo from the villages to the processing site. Again, tumbling the fruit bunches from the carriers is rough, resulting in bruising of the soft exocarp. In any case care should be exercised in handling the fruit to avoid excessive bruising.

One answer to the many ways in which harvesting, transportation and handling of bunches can cause fruit to be damaged is to process the fruit as early as possible after harvest, say within 48 hours. However the author believes it is better to leave the fruit to ferment for a few days before processing. Connoisseurs of good edible palm oil know that the increased FFA only adds 'bite' to the oil flavour. At worst, the high FFA content oil has good laxative effects. The free fatty acid content is not a quality issue for those who consume the crude oil directly, although it is for oil refiners, who have a problem with neutralization of high FFA content palm oil.

3.1.1 Bunch reception

Fresh fruit arrives from the field as bunches or loose fruit. The fresh fruit is normally emptied into wooden boxes suitable for weighing on a scale so that quantities of fruit arriving at the processing site may be checked. Large installations use weighbridges to weigh materials in trucks.

The quality standard achieved is initially dependent on the quality of bunches arriving at the mill. The mill cannot improve upon this quality but can prevent or minimise further deterioration.

The field factors that affect the composition and final quality of palm oil are genetic, age of the tree, agronomic, environmental, harvesting technique, handling and transport. Many of these factors are beyond the control of a small-scale processor. Perhaps some control may be exercised over harvesting technique as well as post-harvest transport and handling.

3.1.2 Threshing (removal of fruit from the bunches)

The fresh fruit bunch consists of fruit embedded in spikelets growing on a main stem. Manual threshing is achieved by cutting the fruit-laden spikelets from the bunch stem with an axe or machete and then separating the fruit from the spikelets by hand. Children and the elderly in the village earn income as casual labourers performing this activity at the factory site.

In a mechanised system a rotating drum or fixed drum equipped with rotary beater bars detach the fruit from the bunch, leaving the spikelets on the stem (Fig. 3).

Most small-scale processors do not have the capacity to generate steam for sterilization. Therefore, the threshed fruits are cooked in water. Whole bunches which include spikelets absorb a lot of water in the cooking process. High-pressure steam is more effective in heating bunches without losing much water. Therefore, most small-scale operations thresh bunches before the fruits are cooked, while high-pressure sterilization systems thresh bunches after heating to loosen the fruits.

Small-scale operators use the bunch waste (empty bunches) as cooking fuel. In larger mills the bunch waste is incinerated and the ash, a rich source of potassium, is returned to the plantation as fertilizer.

3.1.3 Sterilization of bunches

Sterilization or cooking means the use of high-temperature wet-heat treatment of loose fruit. Cooking normally uses hot water; sterilization uses pressurized steam. The cooking action serves several purposes.

· Heat treatment destroys oil-splitting enzymes and arrests hydrolysis and autoxidation.

· For large-scale installations, where bunches are cooked whole, the wet heat weakens the fruit stem and makes it easy to remove the fruit from bunches on shaking or tumbling in the threshing machine.

· Heat helps to solidify proteins in which the oil-bearing cells are microscopically dispersed. The protein solidification (coagulation) allows the oil-bearing cells to come together and flow more easily on application of pressure.

· Fruit cooking weakens the pulp structure, softening it and making it easier to detach the fibrous material and its contents during the digestion process. The high heat is enough to partially disrupt the oil-containing cells in the mesocarp and permits oil to be released more readily.

· The moisture introduced by the steam acts chemically to break down gums and resins.

The gums and resins cause the oil to foam during frying. Some of the gums and resins are soluble in water. Others can be made soluble in water, when broken down by wet steam (hydrolysis), so that they can be removed during oil clarification. Starches present in the fruit are hydrolyzed and removed in this way.

· When high-pressure steam is used for sterilization, the heat causes the moisture in the nuts to expand. When the pressure is reduced the contraction of the nut leads to the detachment of the kernel from the shell wall, thus loosening the kernels within their shells. The detachment of the kernel from the shell wall greatly facilitates later nut cracking operations. From the foregoing, it is obvious that sterilization (cooking) is one of the most important operations in oil processing, ensuring the success of several other phases.

· However, during sterilization it is important to ensure evacuation of air from the sterilizer. Air not only acts as a barrier to heat transfer, but oil oxidation increases considerably at high temperatures; hence oxidation risks are high during sterilization. Over-sterilization can also lead to poor bleach ability of the resultant oil. Sterilization is also the chief factor responsible for the discolouration of palm kernels, leading to poor bleach ability of the extracted oil and reduction of the protein value of the press cake.

Fig. 3 Bunch thresher (Centre de Formation Technique Steinmetz-Benin)

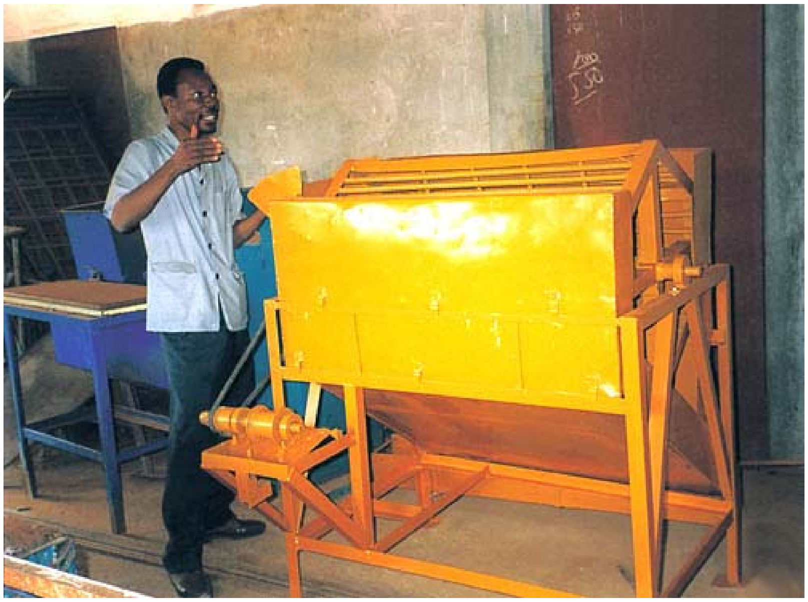


Fig. 4 Fruit sterilizer (Centre de Formation Technique Steinmetz-Benin)

3.1.4 Digestion of the fruit

Digestion is the process of releasing the palm oil in the fruit through the rupture or breaking down of the oil-bearing cells. The digester commonly used consists of a steam-heated cylindrical vessel fitted with a central rotating shaft carrying a number of beater (stirring) arms. Through the action of the rotating beater arms the fruit is pounded. Pounding, or digesting the fruit at high temperature, helps to reduce the viscosity of the oil, destroys the fruits' outer covering (exocarp), and completes the disruption of the oil cells already begun in the sterilization phase. Unfortunately, for reasons related to cost and maintenance, most small-scale digesters do not have the heat insulation and steam injections that help to maintain their contents at elevated temperatures during this operation.

Contamination from iron is greatest during digestion when the highest rate of metal wear is encountered in the milling process. Iron contamination increases the risk of oil oxidation and the onset of oil rancidity.

3.1.5 Pressing (Extracting the palm oil)

There are two distinct methods of extracting oil from the digested material. One system uses mechanical presses and is called the 'dry' method. The other called the 'wet' method uses hot water to leach out the oil.

In the 'dry' method the objective of the extraction stage is to squeeze the oil out of a mixture of oil, moisture, fibre and nuts by applying mechanical pressure on the digested mash. There are a large number of different types of presses but the principle of operation is similar for each. The presses may be designed for batch (small amounts of material operated upon for a time period) or continuous operations.

3.1.5.1 Batch presses

In batch operations, material is placed in a heavy metal 'cage' and a metal plunger is used to press the material. The main differences in batch press designs are as follows: a) the method used to move the plunger and apply the pressure; b) the amount of pressure in the press; and c) the size of the cage.

The plunger can be moved manually or by a motor. The motorised method is faster but more expensive.

Different designs use either a screw thread (spindle press) (Fig. 4, 5, 6) or a hydraulic system (hydraulic press) (Fig. 7, 8, 9) to move the plunger. Higher pressures may be attained using the hydraulic system but care should be taken to ensure that poisonous hydraulic fluid does not contact the oil or raw material. Hydraulic fluid can absorb moisture from the air and lose its effectiveness and the plungers wear out and need frequent replacement. Spindle press screw threads are made from hard steel and held by softer steel nuts so that the nuts wear out faster than the screw. These are easier and cheaper to replace than the screw.

The size of the cage varies from 5 kg to 30 kg with an average size of 15 kg. The pressure should be increased gradually to allow time for the oil to escape. If the depth of material is too great, oil will be trapped in the centre. To prevent this, heavy plates' can be inserted into the raw material. The production rate of batch presses depends on the size of the cage and the time needed to fill, press and empty each batch.

Hydraulic presses are faster than spindle screw types and powered presses are faster than manual types. Some types of manual press require considerable effort to operate and do not alleviate drudgery.

3.1.5.2 Continuous systems

The early centrifuges and hydraulic presses have now given way to specially designed screw-presses similar to those used for other oilseeds. These consist of a cylindrical perforated cage through which runs a closely fitting screw. Digested fruit is continuously conveyed through the cage towards an outlet restricted by a cone, which creates the pressure to expel the oil through the cage perforations (drilled holes). Oil-bearing cells that are not ruptured in the digester will remain unopened if a hydraulic or centrifugal extraction system is employed. Screw presses, due to the turbulence and kneading action exerted on the fruit mass in the press cage, can effectively break open the unopened oil cells and release more oil. These presses act as an additional digester and are efficient in oil extraction.

Moderate metal wear occurs during the pressing operation, creating a source of iron contamination. The rate of wear depends on the type of press, method of pressing, nut-to-fibre ratio, etc. High pressing pressures are reported to have an adverse effect on the bleach ability and oxidative conservation of the extracted oil.

3.1.6 Clarification and drying of oil

The main point of clarification is to separate the oil from its entrained impurities. The fluid coming out of the press is a mixture of palm oil, water, cell debris, fibrous material and 'non-oily solids'. Because of the non-oily solids the mixture is very thick (viscous). Hot water is therefore added to the press output mixture to thin it. The dilution (addition of water) provides a barrier causing the heavy solids to fall to the bottom of the container while the lighter oil droplets flow through the watery mixture to the top when heat is applied to break the emulsion (oil suspended in water with the aid of gums and resins). Water is added in a ratio of 3:1.

The diluted mixture is passed through a screen to remove coarse fibre. The screened mixture is boiled from one or two hours and then allowed to settle by gravity in the large tank so that the palm oil, being lighter than water, will separate and rise to the top. The clear oil is decanted into a reception tank. This clarified oil still contains traces of water and dirt. To prevent increasing FFA through autocatalytic hydrolysis of the oil, the moisture content of the oil must be reduced to 0.15 to 0.25 percent. Re-heating the decanted oil in a cooking pot and carefully skimming off the dried oil from any engrained dirt removes any residual moisture. Continuous clarifiers consist of three compartments to treat the crude mixture, dry decanted oil and hold finished oil in an outer shell as a heat exchanger. (Fig. 10, 11, 12)

Fig. 5 Spindle press (Luapula, Zambia)

Fig. 6 Spindle press (Luapula, Zambia)

Fig. 7 Another model of spindle press (Nova Technologies Ltd., Nigeria)

Fig. 8 Hydraulic press (manual)

The wastewater from the clarifier is drained off into nearby sludge pits dug for the purpose. No further treatment of the sludge is undertaken in small mills. The accumulated sludge is often collected in buckets and used to kill weeds in the processing area.

3.1.7 Oil storage

In large-scale mills the purified and dried oil is transferred to a tank for storage prior to dispatch from the mill. Since the rate of oxidation of the oil increases with the temperature of storage the oil is normally maintained around 50°C, using hot water or low-pressure steam-heating coils, to prevent solidification and fractionation. Iron contamination from the storage tank may occur if the tank is not lined with a suitable protective coating.

Small-scale mills simply pack the dried oil in used petroleum oil drums or plastic drums and store the drums at ambient temperature.

3.1.8 Kernel recovery

The residue from the press consists of a mixture of fibre and palm nuts. The nuts are separated from the fibre by hand in the small-scale operations. The sorted fibre is covered and allowed to heat, using its own internal exothermic reactions, for about two or three days. The fibre is then pressed in spindle presses to recover a second grade (technical) oil that is used normally in soap-making. The nuts are usually dried and sold to other operators who process them into palm kernel oil. The sorting operation is usually reserved for the youth and elders in the village in a deliberate effort to help them earn some income.

Large-scale mills use the recovered fibre and nutshells to fire the steam boilers. The super-heated steam is then used to drive turbines to generate electricity for the mill. For this reason it makes economic sense to recover the fibre and to shell the palm nuts. In the large-scale kernel recovery process, the nuts contained in the press cake are separated from the fibre in a depericarper. They are then dried and cracked in centrifugal crackers to release the kernels (Fig. 13, 14, 15, 16). The kernels are normally separated from the shells using a combination of winnowing and hydrocyclones. The kernels are then dried in silos to a moisture content of about 7 percent before packing.

During the nut cracking process some of the kernels are broken. The rate of FFA increase is much faster in broken kernels than in whole kernels. Breakage of kernels should therefore be kept as low as possible, given other processing considerations.

Fig. 9 Manual vertical press (O.P.C., Cameroon)

Fig. 10 Motorised horizontal screw press (Centre Songhai, Benin)

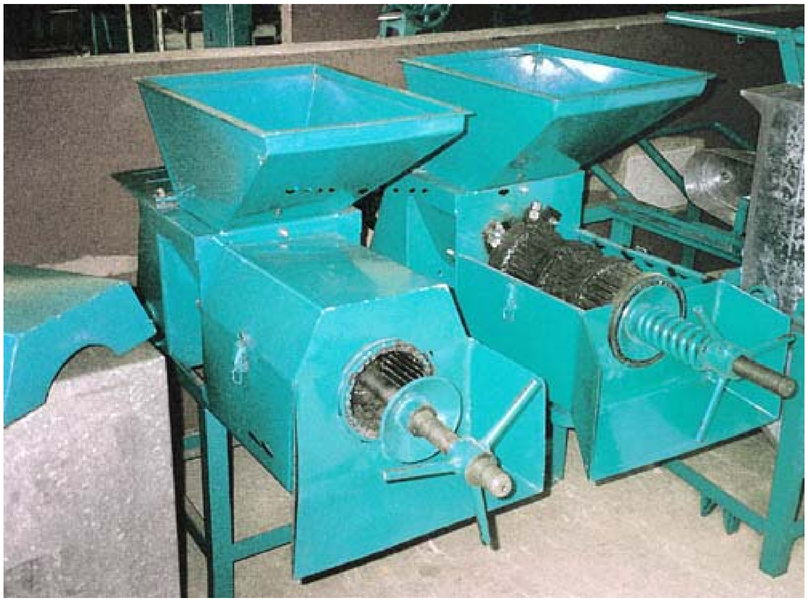


Fig. 11 Combined digester and motorised hydraulic press (Technoserve/Cort Engineering, Ghana)

Fig. 12 Flushing extractor (Cort Engineering Services, Ghana)

Summary of Unit operations

	Unit operation	Purpose
1.	Fruit fermentation	To loosen fruit base from spikelets and to allow ripening processes to abate
2.	Bunch chopping	To facilitate manual removal of fruit
3.	Fruit sorting	To remove and sort fruit from spikelets
4.	Fruit boiling	To sterilize and stop enzymatic spoilage, coagulate protein and expose microscopic oil cells
5	Fruit digestion	To rupture oil-bearing cells to allow oil flow during extraction while separating fibre from nuts
6	Mash pressing	To release fluid palm oil using applied pressure on ruptured cellular contents
7	Oil purification	To boil mixture of oil and water to remove water-soluble gums and resins in the oil, dry decanted oil by further heating
8	Fibre-nut separation	To separate de-oiled fibre from palm nuts.
9	Second Pressing	To recover residual oil for use as soap stock
10	Nut drying	To sun dry nuts for later cracking

Fig. 13 Clarifier tank (O.P.C., Cameroon)

Fig. 14 Clarifier tank (Nova Technologies Ltd., Nigeria)

Fig. 15 Oil filter (Faith Engineering Workshop, Nigeria)

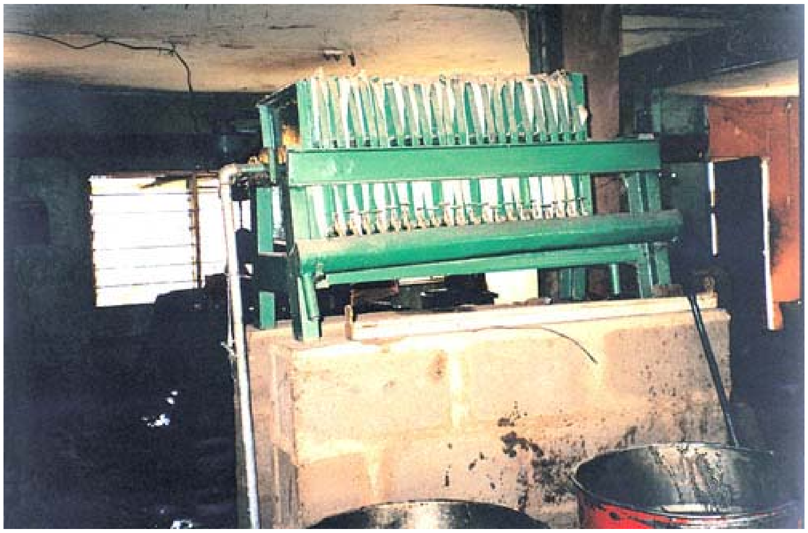


Fig. 16 Palm nut cracker (AGRICO, Ghana)

Fig. 17 Palm nut cracker (NOVA, Technologies, Nigeria)

Fig. 18 Palm nut cracker (Ogunoroke Steele Construction Works Ltd, Nigeria)

Fig. 19 Palm nut cracker combined with Kernel/Shell separator (Hormeku Engineering works, Ghana)

3.2 Process equipment design and selection criteria

In designing equipment for small-scale oil extraction one of the key factors to consider is the quality required. ‘Quality’ is entirely subjective and depends on the demands of the ultimate consumer. For the edible oil refining industry the most important quality criteria for crude oil are:

- low content of free fatty acids (which are costly to remove during oil refining);
- low content of products of oxidation (which generate off-flavours);
- readily removed colour.

The most critical stages in the processing sequence for a processor seeking to satisfy these criteria are: bunch sterilization as soon as possible after harvest; and effective clarification and drying of the crude oil after extraction.

By contrast, for the domestic consumer of crude palm oil, flavour is the primary quality factor. This is boosted by the fermentation that takes place within the fruit when the bunches are allowed to rest for three or more days after harvesting. Thus sterilization immediately after harvesting is not a crucial consideration. Herbs and spices for flavour are introduced during the oil-drying phase of operations to mask off-flavours. Therefore rigid process control during oil clarification need not be prescribed or incorporated in the design.

The free fatty acids and the trace tocopherols contained in the crude palm oil after natural fermentation also have a laxative effect, which is desirable for African consumers for whom synthetic substitutes are a luxury. The acidity imparts a ‘bite’ to the oil which some consumers prefer. Thus the quality requirements of one market, leading to certain processing imperatives, may conflict with those of another market.

The traditional manual methods are normally referred to as ‘low technology’ production. The mechanised units are likewise referred to as ‘intermediate technology’ production.

The village traditional method of extracting palm oil involves washing pounded fruit mash in warm water and hand squeezing to separate fibre and nuts from the oil/water mixture. A colander, basket or a vessel with fine perforated holes in the bottom is used to filter out fibre and nuts. The wet mixture is then put on the fire and brought to a vigorous boil. After about one or two hours, depending on the volume of material being boiled, the firewood is taken out and the boiled mixture allowed to cool. Herbs may be added to the mixture at this point just before reducing the heat. On cooling to around blood temperature, a calabash or shallow bowl is used to skim off the palm oil. Because of the large quantities of water used in washing the pulp this is called the ‘wet’ method.

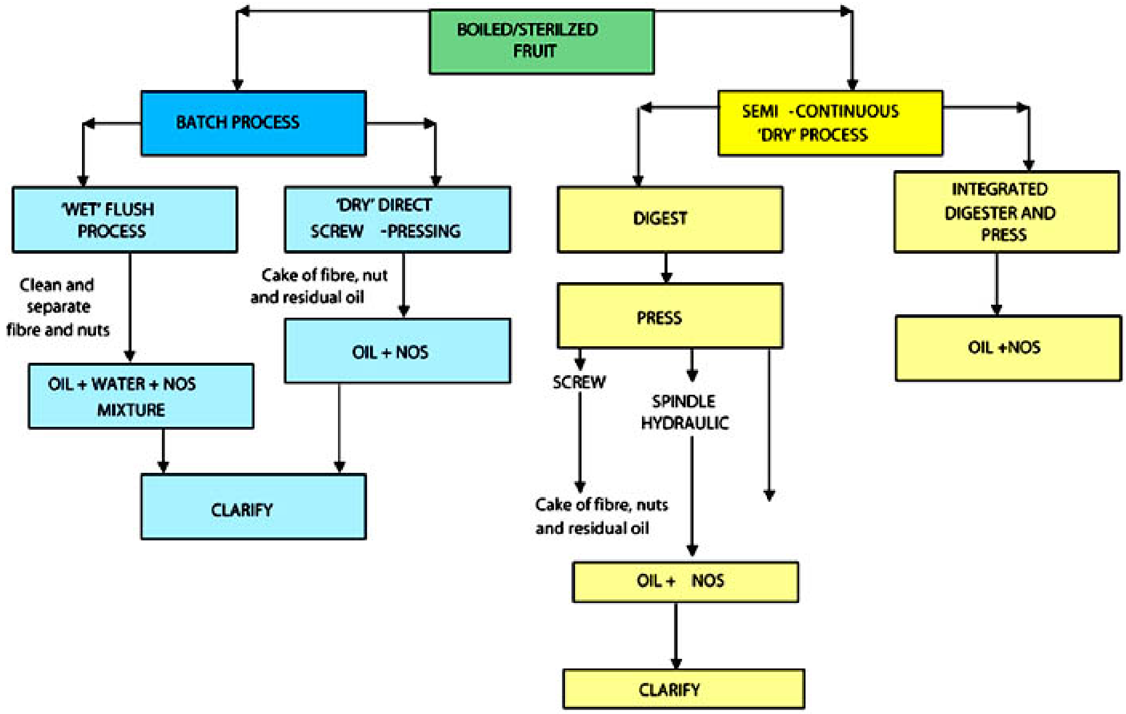
A mechanical improvement, based on the traditional wet method process, is achieved by using a vertical digester with perforated bottom plate (to discharge the aqueous phase) and a side chute for discharging the solid phase components. The arrangement combines digestion, pressing and hot water dilution into one mechanical unit operation.

The ‘dry’ method uses a digester to pound the boiled fruit, which is a considerable labour-saving device. The oil in the digested or pounded pulp is separated in a press that may be manual or mechanical. Motorised mechanical presses are preferred, whether hydraulic or screw type.

Most medium- and large-scale processing operations adopt the ’dry’ method of oil extraction. This is because the fibre and nut shells may immediately used to fire the boiler to generate steam for sterilization and other operations, including electricity generation. If the huge volumes of fibre and shells are not used as boiler fuel, serious environmental pollution problems may result. Too much water in the fibre increases the amount and cost of steam required to dry the fibre. Hence the preference for the dry method in plants handling more than six tonnes FFB per hour.

Processing machinery manufacturers tend to make machines to fit individual processing operations. However, recent developments have been toward the manufacture of integrated machines, combining several process operations such as digestion, pressing and fibre/nut separation into one assembly. It is found that these machines fit into two key process groupings: batch and semi-continuous processes.

Schematic of processing models and associated machinery



NB: NOS = Non -oily solids entrained in oil such as coagulated protein, gums and resins, etc.

The extraction of palm oil from boiled palm fruit can be accomplished by handling successive batches of materials or continuously feeding material to the machines.

3.2.1 Batch systems

The batch systems work directly on successive loads of boiled fruit to extract oil in one operation for clarification. The 'wet' method uses a vertical digester (Fig. 11) with a perforated bottom plate to pound a batch of fruit and then flush out the oil and other non-oil solids from the mashed pulp with hot water. The direct screw-press is designed to pound a batch of boiled fruit in the entry section of the machine while exerting pressure on the mashed pulp in another section to expel the palm oil in one operation.

The advantage of the wet system is that it is simple and completely leaches all oil and non-oily solid substances that can be carried in the fluid stream out of the digested mash to give clean and separated nuts and fibre. The aqueous effluent from the vertical digester goes directly to the clarification stage of processing. The amount of water needed to flush the pulp is normally the same as that required for diluting the viscous oil that comes from the mechanical press in preparation for clarification. An inexperienced operator may use too much hot water to leach out the oil and thus consume unnecessary wood fuel.

The 'wet' method yield of palm oil is severely reduced when the wash water is cold. In the course of digesting the fruit mash, in the presence of water, there is increased tendency to form an oil/water emulsion that is difficult to separate from the fibre mass. The emulsified oil loss in the fibre can be substantial if care is not taken to ensure full loading of the digester. Vertical flushing digesters, requiring loading and discharging of a specific amount of material, can thus only be used in a batch operation.

3.2.2 Semi-continuous systems

Continuous systems work sequentially, with one operation feeding directly into another, related to the arrangement and timing of machine operations. Careful engineering of unit operations is required to minimise discontinuities in the feeding of one stage into another. Otherwise some machines have to be stopped periodically for other stations to catch up. When there are discontinuities in the flow of materials between process stations the operations are known as semi-continuous. The dry extraction systems with separate digestion and pressing stations are usually semi-continuous.

Also when digestion and pressing stations are combined into an integrated unit and there is discontinuous feeding of boiled fruit to the digester inlet the operation is termed "semi-continuous".

Once operations have been integrated to attain full continuity the capital investment capacity of small-scale operators has been surpassed, because both machinery and working capital for raw material increases greatly with the increased level of mechanisation.

The dry systems do not need much water for processing, although they have the disadvantage of leaving substantial residual oil in the press cake. The oil content of the press cake can be quite considerable (2-3 percent), depending on the type of press used and the strength of manual operators.

The efficiency with which the various presses can extract oil ranges from 60 to 70 percent for spindle presses, 80-87 percent for hydraulic presses and 75-80 percent for the Caltech screw-presses. The first-pressing oil extraction rates also range from 12 to 15 percent for the spindle-presses, 14-16 percent for hydraulic presses and 17-19 percent for the motorised screw-presses. (Rouziere, 1995)

In many instances the first press cake is then sorted to remove the nuts, and the fibre is subsequently subjected to a second pressing to obtain more oil (an additional 3 to 4 percent on FFB). The second press oil is generally of lower quality, in terms of free fatty acid content and rancidity. Such low-grade oil is used in soap-making. Some village processors undertake the traditional hot water washing of the entire press cake immediately after pressing instead of sorting fibre and second pressing.

Local manufacturers have developed a wide range of machinery and equipment for processing palm oil and palm kernel to fit any budget. All the relevant unit operational machines can be produced to various degrees of finish and quality in the Sub-Region. It is the combination of the unit operation into an affordable process chain that distinguishes the manufacturers and their supplies.

From traditional technologies that rely solely on manual labour and simple cooking utensils, raising the level of mechanization depends largely on a balance between the quantity of bunches available for processing in a given locality and the money available for investment in machines.

The first consideration should be the availability of raw materials and how to compute the processing scale. Knowing the optimum scale of operations, it is then possible to consider the type of processing techniques. The higher the technology, the more skilful operators will be required to handle the machines. These technical considerations should lead to the equipment selection and examination of the capital investments needed to acquire the necessary machines.

3.3 Plant sizing

Assume a Village Group decides to plant oil palm and establishes a program to plant a certain number of seedlings each year over a seven-year period. In the third year the first set of trees begin to bear fruit. The community wants to establish a processing mill and they call an expert. How is the estimation made of the size and type of processing unit required by the community?

Start by establishing the block of planted areas by year so the age of the trees may be determined. The oil palm tree begins to bear fruit from the third year and the yield per tree increases progressively with age until it peaks around 20 years. The yield begins to decline from year 25 through 40 when the economic life of the tree ebbs.

Table 3 describes the potential yields of palm fruit bunches (in metric tonnes) from the planted hectares per year. Estimates in Table 3 are used to calculate the expected annual yield for each annual block. For example, 8 700 seedlings planted in 1998 began to yield fruit in 2000 at the rate of 3 tonnes per hectare to give 198 tonnes for the year. By Year 7 all planted areas will be in production, at different yield rates. The estimated annual yield per planting block is calculated and then the column for the year is added to give the potential raw materials available for processing. For example, in Year 7, when all planted blocks are yielding fruit, the total is 8 919 metric tonnes (see the row designated 'TOTAL'). How the annual yield is distributed over the entire year needs to be determined in order to know which period demands the attention of processors.

The oil palm tree yield is distributed over the entire year. Most of Central and West Africa experience two rainfall seasons. The oil palm bears fruit in response to the rainfall pattern and hence there are two peak harvesting periods in these regions. Southern hemisphere tropical monsoon regions such as Malawi, Zambia and South East Asia experience only one long rainy season and therefore tend to have a single peak-harvesting season.

For Central and West Africa the annual monthly distribution pattern for produce is expected to show the following variations:

Month	Percent yield	Seasonal contribution

March	9	
April	12	
May	16	50 %
June	13	
July	8	
August	7	
September	8	34 %
October	11	
November	7	
December	5	
January	3	16
February	1	

In the peak harvesting month it is estimated that 12 to 16 percent of the annual yield is generally available for processing. The plant that is installed must be capable of processing the peak month output, which is generally estimated as 15 percent of the annual output. Conservatively, it is estimated that the plant will work two shifts during the peak season.

Table 3: Estimated annual yield per hectare (from year of planting)

Year	1	2	3	4	5	6	7	8	9	10	11	12	15	20
Estimated yield (Tonnes)	--	--	3.0	4.25	5.5	6.0	7.25	8.2	8.6	9.5	10.5	11.0	12.5	13.5

Table 4: Estimated FFB yields after planting and related plant capacity

Year/yield in metric tonnes

Hectares	1 98	2	3	4	5	6	7	8	9	10	11	12	15	20
66	--	-	198	281	363	396	479	541	568	627	693	726	825	891
190		-	-	570	808	1 045	1 140	1 378	1 558	1 634	1 805	1 995	2 375	2 565
800			-	--	2 400	3 400	4 400	4 800	5 800	6 560	6 880	7 600	8 800	10 000
400				--	--	1 200	1 700	2 200	2 400	2 900	3 280	3 440	4 400	5 200
400					--	--	1 200	1 700	2 200	2 400	2 900	3 280	3 440	5 000
Total			198	851	3 571	6 041	8 919	10 619	12 526	14 121	15 558	17 041	19 840	23 656
Peak Month			29.7	128	536	906	1 338	1 593	1 879	2 118	2 334	2 556	2 976	3 548
Plant Capacity/hr Plant			0.09	0.4	1.7	2.8	4.2	5.0	6.0	6.6	7.5	8.0	9.5	11.0

Source: Poku, K. Feasibility study on Malawi palm oil mill establishment

In Year 3 there is the potential of processing 198 tonnes of fresh fruit bunches. Assuming that the total quantity were to be processed in one location over a 20-day period using 8 hours in the day, we would need a processing unit that handles 186 kg per hour, or 93 kilos/hr if the choice was made to operate 16-hours per day. Table 4 shows capacity based on a 16-hour working day. For this capacity a wet type digester or the dry spindle-press operation would be recommended. By Year 5 the community would require a fully mechanised mill using motorised digesters and presses.

Before the sixth year the community would have to decide whether they want to stay in the small-scale milling category or move up to a medium-scale operation using a continuous system of machines. If the option is to stay small-scale then the community will need to place orders for additional small-scale processing modules. The new set of processing machines can be placed to run alongside the existing facility or located in another village to minimise bunch transportation costs.

The best plant size option for rural Africa is still unknown. Large-scale operations normally require high-skilled labour and management expertise. Most villages do not have such a pool of skilled labour. The villages also lack the social infrastructure such as good accommodation, schools and hospitals that would attract high-skilled labour. Thus, in order to establish a large-scale processing operation, labour needs to be imported from other parts of the country. To maintain these 'alien' workers and managers a provision must be made in the capital investment for housing, schools and clinics near the processing estate. Some of the schooling and medical services must be extended to the whole community or there will be resentment towards the 'alien' workers.

Large-scale operations also require rapid transportation of harvested bunches to the processing site, hence the need for investment in roads and civil works. The establishment of large-scale operations creates an overhead burden that is beyond the capacity of a village community.

Many of the large-scale operations established in the early 1970s have declined along with the national economies of African nations. The cost structure of these establishments has rendered the output products non-competitive on the international market.

Today decentralised small-scale processing operations are preferred in most parts of Africa.

3.4 Process technology/capital investment considerations

Once the required plant size has been determined, the next item to consider is the amount of money required to buy the necessary machinery. The more money available, the more units can be bought, to minimise the drudgery of processors.

The wide array of machinery options makes it possible for a processor to start operations with a manual spindle-press used to pound the palm fruit. Another may start with a single motorised vertical wet process digester. Further up the investment scale are those who can afford the combination horizontal digester and screw-press or combination horizontal digester and hydraulic press along with the associated sterilizers, threshers, and oil clarifiers. Another combination that is yet to be tried is the combination of a horizontal motorised screw-press in combination with a second stage vertical flushing digester for maximum palm oil extraction and fibre/nut separation.

Type of unit	**Key machines**	**Rated capacity (k g FFB/hr)**	**Extraction efficiency (%)**	**Capital investment (US$)**
Single batch unit				
Dry	Spindle	100-200	55	150-200
	Hydraulic	200-300	67-74	5 000-7 000
	Screw	250-400	77.4	1 500-6 000
Wet	Vertical digester	500-800	80-90	1 500-2 500
Dry	Motorised horizontal digester (only)	500-1000	55	2 500-3 000
Dual separate units				
Dry	Digester + Spindle presses	200-300	60-70	3 000-5 000
	Digester + hydraulic press	400-800	67-78	7 000-10 000
Semi-continuous combined units	Motorised digester +	500-850	70-87	10 000
Dry	hydraulic + spindle-press			-15 000
	Digester + screw-press	500-850	76-90	12 000-15 000

Source: Compiled from various sources

The extraction efficiency refers to the percentage of oil that the machine can extract in relation to the total oil in the boiled fruit. The type of fruit mix (Dura/Tenera) presented for processing greatly influences the extraction efficiency of all units.

Many of the installations that use single spindle and manual hydraulic press units require manual pounding with wooden mortars and pestles, foot stomping, etc. Thus the throughput capacity of such a mill is determined by the manual pounding rate. The presses are usually not mechanised and hence the processing capacity of the press is also limited by the size of the press cage and the operator's energy level for turning the press screw or pumping the hydraulic fluid mechanism.

Another limiting condition is the affordability of capital equipment. Where the capital equipment cost exceeds a certain value villagers will shy away from taking loans to purchase the combination of operations. The designer must bear in mind that until the rural/urban migration of village youth is reversed the villages will be mainly populated by the elderly. These elders are naturally reluctant to take up long-term loans and the local banks are reluctant to lend to a predominantly aged community group. In Ghana, for instance, capital equipment costs should be around US$10 000 to be affordable to village-based individuals or groups.

Because of the need to keep initial capital investment to a bare minimum it is imperative that unnecessary mechanised unit operations are eliminated. Work that can be done manually - without overly taxing profitability - should be, thereby taking advantage of surplus labour and creating a stream of wages and salaries in the local community. Operations that are usually associated with drudgery by processors, such as fruit digestion and oil extraction, can be mechanised. Other less strenuous tasks, such as fruit separation and fibre/nut separation, can be contracted out to elderly women and unemployed youth.

“Small-scale” does not necessarily mean a significant decrease in efficiency. It does, however, mean a reduction in working capital and operating costs. The small mills can be placed at the heart of local communities, minimising reliance on vehicular transport that is normally unavailable in rural communities, given the poor condition of road networks and other infrastructure. This increased accessibility serves to dramatically reduce fruit spoilage and consequent post-harvest losses.

Culturally, men cultivate or produce while women process and sell. Traditionally, women decide the form in which the produce is to be traded and hence determine the degree of processing they are willing to undertake. These decisions form the basis of traditional technologies upon which innovations are to be derived.

The operating philosophy for equipment innovation should therefore be an attempt to develop machinery to alleviate the drudgery of female processors while providing additional avenues for the employment of those displaced by the improved technologies, keeping some operations labour-intensive. It is therefore important to mechanise the key drudgery-alleviation equipment that can be easily handled by women.

Prime mover power is also a major consideration. Most villages do not have electricity and hence the diesel engine is the main source of power. Thus, for cost reasons there cannot be a multiplicity of these engines to drive the required unit operations. Where there is the need to drive several machines the answer could be to use diesel power to generate electricity. The cost and maintenance of this power source would eliminate most small-scale processors and communities. The power source in such instances acts as a limitation to the number of unit operations that can be mechanised and powered. Systems of pulleys and gears to drive operational machines should be actively considered when designing for village based groups.
