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Design concepts of a hybrid drying and winnowing machine for small scale cocoa nibs production processing plant

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Abstract: *Cocoa nibs are the small grains collected from cocoa beans after drying and shell removal (winnowing). These nibs are further processed by roasting, alkalization, grinding, agitation, pressing to get the cocoa cake that is processed to cocoa powder by pulverization for our beverages. and the butter gotten when the liquor of the nibs is pressed. To get the nibs produced requires cleaning, sorting, drying and winnowing. In all cocoa processing plants in Nigeria, three different machines are required for the listed nibs production activities. These caused much capital investment, increase in inventory cost, maintenance cost, and machine layout and manpower requirement. In order to reduce these problems, a hybrid machine capable of processing dry cocoa beans to the nibs level was designed. The components of the machine include 2 hoppers for the drying and the winnowing chambers of $3.36x10^3$ m^3 and $8.49x10^3$ m^3 in volume respectively; 2 chambers for drying and winnowing of $8.42x10^3$ m^3 and $8.5x10^3$ m^3 in volume and 0.5 horsepower electric motor as the prime mover. The machine will be suitable with processing capacity of 600 kg/h and estimated cost of production of four hundred and fifty thousand naira (₦450,000) only.*

Key Words: *Cocoa beans, cocoa processing, cocoa products, development, machines.*

1. INTRODUCTION

Agricultural products processing is generally acceptable as the best method of improving the shelf-life of produce. Crop processing industries are important especially in nations like Nigeria and their existence cannot be over emphasized. In Africa, the crop processing industry is mainly dominated by the informal sector made up mainly of medium and small-scale rural enterprises which are operated by people using indigenous technology (1). Cocoa, soya beans, cashew, palm fruits, cassava, banana, potatoes etc are some of the produce processed and consumed by the rural populace in Nigeria and other African countries. Cocoa (*Theobroma cacao*) has been a very important food material for man for a very long time. Cocoa beans powder is the raw material used for cocoa based confectioneries, butter, ice cream, beverages, chocolates, candies, cosmetics and so on. The economy of many nations of the world depend on cocoa beans harvest and derived products production and consumption (2). Presently, Nigeria ranks among top cocoa producing countries in the world, occupying the fourth position after Côte d'Ivoire, Ghana and Indonesia. (3).

Cocoa beans processing begins with the extraction of cocoa beans from harvested pods (breaking the pods and extraction of wet beans from the husks). This aspect has been a manual process for ages, it is time and labor consuming; however, few works on cocoa pod breaking machines have been documented (4). Freshly harvested cocoa pods are broken to extract the wet pulpy beans which are usually allowed to ferment for 4-7 days. During this process, the color of the bean turns dark brown, while the thick pulp thins and gets ripped off while the distinctive flavor and aroma associated with cocoa beans products develop. The pulp is proven to be rich in ferment-able sugars molecules about 9 to 13% w/w (5). The fermented beans are sun-dried to reduce the moisture content from about 6.0% to 7.5%. Natural or sun drying is the simplest and most popular method used by local farmers and it takes between 7-12 days with adequate sunshine. In some places, drying is carried out artificially at temperatures not exceeding 65°C (6).

Cocoa powder production is a multi-units operation which comprises cleaning, drying, peeling/winnowing, roasting, milling, alkalizing, pressing, butter packing, pulverizing and sifting. The fermented, dried cocoa beans are cleaned by aspiration and de-stoning to remove dry pulp debris, stones and other extraneous materials including chaff and pod residue. The beans are dried (at within a temperature range of 98-120°C for 90-95 minutes) to sterilize them, eliminate the acids formed during fermentation, make the beans amenable to fracture during peeling and enhance the development of the sensory attributes typical of chocolate (2). A winnowing machine is used to remove the shells from

the peeled beans to leave just the cocoa nibs. The cocoa nibs are then milled to create cocoa liquor (cocoa suspended in cocoa butter). Only about 20% of global cocoa bean processing takes place in West Africa; the majority are sent to Europe, Asia and North America for processing. (7).

Drying is an important step which affects the quality characteristic of cocoa bean during industrial processing. (8). Drying of cocoa beans before winnowing is very crucial because it makes the beans amenable to fracture easily, thereby releasing the much desired nibs from the shells. Drying conditions can promote reactions that form new compounds that are responsible for the development of the distinctive chocolate color. There is evidence that during drying, there is a reduction in polyphenol content due to enzymatic browning caused by a polyphenoloxidase reaction, followed by non-enzymatic browning resulting from the quinone polymerization due to the accumulation of insoluble compounds (9). Drying is also responsible for reducing the acidity of cocoa beans and should be conducted in such a way as to obtain a moisture content of about 7% (10).

The most valuable part of cocoa bean is the nib. Winnowing involves peeling the beans and using air to separate shell particles from the nibs. There should be no more than 1.5 - 2% shell in the nib fraction. The shells can be utilized as fuel for the factory or as fertilizer. The peeling operations generates large quantities of dust which must be controlled to minimize the risk of explosion and fire.

Winnower machine separates dried, peeled cocoa beans from shells, consequently dried cocoa nibs can be processed into cocoa mass (11). In using winnower machine, it is expected that the shell texture is fragile, as a result, it is easier to break and separate. Dried cocoa beans should also have low water content in order to get uniform fractions of dried cocoa nibs. Another method to get uniform fractions of dried cocoa nibs is by sieving the nibs (12).

Previous type of winnower machine consisted of double rolls with some space in-between for breaking down cocoa beans without grinding them and then sieving the broken beans. Other type was in form of serrated con cylinder installed to hallowed cone stator widely known as kibbing cones type. The machine was later developed by providing air suction and cyclone-shape funnel. Dried cocoa beans are peeled using rotor-stator and then, they go to exhausted channel that is connected to suction fan, as a result, smaller fractions of cocoa shell parchment will be sucked out of the exhausted channel and the nibs are collected on the storage funnel (12). Another winnower machine to process dried cocoa nibs was previously developed by Widyotomo *et al.* (13) for farmers-group scale and the capacity of the machine was 268kg/hour. It is expected that the winnower produces cocoa nibs with uniform size and there is not any tiny cocoa shell parchment mixed with the cocoa nibs (14). Processing of cocoa beans into confectionery products such as chocolate bar can be done in small-scale in order to get chocolate directly from cocoa beans instead of cocoa mass. Chocolate products made directly from cocoa beans have better flavor and aroma due to self-choosing cocoa beans quality by the operator (15). Cocoa processing mechanization using less sophisticated machine is the most suitable for developing home or small-scale industries with relatively low processing cost.

In all cocoa processing plants in Nigeria, three different machines are required for the listed nibs production activities. These machines requires much capital investment, increase in inventory cost, maintenance cost, machine layout and manpower requirement The machines are all industrial, expensive and out of the reach of the ordinary farmers who are the real producers of the raw materials (cocoa beans).. In order to alleviate these problems, an hybrid machine capable of processing dry cocoa beans to the nibs level was designed for production using locally sourced materials. The design of this machine was aimed at bridging this gap and giving the local farmers an opportunity to process the beans themselves to maximize their profits.

2. METHOD

2.1 Machine Description and Operation

2.1.1 Machine Description

The components of the machine include the main frame, the A.C electric motor, the hopper, the roasting chamber (drying cylinder), the winnowing chamber, (this includes the cylinder housing the abrasive material), the blower (fan for separating cocoa nibs from shells due to difference in weight), D.C electric motor, the stirrer for stirring cocoa beans etc. Details of these components are subsequently presented

2.1.1.1 The main frame

Mild steel angle iron of dimensions 50mm x50mmx4mm will be used for the construction of the main frame for strength. This will be cut to sizes and then joined together by arc welding method for rigidity. The frame must be very strong for it to be able to bear all the loads that will be coming on it.

2.1.1.2 The hopper

The basic function of hoppers in industrial machines is to feed raw materials into the machine. The type of raw materials to be fed into the machine determine the design of the hopper to be used and how its passage may be designed. The

hopper of this machine was made of stainless steel and it came in form of a pyramid. The angle of inclination of the hopper to the horizontal surface is 45º, this is so to facilitate easy feeding. Stainless steel was chosen as material because it is corrosion resistant, since cocoa is acidic, stainless steel will be able to resist its corrosive nature on materials.

2.1.1.3 The drying chamber

This part consists of the heating chamber and the drying area with stirrer which is connected directly to an electric motor with a speed reduction gear for stirring the cocoa seeds during drying for even distribution of seeds to receive equal heat, thus preventing burning or under-drying of some seeds. The drying chamber is at the top of the heating element producing the heat. The stainless steel is a good conductor of heat. It conducts the heat generated from the heating element, and pass it onto the cocoa seeds for drying. An opening is provided for discharging the dried beans. The drying chamber must be lagged to prevent heat loss during drying.

2.1.1.4 The winnowing chamber

The winnowing chamber is cylindrical, housing the winnowing cylinder that is connected to it's own speed reduction geared electric motor. This part also has its own hopper for receiving the dried cocoa seeds ready for winnowing. This part was designed such that as it receives the dried beans, peeling is carried out on them by abrasion. The drum was wrapped with abrasive material which rubs on the cocoa seeds, thus effecting peeling of the dried beans. The abrasive material was wrapped on the drum in a helical form. This was done to prevent choking of the chamber with the beans. Also, any of the seeds that escapes peeling in the front will still get peeled before getting to the end of the drum. The chamber consists of two exit troughs. The first trough is the exit for shells while the other trough is for the nibs.

A fan was incorporated with the winnowing chamber. The fan performs two functions: (i) to cool the dried beans that are coming directly from the drying chamber into the winnowing chamber and (ii) to blow away or separate the nibs from the shells due to weight difference during winnowing.

2.2 Design analysis

The drying chamber hopper of the machine was designed for 2 kg of cocoa beans. The density (ρ) of cocoa beans is 593 kg/M^3 (16). The drying chamber cylinder (inner) was designed for 5 kg of cocoa beans while the outer part was designed to accommodate the insulating material (fiber glass) between it and the inner cylinder. The volume of the insulating material was also determined. The stirring shaft was designed against torsion and the effective diameter was determined. 0.5 hp (373 Watts) geared electric motor with gear reduction ratio of 50:1 was used for the stirring to achieve a desired speed of 25 rpm. This was done to achieve good drying of the cocoa beans. The heating element needed to supply heat was also designed for. 1500 Watts coil was chosen. The total energy requirement of the roaster was calculated. The winnowing chamber's hopper's volume was designed for 5 kg of cocoa beans, while the winnowing chamber's volume was also designed for 5 kg. The winnowing shaft was designed against torsion and the diameter was calculated. 0.5 hp geared electric motor with gear reduction ratio of 50:1 was chosen and this will be connected to the winnowing shaft through a flange coupling. In designing for the coupling, the hub shear stress, flange shear stress and the bolts were all calculated (17). The power needed to peel the beans was also determined using the equation of Akintade *et al*, (18).

2.3 Machine Operation

The mode of operation of the cocoa beans drier is in this form: the cocoa beans are fed through the hopper, the discharge opening would have been shut before then, the heating element switched on, the temperature at which to dry is chosen and the timer set for the required time. The stirrer also should be switched on immediately with the heating element. As the temperature of the drying chamber gets higher, the stirrer continues stirring the beans for even distribution of the beans to heat. This is to prevent burning of some of the beans while some at the center will not receive enough heat for even drying. At the expiration of the time chosen, the beans are sampled for dryness, if satisfactory dryness is achieved, the heating element is switched off to conserve energy while the discharge opening is opened and the stirrer will stir all the dried beans out of the chamber into the winnowing chamber hopper in preparation for winnowing operation. The winnowing chamber, having received the dried cocoa beans, is switched on and the blower fan also switched on. The beans will be shelled and the fan will separate the nibs from the shells by difference in weight. The nibs are collected at the first opening while the shells will be blown to the extreme end of the winnower where they are collected in a sack that will be provided for it.

3. RESULTS AND DISCUSSION

3.1 Results

The results of the component design of the machine is presented in Table 1. The AutoCAD drawings produced based on the designed values are presented in Figures 1 to 4.

Table1: Results of the Component Design of the Machine

S/N	Component	Designed factor	Mathematical model used	Equation number	Source	Designed value
1	Drying chamber hopper	Volume	$V = 1/3(a^2+ab+b^2)h$	1	www.cuemath.com	0.0034 m^3
2	Drying chamber cylinder (inner)	Volume	$V = \pi r^2 h$	2	www.cuemath.com	0.0084 m^3
3	Drying chamber cylinder (outer)	Volume	$V = \pi r^2 h$	2	www.cuemath.com	0.0103 m^3
4	Insulating material	Volume	$\Delta V = V_1 - V_2$	3		0.0019 m^3
5	Stirring shaft	Diameter of shaft	$J = \frac{\pi \times d^4}{32}$	4	(Khurmi & Gupta, 2005)	3 mm
6	Heating element	Power rating	$P \times t = mc\theta + ml$	5	www.answers.com	1500 watts
7	Energy requirement of the drier	Energy (KWh)	$E = P \times (t/1000)$	6	www.vendatu.com/ formula.	1.88 KWh
8	Energy requirement of the winnower	Energy (KWh)	$E = P \times (t/1000)$	6	www.vendatu.com/ formula.	0.078 kWh
9	Winnowing chamber hopper	Volume	$V = 1/3(a^2+ab+b^2)h$	1	www.cuemath.com	0.0085 m^3
10	Winnowing chamber	Volume	$V = \pi r^2 h$	2	www.cuemath.com	0.0065 m^3
11	Winnowing shaft	Diameter of shaft	$J = \frac{\pi \times d^4}{32}$	4	(Khurmi & Gupta, 2005)	22 mm
12	Peeling dried cocoa beans	Power	$P_{total}=P_{innerdrum}+P_{shaft}+P_{peeling}$	7	Akintunde *et al.*, (2005)	0.3 hp
13	Coupling	Hub shear stress	$T = \frac{\pi\tau_c(D^4-d^4)}{16D}$	8	(Khurmi & Gupta, 2005)	0.27 MPa
14	Coupling	Flange shear stress	$T_{max} = \frac{\pi D^2 \tau_c t_f}{2}$	9	(Khurmi & Gupta, 2005)	0.12 MPa
15	Coupling	Bolts diameter	$T_{max} = \frac{\pi(di)^2}{4}\tau_b n Di$	10	(Khurmi &Gupta, 2005)	15 mm

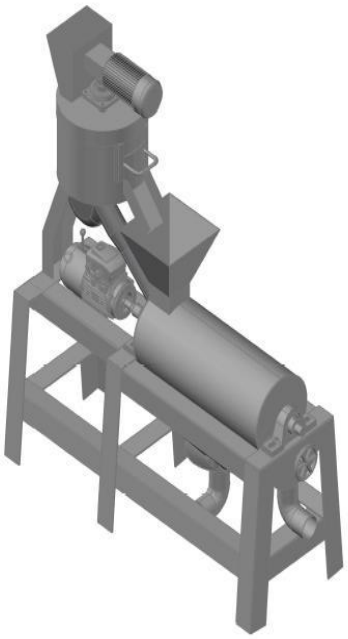

Figure 1: Isometric View of the Drying and Winnowing Machine

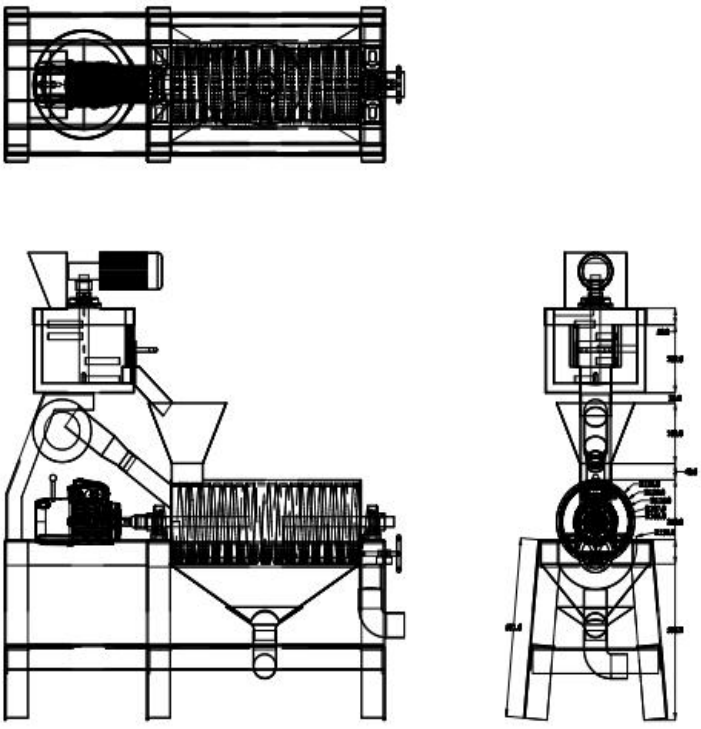

Figure 2: Orthographic View of the Drying and Winnowing Machine

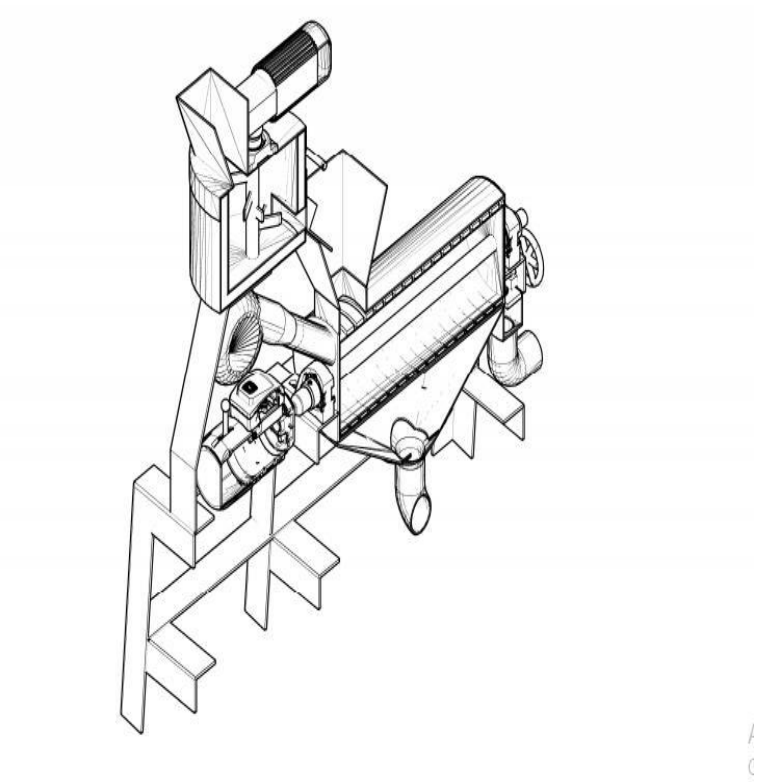

Figure 3: Cutaway View of the Drying and Winnowing Machine

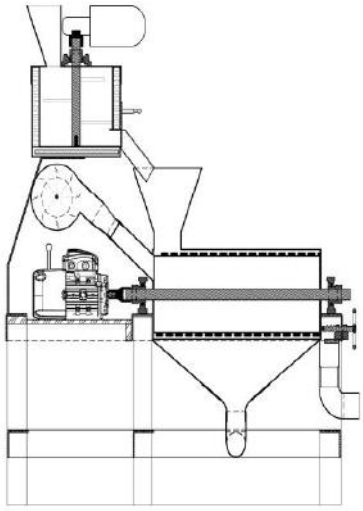

Figure 4: Side View of the Drying and Winnowing Machine

3.2 Discussion

The idea of developing a hybrid dual-purpose drying and winnowing machine for nibs production for small scale cocoa processing plant is to further encourage the local processing of cocoa beans into its different products through local technology. A review of the existing industrial cocoa processing (i.e drying and winnowing) machines was first carried out, the findings there was used to develop this machine that can be used for the processing of cocoa beans by small holders. The processing capacity of the machine is estimated at about 600 kg/h. The calculated average power consumption of this machine is about 2 hp (about 1.5 kW), this means that with a 5 kW petrol engine power generator, the small holder will be able to carry on with production compared with the heavy industrial machines that require much power to run. The production cost of this machine (₦450,000) is also within the reach of the average small holders.

4. CONCLUSION :

The following conclusions were drawn from this study;

- The components of the machine have been designed and appropriate materials have been identified.
- The cost of the machine will be affordable as all the materials for its production will be locally sourced.
- The machine will also easy to operate and
- It can be powered by a low horsepower prime mover.

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