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Design and Sizing of a Press Based on Sawdust Pellets in Cameroon

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Abstract:

This paper presents the procedure of setting up an industrial production unit of wood pellets from sawdust in Cameroon and in sub-Saharan Africa in general. The purpose of this work is to present a designing and sizing approach of a prototype for a wood pellets press with a reasonable capacity between 100 kg and 500 kg/h. From the analysis done, it appeared that the appropriate technique is that of the category of pelletizers, precisely the one related to the «Flat Die Pellet Mill» according to which we designed and sized the prototype with a production rate of 256 kg/h. This choice is based mainly on the strong yields of densification of pelletizers. These types of press are adapted to a wide range of raw material and are easy to maintain, space saving, and have a long-life span if the wear of the die and rollers is well monitored. Ultimately, a tool to assist in the sizing of the pellet press is designed to facilitate the analysis and design of large capacity in the industrial production units of wood pellets made of sawdust. It is also known that the cost of production is strongly influenced by the cost of the motor and the speed reducer at a range of 64%.

Key Words: Design, Pellets, Press, Sawdust, Sizing.

Introduction

Sawdust is an ecological alternative to oil in industries and domestic households. According to the bioenergetics report of (Pierre MARTIN, 2015) he finds out that sawdust has a high calorific value (usually between 1600 and 2800 kWh/T for 30 to 40% moisture), and a small percentage of ash of around 4% and has a low emission rate also allows industries to reduce their carbon footprint. However, sawdust in its powder state has a low combustion efficiency and must necessarily be improved by packaging of densification in wood pellets. This packaging requires specialized densification machines, with a technical and technological mastery which is mostly not available in some countries such as Cameroon in sub-Saharan Africa, moreover with a capacity of an annual production of 400,000 m^3. For this reason, (Elie TOLALE, 2007) stated that sawdust is mostly abandoned in ditches, whereas after fermentation produces greenhouse gases such as methane are 20 to 25 times more harmful than CO_2 (M. ALBERGANTI, 2011). This work is therefore part of the clean energy project in Cameroon, as the preliminary step starts with the definition, design, technology appropriate and adapted of the context for the manufacturing of wood pellets. To achieve the desired objective, the sequence to carry out this work begins with the presentation of a research literature on the manufacturing principle of wood pellets, and description of the designed wood pellet press. Then followed, is the development of sizing, and the designing formulas of the wood pellet press, which will lead to the integration of sizing formulas in the computing platform. The implementation of software support tool that facilitated the design of the machine was conducted by adding a database of the elements in the design of pelletizers. The software finally solved the problem presented and highlights results that allow all the implementation of the mechanism designed. The tool aid for sizing through scenarios will allow a criticism of the pellet press model designed.

Material:

Principle of manufacturing the wood pellets: The granule of densified wood or pellet is a small cylinder of compressed sawdust. Its diameter usually varies between 5mm to 10mm, and of a length between 10mm to 50mm. Its high energy density and its regular size make it a modern fuel for the full automation of the heating systems (Ginette DOUVILLE and Sylvie FILION, 2008). The basic principle of manufacturing the pellet with sawdust as raw material consists of firmly pressing particles of wood so as to increase their temperature and thus reactivate the lignin which is a natural wood binder. The characteristic tubular shape of the pellet is obtained by extrusion and compaction in the pellet press. At the exit of the presses, the produced pellets are very hot and must be cooled to maintain their form after having been cut to the required dimension. To be densified by various commercially available presses, materials must be free of foreign bodies and have a moisture level less than a determined value varying according to the process from 15% to 20%. Densification processes differ from each other depending on the type of press used. Various types of press are distinguished not only by their operational principle but also by their technical and technological requirements been specific. The processes of densification of sawdust wood, and in the light of the technological and operational constraints, the «Flat Die Pellet Mill» technique is one that is permanently retained in the family of pelletizers (TOGUEM T.S.C, 2016). In their principle of operation described in Fig. 1 below, the sawdust falls on a horizontal die and is pressed on by rollers. Then compacted material will pass through the meshes of the die to exit in the form of granules. In some machines the rollers are fixed while the die is rotational, in others the rollers are rotational while the die remains fixed.

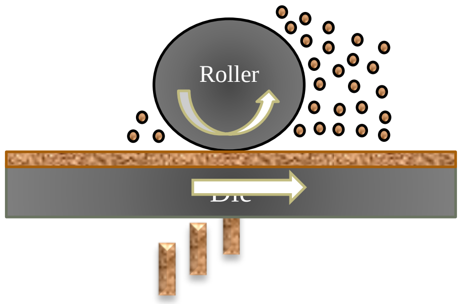
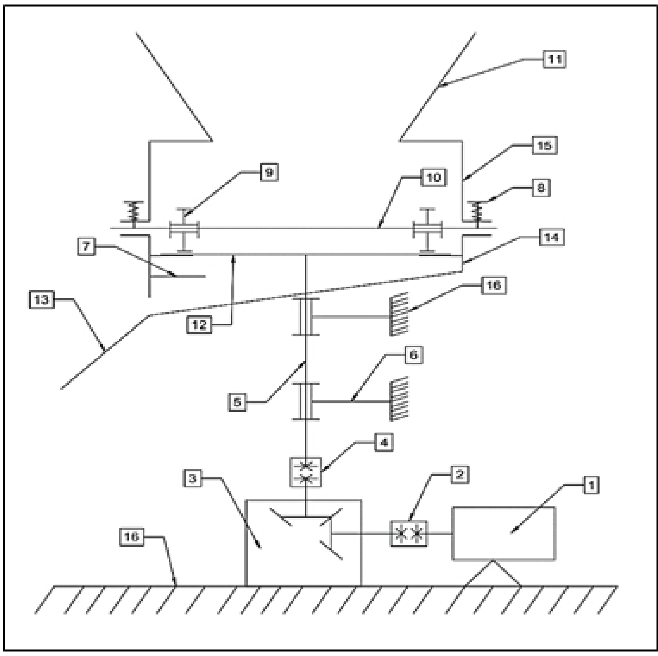


Figure 1: Working principle of a Flat Die Pellet Mill

Description of the wood pellet press: The mechanism shown in Fig. 2 below is a functional analysis of the need to be satisfied, it consists of a motor 1 which transmits its movement to the speed reducer 3 through the first coupling 2. Then 3 transmits it to the main shaft 5 through the second coupling 4. However, 5 is bound to frame 16 through a vertical axis swivel link made up of bearing 6 and is embedded in the die 12 which when moves will cause the rollers 9 to rotate by friction around the rollers axis 10. The part 10 is linked to the top cover 15 via the adjusting screw 8. To be densified, sawdust enters the compaction chamber through the hopper 11, then it is trapped between 9 and 12 it will be compacted and then forced to follow the holes placed on the basic surface of 12. The knife 7 fixed on the bottom cover 14 will handle length implementation. Finally, the pellets formed will be expelled from the compaction chamber through the sieve 13 for the sorting of waste.



Number	Designation
1	Motor
2	First coupling
3	Speed reducer
4	Second coupling
5	main shaft
6	Bearing
7	Knife
8	Adjusting screw
9	Roller
10	Rollers axis
11	Hopper
12	Die (Plate)
13	Sieve
14	Bottom cover
15	Top cover
16	Frame

Figure 2: kinematic schema of the wood pellet press

Support tools for sizing: This is a computer program set up and which allows us to calculate the key parameters of the machine such as the motor power in kW, rotation speed of the main shaft in RPM, diameter of the die in mm, torque on the main shaft in N.mm and number of holes on the die, by applying the formulas of sizing of elements in its design. Programming languages generally used for the creation of applications are Java, Turbo Pascal, Visual Basic, Matlab, Lingo, etc. The two different tools selected for the software and for the calculation where Matlab and Lingo respectively. Many authors like (SVEN LEYFFER and ASHUTOSH MAHAJAN, 2010) noted that it is the software that permits us to easily and rapidly develop applications to solve complex optimization problems. The application's interface on Fig. 3 below consists of a single window on which are two buttons and six text boxes whereby only one is editable. It allows us to inform the user on the main features of the pelletizer and have a clear idea of the cost of the machine from a certain fixed rate. The results of the calculations can be generated in a file format.

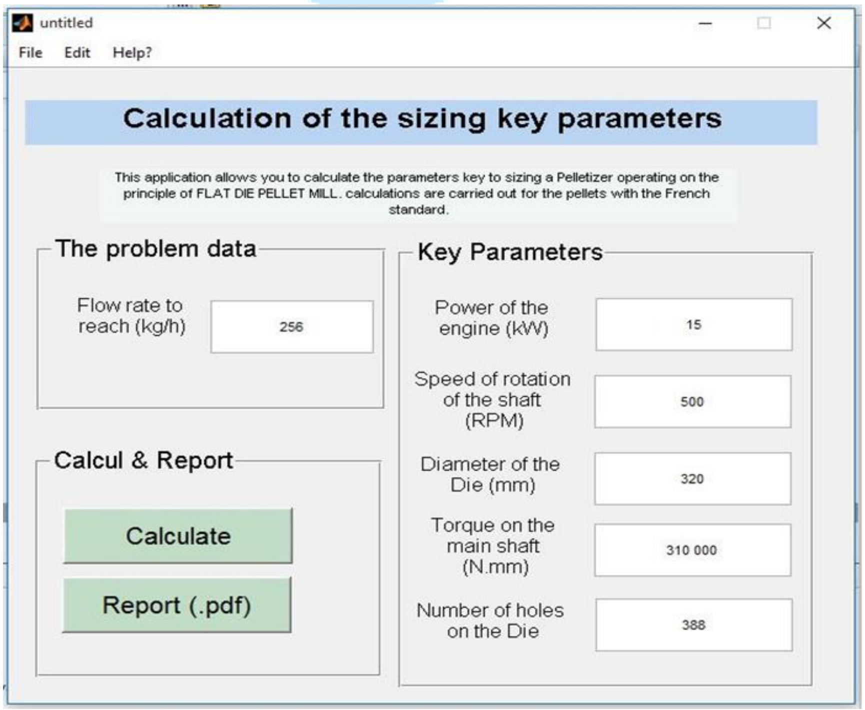


Figure 3: Application Interface for calculation of the key parameters of the pellet press

Method of Sizing:

Key parameters of sizing and functional requirements

A carefully analysed mechanism leads to the four key parameters of sizing, ie the rotation speed and the diameter of the die, the torque and the number of holes on the die. These key parameters for sizing are related to two main elements responsible for the realization of functions of compaction and extrusion of pellets. Moreover, according to the above principle, the technique and the technology for the machine to perform its main function to suit the client's specifications requires that the flow rate be between 100 kg/h and 500 kg/h. The die turns despite the presence of sawdust in the hopper to ensure there is no sliding in contact zone between rollers and sawdust, and the holes must all be able to hold on the die, with all minimal energy consumption. This is the functional requirements of the mechanism which will be translated according to the calculation principle of (J.P. MATAS, 2013) and (S.H. LOEWENTHAL, 1984).

Mathematical modelling of the problem

Here we will translate mathematically the above mentioned functional requirements.

Deposit flow rate q_p between 100 kg/h and 500 kg/h: Let us call *N* (RPM) the rotation speed of the rollers or 60 × *N* (SI/h). However, the flow of pellets q_p at the output of the machine must be between q_1 = 100kg/h and q_2 = 500kg/h.

Then $q_1 \leq q_p \leq q_2$.
By expressing the flow in terms of pellets produced per hour we get:

$$\frac{q_1}{m_p} \leq \frac{q_p}{m_p} = n_p \leq \frac{q_2}{m_p}$$

Whereas, n_p is the number of pellets produced per hour of operation

$$mass\ of\ one\ pellet = m_p = \frac{\pi d_p^2 d_e l}{4}$$

Whereas, d_p is the diameter of the pellets in mm, d_e is the relative density of pellets in $kg/m3$ and l is the length of the pellets in mm.
Let n_0 , be the number of turns needed to form a wave of pellets and *n* the number of pellets per wave (*n* = number of holes on the die), thus:

$$60 \times N\ turns \rightarrow 1h$$

$$n_0\ turns \rightarrow n\ pellets$$

$$Therefore,\quad 1h \rightarrow \frac{60 \times N \times n}{n_0}\ pellets$$

If j is the gap between die and rollers and n_R the number of rollers, we have:

$$n_0 = \frac{l}{j} \qquad \text{Therefore,} \qquad q_p = \frac{60Nnjn_R}{2l}$$

$$\text{However,} \quad \frac{q_1}{m_p} \leq q_p \leq \frac{q_2}{m_p}$$

$$\text{Therefore,} \quad \frac{q_1}{m_p} \leq \frac{60Nnjn_R}{2l} \leq \frac{q_2}{m_p} \qquad (1)$$

The die should be able to turn despite the presence of sawdust in the hopper: To be able to turn despite the presence of sawdust in the hopper, the die must develop enough torque to overcome this burden.

- The rollers must overcome the resistant effort F_{r1} generated by the displacement of the sawdust.

$$F_{r1} = \mu M g$$

Whereas, μ is the coefficient of friction to contact sawdust rolls in *USI*, *M* is the mass of sawdust present in the hopper in kg, and g is the gravitational constant 10 m/s^2.

We have, $C = D\,F_t$

Whereas, C is the torque transmitted by the die in *N.mm*, F_t is the tangential effort that generates torque *C* in *N*, and *D* is the diameter of the circle described by the ends of the rollers in *mm*.

$$\text{Haven known that,} \quad F_t = \frac{C}{D} \geq \mu M g$$

$$\text{Therefore,} \quad \mu M g D - C \leq 0$$

- By assimilating the sawdust to a fluid, we noticed that the rollers are subjected to a viscous force of friction due to the presence of the sawdust during their rotation. This frictional force for a roller is given by the following equation:

$$F_{r2} = \alpha\, V = \alpha \pi D N$$

Whereas, α is the coefficient of viscous friction sawdust/rollers, and *V* is the linear speed of the rollers in *m/s*.
Therefore, the rollers must overcome this resistant

effort, and for a roller we have:

$$F_t = \frac{C}{D} \geq \alpha\pi DN$$

However, these two strong efforts are acting simultaneously, and therefore for a roller we have:

$$F_t = \frac{C}{D} \geq F_{r1} + F_{r2}$$

Considering all the rollers n_R, we have:

$$Dn_R(\alpha\pi DN + \mu Mg) - 2C \leq 0 \qquad (2)$$

No sliding in contact zone between rollers and sawdust: Compaction effort is none other than the action of the rollers (A) on the sawdust or rather on the die (B). This is the normal reaction contact die-rollers or rather contact roller-die-sawdust as shown in Fig. 4 below.

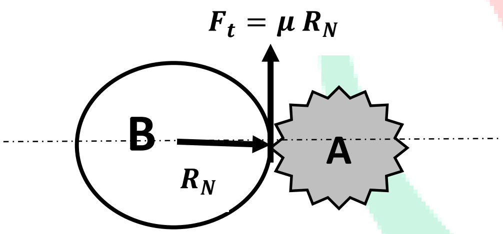


Figure 4: Efforts of contact roller-die-sawdust

Compaction effort is designated R_N by applying the theorem of dynamic moments to the rollers.

$$\sum M_{ext} = J_\Delta\ddot{\theta}$$

Whereas, M_{ext} is the external torque, J_Δ is the moment of inertia and $\ddot{\theta}$ is the angular acceleration.

$$C - \mu R_N D = J_\Delta\ddot{\theta}$$

However, the rollers rotate at constant speed, therefore $\ddot{\theta} = 0$.

Therefore, $C = \mu R_N D$ and $R_N = \frac{C}{\mu D}$

However this effort of compaction must be enough to compress the sawdust until the desired density ($d_e \geq 350\ kg/m^3$).

Let n_0 be the number of holes covered by a roller. Thus, the roller must provide an effort R_N enough to compact n_0 pellets simultaneously.

$$R_N = \frac{C}{\mu D} \geq n_0 F_0 \frac{n_R}{2}$$

Whereas, F_0 is the effort of compaction of a pellet obtained by experiment in N, and n_R is the number of rollers.

Therefore, $n_0 F_0 \mu D n_R - 2C \leq 0 \qquad (3)$

The holes must all be able to hold on to the Die: The area occupied by the holes on the base of the die must be less than the surface area of the latter. This is why we must make an appropriate choice of the distribution of the holes on the die. The spiral distribution is highly recommended in this case because it allows a uniform distribution of the holes on the surface of the die and it is easy to be implemented. The holes are distributed along a logarithmic spiral with a constant pace. The length of a spiral with a pace P and whose starting and ending points are located respectively at a distance R_0 and R_1 is given by the eq. (4) below.

$$L = \frac{P}{4\pi}\left[\left(\frac{2\pi}{P}\right)^2 (R_1^2 - R_0^2) + \ln\left(\frac{R_1}{R_0}\right)\right] \qquad (4)$$

The number of holes that can fit on this spiral is obtained from (GEMCO Energy, 2011) and using the eq. (5) below.

$$\text{Number of holes} = E\left(\frac{L}{d_p + e}\right) \qquad (5)$$

It is necessary therefore that the number of holes of the die be less than or equal to that on the spiral. Thus, as shown in eq. (6) below.

$$n \leq E\left(\frac{P}{4\pi(d+e)}\left[\left(\frac{2\pi}{P}\right)^2 (R_1^2 - R_0^2) + \ln\left(\frac{R_1}{R_0}\right)\right]\right) \qquad (6)$$

Whereas, P is the propeller pace in mm, R_0 is the radius of the front hole in mm, R_1 is the radius of the die in mm, e is the gap between two holes in mm, d_p is the diameter of the hole / the pellets in mm, $E(x)$ is the function whole part and n is the number of holes on the die.

Limiting energy consumption: The power supplied by the main shaft is given by the eq. (7) below:

$$\text{Minimise } P_a = C \times \omega = \frac{2\pi CN}{60.10^6} \qquad (7)$$

Whereas, N is the rotational speed of the main shaft in rpm , and C is the torque transmitted to the main shaft in $N.mm$, and P_a is the power provided to the shaft in kW.

Optimization problem to solve: The objective is to minimize the power provided to the main shaft in order to have a possible low capacity motor that will allows us to meet all the technical stress, this concern boils down to the formulation of the operational research problem and shown in the eqs. (1) to (7) above.

Calculating the strain of the parts of the mechanism

The calculation of the components size for the mechanism starts with the identification of functional requirements, then the choice of material, then comes a pre-sizing, followed by a calculation of dimensions, drawings and finally the verification of the results obtained using computer designing tools.

Calculating the cost of the machine

Taking into account value added taxes (VAT) amounting currently to 19.25% in Cameroon, the cost of the machine is calculated using the eq. (8) below.

$$Total\ cost = 1.1925(C_{material} + C_{equipment} + C_{consummable} + C_{realization} + hazard) \quad (8)$$

Calculation hypothesis:

$$C_{realization} = C_{manufacturing} + C_{studies}$$

Results and Discussion:

Problem solving

The resolution of the system formulated by the five eqs. (1) to (7) above was made using two different tools (Matlab for software and Lingo for the calculation). To do this, it was necessary to set some basic parameters whose values and the justifications of the chosen values are presented in Table 1 below. From these values the characteristic quantities can be obtained.

Table 1: Fixed Parameter value

Parameter	Symbol	Fixed value	Justification
The number of holes covered by the rollers	n_0	$n_0 = \frac{1}{20}n$	It represents the $\frac{1}{20}$ th of the number of holes on the Die
The coefficient of friction in contact with sawdust-rollers	μ	0.002 USI	Value commonly encountered in the literature
The coefficient of viscous friction	α	0.005 USI	Value commonly encountered in the literature
Compaction effort	F_0	1000 N	Starting with a compaction pressure of 100 bars, and the dimensions of a pellet, we arrived at: $F_0 = \sigma_{compact}.S_{pellet}$ Or (for a diameter of 10 mm pellets) 1000N compaction effort
Mass of sawdust in the compaction chamber	M	10 kg	We have considered this quantity indicatively.
The intensity of the Galilean acceleration	g	10 m/s^2	This value is typically used in pre-sizing calculations
Whereas, d_p = 10mm; d_e = 350kg/m^3 ; P = 13,5mm ; e = 5mm ; l = 30 mm; g = 10m/s^2.			

The comparative Table 2 below shows the reading of the results on the two calculation tools for the machine with an estimated capacity of 256 kg/h and also shows the relative gaps between them. The relatively small gap between the results of the test on the Matlab software and those obtained by calculation on Lingo is due to the fact that the resolution was made to tolerances of the different calculations by the two tools. Indeed, the tolerance interval of Lingo is much tighter making it more accurate but less realistic. Matlab meanwhile has been configured to perform calculations with much larger tolerances to achieve results increased by a factor of safety which represents risks and contingencies.

Table 2: Summary of results (characteristic parameters)

Parameter	Test results on Matlab	Calculation results on Lingo	Relative gaps
Power of the motor (kW)	15	15	0 %
Rotation speed of the main shaft (RPM)	500	500	0%
Diameter of the die (mm)	320	300	6.25%
Torque on the main shaft (N.mm)	310 000	300 000	3,23 %
Number of holes on the die	388	400	3 %

Sizing of the machine's components

The sizing calculations give the main characteristic of the mechanism parts, allowing us to go to the different designs and drawing. Table 3 below is a summary of the sizing results.

Table 3: Summary of the sizing results

Code	Components	Designation	Qty	P.U. HT (FCFA)	P.T HT (FCFA)	Frequency (%)
1	Tapered roller bearings	SKF 32014X	2	60000	120000	4.58
2	Speed reducer 1 :3	XRS 202	1	750000	750000	28.61
3	Electric motor of 15 kW	3GBA162 044 G	1	920000	920000	35.10
4	Extension cable 25m	Tayg 785511	2	8000	16000	0.61
5	Male and female plugs	16 A2P+T/ 16A 2P+T	1	4000	4000	0.15
6	Relay	TeSys LRD	2	10000	20000	0.76
7	Contractors	TeSys D	2	20000	40000	1.53
8	Control knobs	Harmony XB4	2	500	1000	0.04
9	Electrical box	EPS 46x150x60	1	10000	10000	0.38
10	Cable 6 m section 2,5 mm four-wire	684185	1	5000	5000	0.19
11	Hex screws	Hex screws M5, M8, M12, M14, M10	87	250	21750	0.85
12	Washers	NM d=5, d=14, d=10, d=8, d=16, d=12	87	100	8700	0.48
13	Hex head bolt	Bolt M16 130/45	50	550	27500	1.05
14	Rivet (package)	GESIPA F/120 D=2,4	1	5000	5000	0.19
15	Circlips	7002-Φ 30 mm	4	5000	20000	0.76
16	Ball bearing	SKF 6006	2	25 000	50000	1.91
17	Joint	IE 722 500	4	5000	20000	0.76
18	Ring spacer	REF 1006-30-52	2	5000	10000	0.38
19	Fixed casters	LS-GTH 127 K n°=267260	2	80 000	160000	6.10
20	Swivel casters with clamping device D=125 mm	LS-GTH 127 K-ST n°=316984	2	100 000	200000	7.63
21	Binder	640/73X7FDSS	2	100 000	200000	7.63
22	Keyway	Keyway bar 18X11	2	4000	8000	0.31
TOTAL AMOUNT					**2621250**	**100**

Critical study of the machine

The Table 4 below gives the different results obtained from the calculation software for a wide range of flow rates ranging from 100 to 2100 kg/h.

Table 4: Software simulation results

Flow rate (kg/h)		Power (kW)	Diameter of the die (mm)	Rotation speed of main shaft (RPM)	Number of holes max
100	120	4	150	750	125
120	200	11	240	750	179
200	250	15	280	750	208
250	300	18.5	320	750	250
300	400	22	360	750	291
400	500	30	380	750	417
500	600	37	400	750	500
600	750	45	450	750	625
750	1000	55	520	750	834
1000	1700	75	680	750	1417
1700	2100	90	730	750	1750
2100	2500	110	800	750	2084

The analysis of table 4 above shows that from 1000 kg/h the machine designed has becomes difficult to be achieved. In fact, the diameter of the die takes values greater than 600 mm resulting in two major difficulties notably the difficulty of obtaining the crude and that related to the implementation. Indeed, the circular shape of the die is a functional feature of the mechanism and requires high-capacity machines. Beyond 1000 kg/h the machine becomes expensive and technically difficult to be achieved, because there is a need for a machine park with a large capacity in terms of maximum machinable dimensions. Thus, to achieve flow rates greater than 1000 kg/h, two choices will be available, it must either change the technique and technology of manufacture of pellets or maintain the technique and change only the technology.

Financial analysis of the machine

Total cost of the machine: The calculations of the machine is done using the eq. (8) which gave the values in the Table 5 below. Studies were assessed at 10% of the cost of acquisition of elements (raw materials, hardware and consumables) and hazards have been assessed at 5% of the acquisition cost of items. The total cost of the machine is 8,573,583 FCFA (eight million five hundred and seventy-three thousand five hundred and eighty-three francs CFA) for the design and manufacturing of the prototype and all taxes included.

Table 5: Total cost of the machine

Rubric	Total Cost (FCFA)
Cost of two tonnes of raw material	67,000
Cost of the working material	2,471,000
Cost of material	2,621,250
Cost of consummables	68,000
Cost of studies and realization	1,707,725
Cost of logistics and hazards	254,613
Total without taxes	7,189,588
VAT = 19.25%	1,383,995
TOTAL Cost All taxes included	8,573,583

The weight of the cost of each material: Frequency, according to (TAMO O.,2016) meaning the cost of the component on the total cost of the machine of each material mentioned in Table 3 above. It appears from the analysis of the stick diagram on Fig. 5 below that the total cost of the standard material is dominated by the motor and the speed reducer costs because these components generate nearly 64% of the total cost of the standard material. So approximately the total cost of the standard materials is calculated using eq. (9) below.

$$\text{cost}_{\text{standard mat}} = \text{cost}_{\text{motor}} + \text{cost}_{\text{speed reducer}} + \text{constant } 1 \quad (9)$$

Whereas, *constant 1* is the other components of the standard material cost which is 951250 F CFA.

It is therefore clear that for a pellet press using the technique of the «Flat Die Pellet Mill» with a flow rate between 100 kg/h and 500 kg/h, the cost of the work material, manufacturing, studies, of consumable and hazards will fluctuate while remaining in a very close amount as those machine with a flow rate of 256 kg/h. We therefore consider that for any «Flat Die Pellet Mill» with a flow rate between 100 kg/h and 500 kg/h, the different costs is equal to that of a machine with a flow rate of 256 kg/h.

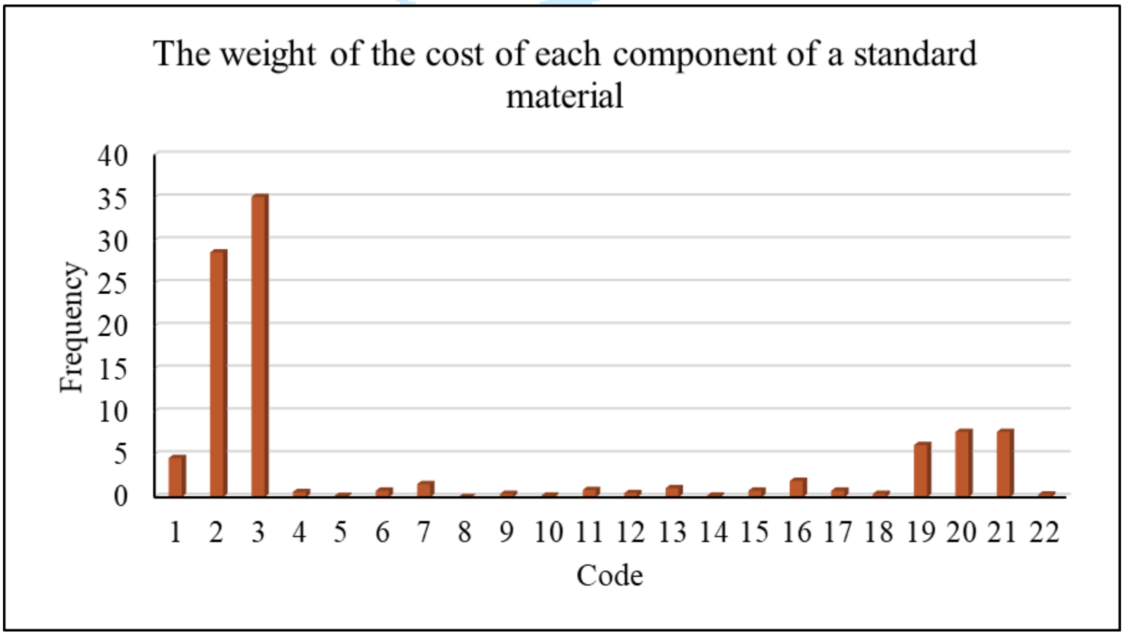


Figure 5: Stick diagram of the frequencies of cost

On this basis, the relationship of the total cost previously established for the machine has the formulation on eq. (10) below.

$$\text{Total cost} = 1.1925(C_{\text{matérials}} + C_{\text{motor}} + C_{\text{speed reducer}} + \text{constant } 1 + C_{\text{consumable}} + C_{\text{realisation}} + \text{Hazards}) \quad (10)$$

We can therefore develop eq. (11) as follow.

$$\text{Total cost} = 1.1925(C_{\text{motor}} + C_{\text{speed reducer}} + \text{constant}) \quad (11)$$

Whereas the $\text{constant} = \text{constant } 1 + C_{\text{consumable}} + C_{\text{realisation}} + \text{Hazards} + C_{\text{materials}}$

Therefore, the final eq. (12) is as follow.

$$\text{Total cost} = 1.1925(C_{\text{motor}} + C_{\text{speed reducer}} + 5\,452\,588) \quad (12)$$

Conclusion

The work carried out in this paper focused on the design and sizing of a press based on sawdust pellets. The main objective was to define the technique and the technology of manufacturing pellets made from sawdust of low production rates within 100 kg to 500 kg. With regard to the analysis and the constraints related to the cost and the difficulties of constructing the machine, the technique and technology adapted, the Flat Die Pellet Mill turns out to be the best. Then, the sizing methodology has led to the designing of the machine with a production capacity of 256 kg/h. A latter study on the manufacturing and the financial analysis was conducted which led to a cost amounting to 8,573,583 FCFA. Finally, the technique and the technology retained have been improved through a critical study made possible by a support tool for sizing that was designed. It was therefore observed that, for the technology of two rollers retained, the production capacity limit is 1000 kg/h. Also, the cost of the machine is highly dependent on the cost of the motor and the speed reducer at a range of 64%.

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