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Design of a Unit Semi-Industrial Palm Oil Production is Technically Efficient and Economically Viable in Rural Areas

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ABSTRACT

Palm oil processing represents an important economic activity in many rural areas of tropical regions. However, traditional palm oil processing methods are often characterized by low extraction efficiency, significant raw material losses, inconsistent oil quality, and high labor requirements.

This study focuses on the design of a technically efficient and economically profitable semi-industrial palm oil processing unit adapted to rural conditions. The approach is based on assessing the availability of raw materials, selecting and sizing appropriate equipment, organizing the processing line, optimizing energy use, valorizing by-products, and evaluating the economic feasibility of the facility.

The proposed process includes fresh fruit bunch reception, sterilization gold cooking, threshing, digesting, mechanical pressing, clarification, drying, and oil storage. Particular attention is given to the recovery and valorization of fibers, nuts, shells, and empty fruit bunches in order to improve the overall profitability of the processing unit.

The design emphasizes robust, simple, energy-efficient, and locally maintainable equipment. Such a unit could improve extraction efficiency and oil quality, create rural employment, increase producers' incomes, reduce post-harvest losses, and promote local value addition. The proposed approach provides a practical framework for establishing sustainable semi-industrial palm oil processing facilities adapted to the technical, economic, and infrastructural conditions of rural areas.

KEYWORDS: *palm oil, semi-industrial processing unit, oil palm, rural area, extraction efficiency, equipment sizing, economic profitability, by-product valorization.*

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1. INTRODUCTION

The oil palm is grown as an oil major in the humid tropics. Its production is a major source of income for many rural households and contributes to the development of economic activities related to agriculture, transportation, processing and trade.

In many rural areas, the transformation of regimes of palm nuts is still done according to processes which are handmade. These processes have the advantage of being available to producers, but they are usually associated with a low production capacity, a large consumption of labour, an extraction incomplete oil and a variable quality of the final product [1].

The complete industrialization of the sector requires investments that are sometimes difficult to harness in the rural areas. Between the transformation of the artisanal and the industrial plant of large capacity, the unit semi-industrial, therefore, represents an interesting intermediate solution.

It allows to mechanize the critical operations while retaining a capacity adapted to the local potential of

production. Its location in the vicinity of the plantations can also reduce transport distances and to foster the creation of value in the producing communities.

The present study aims to provide a technical and economical design of a unit semi-industrial production of palm oil is adapted to the realities of a rural setting.

The specific objectives are:
a) define a schema adapted technological transformation of the plans;
b) identify the main equipment required;
c) propose a design method of the unit;
d) recovering by-products;

2. MATERIALS AND METHODS

2.1. Methodological approach

The study is based on an approach combining process engineering, the techno-economic analysis and assessment of constraints to the rural areas.

The approach includes the following steps:
a) characterization of the raw material;
b) estimation of the amount of plans available;
c) definition of the capacity of the processing;
d) development of the block diagram of the processing;
e) selection of equipment;
f) sizing preliminary;
g) estimation of energy needs and water;
h) identification of by-products;
i) costs and cost analysis;
j) estimate of revenue;
k) assessment of the profitability.

2.2. Raw material

The main raw material is made up of fresh fruit bunches of oil palm. Their quality directly affects the performance of extraction and the quality of the oil.

The main parameters to consider are:
a) the degree of maturity of the plans;
b) the average mass of the plans;
c) the oil content of the fruit;
d) the time between the harvesting and processing;
e) the conditions of transport and storage.

An effective organization should transform the plans as soon as possible after harvest.

2.3. The palm oil and the production of crude palm oil

2.3.1. General information on the oil palm

The oil palm tree, scientifically called Elaeis guineensis, belongs to the family Arecaceae. It is a plant monocot tropical mainly cultivated for its fruits that are high in fat [2].

The palm tree produces plans that consist of numerous fruits arranged around a central axis. At maturity, these fruits contain a large amount of oil. Two main fractions can be obtained: crude palm oil, mainly extracted from the pulp, and palm kernel oil derived from the kernel of the kernel.

The production depends on several factors, including variety, the age of the plantation, the climatic conditions, cultivation practices and the degree of maturity of the plans. The treatment should be carried out in a relatively short period of time after the harvest in order to limit the degradation of the quality.



Figure 2.1: the oil Palm (Elaeis guineensis), is the main species grown for the production of crude palm oil [3]

2.3.2. Structure of the fruit of the palm tree

The fruit of the oil palm is the major raw material used for the production of crude palm oil. They are grouped in clusters called diets, the weight of which varies typically between 10 and 30 kg, depending on the variety, the

age of the palm tree and the growing conditions. Each plan can contain between 1 000 and 3 000 fruit, of ovoid shape, and color ranging from red-orange to dark red at maturity. Each fruit is made up of four main parts:

- the flavedo, which corresponds to the outer shell of the fruit;
- the mesocarp, fleshy part that is rich in crude palm oil;
- the endocarp, also called shell, which protects the seed;
- the palm kernel (almond), located on the inside of the shell, used for the production of palm kernel oil.

The quality of the fruit directly influences the efficiency of oil extraction. The plans must be harvested at their optimum maturity, characterized by the detachment of the natural first-fruits. A harvest early or late leads to a decrease in performance, as well as a degradation of the quality of the oil obtained. For this reason, the fruits are usually routed to the oil immediately after harvest in order to limit the phenomena of fermentation and the increase in the acidity of the oil [5].

From the genetic point of view, there are three main types of fruit:

- Dura, characterized by a thick shell and a small proportion of pulp;
- Pisifera, devoid of the hull, but not very productive;
- Tenera hybrid resulting from the cross between the previous two.

Thanks to its thin shell and its mesocarp abundant, the type Tenera is today the most widely cultivated in commercial plantations because of its excellent performance in oil.



Figure2.2*: *Structure of the fruit of the oil palm and diet of fresh fruit.

2.3.3. Crude palm oil

1° Definition

Crude palm oil (BPH), also called *Crude Palm Oil (CPO)*, is a vegetable oil extracted from the mesocarp of the fruit of the oil palm (*Elaeis guineensis*). It is obtained after sterilization operations, digestion, pressing and clarification of the plans of palm. In the natural state, the oil has a reddish-orange color due to its richness in carotenoids, including β-carotene and α-carotene. It is the main product resulting from the processing of palm fruit oil and represents a major raw material for many industries [6] and [7].

2° Composition of crude palm oil

Crude palm oil is composed mainly of triglycerides, which represent approximately 95% to 98% of its composition. The 2 remaining 5% is made up of minor compounds that play an important role in its nutritional properties, physico-chemical and technological.

The main fatty acids present in the crude palm oil are palmitic acid (C16:0), oleic acid (C18:1), linoleic acid (C18:2) and stearic acid (C18:0). This combination of saturated and unsaturated fatty acids gives the oil a good thermal and oxidative stability, which makes it suitable for industrial processes and food applications(Table 2.1).

In addition to triglycerides, crude palm oil contains minor compounds such as carotenoids, which are responsible for its coloring, red-orange, tocopherols and tocotrienols (vitamin E), phytosterols, phospholipids, as well as low amounts of free fatty acids, the content of which depends on the conditions of harvesting, transport and processing of the fruit. These compounds contribute to the nutritional value of the oil as well as its resistance to oxidation.

Table 2.1. The main constituents of the average crude palm oil [8]

Components	Containing Approximately
Triglycerides	95%, 98%
palmitic Acid (C16:0)	40 to 45 %
oleic Acid (C18:1)	39 to 45 %
linoleic Acid (C18:2)	8% to 12%
stearic Acid (C18:0)	4 to 5 %
Carotenoids	500 to 700 mg/kg
Tocopherols and tocotrienols	600 1000 mg/kg

3° Properties of crude palm oil

Crude palm oil has properties of physical, chemical and nutritional properties that explain its use in many industrial sectors. At room temperature, it has a consistency of semi-solid**,** resulting from the balance between saturated and unsaturated fatty acids. Its density generally ranges between 0.89 and 0.92 level**,** while its melting point ranges from 33 to 39 °C, depending on its composition (Table 2.2).

On the chemical level, the crude palm oil is characterized by a good stability to oxidation due to its richness in natural antioxidants, including carotenoids and the compounds of vitamin E. This stability allows it to withstand the heat treatment and it can be used in various industrial applications.

From the nutritional point of view, the crude palm oil is an important source of provitamin A (carotenoids) and vitamin E**,** in the form of tocopherols and tocotrienols. However, the quality of this oil is influenced by the rate of free fatty acids, which increases when the fruits are stored for too long before their transformation. In order to preserve its organoleptic properties and nutritional plans, palm must be processed quickly after harvest.

Table 2.2: Main properties of the crude palm oil

Property	Value indicative
Color	Red orange
physical State at 25 °C	Semi-solid
Density (40 °C)	0.89 to 0.92 by
melting Point	33 to 39 °C
Main antioxidants	Carotenoids, tocopherols, tocotrienols
Main uses	in food Industry, cosmetics, pharmaceuticals, soap making, biofuels

2.3.4. Products and sub-products

The transformation of regimes of oil palm into crude palm oil and implements a main raw material and generate multiple products and by-products recovered. The proper management of these different streams helps to improve the technical performance, economic and environmental production units (Table 2.3).

The main raw material used in the manufacturing process is made up of fresh fruit bunches (*Fresh Fruit Bunches* – FFB) from the oil palm (*Elaeis guineensis*). The plans are harvested at optimum ripeness to ensure a high-yield oil and a good quality of the final product. In normal conditions, culture, palm oil is the oil crop the most productive in the world, with an average production of more than 3.5 tonnes of oil per hectare per year, of which about 2 to 3 tonnes of crude palm oil and nearly 300 kg of palm kernel oil [9] and [10].

1° main Products

The transformation plan oil palm achieves two main products:

- **Crude palm oil (Crude Palm Oil – CPO):** extracted from the mesocarp (pulp) of the fruit, it is the main product of the processing unit. After refining, it is suitable for industries of food, cosmetics, pharmaceuticals and energy.
- **Palm kernel oil (Palm Kernel Oil (PKO):** obtained from the kernel (palm kernel) contained in the nuts after the crushing and extraction. This oil is mainly used in the industries of cosmetics, pharmaceuticals, chemical, and in the manufacture of soaps and detergents.

2° Sub-products gems

In addition to the oils produced, the process generates several by-products that could be valued:

- Plans empty (Empty Fruit Bunches – EFB): used as a soil amendment, as raw material for composting or fuel biomass.
- Palm Fibres: used as a fuel in the boiler to produce the steam necessary for the processing operations.

- Shells of palm oil: used as a source of renewable energy in industrial boilers or as a fuel in some installations.
- Meal kernel: residue obtained after extraction of palm kernel oil, rich in protein and used in animal feed.
- Liquid effluent of palm oil mills (Palm Oil Mill Effluent POME): waste water from the process of transformation. After treatment, especially for anaerobic digestion, these effluents may be used for biogas production, thus contributing to the reduction of the environmental impact of the production units.

Table 2.3: raw Materials, products and by-products of the transformation plan palm *oil*

Category	Elements	Main uses
raw	fresh fruit bunches (FFB)	Production of crude palm oil
main Product	crude palm Oil (CPO)	Industry food, cosmetic, pharmaceutical
main Product	of palm-kernel Oil (PKO)	Soap making, cosmetics, detergents
by-product	Diets empty (EFB)	Compost, biomass
by-product	Fiber	Fuel boiler
by-product of	Cockles	energy Production
by-product	Meal, palm kernel	animal Feed
by-product	Effluent (POME)	biogas Production after treatment

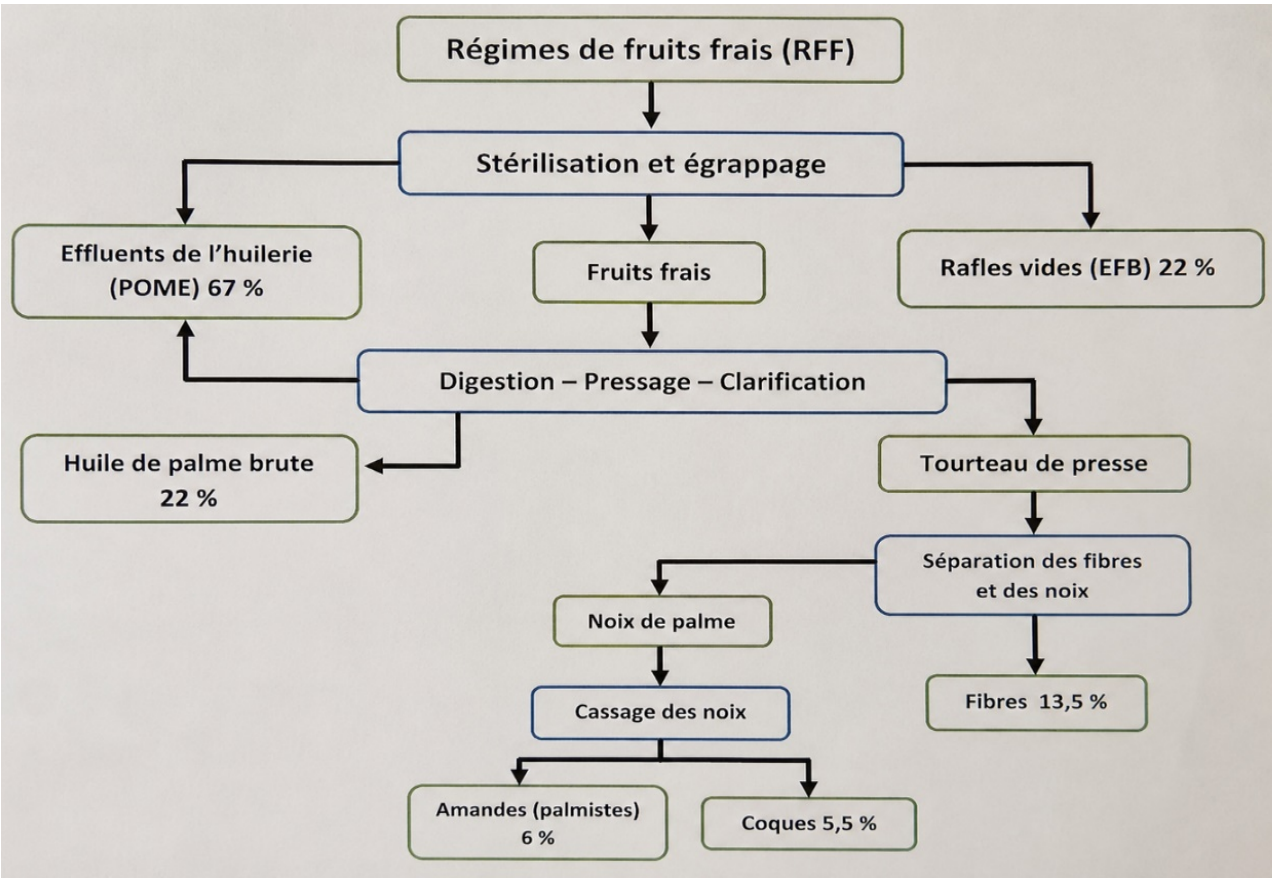


Figure 2.3: block Diagram of the chain overall production of crude palm oil from fresh fruit bunches.

3° Equipment used

The traditional process primarily uses simple equipment, manufactured locally and easily accessible to rural communities (figure 2.4). The main equipment are:

- a machete to the stalking of the plans;
- a metal drum of about 200 litres used in the cooking of the fruit;
- a traditional fireplace, three-stone, or an improved stove powered wood;
- a tray of banco intended for the mixing of cooked fruit;
- baskets in large meshes used for the separation of the fibers, and nuts; and
- gourd, bowl and sieve used for scooping, filtration and storage of the oil.



(a)



(b)



(c)

Figure 2.4: **traditional Process of transformation**

4° Advantages of the traditional process

The traditional process has several advantages, including in rural areas, where financial resources and industrial infrastructure are limited. It requires an initial investment is relatively small, the equipment is simple, inexpensive, and locally made. It mainly uses wood as a source of energy, fuel is generally available in the areas of production.

Moreover, this method is easily controlled by the local populations and does not require skills specific techniques. In some regions, it also allows us to obtain an oil crafted of quality appreciated by consumers, including the red oil in the traditional way.

5° Boundaries of the traditional process

Despite its simplicity, the traditional method has several limitations, which reduce its efficiency. The yield of extraction remains relatively low compared to the processes, semi-industrial and industrial due to the loss of oil during different operations.

In addition, the work of transformation are particularly painful, especially during the kneading manual of the fruit. The hygienic conditions are often insufficient, which may cause variability in the quality of the oil produced. Finally, the production capacity is still limited, which makes this method unsuitable for commercial production on a large scale. Table 2.4 brings into view the synthesis of the traditional process of transformation

Table 2.4: Overview of the traditional process of transformation

Recap	Criterion	Description
1	Level of mechanization	Very low
2	power Source	- Wood
3	Investment	Low
4	workforce	Important

5	Extraction	Low
6	Quality of the oil	Variable
7	production Capacity	Low
8	Area of use of	family Farms and village

3. PRESENTATION, INTERPRETATION AND DISCUSSION OF RESULTS

3.1. Production capacity and plan of operation

The production capacity is a critical parameter for the design and sizing of the unit semi-industrial. It lets you determine the amount of fresh fruit bunches treated as well as the flow of the material is necessary for the operation of the various equipment of the production chain. In the framework of this study, the treatment capacity of the unit is set to 2 tonnes of fresh fruit bunches (RFF) per day, or:

$$M_j = 2000\ kg/d$$

The unit semi-industrial is expected to work 8 hours per day, the hourly flow of raw material is determined by:

$$Q_h = \frac{M_j}{M_f}$$

With;

$$Q_h = \frac{2000}{8}$$

$$Q_h - 250\ kg/h$$

Thus, the unit semi-industrial will be sized to treat a nominal flow rate of 250 kg of fresh fruit bunches per hour, which corresponds to a daily capacity of 2 tons.

Considering 300 days of operation per year, the annual amount of plans that can be handled is:

$$M_a = 2x300$$

$$M_a = 600\ t/year$$

The capacity retention is, therefore, the basis for calculation of the material balance, energy balance and the sizing of the equipment of the unit.

The plan of operation adopted is summarized in table 3.1 below:

Table 3.1: production Capacity and plan of operation

Parameter	Value
daily Capacity	2 tons/days
operating Time	8 hours/day
nominal Flow rate	250 kg/hours
Days of operation	300 days/year
raw Material annual	600 tons/year

3.2. Extraction

The yield of extraction is the proportion of crude palm oil obtained from the fresh fruit bunches (RFF) treated.

According to the FAO, the content of potential oil fresh fruit bunches is about 25 %. However, this amount may not be recovered in the course of the process, due to losses that occur during the various processing operations.

For a small processing unit similar to the one studied, the FAO says, for the system NIFOR Mini with a capacity of about 250 kg/h, the extraction rate is between 12 and 13 % on RFF.

In our study, the production capacity is set to 2 tons of RFF per day, with an operation of 8 hours per day, either:

$$Q = \frac{2000}{8} = \frac{250kg}{h}$$

This capacity is comparable to that of the reference system, we use a yield of extraction of 13 % for the sizing of our unit.

The amount of oil produced on a daily basis is thus:

$$M_{HPB} = 2000\ x\ \frac{13}{100}$$

$$M_{HPB} = 260\ kg/d$$

Thus, for 2 tonnes of fresh fruit bunches processed per day, the estimated production is 260 kg of crude palm oil per day.

For 300 days of operation per year:

$$260\ x\ 300 - 78\ 000 \frac{kg}{year}$$

Either:

$$78 \frac{t}{year}$$

The return of 13 % is selected as the reference value for the design of the unit semi-industrial.

Reference: FAO, *Small-Scale Palm Oil Processing in Africa*.

3.2.1. Calculation assumptions

To perform the various calculations for sizing of the unit semi-industrial level, the following assumptions are used (table 3.2):

Table 3.2: calculation Assumptions

Parameter	Value selected
processing Capacity	2 tons of RFF/day
operating Time	8 hours/day
hourly Flow	of 250 kg/hour
extraction	13 %
oil Production	260 kg/day,
Days of operation	300 days/year
annual Production of oil	78 tons/year

These assumptions will be the basis for the material balance, the energy balance, the sizing of the equipment and the technical-economic study presented later in this chapter.

3.3. Material balance of the unit

The material balance of the unit is determined from a power supply of 2 000 kg of fresh fruit bunches (RFF) per day. The yield of extraction whichever is 13 %, the daily production of crude palm oil is 260 kg.

The FAO indicates that palm oil can contain about 25 % oil based on the fresh fruit bunches. This value represents the theoretical potential oil and not the amount actually recovered by the unit.

3.3.1. Material balance overall

The amount of the theoretical oil contained in the RFF is:

$$M_{oil,th} = 2\ 000 \times 25\%$$

$$\boxed{M_{oil,th} = 500\ kg/j}$$

The yield of extraction selected for our unit is 13 %:

$$M_{HPB} = 2\ 000 \times 13\%$$

$$\boxed{M_{HPB} = 260\ kg/d}$$

The amount of the theoretical oil not recovered is therefore:

$$M_{oil,nr} = 500 - 260$$

$$\boxed{M_{oil,nr} = 240\ kg/d}$$

This amount does not constitute an additional stream. It corresponds to the oil remaining in the different residues of the process, including fiber, nuts, and sludge clarification.

The FAO identifies precisely, after pressing, a residue consisting mainly of a mixture of fibre and nuts, while the raids empty are separated during the stalking.

For our unit, (Table 3.3) the main flows are therefore:

Table 3.3: material Balance overall

Flow of material	Percentage of the RFF	Quantity of
fresh fruit bunches incoming	100 %	2 000 kg/d of
crude palm Oil recovered	13 %	260 kg/d
Roundups empty	≈ 23 %	≈ 460 kg/d
Fibre	≈ 14,5 %	≈ 290 kg/day
Nuts	≈ 6,5 %	≈ 130 kg/d
Other waste, process water, sludge and losses	≈ 43 %	≈ 860 kg/d
TOTAL	100 %	2 000 kg/j

The values of 23 % for the raids, 14-15 % for fibers and 6-7 % for each of the kernel and the shell are reported in the literature FAO.

For nuts, so we have:

$$6{,}5\% + 6{,}5\% = 13\%$$

Either:

$$M_{nuts} = 2000\ x\ 0{,}13$$

$$M_{nuts} = 260\ kg/d$$

The amount of material remaining after accounting for the oil and main by-products is:

$$M_{residual} = 2000 - (260 + 460 + 290 + 130)$$

$$M_{residual} = 860\,\frac{kg}{j}$$

This fraction consists mainly of water eliminated during the process, the effluent from the clarification and washing, as well as the loss of material in the process.

3.3.2. Production of crude palm oil

With a yield of extraction of **13 %**, the daily production is:

$$M_{HPB} - M_{RFF} \times R_e$$

$$M_{HPB} = 2\,000 \times 0.13\ in$$

$$\boxed{M_{HPB} = 260\ kg/d}$$

The unit produces about 260 kg of crude palm oil per day.

For 300 days of operation:

$$M_{HPB,year} - 260 \times 300$$

$$\boxed{M_{HPB,year} = 78\,000\ kg/year}$$

Either:

$$\boxed{78\ t/year}$$

The reference FAO concerning the system NIFOR Mini shows just a nominal capacity of 250 kg/h and extraction rate of 12% to 13% on the fresh fruit bunches, which is consistent with our flow of 250 kg/h

3.3.3. Quantification of by-products and effluents

For a power supply of 2 000 kg of RFF/j, the main by-product solids can be estimated from the coefficients of composition available in the literature.

1° Raids empty

Retaining approximately 23 % of raids:

$$M_{cobs} = 2\,000 \times 0{,}23$$

$$\boxed{M_{roundups} \approx 460\ kg/d}$$

The raids are a by-product of the de-stemming. They may be valued such as organic matter or combustible. The FAO indicates that the raids empty can be used as a fuel in some of the smaller units.

2° Fibers

Holding up to approximately 14.5% of fibers:

$$M_{fiber} = 2\,000 \times 0{,}145$$

$$\boxed{M_{fibre} \approx 290\ kg/d}$$

The fibers are mainly from the pressing of the fruit. They can be recovered for energy production.

3° Walnuts

Holding up to approximately 6.5 % of nuts:

$$M_{nuts} = 2\,000 \times 0{,}065$$

$$\boxed{M_{nuts} \approx 130\ kg/d}$$

In our process, the nuts are not transformed in palm kernel oil. They are therefore considered as a by-product recoverable, which may be sold or intended to be further processed.

4° Oil not recovered

The theoretical potential of oil of 500 kg/day and the recovery is 260 kg/j:

$$M_{otl,nr} = 500 - 260$$

$$\boxed{M_{oil,nr} = 240\ kg/d}$$

This value represents the oil that is not recovered in the form of crude palm oil. It is found mainly associated with solid waste and sludge from the process (Table 3.4).

5° summary Table

Table 3.4: Quantification of by-products and effluents

Flow of material	Percentage of the RFF	Quantity of
fresh fruit bunches incoming	100 %	2 000 kg/d of
crude palm Oil recovered	13 %	260 kg/d
Roundups empty	≈ 23 %	≈ 460 kg/d
Fibre	≈ 14,5 %	≈ 290 kg/day
Nuts	≈ 6,5 %	≈ 130 kg/d
Other waste, process water, sludge and losses	≈ 43 %	≈ 860 kg/d
TOTAL	100 %	2 000 kg/j

4. CONCLUSION

The study resulted in the selection process, including the reception of fresh fruit bunches, sterilization, stalking, digesting, pressing, clarification, drying and storage. For the dimensionnement, a capacity of 2 tonnes of RFF-by-day, an operation of 8 hours per day, 250 kg/h, and 300 days of operation per year have been selected. With a yield of extraction of 13 %, the estimated production reached 260 kg of crude palm oil per day, representing about 78 tons per year.

These results confirm the first hypothesis, according to which a process in a semi-industrial adapted to the local conditions can ensure the efficient processing of fresh fruit bunches.

However, it should be clear that the results obtained are based on assumptions sizing and reference data. The return of 13 %, the annual operating time, some kind of consumption as well as the economic costs will have to be confronted with the actual operating conditions, the local prices and practical tests before the final completion of the unit.

Ultimately, this study shows that a unit semi-industrial 2 tons of RFF/day, focusing on simple equipment, a manual intervention important and a technology adapted to the local context, provides a solution that is technically feasible and economically attractive in order to contribute to the local transformation of the palm oil in the DRC.

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