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Design Enhancement Evaluation of a Castor Seed Shelling Machine

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

A milling roller type Castor Seed Shelling Machine (CSSM-1) was designed and produced, considering all active parts on the basis of strength and rigidity. In this current work, the machine was modified to CSSM-2 to correct all the short comings of CSSM-1. The design and characteristics was based on the use of Nigeria-Small Castor Seed size to obtain the performance characteristics by grouping the seeds into six batches. By the reduction in size of CSSM-2, the machine was made portable and lighter by the design improvement on the roller shaft and other component parts. At the optimum milling shaft speed of 276.92 rpm, the shelling, cleaning (separation), and breakage efficiencies of the new machine were recorded as 96.34%, 96.24% and 11.05% respectively; hence CSSM-2 was effectively enhanced up to 96%.

Keywords: Milling roller shaft; castor seed; Nigeria-small; shelling machine; shelling efficiency.

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1. INTRODUCTION

A rolling shaft type castor seed shelling machine (CSSM-1) incorporating a cleaning unit (CU) was designed and constructed as a PGD project [1] The machine (CSSM 1) had a solid milling shaft 750mm long and 130mm in diameter in the shelling chamber (SC) with a step down of 650mm diameter on both sides and a total weight of 62kg, mounted on a frame of 700X500X814mm (LxWxH). The machine (CSSM-1) was tested and it achieved 60% shelling efficiency and 40-50% separation efficiency. The breakages of the seeds were not quantified and it was realized to be due to the low separation efficiency, these low performance indices made it necessary for improvement.

A second proto-type named CSSM-2 Fig. 1 is now designed in this work putting into consideration all observable parameters which contributed to the low performance of the machine CSSM-1. These parameters include; (i) speed of the shaft (ii) distance between the shaft and the blower (iii) weight of the shaft (iv) speed of the blower (v) size and shape of the blower blades and (vi) moisture content of the seeds. Based on these observable parameters the design of the machine was modified by increasing the dimensions of the frame to 700X750X1017mm (LxWxH). With this adjustment, the space inside the machine was increased by almost 100%, giving enough falling gap from the shelling chamber for the chaff/seed mixture to travel. Also the weight of the milling shaft was reduced by replacing the solid shaft with a hollow steel pipe of 15mm thickness but of the same outside dimensions as the solid shaft, hence reduced weight by 47%. The optimum speed required for maximum efficiency was determined by trial and error method using different sizes of pulleys. This improved the efficiency of the machine to 96%, when tested by carrying out shelling processes and measuring various outputs.

Fig. 1. CSSM-2

2. REVIEW OF LITERATURES

The castor seed (*Ricinus communis*) is a seed of large plant, castor oil plant, grown throughout the tropics. This plant is believed to be a native of Africa new Encyclopedia [2] particularly in Nigeria where all the species are found [3]. Today India and Brazil are the largest producers of castor seeds and castor oil, while USA and UK are major buyers. The castor oil plant is grown commercially for pharmaceutical and industrial uses of its oil. It is used in the production of synthetic resins, plastics, fibres, paints, vanishes and various chemicals including drying oils and plasticizers. In addition to these, castor oil and its derivatives are used in cosmetics, hair oil, fungistatic (fungus-growth inhibiting) compounds, embalming fluid, printing inks, soap, fat liquor, grease and hydraulic fluids, dying and textile finishing materials [1]. Outlined the economic values of castor seed and its derivatives and the urgent need for design efforts to be made to harness the commercial potentials in castor seed.

2.1 Grain Husking/Hulling Process

The husking of grain has been described as the primary refining process by which the texture and culinary properties of such grains are improved by the removal of fibrous seed coats [4-6,5] defined husking or shelling as the process of removing the fibrous coloured hulls of legumes seeds as traditionally practiced as primary process in Asia and African countries where such legumes are grown in large quantities and consumed in a variety of food preparations. It also helps in promoting ease of digestion and effective utilization of nutrient by the body tissue [7]. It has been reported that hulling may efficiently shorten the cooking period of grains. The hull contributes very little to the food value hence they can be disposed of [4].

[8] reported that commercial processing of legumes is mostly based on the dry process techniques and many of the operations particularly hulling/husking have been mechanized. Three types of machines; (a) the shearing type disc shellers (b) types working by attrition mechanism and (c) the abrasive huller employing carborandum stones or other abrasive devices, are being used in hulling and splitting of legumes [5]. Reported the use of types (a) and (b), while [9] gave similar report and suggested a third type which makes use of the roller-milling principles. All three types require pre treatment of the grains. The disc sheller is successfully used for soaked and dried legumes where the husk is fairly loose, while the roller machine is suitable for hulling legumes moistened with water. The abrasive huller has been tested for dry seeds such as cowpea and found effective. The problem with the disc-sheller is that it results in excessive breakages of grains not graded into uniform sizes. It is for this reason that [4] concluded that the machine is more suitable for the production of hulled splits. However, good design and operation will yield highly split grains. It has been also reported that grains with thick and rough seed coats require a greater force than those with thin ones. The roller machine is therefore generally more suitable for splitting than hulling.

Inadequacy of pre-milling treatment is often made-up by the use of greater abrasive force, and hulling is usually achieved after several passes. Moisture on its part has a contrasting effect on hulling and splitting. A reduction in moisture level helps in achieving hulled whole grains while excessive moisture results in splitting of the grains [7]. Some other methods have been applied in West African countries for products such as cowpeas in which the seeds are sorted and agitated until husks are separated out. While some of these methods are applicable to the shelling of castor seeds, majority are not. The husks are thick and ductile and shelling can only be achieved by impact and tearing using roller-milling mechanism.

3. MATERIALS, METHODS AND DESIGN ANALYSIS

The principle element in the design of the castor seed shelling machine is the milling shaft Fig. 2. This should be made of material that is suitable for conditions of service as well as the loads and stresses that are accurately calculated. The shafting material chosen for this project was the plain (medium) carbon steel (080M40), which contains between 0.4 to 0.46% carbon. This was because of its enhanced strength, hardness, and good ductility through heat treatment and moreover, its low cost and availability.

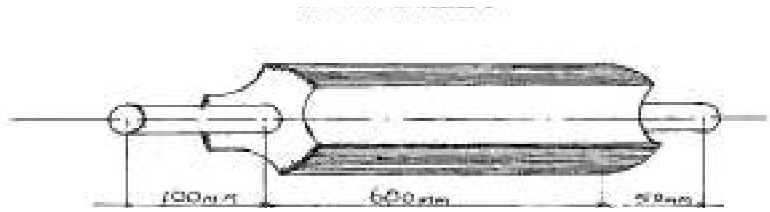

Fig. 2. The Milling Shaft Roller

3.1 Machine Components' Design

3.1.1 The milling shaft

This is a case of a shaft subjected to twisting moment or torque only, we have the torsion equation given as;

$$\frac{T}{I} = \frac{\tau}{r} \tag{1}$$

Where T is twisting moment, I is polar moment of inertia of the shaft about the axis of rotation, τ is torsional shear stress, and r is the distance from the neutral axis to the outermost fibre.

For CSSM-1 the polar moment of inertia, I, was as follows;

$$I = \left(\frac{\pi}{32}\right) \times d^4 \tag{2}$$

By ASME code equation;

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

But $M_b = 0$, then equation (3) reduces to

$$d^3 = \frac{16}{\pi\tau_a}\sqrt{(K_t M_t)^2} \tag{4}$$

For a hollow shaft as modified in CSSM-2 in order to reduce weight, the polar moment of inertia, I, is;

$$I = \frac{\pi}{32}\left({d_o}^4 - {d_i}^4\right) \tag{5}$$

Where d_0,is the outside diameter of the shaft, and $d_{i,}$ is the inside diameter of the shaft. By substituting equation (5) into equation (1), we have;

$$T = \frac{\pi\tau\left({d_0}^4 - {d_i}^4\right)}{16d_0} \tag{6}$$

Equation (6) can be re-written as follows;

$$T = \frac{\pi\tau {d_0}^3[1 - (d_i/d_0)^4]}{16} \tag{7}$$

Where $d_i/d_0 = k$, therefore equation (7) becomes;

$$T = \frac{\pi\tau {d_0}^3(1 - k^4)}{16} \tag{8}$$

When the hollow shaft is desired to be of the same material as the solid shaft and have the same outer diameter, then the twisting moment of the hollow shaft must be less than that of the solid shaft, this expressed as;

$$T_h = \frac{\pi\tau\left({d_0}^4 - {d_i}^4\right)}{16d_0} < T_s = \frac{\pi\tau d^3}{16} \tag{9}$$

And the body weight calculated with the expression;

$$\rho V_h < \rho V_s \tag{10}$$

Where T_h, is torque of the hollow shaft and T_s, is torque of the solid shaft, V_h, volume of the hollow shaft and V_s, volume of the solid shaft, and also d, is the diameter of the solid shaft. Equation (10) is used in calculating the mechanical energy impacted by the system onto the castor seed. Finally, the milling shaft was designed such that it prevents pumping or jumping of the three lobed seeds when being fed into the milling chamber by means of feed grooves. These feed grooves are staggered at 120° to each ot her on the milling roller to enable self feeding of the machine. The body of the shaft is serrated to increase the biting and tearing of the thick shells.

3.1.2 The belts and pulleys

The belts and pulleys were designed based on the standard formulae such as [10];

$$Power = (T_1 - T_2)V \tag{11}$$

Where T_1 is the tension on the tight side and T_2, is the tension on the slack side. And linear velocity V, is given by the expression;

$$\frac{2\pi rN}{60} ms^{-1}\ (without\ slip) \quad (12)$$

The diameters of the pulleys were determined thus;

$$\frac{N_a}{r_b} = \frac{N_b}{r_a} \quad (13)$$

Where N_a, is rpm of pulley A, N_b, is the rpm of pulley B, r_a, is radius of pulley A and r_b, is radius of pulley B. These were then used to determine the center distance C, of the two pulleys, leading to the calculation of the angle of wrap, ψ see Fig. 3. This consequently is used to determine the load carrying capacity of the belt. A minimum ratio of the diameter of pulley to the thickness of the belt is about 30 for reasonable life. Although center distance can be calculated from equation (20), this equation can be difficult to handle since there are two unknowns, C and L. To an excellent degree of approximation, length ABOD, in Fig. 3 will be equal to half of the belt. From geometry of Fig. 3, angle α, is calculated as follows;

$$Sin\alpha = \frac{ON}{BN} = \frac{r_b - r_a}{C} \quad (14)$$

Where BN is the center distance expressed as;

$$C = \frac{r_b - r_a}{Sin\alpha} \quad (15)$$

From Pythagoras theorem and considering triangle BON, we have that,

$$BO = \sqrt{C^2 + (r_b - r_a)^2} \quad (16)$$

Half the circumference of each of the pulleys is given thus;

$$For\ pulley\ A = \frac{2\pi r_a}{2} \quad (17)$$

And

$$Pulley\ B = \frac{2\pi r_b}{2} \quad (18)$$

Total length of belt is L, such that;

$$\frac{L}{2} = \frac{\pi r_a}{2} + \sqrt{C^2 + (r_b - r_a)^2} + \frac{\pi r_b}{2} \quad (19)$$

Solving for C, from equation (19), we obtain;

$$C^2 = \frac{[L - \pi(r_a + r_b)]^2}{4} - (r_b - r_a)^2 \quad (20)$$

However, C was estimated from design configurations as = 354mm and applying equation (14), for CSSM-1 angle α was 5.35^0. While in CSSM-2, the milling shaft (driven) pulley diameter was increased to 370mm so as to reduce speed for maximum efficiency, hence angle α is obtained as 22.42^0. Then to determine the length of the belt, from equation (19) we can deduce that;

$$L^2 = 4\left\{\left[\frac{\pi}{2}(r_a + r_b)\right]^2 + C^2 + (r_b - r_a)^2\right\} \quad (21)$$

$$= 4\left\{\left[\frac{\pi}{2}(50 + 185)\right]^2 + 354^2 + (185 - 50)^2\right\}$$

Therefore, L was computed as 959.78mm, hence from the standard length of V-belt 950mm was selected for the design. The load carrying capacity of a pair of pulleys is determined by the one which has the smaller $e^{\mu\theta}$, and here θ, is equal to the angles of wrap for the pulleys which were obtained through the relation;

$$\psi_a = 180° - 2\alpha \; and \; \psi_b = 180° - 2\alpha \quad (22)$$

The coefficient of friction μ, is taken as 0.3 for rubber on cast iron or steel [11], hence by computation pulley A has the smaller $e^{\mu\theta}$ and has to be chosen in preference. Linear velocity of the belt of determined as;

$$V = \frac{\pi d N}{60} \quad (23)$$

Tensions T_1 and T_2 for the belts can be determined also from the expression;

$$\frac{T_1}{T_2} = e^{\mu\theta} \quad (24)$$

Power transmitted can now be determined by computing these values into equation (11).

3.1.3 The hopper

The design of the hopper involves the mapping and dimensioning of the hopper profile using steel metal sheet of G18 or 2mm thickness. This selected material was able to withstand the weight of the castor seed being shelled Fig. 4.

Approximate weight of CSSM-1 hopper was 2.12kg while the CSSM-2 hopper bed was modified with a sheet of magnetic material to enable the machine isolate the metallic materials such as nails, washers, pins, pieces of metals etc which come along with the castor seeds in bags. This magnetic lining increased the weight of the hopper to 2.62kg.

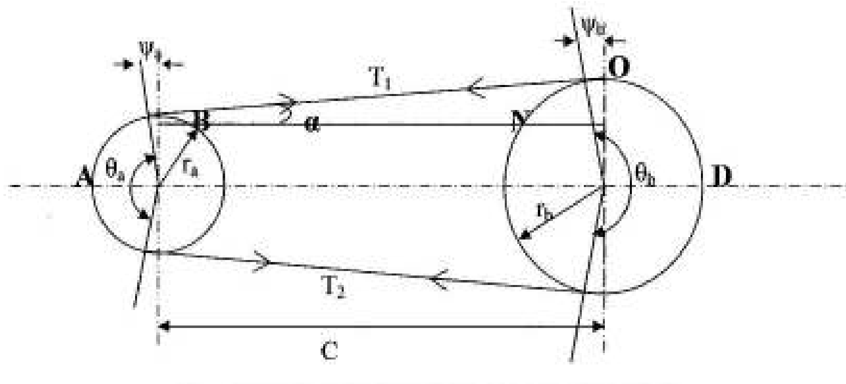

Fig. 3. Belt and Pulley arrangement

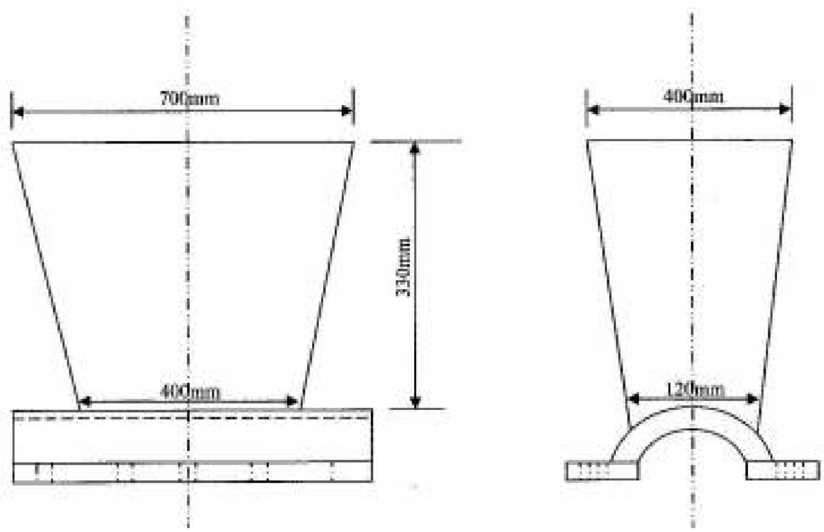

Fig. 4. Schematic Diagram of the Hopper

3.1.4 The blower

In CSSM-1 the fan was placed at 45º and 250mm away from the Milling shaft roller axis, while in CSSM-2 it Fig. 5. is placed at 45º and 500mm away from the axis of the Milling Shaft roller. The speed of the fan was calculated using the pulley diameter of 165mm, substituted into the relation;

$$N_2D_2 = N_3D_3 \tag{25}$$

This speed was not good enough to winnow the shelled seeds, hence there was a modification. The fan pulley diameter D, and the length of the V-belts were iteratively changed down to 100mm and 950mm respectively, yielding the optimum speed of 1466rpm.

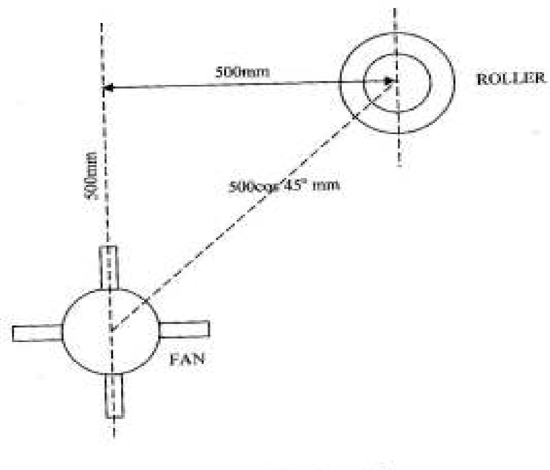

Fig. 5. Blower and Milling configuration

3.1.5 The selection of bearing

The New Departure [12] catalogue, bases its rating on the expected average life of a bearing of 3800hrs at a speed 1000rpm to another life in hours and another speed in revolution per minute, given mathematically as;

$$Desired\ life\ \ in\ hours = \frac{3800 \times 1000}{N} = \frac{catalogue\ rating, N\ at\ 1000rpm}{F} \qquad (26)$$

Where N, is the revolution per minute, and F, is the actual load in Newton. But for purpose of this work, the load carried by each bearing of the milling shaft was 306.66N or 31.26kg and the inner diameter of the bearing is 65mm. From a standard table, the bearing was selected to be any of the following numbers, 113.213, or 313 depending on whether the load was light, medium, or heavy respectively. For static load of 31.26kg or 306.66N compared to the static loading rate of 1112.81N or 113.44kg, the load is considered a light load, therefore, bearing No. 113 is quite adequate for the work. The life (L_f) of this bearing can be determined with a speed of 276.92rpm from the dynamic load rating of the bearing No. 113 which is 118.05N.

$$L_f = \left(\frac{c}{p}\right)^3 million\ revolutions \qquad (27)$$

Where c is basic dynamic load rating, and p, is the equivalent load, given as;

$$p = xvF_r + yF_a \qquad (28)$$

Where v, is rotating factor = 0.1 for inner ring rotating in relation to the load and 1.2 for inner ring stationary in relation to the load, x, is a radial factor = 0.56, y, is thrust factor, F_r, is radial load, and F_a, is axial load. The values of x and y can be obtained from standard table. As there was no axial load in the system,

$$p = xvF_r \quad (29)$$

Hence, applying equation (27) with c = 1187.05 [12] Catalog, life of the bearing is computed as 191.12millions revolution. This is the number of revolutions the bearing will go before the first evidence of fatigue will show for 90% of this group of bearings. Therefore, working 8hrs a day, it will take the bearing 15 months for the first fatigue evidence to show. For the CSSM-2, the load carried by the bearing was cut down by 47%, this implies that the life of the bearing will be increased up to 23 months, which is an enormous economic advantage.

3.1.6 The fixed bar

The Fixed Bar is a sieve like component mounted under the rotating shaft to enable shelling of the seeds and allows both the chaff and the shelled seeds to drop into the cleaning unit. The design of the Fixed Bar for CSSM-1 was based on the size of the Nigeria Large specie while that of CSSM-2 is based on the size of the Nigeria Small specie, having discovered that the Nigeria Small has greater economic and industrial values. The diameter of the rotating shaft and the strength of the material are critical factors in the design of the fixed bar. The radius γ, of the fixed bar is expressed as;

$$\gamma = radius\ of\ shaft + radius\ of\ seed\ specie \quad (30)$$

The same material used for the shaft was used for the construction of the fixed bar Fig. 6.

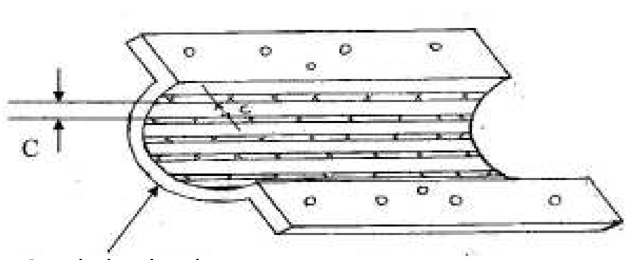

Fig. 6. The Fixed Bar

3.1.7 The shelling chamber

The castor seed is made up of a fibrous, hair like coat (shell) of about 0.8mm thickness and inner black seed that is not perfectly cylindrical. It has major and minor diameter. According to [2] of the three species; Nigeria Large (NL), Nigeria Medium (NM) and Nigeria Small (NS), the Nigeria large is the dominant, but recent studies show that Nigeria Small has taken over dominance. So while the CSSM-1 was targeted at the Nigeria Large, the CSSM-2 is targeted at processing the Nigeria Small, whose dimensions are shown in Table 1.

However, the shelling chamber Fig. 7 has been built to fit the Fixed Bar of any of the three species without adjustment. The dimensions of these castor seeds (Nigeria Small) were taken and the mean diameter determined from many samples of the seed and finally the average of these mean was taken. This average diameter is then used in designing the milling gap and the fixed bar gap to allow the shelling and the passage of the shelled seed. The castor seed has irregular shapes, hence the need for determination of the mean diameters, whose average of the summation is necessary for the calculation of the milling and fixed bar gaps.

$$Milling\ gap = Fixed\ Bar\ gap = \frac{Major\ \phi + Minor\ \phi}{2} = \frac{a+b}{2} \quad (31)$$

Table 1. Physical Dimensions of Nigeria-Small (NS) Castor Seeds

$\boldsymbol{a+s}$	$\boldsymbol{b+s}$	$\boldsymbol{(a+s)+(b+s)}$	$\boldsymbol{\frac{(a+s)+(b+s)}{2}}$	$\boldsymbol{a}$	$\boldsymbol{b}$	$\boldsymbol{a+b}$	$\boldsymbol{\frac{a+b}{2}}$
8.00	6.30	14.30	7.15	6.80	4.65	11.45	5.725
8.75	7.00	15.75	7.875	7,15	4.75	11.90	5.95
5.00	5.60	10.60	5.30	4.90	4.00	8.90	4.45
7.60	7.50	15.10	7.55	6.30	5.45	11.75	5.875
7.00	6.30	13.30	6.65	5.20	4.10	9.30	4.65
7.30	6.30	13,60	6,80	5.20	4.00	9.20	4.60
6.60	6.00	10.20	6.60	5.55	4.40	9.95	4.975
7.50	6.80	14.30	7.15	6.20	4.85	11.15	5.525
7.25	6.00	13.25	6.625	6.00	4.30	10.30	5.15
8.20	7.20	15.40	7.70	6.55	4.70	11.25	5.625
8.00	6.40	14.40	7.20	6.70	4.75	11.45	5.725
7.90	6.85	14.75	7.375	6.50	4.80	11.30	5.65
7.50	6.30	13.80	6.90	6.35	4.45	10.80	5.40
7.00	6.25	13.25	6.625	5.90	4.45	10.46	5.23
7.50	6.60	14.10	7.05	5.75	4.45	10.30	5.15
7.00	6.45	13.45	6.725	5.50	4.45	9.95	4.975
8.35	6.70	15.05	7.525	6.45	4.60	11.05	5.525
8.00	6.80	14.80	7.40	6.65	4.65	11.30	5.65
7.90	6.40	14.30	7.15	6.00	4.35	10.35	5.175
8.00	7.00	15.00	7.50	6.45	5.00	11.45	5.725
Mean			**7.043**				**5.339**

KEY: a = Major diameter of the seed (mm); b = Minor diameter of the seed (mm); s = Shell of the seed (mm)

3.2 Design Characterization and Discussion

The characterization of CSSM-2 started from the modification of CSSM-1, which some of its constraints parameters are (i) speed and weight of the milling shaft and (ii) speed, weight and size of the blower. These are the parameters that determine the independent variables (centrifugal force and shear stress) whose values determine the amount of shell thickness that is removed in a single sweep. The amount of thickness removed is the functional parameter that is required to determine the shelling efficiency of the machine. The optimum force as input variable was determined by iteration. The pulley of the milling shaft was changed severally to different sizes thereby varying the speed until the optimum speed was achieved. At a constant speed and pulley diameter of the electric motor, the speeds and pulley diameters of the milling shaft (MSS and MSD respectively) and the blower (BSS and BPD respectively) were adjusted as shown in Table 2.

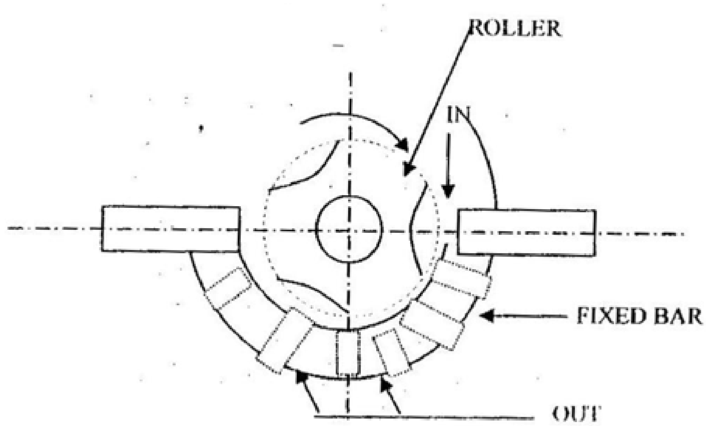

Fig. 7. The Shelling Chamber unit

3.2.1 Characterization procedure

Thirty bags out of the three hundred bags of the NS castor seeds supplied by the National Research Institute for Chemical Technology (NARICT) Zaria in Kaduna State, Nigeria, were randomly selected and labeled one to thirty (1 to 30). These were again randomly divided into six (6) groups or batches. Each of the bags was weighed using Avery Scale and recorded. They were then winnowed to remove excess dust and weighed again. Each batch of five (5) bags was processed through the machine in the following order; batch 1 was processed based on conditions of S/N 1 of Table 2, batch 2 with S/N 2, batch 3 with S/N 3 etc. After the machine processing the separated chaffs were collected and weighed.

The kernels produced from the machine were further winnowed manually in order to remove the remnant chaffs from the shelled seeds. The remnant chaffs were also weighed and recorded separately and added to the previous chaffs from the machine. Also the unshelled seeds were sorted out from the shelled seeds and weights of both were measured and recorded. Tables 3 show the mean output value of the measured parameters from each of the batch.

Table 2. Adjusted Speeds for Various Pulley Sizes

S/N	MSD (mm)	MSS (rpm)	BPD (mm)	BSS (rpm)
1	190	568.42	165	654.54
2	270	400	50	75
3	280	385.71	75	1439.98
4	350	308.57	100	1080
5	390	276.92	100	1080
6	420	257.14	100	1080

Table 3. Mean Output Results of Parameters for the Six (6) Batches

Bag Nos.	Wt_{wd} (kg)	Wt_{wod} (kg)	Wt_{mc} (kg)	Wt_{rc} (kg)	Wt_{tc} (kg)	Wt_{kn} (kg)	Wt_{uss} (kg)	Wt_{ss} (kg)	Wt_{bs} (kg)
1	41.26	38.96	5.31	6.40	11.71	8.86	18.36	20.56	1.03
2	40.28	38.28	13.32	4.50	17.82	8.68	11.78	26.50	3.42
3	41.59	39.64	11.30	3.50	14.80	11.49	13.48	26.15	2.31
4	39.99	38.36	17.09	1.55	18.64	13.72	5.99	32.36	2.58
5	41.24	37.66	19.90	0.88	20.70	15.60	1.36	36.30	1.80
6	42.58	40.74	21.27	1.31	22.58	17.04	1.12	39.62	3.26
Mean	41.16	38.94	14.70	3.02	17.71	12.57	8.68	30.25	2.40
Standard Deviation	0.9339	1.1082	5.9591	2.1614	3.9497	3.4799	6.9903	7.1221	0.9008

3.2.2 Results and discussion

To finally obtain the real character or efficiency of the CSSM-2 machine data of Tables 3 was further analyzed using some mathematical relations applying only the mean value of each parameter to get the following characters:

$$(1)\ Shelling\ Efficiency\ (\%) = \frac{Wt_{wod} - Wt_{uss}}{Wt_{wod}} \times \frac{100}{1} \tag{32}$$

$$(2)\ Cleaning\ Efficiency\ (\%) = \frac{Wt_{mc}}{Wt_{tc}} \times \frac{100}{1} \tag{33}$$

$$(3)\ Breakage\ Efficiency\ (\%) = \frac{Wt_{ss} - Wt_{bs}}{Wt_{ss}} \times \frac{100}{1} \tag{34}$$

$$(4)\ \%\ Weight\ of\ Shelled\ Seeds = \frac{Wt_{ss}}{Wt_{wod}} \times \frac{100}{1} \tag{35}$$

Where, Wt_{wd} is the weight of seed with dust, Wt_{wod} is the weight of seed without dust, Wt_{mc} is the weight of chaffs from machine, Wt_{rc} is the weight of remnant chaffs, Wt_{tc} is the total weight of chaffs, Wt_{kn} is the weight of kernel, Wt_{uss} is the weight of unshelled seeds, Wt_{ss} is the weight of shelled seeds, Wt_{be} is the weight of breakage.

Therefore by the application of equations (32) to (35) the efficiency data of Table 4 was obtained and graph of Fig 8 was plotted;

Table 4. Characteristic Efficiencies of CSSM-2

Batch No.	MSS (rpm)	BSS (rpm)	Shelling Efficiency (%)	Cleaning Efficiency (%)	Breakage Efficiency (%)
1	568.42	654.54	52.26	45.24	11.69
2	400.00	21600.00	64.24	74.80	39.37
3	385.71	1439.98	65.96	76.33	20.09
4	308.57	1080	84.35	91.69	18.77
5	276.92	1080	96.34	96.26	11.05
6	257.14	1080	97.23	94.12	19.09
Mean Efficiency			76.73	79.74	20.01
Standard Deviation			18.6206	19.2290	10.2636

From above analysis, it can be observed that the Shelling and Breakage efficiencies are related to the milling shaft speed, while cleaning efficiency is related to the blower speed. The high speed of the blower in the case of Batch 2 resulted in very high speed breeze which blew off some seeds along with the chaff, hence a low yield on the quantity of shelled seeds. Batch 5 processed with milling shaft speed of 276.92 rpm and blower speed of 1080 rpm showed the best performance indices of 96.34% shelling, 96.26% winnowing and 11.05% breakage. A further reduction in milling shaft speed for Batch 6 resulted to a low winnowing efficiency and higher breakage, even though there was slight increase in shelling, hence the processing condition used on Batch 5 is the optimum.

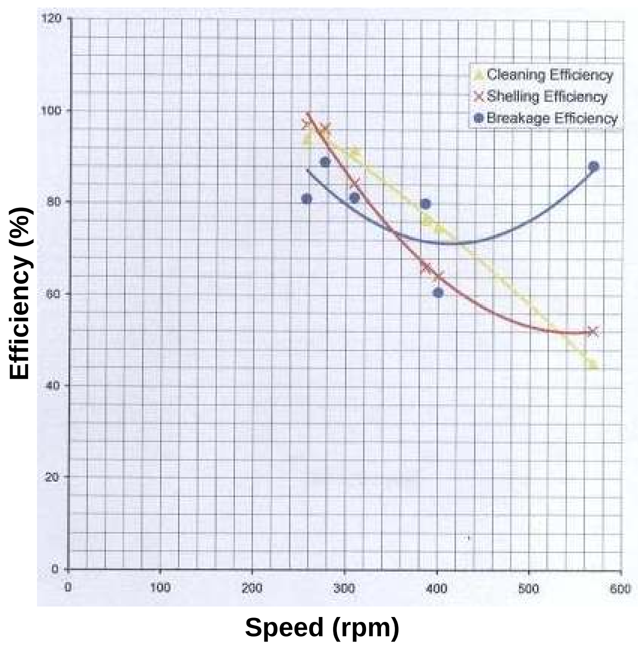

Fig. 8. Characteristic Efficiencies against MS

4. CONCLUSION

The design of CSSM-1 was actually a primary research which may not easily be compared with any previous work, hence the enhancement on its design was basically on the improvement of the flaws found on its production output. The modifications made on the CSSM-1, which gave rise to CSSM-2, have improved the efficiency of the machine from 60% up to 96% after it has been put to production. The dust (shell) generated from CSSM-1 constitute environmental hazard, but the modified CSSM-2 has a reduced weight making it portable to be used on the farm site.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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