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Design And Construction Of Machine For Processing Palm Fruits

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Abstract: Sorting of palm nuts for fruit cake, a by-product obtained after palm oil has been extracted from the batch of digested palm fruit, is burdensome especially to small-scale entrepreneurs involved in palm oil processing business in Africa. This research work has triumphed over the perceived difficulties by using the knowledge of Process engineering to design a digester, nut/fiber separator and a nutcracker. Each component was designed and manufactured before overall assembly to produce the entire machine. All the materials used for fabrication were locally sourced, the nut/fiber separating machine comprises the following components: hopper, separating filter, shaft, beaters, turning handle, discharge chute. Upon testing of this equipment, it was observed that the machine brought about improvement in all its functions compared to the traditional methods as the efficiency was 98% with an average processing rate of 95 nuts per seconds and it also greatly reduced the drudgery, tedious, and laborious nature of the traditional ones.

Keywords: Nut cracker, kernel, hammer, Dura, nut, Tenera

I. INTRODUCTION

At the beginning of the twentieth century, Nigeria was the world's largest exporter of palm produce. At that period, oil palm accounted for 90% of the national total export. In fact, up till 1956, according to [1], Nigeria was one of the foremost world's producers and exporter of palm produce which accounted for over 40% of the total kernel exported and about 20% of palm oil in the world market. But between 1929 and 1974, there was a decline in the proportion of Nigeria's total exports from 47 - 13.2%. Oil palm is one of the important economic crops in the tropics. It is the most important source of cooking oil and produces more oil per hectare than any of the oil producing crops. It originated from Africa mostly in the southern parts of Ghana and Nigeria, but is grown in plantations in equatorial tropics in Southeast Asia and South America in different varieties [2]. As observed by [3], [4] and [6], a steady evolutionary development had taken place in machinery and equipment required to process palm fruit bunches to meet changing circumstances of the small-scale palm oil processing industry [7],[8], [9], and [10]. These innovations have progressed from the development of individual machines to carrying out particular operations to machines that combine several operations in the process [11]. The challenge of designing and actualizing the successful fabrication of machines for palm produce processing with lesser production time and cost, and also achieving an equivalent purpose cannot be over emphasized. This development is worthy of acceptance by engineers and investors as a result of the benefits derivable from the successful operations of the machine. Fresh fruit from plantation need to be sent quickly to the mill for processing to obtain crude palm oil. There are several stages of processing the extraction of palm oil from fresh fruit bunches. These include reception, sterilization, bunch stripping, digestion, clarification, purifications and finally oil extraction.

However, the existing process is laborious and time consuming. This led to the design of a simple and robust one which will be able to overcome these existing challenges.

II. DESIGN ANALYSES AND CALCULATIONS

For the purpose of this research paper, only the design analyses of the nut cracker were included. The designs were on the energy of deformation of cracking chamber, rotational speed of the hammer, shaft strength; and mechanical power requirement The driver unit of the nutcracker consists of the prime mover, the electric motor, the two-way pulleys and the belt drive. The electric motor is rated 3hp, with the pulleys ranging in diameter sizes of 120mm to 80mm. The belt drive is a V-belt (A60) spanning through a length of 630mm.

A. THE ENERGY OF DEFORMATION

According to [12], the impact energy of nuts on the cracking wall which is as a result of the kinetic energy of the nuts is equivalent to the energy of deformation of the nuts. This is expressed as

$\frac{1}{2} mv^2 = Pe$ (1)

Where: m is the mass of nut; v is the velocity required for cracking the nut and Pe is the energy of deformation of the palm nut.

a. *ROTATIONAL SPEED OF THE HAMMER*

According to [15], the physical property of Dura and Tenera variety of nuts in terms of their masses are $0.00766kg$ and $0.0085kg$ respectively. The product(Pe), defined as the energy of deformation of the nut is given from the experimental result of [13] as 0.9012 and $2.00015Nm$ for Dura and Tenera nuts respectively.

DURA VARIETY:

By substituting the value of mass and energy of deformation of Dura nut into (1), the velocity of cracking is obtained as $v = 15m/s$.

According to [14], $\omega = \frac{v}{r}$ (2)

Where: ω and r are the angular velocity and the radius of the cracking impeller blade respectively. For a cracking impeller blade radius of $r = 100mm$, $\omega = 153.13rad/sec$

Also, $\omega = \frac{2\pi N}{60}$ [14] (3)

Thus, $N = \frac{60\omega}{2\pi}$ (4)

Where: N is the rotational speed of the impeller blade

By substituting the value of ω into (4), we have that $N = 1464rpm$

TENERA VARIETY:

By substituting the value of mass and energy of deformation of Tenera nut into (1), the velocity of cracking is obtained as $v = 21.70m/s$.

According to [14], $\omega = \frac{v}{r}$

Where: ω and r are the angular velocity and the radius of the cracking impeller blade respectively. For a cracking impeller blade radius of $r = 100mm$, $\omega = 217rad/sec$

Also, $\omega = \frac{2\pi N}{60}$ [14]

Thus, $N = \frac{60\omega}{2\pi}$

Where: N is the rotational speed of the impeller blade

By substituting the value of ω into (4), we have that $N = 2072rpm$

It can therefore be deduced from the above results that:

The average linear speed (v) required for the machine is $18.52m/s$

The average angular speed (ω) required for the machine is $185.15rad/s$

The average rotational speed (N) required for the machine is $1768m/s$

b. *THE SHAFT DESIGN*

The shaft is designed on the basis of satisfying the strength, rigidity and stiffness requirements for the machine. When shaft is transmitting power under various operating and loading conditions, shafts are usually subjected to torsion, bending and axial loads [14], [15].

Taking the cracking impeller and tube as a rectangular cross-section, just as shown in figure 1, the radius of gyration (k) according to [14] is expressed as:

$k = 0.289h$ (5)

Where h is the height of the cracking impeller given as 350mm

By substituting the value of h into (5), we have that $k = 0.1012m$

The moment of inertia about the x- axis (I_{xx}):

$I_{xx} = mk^2$ [14] (6)

Also $I_{xx} = \frac{bh^2}{12}$ [14] (7)

Where b is the breadth of the cracking impeller given as 70mm

By substituting the value of b into (7), we have that $b = 2.5 \times 10^{-4}m^4$

The mass of the cracking channel and tube referred to the axis of rotation from equation (6) becomes:

$m = \frac{I_{xx}}{k^2}$

Thus by substituting the values of I_{xx} and k we have that:

$m = 0.024kg$

According to [14], the tangential force (F) to the axis of rotation is expressed as:

$F = m\omega^2 r$ (8)

By substituting the values of I_{xx} and m into (8), the tangential force becomes:

$F = 83.76N$

The torque (T) of the cracking impeller according to [16] is expressed as:

$T = Fr$ (9)

By substituting values of F and r we have that:

$T = 8.376Nm$

c. *MECHANICAL POWER REQUIREMENTS*

The minimum power requirement (P) is expressed as $P = T\omega$ [14] (10)

Therefore, substituting the values of the torque (T) and angular speed (ω) into (10) we have that:

$P = 1.55KW$

d. SHAFT SELECTION

The shaft strength for this machine is designed to handle both bending and torsion stresses. The cracker and the separator shafts were selected in accordance with the ASME code equation for solid shaft having little or no axial loading [14].

$$d^3 = \frac{16}{\pi S_s}\sqrt{(K_b M_b)^2 + (K_t M_t)^2} \qquad (11)$$

Where: d= shaft diameter (m); M_b= maximum bending moment (Nm); M_t= maximum torsional moment (Nm), K_b=combined shock and fatigue factor applied to bending moment = 1.5; K_t= combine shock and fatigue factor applied to torsional moment = 1.0; and S_s = maximum allowable stress of mild steel without keyway = 55MN/m^2.

An estimated shaft length of 450mm was chosen to correspond with the width of the machine and the calculated shaft diameter is 26.24mm

III. MATERIALS AND METHOD

In this work, mild steel plate ranging from 1mm to 5mm coated with red oxide were used. Assembling drawings, production drawings, tolerances and fits were also produced. The basic manufacturing processes involved in the machine fabrication after design are as follows: Bending of each of the components into required shape; cutting of all the parts; welding of the necessary joints together to form the entire unit; machining Operations; use of bolts and nuts, screws etc., drilling of needed holes in the internal cylinder.

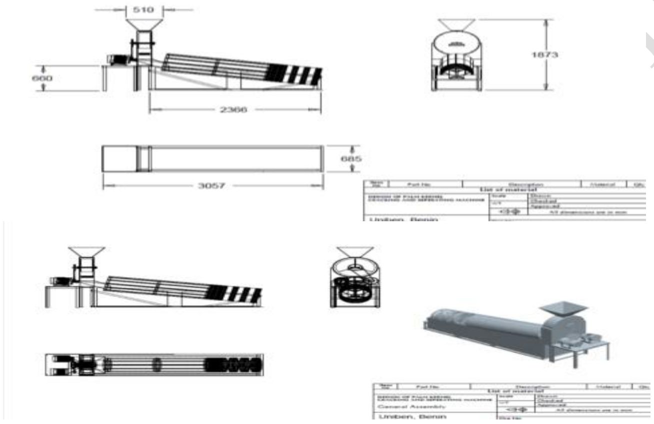

Figure 1: Orthographic and isometric Projection of the machine

IV. DETERMINATION OF THE CRACKING EFFICIENCY

We applied statistical analysis in the determination of the efficiency of the machine. The result of the statistical test analysis using Van der Waerden (normal score) test is shown on table 1.

Set	Operation Time (Pilot)	Operations Time (Industrial)	Difference Di	Rank Di	Signed Rank Ri	Signed Normal Score Ai
1	6.88	7.09	-0.21	1	-1	0.4444
2	6.44	7.09	-0.65	4	-4	0.2778
3	8.188	7.50	+0.69	5	5	0.7778
4	7.766	6.46	+1.31	8	8	0.9444
5	4.834	5.79	-0.96	6	-6	0.1667
6	8.034	7.58	+0.45	3	3	0.6667
7	6.70	8.33	+0.37	2	2	0.6111
8	5.55	6.52	-0.97	7	-7	0.1111
						2.4540

Table 1: Application of Van der Waerden (Normal Scores) Test

To obtain signed normal score, use the relation:

$$A_t = \frac{1}{2}\left[1 + \frac{R_i}{n+1}\right], n = 8$$

$$T_1 = \frac{\sum_{i=1}^{n} A_i}{\sum_{i=1}^{n} A_i^2} = \frac{2.4540}{\sqrt{2.4540}} = \frac{2.4540}{1.5665} = 1.5665$$

And the corresponding p-value from standard table, Conover [(8)] is 0.9414. And p-value is the minimum significance level at which the null hypothesis would be rejected for the given data. Since $\alpha = 0.05 < \alpha_{T_2} = 0.9414$, there is no reason to suspect the null hypothesis, which claims that the two machines have similar processing time, is not true, based on the data of Table 1.

Van der Waerden's location shift model was used to analyze our data. Let f be the distribution function corresponding to our experimental data (X) and G be the distribution function corresponding to data (Y) from industrial machine. Then

$G(t) = F(t - \Delta), \forall t$

Δ is the amount of location shift between the two populations (data)

Also Y d X + Δ

d "Mean has the same distribution as", The test reduces the matched pair $(X_{ij} J_j)$ to a single observation by considering the difference, D_i.

$D_i = Y_i - X_i, \forall i = 1, 2, \ldots, n$

Only non-zero values of D_i are valid.

Let R_j represent signed rank for $|D_i|$ column vector.

Signed normal score A_i, obtained from Standard Normal Distribution Table, is given by:

$A_i = {}^1/_2\,[1 + Ri/(n+1)]^{th}$ quartile.

$$T_2 = \frac{\sum_{i=1}^{n} A_t}{\sqrt{\sum_{i=1}^{n} A_t^2}}$$

T_2 = test statistic

V. PERFORMANCE EVALUATION

The traditional method of separating units from nut/fiber cake is by hand picking most often by women. However, effort has been made by indigenous manufacturers to produce nut/fiber separator. But the efficiency has been quite inadequate. At large scale level, the use of cyclone machine has provided efficient method but the equipment is quite unaffordable in cost terms and so only rarefied firms can afford this. In consideration of this technical problem, this study designed out some features in the existing small-scale nut/fiber separator and designed in some desirable features that have made the present pilot scheme meet design expectation. Our pilot nut/fiber separator can process away several metric tons of polished nuts per day. The nut/fiber separator performed efficiently when it was subjected to performance evaluation test. The hallmark of this efficiency is the highly polished nature of the nuts suggesting that the machine was well designed and developed. Another fascinating thing about this machine is that the arrangement between the stator blade and rotor blade enhances the separation of fiber from nuts and assures that the processed nuts take up well polished texture.

VI. RESULTS AND DISCUSSION

A. RESULTS

Key results obtained in the design considerations for nut/fiber separator design have been collated and depicted in table 1. The performance attributes were compared with a typical industrial model and they are shown in table - 1. Furthermore, table -2 shows the comparative performance data for pilot and industrial nut/fiber separators.

Criteria	Comparative Results	
	Pilot Nut/fiber Separator	Industrial Nut/fiber Separator
Efficiency (%)	90.6	90.2
Rate of separation (Kg/hr.)	91.96	90.69
Capacity (Kg/hr.)	90	100

Table 2: Depicts the comparative performance result for Nut/fiber separator

This incontrovertibly demonstrates that the pilot Nut/fiber separator is suitable for separation process.

The machine evaluation results from Table - 1. Using Van der Waerden (Normal Scores) Test shows that this machine is faster with average process rate (cracking and separating) of 95 nuts per second with higher efficiency of 98% than existing cracking machine with average process rate (cracking) of 89nuts per second with 90% efficiency.

B. DISCUSSION

In the course of this research work, we made use of the library and the internet concerning different types of palm kernel shell cracking machines in some countries. Also, some small-scale industries in our locality were visited.

Based on the findings, the design concept for this project was modified to bring to the fore advantages of an effective palm kernel shell shaft which carries the beaters (hammers) that does the actual cracking. In addition, the advantages of this machine include cost reduction relative to other methods of cracking; fast turn-out/put rate; easy and simple manufacture of machine, easy accessibility to parts with regards maintenance and repair works, detachable features, regulation/control unit, low capital involvement which makes it quite affordable to small scale establishments.

The size of the machine was also put into consideration and can be observed that it required little space for installation.

In addition to all the above, the machine can produce an output of 850kg/m of cracked palm kernel nuts.

VII. RECOMMENDATION AND CONCLUSION

A. RECOMMENDATION

In other to improve upon this model of palm-kernel cracker, we recommend that:

- ✓ The machine should be designed to incorporate in it a separator, which would separate the shells from the palm kernel nuts.
- ✓ The nut/fiber separator and digester should be automated.

B. CONCLUSION

In addition, the incorporation of added features which made it unique in its sense provides control/regulation of amount of palm kernel that enters the cracking drum vis-à-vis the turn out rate, and also the prevention of fly-off of palm kernel during cracking process. Also the machines are simple to use, designed for safety and in fact user-friendly.

This model as presented when patronized by investors would be a boost to the Nigerian palm kernel industry as well as the Agricultural sector. All these would improve the nation's economy as small scale enterprises would be encouraged to participate in the export of palm kernel which is widely used in the soap industries and some pharmaceutical companies. Furthermore, this would create job opportunities in rural and urban communities.

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