A Rotary Separator for the Dry Mixture of Palm Kernel and Shell

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Abstract

Effective separation of palm kernel and shell is an important process in the downstream industrial utilization of the constituents. In view of the limitations of the conventional wet separators, a rotary separator employing a multi-cyclic separation process was developed for the dry mixture. Machine parts were designed following standard engineering principles for part-sizing, using locally available materials. Cracked palm nut mixture was classified by sieve analysis, and the fractions retained on the 10 and 15 mm sieves were used for the evaluation of the machine performance. Operating the separator at 55 rpm yielded kernel recovery and kernel purity of 96% and 42.86%, respectively, for the mixture retained on 10 mm sieves. Corresponding shell recovery, shell purity, separation efficiency and throughput capacity, at the same speed were 100, 81.71, 78.45% and 277 kg/h, respectively. Separation of the mixture retained on 15 mm sieve was feasible at 60 rpm with kernel recovery and kernel purity of 91.89 and 73.12%, respectively. The shell recovery, shell purity, separation efficiency and throughput capacity were 80.16, 94.17, 73.66 % and 313 kg/h, respectively. The results showed that the separation technique is viable for effective separation of the dry palm kernel and shell mixture.

Keywords: Machine Design, Rotary separator, Dry mixture, Kernel, Shell, Palm nut.

1. Introduction

The product from nut-cracking operation is a mixture of kernel and broken shell of irregular shapes and comparable sizes. Therefore, the requirements for kernel cleanliness and quality present a major challenge in the palm kernel oil extraction process for other downstream industrial applications. At present, techniques employed in the separation of the mixture are of two types: wet and dry methods. The wet method is implied when the separation is done in a liquid medium, based on the difference in specific gravities of the constituents; while in the dry method, no liquid medium is used. However, kernels recovered in the wet systems must be sterilized against the growth of moulds and re-dried for 14 – 16 h in silos to remove moisture absorbed during the separation process (Akubuo and Eje, 2002). The energy and time required for re-drying the kernels, as well as the requirement of handling a large volume of water for the separation process , makes imperative, the development of dry systems. However, proposed proprietary machines employing dry separation techniques are either still at the experimental stages or, may only function as pre-cleaners (Olie & Tijeng, 1974; Akubuo and Eje, 2002; FAO, 2005; Koya and Faborode, 2006; Rohaya *et al*., 2006; Amoah *et al*., 2007).

A recent research effort in developing a new dry separator (Koya and Faborode, 2006) had considered the difference in the dispatch of kernel and shell from a spinning disc, to effect separation. However, a practical device in the realisation of the theory would require series of discs, and the material handling capacity of the proprietary machine may be quite low. Similarly, the incline table separators, with or without induced vibration (Akubuo and Eje, 2002; Koya and Faborode, 2011), are plagued with some limitations; particularly, the inability to separate kernel and shell of the same size grade. In addition, the mixture freshly introduced onto the incline interact with the separated fractions and, due to the resulting impact, some shell particles are propelled down the incline; while, some kernels are entrapped with the shells moving up the incline. It, however, appears that the limitations of the two systems may be eliminated if a rotating cylinder equipped with internal spirals is used. The spirals may be considered as a series of discs, or a fairly long incline, where the mixture is fed into the separator at one end of the drum and the separated fractions are discharged at the other end.

It was expected that, based on the difference in physical properties, such as size, shape and friction coefficient, differences will occur in the motions of palm kernel and shell in a rotating drum. The analysis of the underlying theory formed the subject of an earlier report (Koya and Olasumboye, 2012). Consequently, the objectives of this work were to design, fabricate and evaluate the performance of a rotary drum separator for the dry mixture of palm kernel and shell.

2. Materials and Methods

2.1 Theoretical Background

The theory was set to evaluate the probable dispatch angles for kernel and shell particles. Dispatch angle was defined as the angular displacement from the lowest point in the drum (where the particle was fed) to the point where the particle was dislodged from contacting the surface of the drum; that is, where the gravitational force on the particle just overcomes its centrifugal force as the drum rotates ($g \geq \omega^2 R$). Although, cracking palm nuts yields kernels and shells of irregular shapes and sizes, the kernels are usually spherical, ellipsoidal, and sometimes, oblong in shapes; while shells are mostly flat, dome, or dish shaped (Koya et al., 2004). Therefore, the shell may slide, while the kernel may slide or roll. Hence, two possible combinations of motions contemplated in the theoretical analysis (Koya and Olasumboye, 2012) were that: (i) kernel and shell slide, and (ii) kernel rolls, while shell slides. The motion of each particle in the rotating drum is controlled by its inertia, centrifugal and gravity forces, and the coefficient of friction at the particle-drum interface. It was assumed that the drum is rotating at a specified angular velocity, and that, the particle was fed into the drum at its lowest point, without impact, such that, bouncing does not occur.

It can be shown that a particle (kernel or shell) will slide off the inner surface of the drum if,

$$\theta_{sp} = \sin^{-1}\left(\frac{\mu_s}{g\sqrt{1+\mu_s^2}}\right) + \tan^{-1}(\mu_s) \quad , \qquad (1)$$

where θ_{sp} is the angle of dispatch for the sliding particle; ω is the angular velocity in rad/s; μ_s is the static coefficient of friction of the particle on the drum wall; R is the drum radius; and g is the acceleration due to gravity.

And that a particle (kernel) rolls, when,

$$\theta_{rp} < \cos^{-1}\left[1 - \frac{\omega^2 R}{g}\left(1 + \frac{k^2}{n^2}\right)\right], \qquad (2)$$

where, θ_{rp} is the dispatch angle of the rolling particle, k is the radius of gyration of the particle about the centroidal axis, and n is the particle radius.

Also, it is reasonable to assume that kernel rolls about its longitudinal axis, so that its radius of gyration k equals$n/2$; where, n is the minor radius of an equivalent ellipsoid. Thus, Equation 2 becomes

$$\theta_{rp} > \cos^{-1}\left(1 - \frac{5\omega^2 R}{4g}\right) \tag{3}$$

Typical values of the coefficients of friction of kernel and shell on some structural surfaces are available in the literature (Koya et al., 2004; Koya and Faborode, 2006). Therefore, the dispatch angle for a particle inside a drum of known diameter, rotating at a specified speed may then be estimated. In design applications, the speed of offering the largest deviation in the dispatch angles for the kernel and shell provides the theoretical baseline for the operation of the rotary separator. An experimental verification of the theory had been reported (Koya and Olasumboye, 2012). The kernels oscillated between 0 and 70^o, while the kernels were dispatched between 112 and 153^o in a drum of 500 mm internal diameter, rotating at 62 rpm.

2.2 The experimental rotary separator

The rotary separator (Fig. 2.1), whose orthographic details are shown in Fig. 2.2, was designed based on the theory, and following standard engineering principles for part-sizing and materials selection. The drum was a cylindrical framework 1500 mm long and 500 mm in internal diameter. Apparently, in a mass flow system, separation may not be effected in a single cycle; therefore, the drum was fitted with a ten-pitch internal screw conveyor to replicate the separation process. A section of the drum, 300 mm long, near the feed-end, was overlaid with 10 mm steel-wire netting, to sieve out small shell particles and immature kernels. The remaining section of the drum was overlaid with expanded steel wire of smaller apertures to functions as the separator. A semi-cylindrical trough, equipped with a screw auger, was suitably located inside the drum. The trough intercepts particles discharged at the higher dispatch angles, while those discharged at the lower dispatch angles oscillate inside the drum as they travel through the length of the drum. The unit was housed in a drum, 570 mm internal diameter and opened at one end. The hopper is fixed on plate which covered the open end. The trough discharges into a chute on the closed end; while, the drum discharges into a lower chute. The prototype separator is shown in Figure 2.2. The drum and the screw conveyor in the chute were driven by a 3.5 kW electric motor, via a belt and pulleys arrangement. The motor was connected to a variable speed control device (Model M4kW, OMRON SYSDRIVE^{TM}, USA). The design details are contained in Olasumboye (2012).

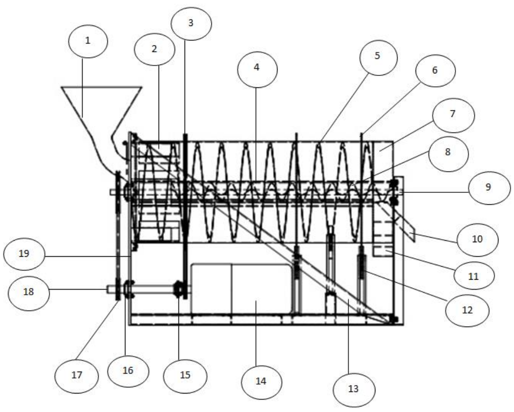

Fig. 2.1: Components of the rotary separator

(1) Hopper, (2) drum sieve section, (3) chain drive, (4) trough, (5) kernel conveyor, (6) constraining ring,

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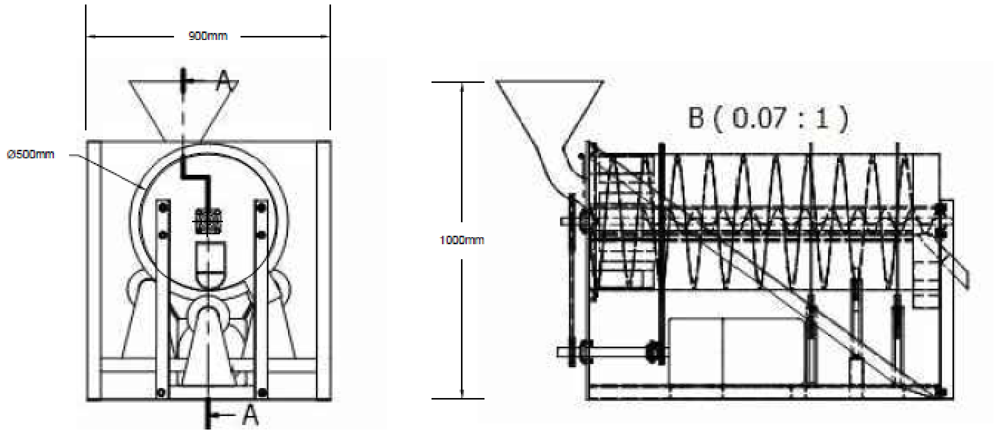
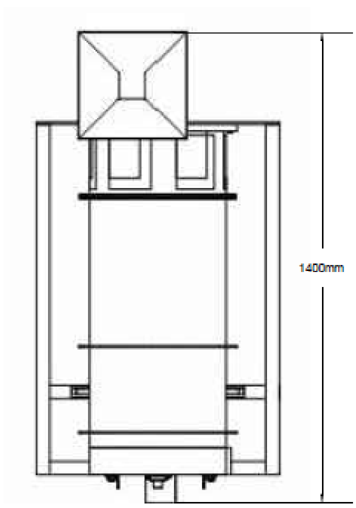
(7) fixed outlet chamber, (8) shell auger, (9) shell auger shaft, (10) shell outlet, (11) kernel outlet, (12) roller support, (13) chassis member, (14) electric motor, (15) shaft coupling, (16) self-aligning friction bearing, (17) pulley system, (18) transmission shaft, (19) chassis.





Bill of Quantity		
S/No	Part Name	Quantity
1	Separating Drum	1
2	Conveyor	1
3	Trough	1
4	Hopper	1
5	Pulley	2
6	Coupling	1
7	Roller support	2
8	Surface bearing	4
9	Pillow bearing	3
10	Frame	1
11	Fixed Rim cover	1

Figure 2.2: Orthographic details of the separator.

2.3 Performance evaluation of the separator

Ten kilogrammes of dried palm nuts at 13.4% moisture content (wet basis) were cracked in a conventional mechanical nutcracker. The mixture of palm kernels and shells as received from the nutcracker were graded using a set of BS 410 standard sieves (Endecott Ltd., London) with apertures of 10, 14, 20, 28 mm. The mixtures retained on 10 and 14 mm sieves were fed in batches of 2 kg into the machine. Based on the prediction from the theory, the machine was operated at five speed levels: 50, 55 60, 65 and 73 rpm. The speed was monitored using an electronic tachometer (Smith Industrial Division, London), with an accuracy of ± 0.001 rpm. All weight measurements of samples were taken on PM-30 analytical balance (Mettler, Switzerland) and replicated three times each. The kernels in the mixture were sorted manually and weighed, to determine the proportion of each constituent before it was fed into the machine.

The performance of the machine was measured in terms of its throughput capacity, separation efficiency, and the quality of the product. The performance indices were defined as follow:

(a) Throughput capacity

The throughput capacity was defined as the rate in kg/h at machine process the mixture for separation.

(b) Kernel recovery

Kernel recovery K_r was set to assess the percentage of the kernels which were recovered from the mixture introduced into the machine. It was expressed as,

$$K_r = \left(\frac{a}{a+c}\right)100\% \quad , \qquad (4)$$

where, c is the mass of kernels apparently lost (discharged) with the shells.

Consequently, kernel loss defined the percentage of the kernels, which were discharged with the shell; so that it is a complement of the term kernel recovery.

(c) Separation efficiency

The separation efficiency η_s of the rotary separator was computed as,

$$\text{Separation efficiency, } \eta_s = \frac{K_r S_r}{100} \quad . \qquad (5)$$

where, K_r is the percentage kernel recovery and S_r is the percentage shell recovery.

(d) Kernel purity

Kernel purity K_p defined the percentage of the kernels in the mixture, which were actually discharged through the outlet meant for kernels.

Mathematically, kernel purity was expressed as,

$$K_p = \left(\frac{a}{a+b^*}\right)100\% \qquad (6)$$

where, a is the mass of separated kernels in kg; and b^* , mass in kg, of the shells and impurities contained in the separated kernels.

(e) Shell purity

Kernel purity S_p was defined as the percentage of the shell fragments in the mixture which were discharged through the appropriate outlets for shell particles. It was expressed as,

$$S_p = \left(\frac{b}{a^*+b}\right)100\% \quad , \qquad (7)$$

where, b is the mass in kg of shells in the mixture, and a^* is the mass in kg of the shell and impurities discharged through the spout for shells and through the sieve section.

In addition, a two-way Analysis of Variance (ANOVA) was employed (Decoursey, 2003) to investigate the interplay between the size-grade of the mixture, rotational speed of the drum, and machine separation efficiency.

The experimental runs were conducted at the speeds yielding the highest separation efficiencies for the two grades of mixture.

3. Results and Discussion

3.1 Performance of the machine

A picture of the fabricated prototype of the experimental rotary separator is shown in Plate 3.1. Pictures of the palm kernel and shell mixture fed into the machine, as well as the product of the separation process using the machine are shown in Plate 3.2. The throughput of the machine, kernel recovery and the shell purity in cleaning the two grades of palm kernel and shell mixtures are shown in Table 3.1. From the table, the best operating condition on account of kernel recovery and shell purity is at the drum driven at 55 rpm in handling the mixture retained on 10 mm standard sieve, and throughput capacity is 257 kg/h; 60 rpm for mixture retained on 14 mm standard sieve and throughput capacity is 313 kg/h. The corresponding separation efficiencies for the mixtures are 78 and 74%, respectively; while the corresponding kernel losses are 4 and 5%. The observed throughput capacities are higher than the 60 kg/h reported employing the traditional hand-picking method, and are comparable with 300 kg/h reported in respect of a prototype wet separator (Nwachukwu and Obasi, 2006).

Furthermore, corresponding purity of the two grades of the shells (Fig. 3.3) are 100 and 94%, but kernel purity for the two grades of the mixture are low (55 and 60%). The high shell purity is promising, because it indicates that kernel loss (discharged with the shell) is minimal (Fig. 3.1 and 3.2). However, the low shell purity shows that some shell particles are entrapped with the kernel. Subject to experimental verification, recycling the discharged kernels, or increasing the length of the separation section should improve kernel purity. Also, a small fraction of the kernels are unexpectedly too small, and are discharged through the pre-cleaning screen; while some are entrapped with the shell, where shell purity is less than 100%. Therefore, it may be quite beneficial to pre-clean the mixture, with the view to removing small-sized kernels, before being introduced into the machine. It is also interesting to note that the speeds yielding the best separation efficiencies are close to the theoretical speed 60 rpm at which a particle adheres fixedly to a rotating drum of 500 mm in diameter.

Plate 3.1: The experimental rotary separator for the dry mixture of palm kernel and shell

(a)

(b)

(c)

Plate 3.2: Snapshots of the separated mixture and products; (a) – mixture, (b) – separated shell, (c) – separated kernel.

Table 3.1: Machine performance at different drum speeds for the mixtures

Drum	Mixture retained on 10 mm sieve			Mixture retained on 14 mm sieve		
Rotation, rpm	Throughput Capacity, kg/h	Kernel Recovery, %	Shell Purity,%	Throughput Capacity, kg/h	Kernel Recovery, %	Shell Purity,%
50	240	88.0	98.2	257	94.6	94.0
55	257	96.0	100.0	277	94.6	93.0
60	288	60.0	94.8	313	91.9	94.4
65	300	48.0	93.3	327	77.0	84.6
70	313	20.0	90.1	360	55.4	77.9

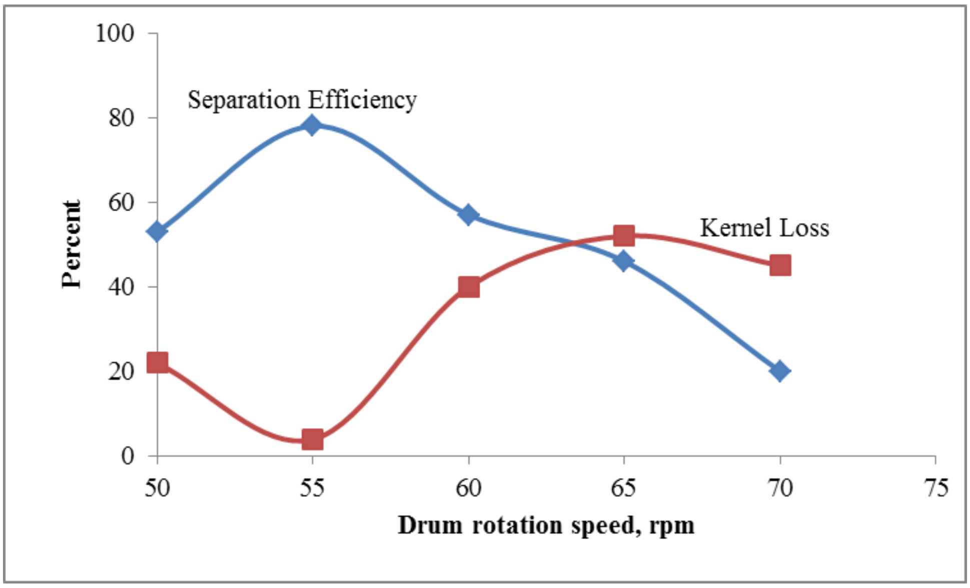


Fig. 3.1: Machine performance in handling mixture retained on 10 mm standard screen

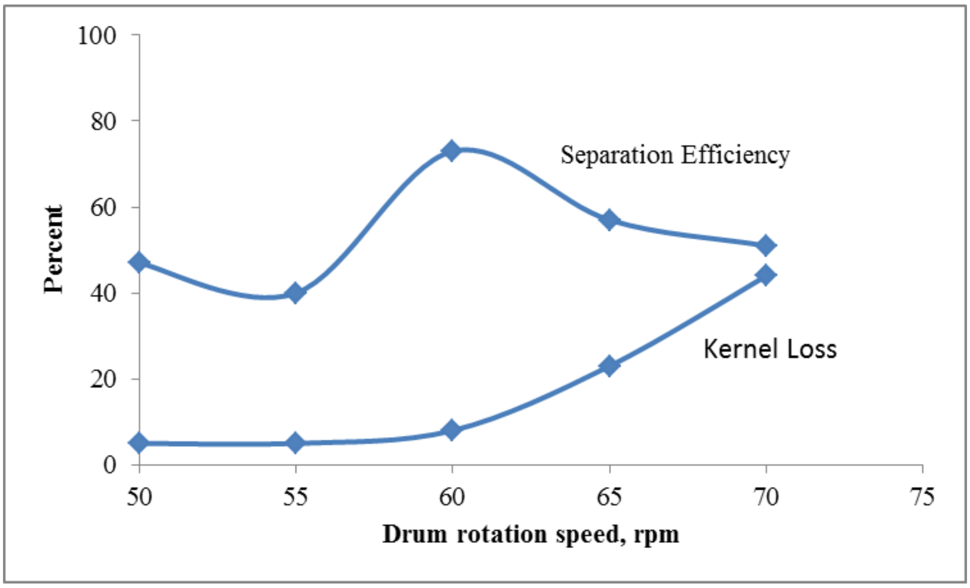


Fig. 3.2: Machine performance in handling mixture retained on 14 mm standard screen

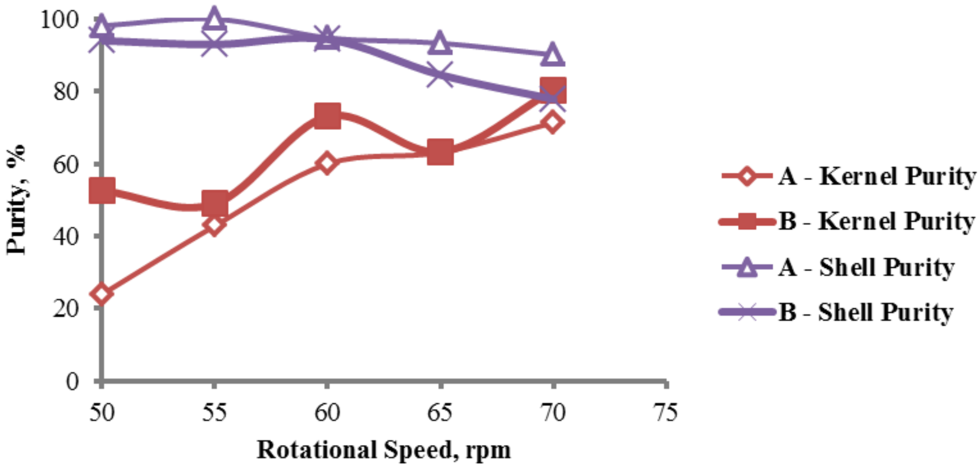


Fig. 3.3: Relationship between drum speeds and percentage purity of products for mixture A (retained on 10 mm sieve) and B (retained on 14 mm sieve).

3.2 Effect of size-grade of mixture on machine performance

A summary of the effects of size-grade of mixture and speed of the separator is shown in Table 3.3. It is shown that the separation efficiency of the experimental machine was significantly affected ($p < 0.05$) by both the speed and the interaction between speed and size, but not by the main effect of size. Thus, the rotation speed of similar separator must be synchronized with the diameter of the drum; albeit, it is required that the effect of increasing the length of the separation section be investigated.

Table 3.2: Two-way ANOVA table for the statistical investigation of the effects of size and speed on separation efficiency

Sources of Variation	Sums of Squares(SS)	Degrees of Freedom	Mean Squares (MSS)	Variance Ratios (F)
Main Effect, speed (A)	426.38	1	426.38	37.34*
Main effect, size (B)	0.37	1	0.37	0.03
Interaction between speed and size (AB)	1442.55	1	1442.55	126.32*
Error	91.33	8	11.42	
Total		11	1960.63	

*Significant at 95% confidence level.

4. Conclusion

A rotary separator for the dry mixture of palm kernel and shell was developed, based on the motion of granular particles of dissimilar shapes in a rotating drum. Separation of the mixture was feasible at low rotational speeds of the drum: 55 rpm for mixture of kernel and shell retained on 10 mm sieve, and 60 rpm for mixture on 14 mm sieve. The corresponding performances of the machine for the two grades of the mixture were: throughput capacity, 257 and 313 kg/h; separation efficiency, 78.5 and 73.7%. Furthermore, the study showed that the interactive effect of the size-grade of the mixture and the operating speed of the machine had significant effect (at 95% confidence level) on the machine performance, but effect of size-grade alone was not significant. The machine thus provides a viable technique for the practical separation of dry palm kernel and shell mixture.

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