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Comparative evaluation of the digester–screw press and a hand-operated hydraulic press for palm fruit processing

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Abstract

In order to demonstrate the strength and possible weaknesses of the digester–screw press (DSP) system for small-scale oil palm fruit processing, a comparison was made of its performance and that of the erstwhile hand-operated hydraulic extraction system. Indices of evaluation include oil yield and quality, and operational economics. The results indicate that the throughput of the DSP system was four folds of that of the hydraulic system, whilst also operating at higher oil extraction efficiency (89.1%). There was no significant difference between the quality of the palm oil obtained from the two systems. However, the economic analysis of the systems indicates that at throughput of 0.75 t/h and above, the DSP system was more economical than the hydraulic system in terms of equipment, labour, material and floor space requirement and revenue accruing from the processing operation.

Keywords: Palm fruit; Palm oil; Screw press; Oil extraction

1. Introduction

Palm oil, the most important product of the oil palm (*Elaeis guineensis*), is the world's main edible oil as well as the most important oil for soap making (Bek-Nelson, 1974). High quality palm oil is required for domestic and industrial applications. The commercially important quality parameters of palm oil are its free fatty acid (FFA) value and oxidation level. Other quality parameters include colour, peroxide value, iodine value, moisture content, specific gravity, refractive index and viscosity (Hartley, 1988, Chap. 14).

The palm fruit is a sessile drupe, one-seeded fruit enclosed in a fleshy pulp of variable shape of about 20–50 mm long. The fruit has a kernel consisting of an irregularly shaped mass of white soluble proteins or albumen enclosing a cylindrical embryo, an endocarp or shell, a mesocarp or fleshy part (pulp) with cells filled of oil (in which individual bodies are clubbed together) and a coloured exocarp or outer skin (Tropical Agriculturalist, 1998; Rajanaidu, 1994).

The unit operations involved in palm oil processing include fruit sterilisation, fruit loosening/stripping, digestion, oil separation and clarification (Fig. 1). Fruit sterilisation is a heat rendering and moisture absorption process which inactivates the lipolytic enzymes in the fruit mesocarp tissue. The hydrolysis of the colloidal mucilage in the cell wall and the breakdown of carbohydrate molecules into glucose molecules initiates osmotic pressure in the cell. The pressure of the liquid fat assists in heat transmission of the cell walls. In mechanical processing of palm fruit, sterilisation enhances fruit recovery during fruit stripping and facilitates fruit digestion by softening the mesocarp tissue. Fruit loosening or stripping refers to the separation of fruits from bunches, quarters or spikelets. It is usually done to facilitate handling of fruits in subsequent operations. Fruit digestion means crushing and detachment of the steamed or heat-weakened mesocarp from fruit nuts. The main purpose of fruit digestion, which is a form of size reduction and wet comminution operation, is to break up the pulp of the fruit and liberate oil from the cells in which it is contained. The extent of the digestion of the fruit determines the degree of exposure of the oil cells. Thus, sterilisation and digestion operations are essential pre-treatment operations for palm fruit. Oil separation entails separating the crude oil from

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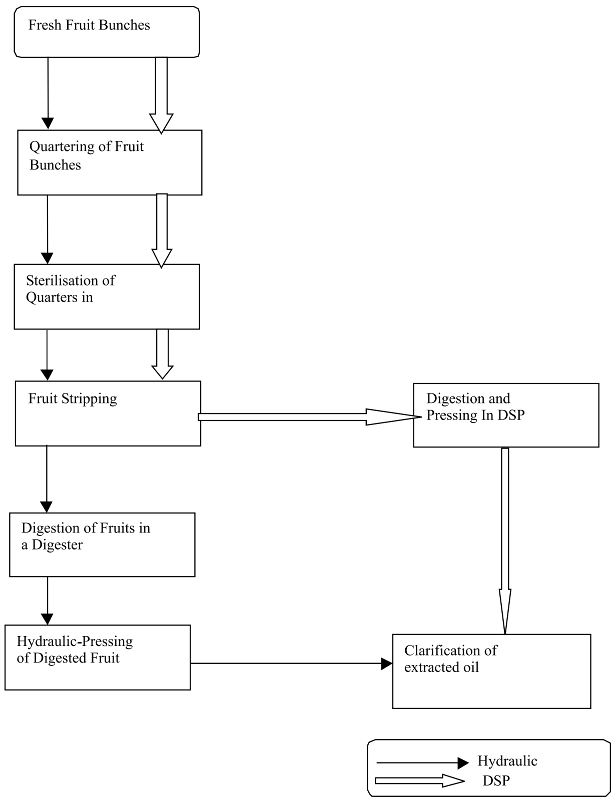


Fig. 1. Flow chart of hydraulic and DSP systems.

the mash, while clarification is the separation of pure oil from the sludge in boilers or clarification tanks.

All the operations are carried out in different ways in large scale, intermediate and small-scale plants. The methods employed invariably influence the yield of oil and its quality. In the large scale plant, all the processing operations are fully mechanised, with sophisticated conveyance systems. The use of screw expellers in oil separation and the recapturing of oil by a sludge centrifuge for further clarification enables over 90% of the oil to be extracted (Hartley, 1988, Chap. 14). However, there is a contention that screw expellers are generally too expensive, such that small-scale processors find it difficult to embrace the technology (Badmus, 1991).

The throughput of a small-scale processing plant is expected to be in the range 1.0–1.5 t/h (Badmus, 1991). Most small-scale processing plants are unable to meet this expectation due to the level of technology being employed. Consequently, a large quantity of fruits are not processed promptly, leading to considerable losses especially in the peak period of palm fruit processing. Delay in processing of the fruits also results in low quality palm oil. While palm oil from small scale processing plant is expected to, at least, meet the quality criteria for standard palm oil, this is hardly always the case. The FFA value for standard palm oil is fixed at 3–5%. and its moisture content 1%, while special palm oil should have FFA below 3% and moisture content of less than 1%.

A variety of small-scale mechanical processing devices have been developed. The hand-operated hydraulic system, which uses a separate digester (horizontal or vertical types), is very popular and prevalent (Ajibola et al., 1998). The oil yield of the hydraulic system is generally between 70% and 90% depending on the strength of the man who operates the hand pump and whose work efficiency diminishes in the latter part of the work-day due to tiredness.

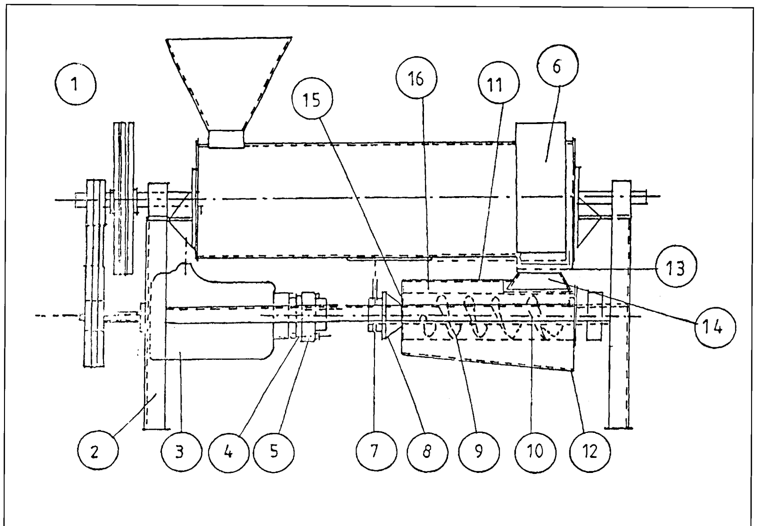
A new concept, the digester–screw press (DSP) system, was recently developed by the Nigerian Institute for Oil palm Research (NIFOR), Benin City (Owolarafe, 1999). The system has the digestion and pressing units combined into a single machine. The complete system also comprises of a steriliser and a clarifier (as in the hydraulic system). The development of this machine was aimed at stemming the losses incurred by small-scale processors during the peak season of palm fruit processing mostly in April and September. In order that the good attributes of the new system be not achieved at the expense of oil yield and oil quality, this study was undertaken to obtain a comparative evaluation of the emerging technology with the existing hydraulic system, in order to ascertain its appropriateness for small-scale palm fruit processing.

2. Material and methods

2.1. Process equipment

The equipment constituting the digester screw press system, Fig. 1, used in the study include:

(a) A steriliser which is a cylindrical drum (φ900 mm $\times$ 1800 mm), divided into three compartments, namely, the furnace, the water chamber and the fruit chamber. The water chamber and the fruit chamber are demarcated by an elliptical plate, which is perforated to facilitate steam intake into the fruit chamber.
(b) A hand-operated 400 mm long palm fruit stripper consisting of a shaft with stripping arms enclosed inside a cylindrical drum, perforated to allow passage of fruits into the discharge chute.
(c) A diesel engine-powered DSP. The DSP essentially consists of an upper part (horizontal digester with beater arms) and a lower part (the screw press with worm in a cage) resting on a supporting frame. The horizontal digester is 1200 mm long and 360 mm in diameter. It is provided with a feed hopper at one end, and discharges its content into the screw press 150 mm away from the other end (Fig. 2). Thus, with the arrangement of the digester and screw press,



1	DIGESTER FRUIT INLET HOPPER	9	SCREW THREAD
2	FRAME	10	SCREW SHAFT
3	GEAR BOX	11	PRESS TOP COVER
4	GEAR BOX FLANGE	12	INCLINED BOTTOM COVER
5	PRESS SHAFT FLANGE	13	DIGESTED FRUIT OUTLET
6	FRUIT TRANSFER POT	14	SCREW PRESS FRUIT INLET POT
7	CONE ADJUSTMENT NUT	15	NUT- FIBRE OUTLET GAP
8	CONE	16	PERFORATED CAGE

Fig. 2. Digester screw press parts.

the content of the digester is subjected to further crushing and pulverisation in the press and this is expected to enhance oil recovery.

(d) A clarifier, consisting of the oil separating and drying units as well as an auxiliary water reservoir and a furnace. The oil separating unit consists of three concentric cylinders with the inner one equipped with a sieve which receives the crude oil.

The complete suite of devices making up the hydraulic system, as found in small-scale palm oil processing centres (Ajibola et al., 1998), also includes a stripper, a steriliser and a clarifier as well as the following:

- A separate diesel engine-powered horizontal digester consisting of a cylinder cage of φ360 mm diameter and 1200 mm long, provided with a hopper at one end and a discharge chute beneath the other end. The whole assembly is mounted on a supporting frame of 750 mm height.
- A hand-operated hydraulic press.

2.2. Comparative oil extraction

For the two systems used, the fruits were run through the machines once without recycling. The digestion and pressing times were determined based on this. Digestion is considered adequate when a consistent uniform paste has been obtained. The operating conditions were ensured to be optimal based on a preliminary experiment. The batch experiment was replicated twice for each system.

2.2.1. Digester–screw press system

Fresh fruit bunches were quartered (cut into approximately four pieces) and sterilised for 1 h in the steriliser. The sterilised quarters were passed into a stripper. About 480 kg of hot stripped fruits, being the full capacity of the two sterilizers used at the small-scale unit of NIFOR, were processed using the DSP. The digestion/pressing times were noted. The crude oil collected was then transferred into the clarifier and the time taken for complete clarification was also noted. Pure oil collected was weighed using a Mettler 750 scale with 0.02 kg accuracy.

2.2.2. Hydraulic pressing system

For the hydraulic system, 480 kg of fruit were also digested in a separate horizontal digester and subsequently subjected to oil expression in the hand-operated hydraulic press. Digestion time and pressing time was noted and the crude oil weighed. The crude oil collected was clarified and the pure oil collected.

2.2.3. Analysis of results

The throughput of each of the two systems was calculated as the ratio of the weight of fruit processed in tonnes to the time taken in hours. The pure oil yield was taken as the ratio of the weight of oil collected over the weight of fruit processed. The extraction efficiency was calculated as the ratio of oil yield to the oil content of the palm fruit.

2.3. Analytical methods

Some physical properties (specific gravity and colour) and chemical quality parameters of the purified oil were determined. The chemical quality parameters were FFA, saponification value, peroxide value, iodine value and moisture content. The specific gravity was determined using a 10 ml constant volume specific gravity bottle, while Munsell colour charts were used for colour determination. Titration and titrimetric methods as recommended by AOAC (1998) were used in the determination of FFA and saponification number. The peroxide value and iodine value were determined by titration and Wijs methods, respectively, while the oil content and moisture content of the oil were determined by Soxhlet extraction method (AOAC, 1998).

2.4. Economic analysis

The economic analysis was based on a work study of the material and labour input against returns for the small-scale processing unit of NIFOR. The number of items of each equipment required, labour requirement and space requirement at different throughput were estimated for each of the systems. The total cost of equipment including running cost, maintenance cost and labour cost were also calculated. The estimated gross returns over a period of time for each throughput and the net profit were determined. The yearly processing cost and revenue were based on the peak production periods (April and September). NIFOR, being a government establishment has 20 working days per month, giving a total of 40 days for the yearly processing period (Table 5). Furthermore, the Institute operates between 8.00 a.m. and 4.00 p.m. daily giving a total of 8 h/day, out of which 2 h are used for preprocessing operations, thus leaving 6 h for the actual operation. The calculation of daily throughput was thus based on 6 h effective processing time.

3. Results and discussion

3.1. Oil yield, processing time and extraction efficiency

Table 1 shows the influence of processing system on the processing time, oil yield and extraction efficiency. The results indicate that there was a significant difference between the digestion/pressing time and clarifying time of the hydraulic system and the DSP system.

Table 1
Effect of processing system on processing time, oil yield, extraction efficiency and labour requirement in processing 480 kg of fruits

System processing parameter	Hydraulic system	Digester–screw press system
Digestion/pressing time	1h 24 min	22 min
Clarifying time	2 h 8 min	1 h 8 min
Oil yield (%)	24.4	27.6
Extraction efficiency (%)	78.6	89.1
Labour requirement	10 man-hour	6 man-hour

The use of the DSP machine enabled the throughput of processing to be increased four fold when compared with that of the hydraulic system. The clarifying time was also reduced by half. Obviously, the thoroughness of the digestion operation (crushing and pulverisation of the fruit into a pulp) and the pressing method determine how easily oil is released during extraction. The use of the screw press in the DSP enhances the size reduction operation thus allowing for better exposure of the oil cells and subsequently easing the flow of oil from the cells. The duration of the whole processing operations was also similarly affected. Thus, in a continuous clarifying process as this, the time of completion of the digestion and pressing operations affect the clarifying time as clarification of oil does not end until oil from the expression process is clarified. Hartley (1988, Chap. 14) had observed that screw pressing as a unit operation generally has a high throughput. The higher oil yield obtained from DSP system (Table 1) equates to higher extraction efficiency of 89.1% for the DSP system compared to 78.6% for the hydraulic system. Using the DSP has a significant effect on the final oil yield and the extraction efficiency of palm fruit processing. This may be attributed to the fact that there is further reduction of the oil bearing material notably the mesocarp tissues thereby exposing more of the oil cells. The high pressure developed in the press enables more oil to be expressed from the exposed cells.

3.2. Crude oil and sludge contents

The analysis of the contents of the crude oil from the two systems is presented in Table 2. The result indicates that the DSP system produced crude oil with higher oil content (79.3%) than the hydraulic system (67.0%). This result is in conformity with the earlier results on the extraction efficiencies of the two systems. The higher oil

Table 2
Effect of processing system on constituents of crude oil and sludge

Parameter	Crude oil		Sludge	
	Hydraulic	DSP	Hydraulic	DSP
Oil content (%)	67.0	79.3	11.7	11.1
Moisture content (%)	22.2	11.3	78.4	79.4
Solid impurity (%)	10.8	9.7	9.9	9.5

content of the DSP crude oil may be attributed to the fact that there was better digestion and pressurization of the fruit mash enabling more oil to ooze out of the fruit cells. There was no significant difference between the solid impurities of the crude oil from both systems. Similarly, there was no significant difference between the sludge contents of the two systems (Table 2). The contents of the sludge actually depend on the efficiency of the clarifier. The clarifier oil losses were estimated to be 1.7% and 1.6% for the hydraulic and DSP systems, respectively. Olie and Tjeng (1974) obtained 1.10% and 2.29% for hydraulic and unit screw presses, respectively.

3.3. Palm oil quality

From Table 3, we note that the palm oil from the two systems met the required standard for ordinary palm oil. There was no significant difference between the quality parameters of palm oil samples from the two systems. That they are classified as ordinary palm oil is due to their FFA level, which in actual fact is not strictly dependent on the processing system, but rather on the delay in processing the fresh fruit bunch. Special palm oils are characterised by low FFA and moisture content, and are increasingly in high demand in large scale industries since the cost of refining (bleaching) is relatively low compared with that of the ordinary palm oil. Any of the two systems would produce this grade of palm oil once the fruits are promptly processed after harvest.

3.4. Economic analysis

3.4.1. Comparison of capital cost requirement

Fig. 1 shows the effect of throughput on the fixed cost of the two systems. Fig. 3 presents the fixed cost of the DSP system as a percentage of that of the hydraulic system. At lower throughput, the fixed cost of the DSP system was higher, while the reverse is the case at higher throughput. This is due to the high initial capital cost of the DSP system and its flexibility to accommodate higher throughput. The hydraulic press system needs more units of the machines involved, at higher costs, to accommodate higher throughput.

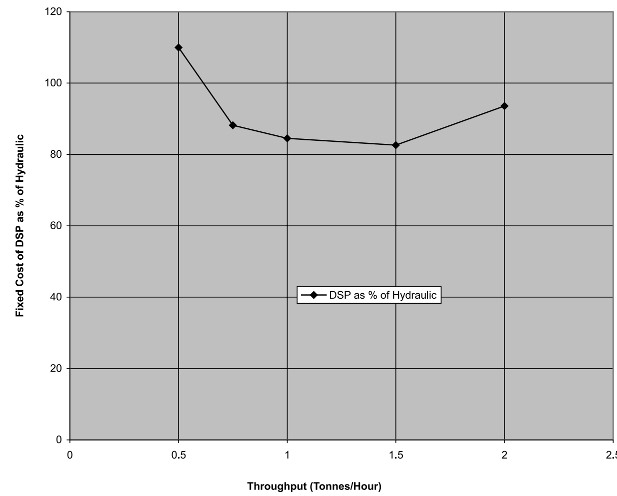


Fig. 3. Fixed cost of DSP as percentage of hydraulic at different throughputs.

3.4.2. Comparison of labour requirement

The labour requirement of the hydraulic system and the DSP system at the throughput used in the experiment were 10 and 6 man-hour, respectively (Table 1). Table 4 shows the projected labour requirement of the two systems from 0.5 up to 2.0 t. The result indicates considerable difference between the labour requirement of the hydraulic system and the DSP system. The difference becomes magnified as the throughput was increased. The higher labour requirement for the hydraulic system at higher throughput is due to the need for additional hands to handle the extra units of the machines at higher throughput. Thus, the DSP is more economical in labour use and also has higher overall efficiency.

3.4.3. Comparison of processing cost and revenue of the hydraulic and DSP systems

The estimated processing (running) cost per annum for the DSP system as a percentage of the hydraulic system is shown in Table 4. It can be observed that the DSP system has lower cost than the hydraulic system. As earlier indicated, increase in throughput for the

Table 3
Effect of processing system on palm oil quality

Quality parameter	Value in processing system		Standard value[a]	
	Hydraulic	DSP	Special palm oil	Ordinary palm oil
Free fatty acid	3.7	3.9	1.0–2.5	3.5–5.0
Moisture content (%)	1.2	1.5	<0.1	>0.1
Saponification value	197	202	–	–
Iodine value	52	54	53 ± 1.5	45–56
Peroxide value	0.5	0.7	0.57–0.60	0.57–2.61
Specific gravity	0.9007	0.9005	0.90	0.90
Colour	Red	Red	Red	Red

[a] Standard values: Swern (1945) and Bek-Nelson (1974).

Table 4
Projected labour (man/h) requirement of hydraulic and DSP systems up to 2 t of fruit/h

Throughput	0.5		0.75		1.0		1.5		2.0	
	H	DSP	H	DSP	H	DSP	H	DSP	H	DSP
Firing	1	1	1	1	2	2	2	2	2	2
Quartering and Weighing	3	3	4	4	5	5	6	6	8	8
Loading, unloading of steriliser stripping of fruit and collection	3	3	4	4	4	4	6	6	6	6
Fruit digestion and pressing of mash	2	1	5	1	6	1	7	2	8	2
Removal of pressed cake residue	1	–	3	–	4	–	4	–	4	–
Disposal of cake	1	1	3	1	4	2	4	2	4	2
Clarification and collection of oil	2	2	2	2	2	2	2	2	2	2
Supervision	1	1	1	1	1	1	1	1	1	1
Total labour required	14	12	23	24	28	17	32	21	35	23

hydraulic system will entail high labour requirement. At the same time, operating and maintenance costs are increased as a result of the additional machines. The overall effect manifests in higher processing cost for the hydraulic system, in comparison with the DSP system. This represents another comparative advantage for the DSP over the hydraulic system.

Based on the extraction efficiency of the two systems and prevailing market cost of palm oil, the expected monthly revenue from the DSP system was found to exceed that of the hydraulic system by 14%, while the processing cost per tonne (of fruit) for the DSP, at a throughput of 1.3 t/h, was found to be 92.4% of that of the hydraulic system. Furthermore, the oil yield and sales per tonne were found to be 113.6% of the hydraulic system. The expectation is that the processing cost of the DSP system will decrease at a faster rate as the quantity of fruits processed increases, while oil yield and sales from the DSP would increases more rapidly than for the hydraulic system. Consequently, the investment payback period for the DSP system is expected to be shorter than for the hydraulic system given the same initial capital investment.

Table 5
Estimated processing cost/year of the DSP system as a percentage of the hydraulic system (20 working days/month and at 7.8 t/day)

Item	Cost (% of hydraulic system)
1. Fruits	100.00
2. Diesel	167.7
3. Wood	100.00
4. Operating labour	64.5
5. Maintenance (10% of fixed capital)	76.3
6. Supervision (20% of operating labour cost)	64.5
7. Miscellaneous material (10% of maintenance cost)	76.3
8. Sales expense (20% of items 1–7)	92.1
Total variable cost	92.1

A period of two full months was taken as a year based on the peak seasons of April and September.

4. Conclusion

The comparative evaluation of the DSP system which is being developed and the conventional hydraulic press system undertaken in this study revealed that the DSP system has many comparatively favourable attributes and is to be preferred to the hydraulic system. The throughput capacity, extraction efficiency and consequent economic advantage of the DSP system over the hydraulic system further enhances its suitability for small-scale palm fruit processors particularly those operating at throughput of about 1.0 t/h of fruits. However, the quality of palm oil from the two systems compares favourably well. The adoption of this new technology by small-scale processors should go a long way in preventing waste of harvested fruits usually experienced in the peak season of production.

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