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Design of a Palm Bunch Stripping Machine Suitable for use in Benin City, Edo State, Nigeria

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Abstract- Palm fruit is an edible oil crop which needs to be processed for oil extraction. However, the manual method of stripping and the existing palm stripper are found ineffective due to prolonged stripping time leading to low quality and quantity of oil produced. Modern methods of stripping have greatly improved production rates and reduced stripping time. The main objective of this Work was to come up with an improved design and fabricate a palm stripping machine with locally available material that is low-cost, higher through put, better efficient, easy to operate, easy to maintain and affordable to both small and medium scale palm oil processors. Work was also done to ascertain the physical characterization of the palm fruit bunch seed and the force required to detach them before sterilization and after using steam was obtained. From the design and experimentation carried out, we found out that the most efficient is the horizontal concept. Here, the beater strikes the palm bunch fruit, throwing it upward to drop on its weight on the beater severally. The dried strip or empty bunches were discovered to be useful fuels for boilers that generate the needed steam for sterilization. Proper bearing selection based on bearing calculation in Solid-Works was done and this in-turn was seen to have improved the installed pillow bearings along with cost savings in maintenance by following a simple lubrication and corrosion control procedures. The results indicated that stripping efficiency of the machine and the clean fruit recovery were 98.91 % and 96.03 %, respectively. The feed rate of the stripper ranges between 341.4 kg/h and 360.02 kg/h, the output capacity ranges between 227.47 kg/hand 275.78 kg/h while the operating capacity is 70.54 g/s. Therefore, the palm fruit stripper is recommended for the small and medium scale oil palm fruit processing industries.

Index Terms- Design and Fabrication, palm fruit stripper, performance evaluation, output capacity

I. Introduction

The oil palm (Elaeis guineensis) plays an important role in the agricultural and economic sectors of those countries where it is found. It originated in the tropical rain forest region of West Africa. The main belt runs through the southern latitude of Cameroon, Cote d'Ivoire, Ghana, Liberia, Nigeria, Sierra Leone and Togo into the equatorial regions of the Republic of Congo and Zaire (Hartley, 1988). However, because of its economic importance as a high yielding source of edible and technical oils, the oil palm is now grown as a plantation crop in most countries with high rainfall (minimum 1600mm/year) in tropical climates within 10^0 of the equator (FAO, 2004). Samuel and Alabi (2012) reported that productivity in Nigeria was poor and such important vegetable oils should be highly produced to meet demands. The total money of $186.65 million was spent by Nigeria to import vegetable oil from Malaysia in 2001, this showed sad state affair of the country (Samuel and Alabi, 2012).

The palm bears its fruits in bunches varying in weight from10 to 40kg. The individual fruit ranges from 6 to 20 grammes and are made up of an outer skin (exocarp), a pulp (mesocarp) that contains the palm oil in a shell (endocarp) and the kernel which itself contains palm kernel oil (Stork,1960). The palm oil and palm kernel oil have a wide range of applications; about 80 % of the palm oil produced finds its way into food products while the rest is feed stock for a number of non-food applications. The by-products of oil palm fruit processing such as empty bunches and fibres can further be processed as raw materials for potash fertilizer, pulp and paper manufacturing (Ologunagba *et al.*, 2009; Salamiah, 2000). The kernels contain 80 % oil and 9 % protein (FAO, 2009) and are processed for oil and cake. The oil is used for the producing edible oil, margarine, confectionary, soap, candle glycerin and ice cream. The cake is used for formulation of animal feeds. The shell fragments can be used as renewable energy (fuels) and for decoration of living apartments (FAO, 2009; Mahmud *et al*., 2009; Antia *et al.*, 2014).

The palm fruits are obvoid in shape and are of three varieties, the dura types have thick mesocarp with a thin mesocarp, the pisifera types are shell-less variety while the hybrid, tenera types have a much thicker mesocarp, and a thinner endocarp (The Tropical Agriculturist, 1998).

As fruits ripen, they change from black (or green) to orange, but have varying degrees of black cheek colour depending on light exposure and cultivar. The fruit bunches are harvested using chisels or hooked knives attached to long poles. Processing of oil palm fruits bunches into palm oil is practiced using various methods which may be grouped into four categories according to their throughput and degree of complexity of the unit operational machinery.

Stripping or threshing of palm fruit involves separating the sterilized fruits from the bunch stalks. Sterilized fresh fruit bunches are fed into a drum stripper and the drum is rotated, causing the fruits to be detached from the bunch; the bunch stalks are removed as they do not contain any oil (FAO, 2004).

In Nigeria today, a lot of work has been done on palm fruit stripping and most of the mechanized systems of stripping oil from palm fruit bunches consist of a rotating drum or fixed drum equipped with rotary beater bars detach the fruit from the bunch, leaving the spikelet on the stem. These strippers are available in NIFOR, Benin and Nigeria (FAO, 2004). Ologunagba *et al.* (2009) reported that when manually operated a dual powered

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palm fruit stripper, the machine had a through put capacity of 0.612 tons/h, stripping efficiency of 68.9% and quality performance efficiency of 47.4% at a sterilization time of 90 minutes. When tested with 2.25KW electric motor at three beater speeds (250, 350 and 450 rpm) and at sterilization time of 30, 60 and 90 minutes, the machine gave best performance at 450 rpm and sterilization 90 minutes.

Traditionally, the harvested palm fruit bunches is heaped and allowed to ferment to facilitate easy stripping of the fruits. The picked fruits are then collected and digested into a mash, after which it is mixed with water and agitated in a pit to separate the crude oil from the mixture. After adequate mixing, the oil that floats at the tip is scooped off for clarification. Apart from the drudgery, time wasting and high labour requirement in this method, it gives poor quality oil as the period of fermentation increases the free fatty acid (FFA) content of the oil. According to Badmus (1991), processing the fruit without delay or fermentation yielded the highest oil extraction of 87 percent and best quality oil with free fatty acid (FFA) of 2.31 percent. Hence, it is important that fresh fruit bunches be processed as soon as possible so as to prevent a rapid rise in free fatty acid which normally affect the quality of crude palm oil.

Though the technology of palm oil production has advanced in recent years with new technological innovation to produce palm oil and palm kernel oil of superior quality (Stock, 1961), survey results showed that 80 percent of Nigerians oil palm resource exist in small holder plantations and wild groove (Badmus, 2002), and thus the nation's oil palm industry is still subsistent with very few large estate plantations that make large mills and imported mills relatively expensive and unaffordable by most farmers, thereby making the traditional method to predominate.

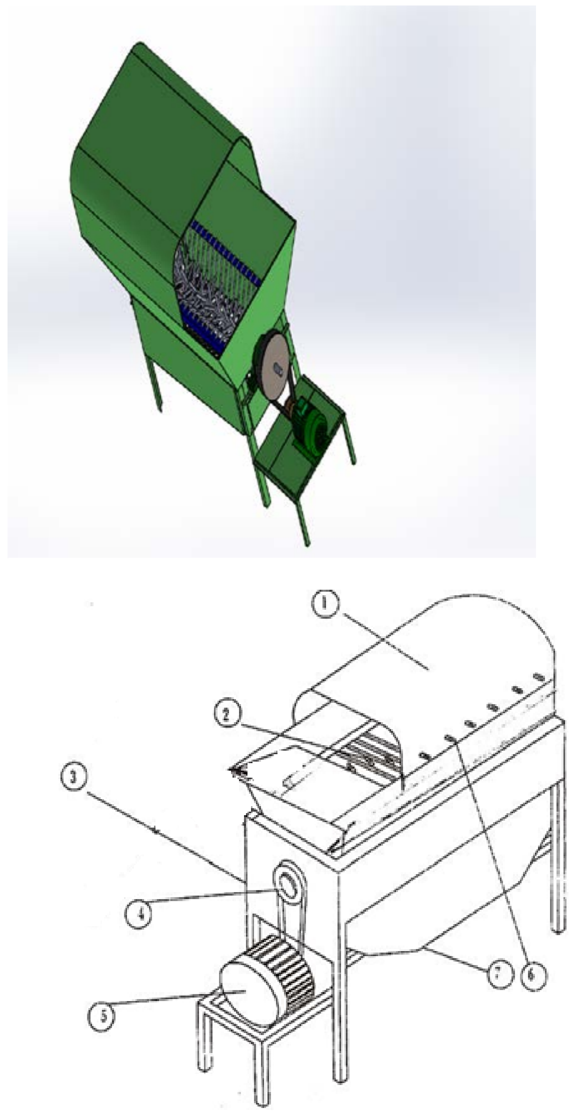
Therefore, this research work is aimed at solving the associated problems and difficulties facing the farmers in the business of palm oil processing in Nigeria by designing and fabricating a machine with locally available material that is low-cost, higher through put, better efficient, easy to operate, easy to maintain and affordable to both small and medium scale palm oil processors.

II. MATERIALS AND METHOD

2.1 Machine Description and Operation

The palm fruit stripper consists of four basic units viz: The feeding unit, the stripping unit, the drive mechanism and the discharge outlets. The quartered palm fruit bunches is fed through the hopper into the stripping unit. The hopper is made from 16-gauge sheet metal formed into a trapezoidal shape designed to handle a targeted machine capacity of 2.0 tons fruit bunch per hour. It has a vertical height of 330mm with sides inclined at 50^0 to the frame work to help slide the quartered bunches into the stripping unit.

The stripping unit is where the fruits are being detached from the quartered bunches. The unit consists of a shaft made up of 25mm mild steel rod, a housing made from 16-gauge sheet metal rigidly mounted on the frame to withstand the load it has to bear, and mild steel rods of 10mm diameter laid horizontally and inclined at 60^0 in spacing of 50mm to the housing to ensure throwing up of the bunches without becoming jammed half-way. The shaft is 1200mm long and attached with beaters, each of 12mm diameter and 100mm long helically spaced at 50mm to produce the necessary impact that detach the fruits as well as convey the stripped bunches from the point of entry to the point of discharge. The machine is powered electrically with the aid of belt and pulley arrangement which has 230mm diameter driven pulley and 75mm diameter driver pulley connected to a single phase 2.25kw(3HP) electric motor. As the shaft rotates, the impact of the beaters on the bunches detach the fruits which are collected at the fruit discharge outlet located beneath the stripping unit while the stripped bunches are conveyed to be discharged at the stripped bunch discharge outlet. Figure1 shows the isometric view of the electrically powered palm fruit stripper.



#	Legend	#	Legend
1	Housing	5	Electric motor
2	Beater arm	6	Bolt and nut
3	Frame	7	Fruit outlet
4	Pulley		

Figure 1: isometric view of the Horizontal Stripping Machine

2.2 Design Considerations

Some of the factors which were taken into account while designing the palm fruit stripper are as described:

Reliability and performance of the various components

Factors such as rigidity, deflection, wear, corrosion, vibration and stability were considered in the selection of appropriate material, sizing and shaping of the various machine components. Also, in order to take into account a number of uncertainties such as variation in material properties, effect of environment in which the machine is expected to operate, and the overall concern for human safety, provisions were made through the use of factor of safety stipulated by standard and experience.

Availability of materials

The machine was constructed of locally available materials so as to enhance the possibility of replacing damaged parts with less expensive but equivalently satisfactory parts that are locally available.

Simplicity

The ease of design and fabrication of machine for productivity were considered, bearing in mind the need of dismantling to carry out routine cleaning and maintenance of the machine when necessary so as to maintain higher level of performance. And also for the possibility of conveying the machine from one point of use to the other whenever the need arises.

Effectiveness

Meeting the farmers general requirements with minimum loss of oil that may arise from oil being absorbed and carried off by the stalks of the stripped bunches or loss due to unstripped fruits still attached to the bunches. And also the need to have a fruit discharge outlet that is different from the stripped bunch discharge outlet for optimum separation.

Cost

The reduction of cost was taken into account through critical value analysis on the phases of design, material selection, production and maintenance of the machine which at the end make it affordable by farmers and other intending users.

2.3 Design Analysis

In the design of this machine, relevant physical and mechanical properties of oil palm fruits were considered as a basic design input for the determination of the mesh size for the drum sieves and power requirement. Other factors considered include availability of materials, cost of materials, durability, and the ease of feeding and discharging of palm fruit bunches, and the condition of palm fruit bunches before stripping.

- **Stripping Chamber:**

The stripping chamber is cylindrical in shape with diameter of 0.580m, the circumference of the circular section of the cylinder is given in equation as suggested Balogun et al (2009).

C_{sc} = Circumference of the circular section of the cylinder (m)

D = diameter of the cylinder = 0.58m

- **Volume of the stripping unit (cv):**

The mathematical expression given by Bologun et al (2009) was adopted to determine the volume of the stripping unit.

$$Cv = \pi r^2 h$$

Where h = height of the stripping unit (m)

r = radius of the stripping unit (m)

- **Gear Speed of the Stripper** Gear speed of the stripper was determined by equation 3 as recommended by Khurmi and Gupta, (2005)

$$\frac{T_g}{T_P} = \frac{N_g}{N_p}$$

Where Tg = Number of teeth of the Gear

Tp = Number of teeth of the pinion

Ng = Speed of the Gear

Np = Speed of the pinion.

- **Shaft Diameter:**

Shaft diameter was obtained from the following expression given by Khurmi and Gupta (2005)

$$d^3 = \frac{16\sqrt{((K_b\ M_b\ )\text{^}2+)}\ \sqrt{((K_t M_t)\text{^}2\ )}}{SS}$$

Where d= $shaft\ diameter(mm)$

Kb=combined shock and fatique factor for the Bending moment =1.5

Mb=maximum bending moment (Nm)

Mt = Maximum Torsional Moment (Nm)

Ss = Allowable shear stress of mild steel = 450mm^2

K_t = Combined Shock and Fatique factor for torsion moment = 1.5

- **Selection of Pulley Speed**

The Type of pulley selected was determined using by equation as stated by Onifade (2016) Stephen and Emmanuel (2009).

$$N_1 D_1 = N_2 D_2$$

Where, N_1 =speed of the driving pulley (rpm)

D_1 = diameter of driving pulley (mm)

N_2 speed of the driven pulley (rpm)

$D_{2\,=}$ diameter of the driven pulley (mm)

- **Belt length and Centre Distance**

The center distance between the two adjacent pulleys and belt length were calculated using equation as determined by Khurmi and Gupta (2005), Akande and Onifade (2015)

$C = \frac{D_2+D_1}{2} + D_1$

For belt length

L = $\frac{\pi}{2}$ (D_2 + D_2) + 2C + (D_2-D_2)^2/ 4C

Where:

C = center distance

Tension in belt was obtained using the expression below as given by Khurmi and Gupta (2005); Akande and Onifade (2015).

T1/T2 = e uØ

Where Ta = Tension in the tight side of the belt, N

T2 = Tension in the slack side of the belt N

$\emptyset$ = angle of warp in red

μ = co-efficient of friction between belt and pulley

- **Power Requirement**

A change in speed of any fan in operation will predictably change the pressure rise and power necessary to operate under a predictable sets of laws concerning its speed, power and pressure (Ojomp, et al, 2010), The law can be applied to Agricultural equipment that uses shaft as a power take off, one of the equations from these laws is given as

$$\frac{Kw1}{kw2} = \left(\frac{N1}{N2}\right)^2$$

Where
Kw1 = power from the motor kw
Kw2 = power required by the Gear shaft, kw
N1 = speed of the gear shaft rpm
N2 = speed of the motor rpm

2.4 Performance Evaluation

The machine was installed on a level and hard surface. Sixty kilogram freshly harvested palm fruit was purchase from a nearby farm and 5kg of oil palm fruit bunch was prepared for the machine test. Each experiment was carried out in four replicates. The stripper was evaluated using the various formular

- **Determination of feed rate**

$$feed\ rate = \frac{QUANTITY\ OF\ BUNCH\ FEED\ IN}{TIME\ TAKEN\ TO\ FEED}$$

$$Fr = \frac{QbF}{TF}$$

- **Determination of the output capacity**

output capacity=

$$\frac{Weight\ of\ palm\ fruit\ Stripped + Weight\ of\ empty\ bunch}{Time\ of\ stripping}$$

$$Q_c = \frac{WFs + We}{Ts}$$

- **Determination of machine efficiency**

Machine efficiency

$$= \frac{Weight\ of\ Stripped\ fruits}{Total\ Weight\ of\ Fruit\ in\ the\ bunch\ prepared\ for\ Stripping} \times 100$$

$$M_E = \frac{WFs}{WFT} \times 100\%$$

- **Determination of quality performance efficiency**

Quality Performance efficiency

$$= \frac{Weight\ of\ Stripped\ fruit}{Weight\ of\ empty\ bunch + Weight\ of\ fruit\ unstripped}$$

$$Q_{PE} = \frac{WFs}{WEb + WFu} \times 100\%$$

III. RESULT AND DISCUSSION

The benefits of the improved stripper are based on the result of the test obtained

Table1: Performance Test Conducted on the Bunch Stripping Machine

S/N	W_{AB} (kg)	N_{SF}	N_{UF}	N_{TF}	W_{FB} (kg)	W_{EB} (kg)	W_{WFB} (kg)	T (Sec)
A	8.8	956	6	962	6.5	2.80	6.55	90
B	8.4	918	4	922	5.7	2.50	584	85
C	15.4	1150	15	1165	10.1	5.10	10.25	160
D	45	345	5	350	3.6	0.98	3.96	47
E	55	355	5	360	446	0.99	4.86	58
F	9.8	980	15	993	6.99	3.2	6.49	98
AV	8.7	784	8.3	793	6.99	2.595	6.325	89.67

AV = Average values
WAB = Total weight of bunch, kg
Nsf = number of fruitlets stripped
Nuf= number of fruitlets unstripped
Ntf = total number of fruitlets
Wfb = weight of fruitlets removed from each bunch kg
Web = weight of empty bunch kg
Wwfb = weight of the whole fruit in each bunch, kg
T = stripping line, sec

Table:2 Result obtained on the output parameters

S/N	Total of Weight of Bunches kg	Time taken sec	strip ability	Input capacity kg/h	Output capacity kg/h	Clean fruit recovery %
A	8.8	90	99.30	352.00	265.00	99.23
B	8.4	85	99.56	355.98	241.52	97.60
C	15.4	160	98.71	346.84	227.47	98.52
D	4.5	47	98.60	344.82	275.78	91.13
E	5.5	58	98.61	341.40	273.74	91.76
F	9.8	98	98.69	360.02	256.79	97.99

IV. CONCLUSION

A palm fruit stripper that can be electric -motor operated was designed and constructed with locally available materials. Based on the performance test results, the throughput capacity, stripping and quality performance efficiencies increase with sterilization time and beater shaft speed. Using the electric motor for operating the palm fruit stripper, it gave the best work performance at 450rpm with throughput capacity of 2.14 tons/hr, stripping efficiency of 96.1% and quality performance efficiency of 81.9%. Therefore, this simple machine can help solve the associated problems and difficulties of palm fruit bunch stripping, especially for small and medium-scale farmers

V. RECOMMENDATION

In large industries processing palm fruit into edible oil, the mechanized stripping machine is recommended for production of palm oil to meet up the growing demand of palm oil in the world market because of its relevance in production of other useful products. More so, the subject of design and manufacturing technology in the tertiary institutions should be greatly encourage and should be well taught so that competent and innovative graduate are produced into the dynamics world of technology.

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