Feature Article

Mongana Basics: Part 23 - Study of Fuel and Valorization of the Waste Products**

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The Waste Product the Palm Oil Mill

The approximate percentage composition of bunches processed in palm oil mills is given in *Table 1*.

The amount of waste products is therefore dependent upon the type of bunch. Moreover, the extraction process affects the amount of non-oily solids and fibre which can be recovered or used. In the wet process, two-thirds of the fibre is washed away in water; in the continuous pressing process, one-third of it finds its way into the crude oil. Finally, in the centrifugal extraction technique or by manual press method, only very little of the fibre are removed.

CATTLE FEED

The food value of cattle feed meal depends primarily on the protein content. The various palm oil mill waste products were analyzed from that point of view. The results show that they all are extremely poor in nitrogen (maximum 2% of nitrogen on dry basis for cellular debris).

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***Continued from p. 33 of* Palm Oil Engineering Bulletin Issue No. 96.

RECOVERY OF OIL FROM BUNCH STALK REFUSE

It has been mentioned in the previous issues of *Palm Oil Engineering Bulletin* that the oil content of wet stripped bunch stalks was 1% to 2%, that is 2.5% to 5% on dry matter. This amount corresponds to 0.3% to 0.6% of oil as a % to fresh bunch or 1.5% to 3% as a % to the oil.

The recovery of a portion of that oil was investigated. Two techniques were tried: washing with surfactants and pressing of the stalks in a continuous press.

At laboratory scale, the washing of stalks led to the recovery of oil amounting to 0.2% of the weight of wet stalks. At larger semi-industrial scale, the operation performed in a rotating perforated drum failed to give satisfactory results.

Pressing carried out on stalks chopped in two or four chunks leads to the extraction of 10% to 20% of the oil present in the stalks but the capacity of the press is only 110 kg to 160 kg of stalks per hour. Moreover, in that kind of work, the press is subjected to dangerous stresses.

TABLE 1. APPROXIMATE COMPOSITION OF BUNCHES PROCESSED IN PALM OIL MILLS

	Palm grove	DxT	TxT	DxP
Ratio of empty bunch of FFB	23	23	23	23
Ratio of dry EFB to FFB	9	9	9	9
Ratio of nut to FFB	39	27	26	13
Ratio of oil to FFB	13	18	20	25
Ratio of wet kernel to FFB	8	6	5	4
Non-oily solid – fibre to FFB	31	22	21	9
Total of empty bunch	4.5	5.5	6.5	8
Shell + non-oil solid + fibre	44.5	37.5	37.5	26

UTILIZATION OF FIBRE FOR THE PRODUCTION OF PRESSED BOARDS

Boards made of fibre and a small quantity of copal resin was produced. They were obtained by the application of 90 bar pressure on the mix heated up to 100°C – 150°C for a period of 15 min. The boards could be sawn and nailed.

UTILIZATION OF STALKS AS FUEL

General

At the outlet of the thresher, the bunch-stalks contained approximately 65% of moisture making it a poor fuel. The calorific value of the wet materials is in the region of 4200 kJ kg^{-1}. Owing to their moisture content and to their very morphology, stalks are a difficult fuel to burn with reasonable efficiency. It is observed that in the boiler furnace, they burn superficially. The core chars but does not burn completely.

Numerous waste products of high moisture content are used as fuel (cotton husk, oil palm bunch fibre, wood chipping and molasses) but all are available in discrete form or very close to it, at least, in granular or fibrous form. The contact surface between fuel and air is very large. Drying is consequently easy. Quite a different situation prevails in the case of oil palm bunch stalks. The contact surface between combustible material and air is small in relation to the weight of the former. It follows that drying is very slow. The use of fuel with high moisture content is generally achieved on a sloping grate on which three zones can be demarcated:

- drying zone;
- distillation zone; and
- combustion zone.

This technique can only be applied to homogeneous fuel ensuring good coverage of the grate which is not the case of bunch stalks as a result of the important unit volume and weight.

Combustion of Bunch Stalks

Three possibilities were investigated:

- drying prior to combustion;
- shredding of the stalks (partial drying); and
- gasification followed by combustion.

Drying of Bunch Stalks

Limited drying was obtained in the trial extraction of oil from the stalks by continuous pressing. Moisture content was reduced from 65% to approximately 45%. An appreciable increase of the colorific value results therefrom. A value of 6930 kJ kg^{-1} is attained for a moisture content of 50%. The treatment is tough on the equipment and presses currently used would not stand up long to it.

A more satisfactory technique allowing for more efficient moisture removal consists in shredding.

Shredding

The operation combines drying and conditioning of the stalks. Shredding converts the stalks in slices of variable thickness and greatly increases the ratio of surface area to the weight of the material.

The rotary knife shredder outlined in *Figure 1* was tried. It is equipped with a feed screw and one which compacts the stalks just before they are hacked. The speed of both can be set to obtain slices of any thickness between 10 and 25 mm. The output of the equipment is approximately 5 t hr^{-1}. The desiccation of the bunch stalks is greatly speeded up by the shredding. *Figure 2* shows the loss of weight in relation to time of desiccation for slices 10 mm, 15 mm, 20 mm and 25 mm thick. The average moisture content was 69.8%.

It can be observed that the practical rate of desiccation at ambient temperature or the loss of weight compared with that recorded for the whole stalk is approximately:

- twice as high for 25 mm thick slices;
- three times as high for 20 mm thick slices;
- four times as high for 15 mm thick slices; and
- five times as high for 10 mm thick slices.

The stalk shredder was used for 15 days during which efficient firing of boiler were achieved. The machine does not seem to be sufficiently rugged for intensive utilization. In particular, the feeding device exhibited a number of shortcomings (warping of the conveyor slats) which should however easily be made good through slight modification of the machine design. The mill in which the shredder was tried has since obtained a more rugged machine.

As shredding is achieved by guillotine slicing and not by rotating knives, the output of the machine is considerably reduced. The feeding device, although of stronger construction, is less suitable for bunch stalks than the conventional screw of large capacity straw shredders.

Gasification and Combustion of Bunch Stalks

Considering the advantage from the calorific point of view afforded by the heat available in bunch stalks, a boiler fitted with a special pre-combustion chamber was acquired. The characteristics of bunch stalks prompted the maker of the experimental boiler to design a combustion chamber which speeds up the drying of stalks and paralyze them. The gases evolved in the

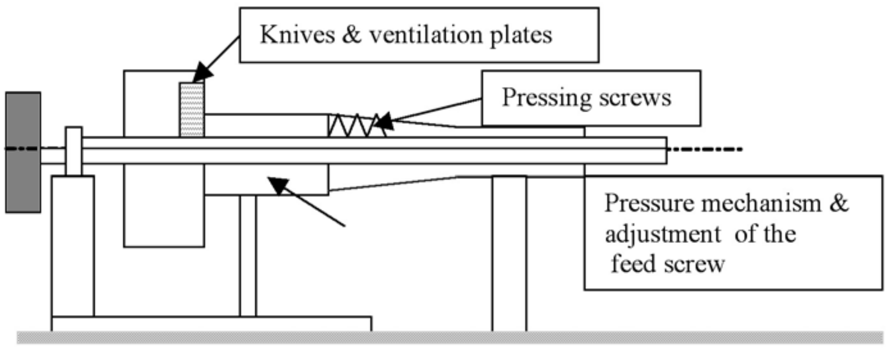

Figure 1. Bunch stalk shredder.

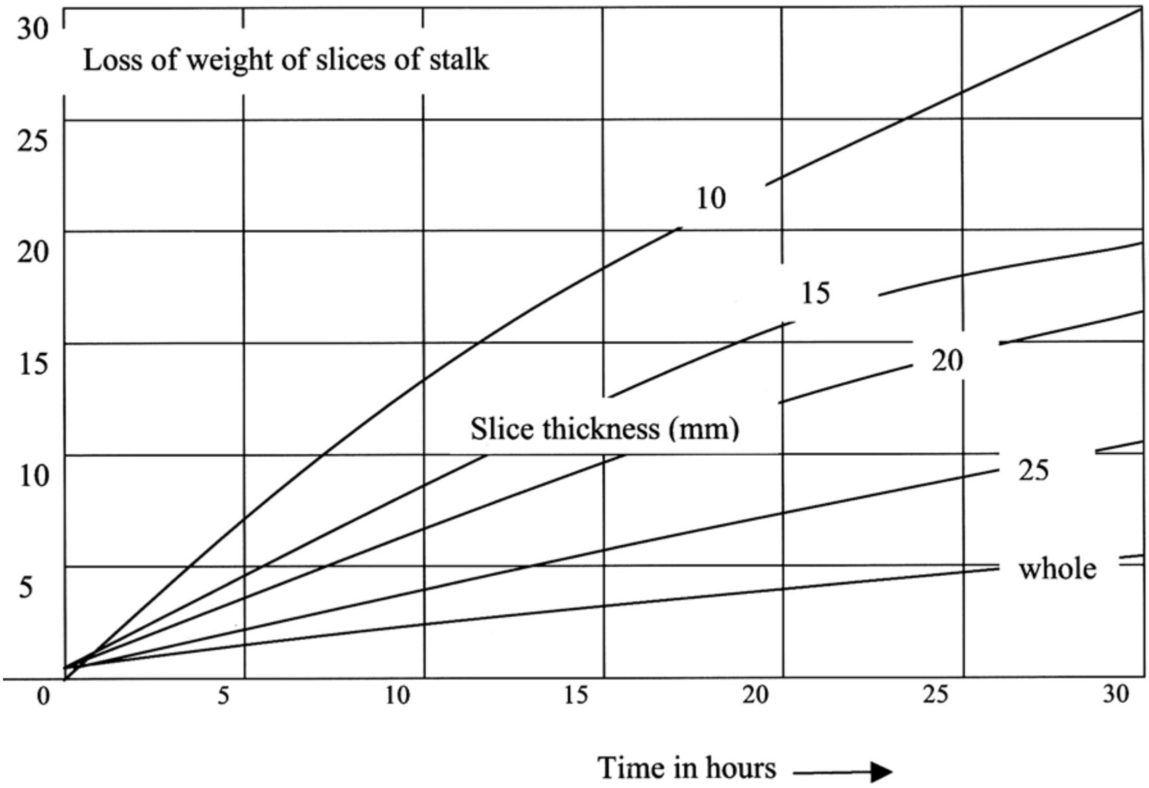

Figure 2. Desiccation curves of bunches stalk in relation to slice thickness and time of desiccation.

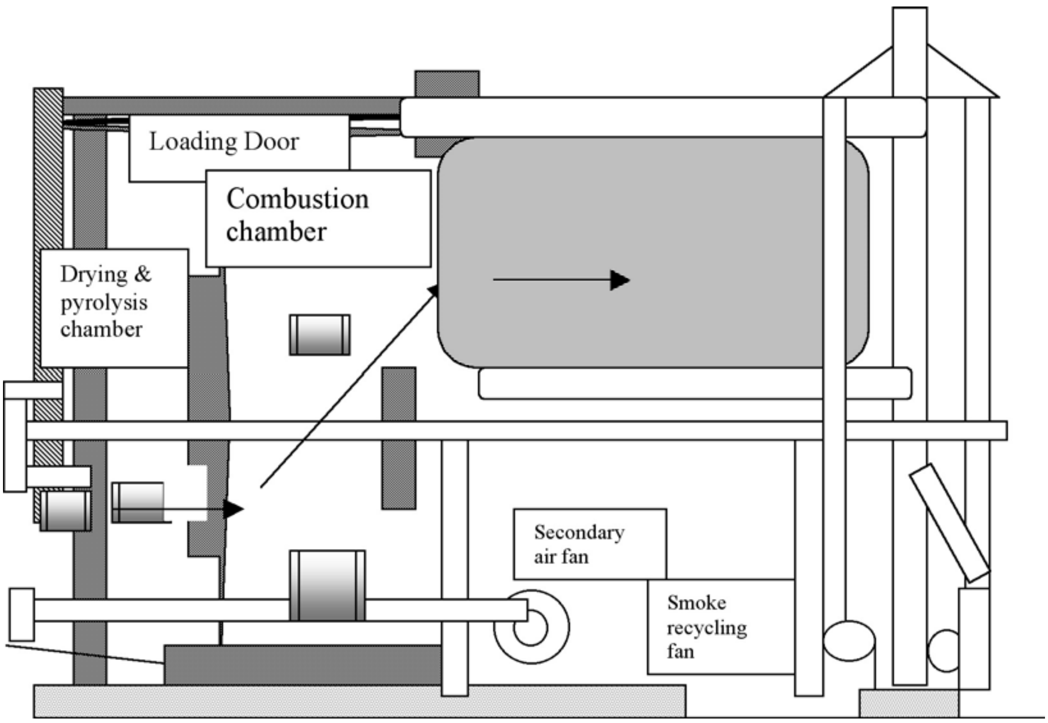

Figure 3. Sectional view of the pre-combustion chamber for bunch stalks.

process are burnt in a combustion chamber. The unit is outlined in *Figure 3*.

The draught can be natural or induced. Smoke is recycled towards the drying chamber. The volume of the drying cum pyrolysis chamber is 10 m^3 and that of the combustion chamber 9.24 m^3. The grate surface area is 3.3 m^2. The heating surface of the smoke tube locomotive type of boiler is 30 m^2.

The operating conditions of the pre-combustion chamber were ascertained. They are as follows:

- maximum introduction of secondary air in the combustion chamber;
- introduction of drying air as close as possible to the grate;
- the drying is not necessary if the stalks have been dried slightly prior to being fed into the furnace (50% moisture);
- very little air blown below the grate. Just enough to sustain combustion on the grate. At times, no air at all is required;
- maximum suction of smoke; and
- a series of heat balances were established.

The results of two of them are given in *Table 2*. The first series was carried out with natural draught and the second with induced draught.

The operating condition data were recorded at 15 min intervals. An electrical analyzer was used for the analysis of smoke.

Conclusion of the Trials

- The gasification and combustion of bunch stalks can be satisfactorily achieved.
- The rate of evaporation specified by the makers of the boiler is exceeded.
- The boiler can be operated by unskilled local personnel solely on the basis of the temperature in the combustion chamber.
- It has not been possible to force the boiler because of the lack of adequate supply of secondary air.
- The maximum temperature recorded in the combustion chamber is 1250°C. It was deemed hazardous to maintain or exceed that temperature.
- Even when the induced draught is set at maximum intensity, smoke evolves from the fuel loading door and auxiliary chimney which is always set at minimum opening (often completely closed).
- The smoke temperature appears too high.
- The pre-combustion chamber could be adequate for a much larger heating surface. The amount of gas produced under normal operating conditions during the trials was small compared with the actual capacity; most of the time hardly any air is blown at all under the grate. Incidental ingress of air is enough to maintain efficient gasification.
- The pre-combustion chamber is somewhat dangerous because it is impossible to draw the fire. Fierce burning of bunch stalks continues even when the dampers are completely closed. It is essential (a serious incident is proof enough of this) to provide three ways of firing the boiler and one of extinguishing the fire (bank of water sprayers).
- During the trials, it has been possible to maintain the ash in pulverulent form. However, it was observed that the melting point had been reached close to the flues.
- The K_2O content of the ash is 30% to 40%. Silica is also present.
- A system of mechanical clearing of the grate should be provided as it is difficult to do so manually under the thick layer of stalks (the drying and

TABLE 2. HEAT BALANCE DURING COMBUSTION

	Natural draught	Induced draught
Duration of the run	71 hr	6 hr
Hourly output of steam	543 kg	807 kg
Hourly output of steam per m^2	17.4 kg	26.9 kg
Fuel consumption per tonne	565 kg	750 kg
kg of steam produced per kg of fuel	0.96 kg	1.1 kg
Average operating conditions		
Pressure	6.1 kg cm^2	6.6 kg cm^2
Furnace temperature	1059°C	1136°C
Smoke temperature	412°C	362°C
Carbon dioxide content of smoke	9.6%	11.7%
Carbon monoxide and hydrogen content of smoke	0.5%	0.6%

gasification chamber is kept full at all times).

- Potash and soot in small but perceptible quantity are carried away with the smoke as are small particles of silica.

Summary

There are two possible ways of using bunch stalk as fuel. One is shredding and drying and the other is the use of a special pre-combustion chamber designed for drying and gasification. From the point of view of efficiency, it seems that the two possibilities are equivalent. From the point of view of capital expenditure, the shredder is evidently less expensive than the pre-combustion chamber. Its installation does not require a great deal of space. Moreover, the apparatus can be easily dismantled and moved to a new location.

In contract, the stalk pre-combustion chamber, which is in fact adaptable to all types of wastes produced in the oil mill (shell, fibre) possibly opens the way to an automatic system of boiler firing the well-known advantages of which lead to the possibility of producing steam without intervention of the human factor would constitute an undeniable progress.

A priori, the automation of firing through gasification of all wastes appears to be financially attractive only for large oil mills. In the case of mills of average or small size, the shredding and drying of bunch stalks appear preferable.

It must be appreciated that in mills treating exclusively fruit of the *dura* type, no problem of fuel availability arises. The utilization of stalks as fuel is therefore not justified but the position is completely different in the case of new plants where some pure *tenera* crop will be processed (*Table 6*).

Recovery of Potash

The slow burning of bunch stalks whether by gasification in an incinerator or in the open yields approximately 1.5% to 3.0% of ash. The ash contains 25% to 40% of K_2O, approximately 4% of MgO, 6% of Na_2O and a variable amount of SiC_2.

The K_2O content of the wet stalks is therefore about 0.7% corresponding to 0.15% on bunch, that is 1.5 kg of K_2O per tonne of bunches.

Under suitable conditions, 1 t of bunches represents the annual yield of approximate-

ly 10 palms. The return to the fields of potash produced by incineration of the bunch stalks would therefore provide each palm with 150 g of potash per year.

For record, it may be stated that the IRHO (Institute de Recherches sur less Huiles at Oleagineux) advises the use of larger quantities of potash (0.5 kg to 1.5 kg of KCl per palm per year).

CARBONIZATION AND PYROLYSIS OF WASTES

Within the frame work of the study on the energy of the extraction process and of the valorization of the by-products, the Francois experiments on the carbonization and pyrolysis of wastes were repeated with a view to ascertain the efficiency of carbonization for planning industrial experiment.

Laboratory Experiments

The experiments were carried out in a carbonization kiln suitable for the treatment of 0.5 to 1 kg of material. After paralysis, the gas was condensed and recovered. Trial runs were set up on kernel, fibre, shell and bunch stalk refuse. Their lower calorific value was found to be as in *Table 3*, as determined in the Mahler bomb.

TABLE 3. CALORIFIC VALUES AS DETERMINED BY MAHLER BOMB METHOD

Kernel	:	6500 kcal kg^{-1} (27 214 kJ kg^{-1})
Fibre	:	4700 kcal kg^{-1} (19 678 kJ kg^{-1})
Shell	:	4950 kcal kg^{-1} (20 724 kJ kg^{-1})
Bunch stalk	:	4200 kcal kg^{-1} (17 585 kJ kg^{-1})

Note: Coke from kernel (obtained at 420°C) 8500 kcal kg^{-1} (935 588 kJ kg^{-1}).
Coke from shell (obtained at 420°C) 7800 kcal kg^{-1} (32 657 kJ kg^{-1}).

The results of carbonization are given in *Tables 3, 4* and *5*. They generally confirm those obtained by Francois (*Table 3*). Briefly, it is observed that:

- a large amount of tar is produced in the carbonization of kernel;
- in contrast, pyroligneous juice is the most abundant component obtained in the carbonization of the other waste products;
- tar contains little light fraction; and
- the calorific value of the evolved gas is directly proportional to the temperature of carbonization.

EXPERIMENTAL AT INDUSTRIAL SCALE

Carbonization at semi-industrial scale was set up in an installation with a capacity of 6 t of waste per 24 hr of utilization and built according to the Francois patents. The apparatus consists of a kiln, a by-product recovery section and a gas purification station. A general outline of the installation is given in schematic form in *Figure 4.*

A fairly large number of difficulties of mechanical origin were encountered when using the oven. The uniform spreading in thin layer of the material and the air tightness of the kiln were difficult to achieve. Without effective air tightness, the gases are diluted as a result of air ingress and are no longer combustible. The feeding device had to be modified and in order to obtain uniform distribution of the material on the grate it was found necessary to station a worker to operate the spreading paddles. As a result of the important expansion of the fire bars, the alignment of the coke removal mechanism had to be carried out whilst hot. Serious warping of the brick-work occurred.

The high impurities content of the gases was responsible for the breakdown of the compressor and the breakage of the rotating vanes. The speed of the rakers had to be increased three-fold.

TABLE 4. CARBONIZATION OF WASTES

Minutes required to reach the temperature shown in the columns	Kernel	Fibre	Shell	Bunch stalk refuse * 1	Bunch stalk refuse * 2	Bunch stalk refuse * 3	Nut
	Fibre in minutes required to reach the temperature shown in the first column						
Temperature 100°C	-	20	30	20	20	15	20
150°C	20	-	-	-	40	-	-
200°C	30	40	50	70	75	30	50
250°C	40	55	-	90	90	-	65
300°C	60	-	80	100	110	45	85
350°C	80	100	100	150	135	60	120
400°C	120	-	135	180	160	75	150
420°C	150	150	150	220	190	90	180
Recovery in g kg^{-1}							
Coke	110	408	388	360	378	352	344
Tar	464	112	100	66	78	74	242
Pyroligneous	206	304	351	354	362	346	280
Gas and losses	120	176	161	220	182	228	134
Acidity of the Pyroligneous							
Acetic acid							
a) By steam distillation in the presence of phosphoric acid							
- in g % of pyroligneous	4.75	12.2	14.8	10.2	11.8	9.3	11.1
- in g % of the initial raw material	0.98	3.8	6.2	3.6	4.28	3.24	3.1
b) Strictly by direct titration							
- in g % of pyroligneous	4.47	11.55	15.8	11.1	11.25	9.48	-
- in g % of the initial raw material	0.92	3.53	5.55	3.92	4.07	3.38	-
Distillation of Tar							
% Recovery							
Up to 100°C	4.5	4.0	4.75	-	3.0	2.5	-
From 100°C to 150°C	4.0	7.0	8.00	-	6.0	8.0	-
From 150°C to 200°C	2.5	11.0	19.50	-	13.0	14.5	-
From 200°C to 250°C	7.5	18.0	27.50	-	25.0	22.0	-
From 250°C to 300°C	55.0	23.0	16.25	-	22.0	22.0	-
Residue	25.5	37.0	24.00	-	31.0	31.0	-

Note: *1st run, slow heating.
2nd run, slow heating.
3rd run, fast heating.

Product Recovery

The recovered gas is combustible if the kiln is air tight. The amount of gas produced and its calorific vale (*Table 4*) appear insufficient to sustain carbonization. The coke contains 16% to 20% of volatile matters and 2% to 6% of ash. The recovery in pyroligneous liquid and tar appears to be lower than recorded in the laboratory.

ENERGY BALANCE AND MISCELLANEOUS RESULTS OF PALM OIL MILLS

According to the test carried out at Mongana and in other mills, the steam consumption for the processing of bunches is in *Table 6*.

The figures differ from one mill to another because of marked differences

TABLE 5. CARBONIZATION AND PRYOLYSIS OF WASTE PRODUCTS

Time in minutes to attain the temperature shown	Kernel	Fibre	Shell	Bunch stalk refuse
Detail of the Experiment				
The paralysis tube is heated up to 700°C before starting the experiment				
Temperature				
100°C	30	-	30	20
150°C	45	-	-	30
200°C	65	50	-	50
250°C	-	80	70	80
300°C	85	-	100	105
350°C	110	140	-	145
400°C	180	170	155	180
420°C	220	200	170	200
Recovery in g per kg of Raw Material				
Coke	227	410	410	358
Pyroligneous	200	358	319	396
Tar	256	26	70	24
Benzol	5	2	-	2
Gas and losses by difference	312	204	201	220
Acetic Acid by Steam Distillation				
% of pyroligneous	6.35	4.0	14.5	6.65
% of raw material	-	1.43	4.6	-
Distillation of Tar				
Up to 100°C	5	-	8.0	-
From 100°C to 150°C	9.5	-	9.0	-
From 150°C to 200°C	11.5	-	34.0	-
From 200°C to 250°C	12.0	-	12.5	-
From 250°C to 300°C	38.0	-	17.0	-
Residue	24.0	-	16.0	-

in the equipment. For instances some conveyors are heated in one plant and not in the other; fruit is heated up in the digester by steam jacket here and not heated at all during digestion elsewhere; some digesters, sterilizers and pipes are lagged, others are not. Finally steam consumption in one type of depericarper may attain 200 kg of steam per hour against nil in a pneumatic separator operating on air at ambient temperature.

In the case of a steam engine operating against a back pressure, the whole of the 3 barg steam output may be used for the various requirement for heating and processing. There is therefore a large saving in steam consumption.

On the average, taking into account the recovery of condensate from various parts of the mill estimates can be made on the basis of a heat requirement of 2 100 000 kJ to 2 520 000 kJ t^{-1} of FFB, that is 0.8 t to 0.9 t of steam per tonne of FFB. The efficiency of boilers in Africa ranges between 50% and 70%. The processing of 1 t of FFB therefore requires approximately 4 200 000 kJ of heat input from fuel.

The calorific value of the various oil mill waste products are given in the previous section. In practice, the waste products are wet and they contain oil. Their calorific values are given to *Table 7*.

TABLE 6. STEAM CONSUMPTION PER TONNE OF FRESH FRUIT BUNCH (FFB)

	kg of steam	kcl
Sterilization	250 – 300	160 000 – 190 000
Heating in digester	30	19 000
a) live steam	40 – 70	25 000 – 45 000
b) steam jacket		
Depericarper		
a) vertical without heating	0	0
b) with cold air	100 – 175	63 000 – 110 000
Kernel drier	25	16 000
Clarification		
a) centrifuge and hydraulic press	50	32 000
b) screw press	100	63 000
Miscellaneous, heating, losses	50	32 000
Power: 25 hp hr^{-1}	250 - 450	165 000 - 300

TABLE 7. ACTUAL CALORIFIC VALUES OF BIOMASS

	Moisture content (%)	Oil content (%)	Lower c.v. (kg) kcl (kJ)
Shell	10	1	4500 (18 841)
Fibre	40	5	2710 (11 346)
	50	5	2175 (9 106)
Bunch refuse (EFB)	60	5	1440 (6 029)
	50	5	1950 (8 164)

TABLE 8. CALORIFIC POWER AND AMOUNT OF WASTE PRODUCTS IN RELATION TO THE TYPE OF FRUIT

	Dura			DxT			*Tenera*		
	Weight (kg)	MJ kg^{-1}	C	Weight (kg)	MJ kg^{-1}	C	Weight (kg)	MJ kg^{-1}	C
Empty bunch	180	8.2	350	180	8.2	350	180	8.2	350
Fibre	90	11.3	345	145	11.3	390	2 710	11.3	540
Shell	300	18.8	1 350	200	18.8	900	4 500	18.8	405
Total	570	-	1 975	535	-	1 640	-	-	1 395

TABLE 9. COMPOSITION AND CALORIFIC VALUE OF GASES

1. EFB	Temperature of carbonization: 250°C		300°C	
	% gas	Lower c.v.	% gas	Lower c.v.
CO_2	45.4	-	37.6	-
O_2	0.6	-	0	-
C_nH_{2n}	1.0	130	1.4	180
CO	35.0	980	36.4	1.020
H_2	11.0	310	9.8	280
$C_nH_{2n}+2$	0.6	50	1.8	150
Ind.	6.4	-	13.0	-
	100	1 470	100	1 630

2. Fibre	225°C		275°C		350°C	
	% gas	Lower c.v.	% gas	Lower c.v.	% gas	Lower c.v.
CO_2	56.0	-	53.8	-	33.6	-
O_2	0	-	0.6	-	0.4	-
C_nH_{2n}	0.8	105	1.4	180	3.2	415
CO	23.0	645	29.4	825	36.0	1 020
H_2	10.8	300	5.8	165	9.4	265
$C_nH_{2n}+2$	1.2	90	2.4	210	5.0	435
Ind.	8.2	-	7.2	-	12.4	-
	100	**1 140**	**100**	**1 380**	**100**	**2 135**

3. Nut	200°C		300°C		350°C		375°C		400°C	
	% gas	Lower c.v.	% gas	Lower c.v.	% gas	Lower c.v.	% gas	Lower c.v. value	% gas	Lower c.v. value
O_2	77.4	-	73.2	-	61.9	-	58.7	-	33.1	-
O_2	0.7	-	1.2	-	0.6	-	0.5	-	0.3	-
C_nH_{2n}	0	-	0.2	25	1.4	180	1.9	250	4.6	600
CO	18.9	525	22.0	615	23.8	670	23.5	660	16.7	465
H_2	0	-	0	-	0.8	45	0.7	20	8.1	230
$C_nH_{2n}+2$	0	-	0.6	50	3.5	305	9.7	845	22.6	1 965
Ind.	3	-	2.8	-	8.0	0	4.9	-	14.5	-
	100	525	100	690	100	1 205	100	1 775	100	3 260

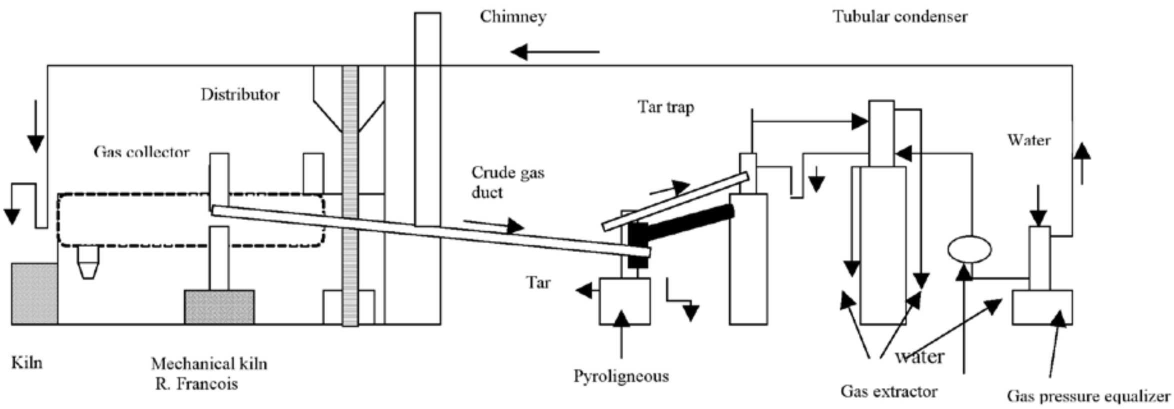

Figure 4. Schematic layout of a carbonization installation.

Available Calorific Energy

Information is given in *Table 8* regarding the heat available per tonne of FFB in the case of *dura, tenera* and DxT (50% *dura* and 50% *tenera*).

It should be noted that no mention is made in *Table 8* of the fact that a portion of the wastes cannot be recorded. It is necessary to bear in mind that:

- one-third of the fibre finds its way into the crude oil in the continuous press extraction process;
- two-third of the fibre goes into the crude oil in the case of the wet extraction process; and
- losses of shell may occur in the clay bath separator or as extraneous matter in the kernel.