

Experimental Verification of a New Technique for the Dry Separation of Palm Kernel and Shell Mixture

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Abstract

Effective separation of the cracked palm nut mixture is an important process in the downstream utilisation of the constituent palm kernel and shell in some existing and emerging agro-economy. Whilst, the conventional wet separators are sophisticated and energy inefficient, the dry systems are at experimental stages and are inadequate for separating kernel and shell of comparable sizes. However, the difference in the path variables of particles of same size, but different shapes, in circular motion, suggests the possibility of separating the dry mixture in a rotating trammel with a co-axial spout. Based on the theory, the study investigated the dispatch angles for palm kernel and shell from a friction lining on the inner curved surface of drums of different diameters and rotating speeds. A built experimental facility allowed estimation of the dispatch angle for particles placed on the lining. The results show that palm kernels oscillate and move axially with the dispatch angle increasing with the drum diameter, but consistently less than 90^o for the different diameters and speeds of the drum. The shells are dislodged at higher dispatch angles and in curvilinear trajectories away from the drum surface, causing a separation of the mixture. It is concluded that the experimental data are in good agreement with the theory and that the theory is sufficiently adequate for the determination of the design parameters of a proprietary separator.

Keywords: Design parameters, Palm kernel, Shell, Separation, Trammel.

1. Introduction

The dry separation of palm kernel and shell mixture has remained an arduous challenge, particularly in handling kernels and shells of comparable size grades. Most industrial processors have therefore maintained the use of wet separators, in spite of the obvious energy inefficiencies of the devices. The wet methods, such as the clay-bath and the hydro-cyclone separators, exploit the difference in the specific gravities of the mixture in liquid media; following which, the recovered kernels are dried in silos for 14 – 16 h, to remove the moisture absorbed during the separation process. Consequently, this requirement represents a huge energy loss, since the nuts had been dried to minimize kernel breakage when cracking the nutshell. Also, the hydro-cyclone is sophisticated and expensive; while, the traditional method, employing the use of clay-bath separator, is cumbersome and the products are contaminated with the ash or clay in the solution. Meanwhile, about 90 percent of annual palm oil production in Nigeria, generating the palm nuts for kernel extraction, is still being processed by clusters of small-scale processors (Owolarafe *et al.*, 2002). Therefore, considering the over-whelming challenges confronting the local processors, there is the need to develop an appropriate dry separator for this group of users.

Although, a number of researchers (Olie and Tjeng ,1974; Akubuo and Eje, 2002; FAO, 2005;Koya and Faborode, 2006; Rohaya *et al.* 2006; Aggey and Amoah, 2007) had attempted evolving viable dry separators, the devices are mostly at the experimental stages, and many of the proposed designs may function only as pre-cleaners, to screen out dirt, small shell particles and immature kernels. However, where the kernel and shell are of the same size grade, with equal chances of passing through the same aperture, the only distinguishing features are the shapes of the particles and their friction coefficients on the structural surface. It is, however, well recognized that the shells are mostly flat or dish shaped, and that the shape of the kernels vary from being nearly spherical to being ellipsoidal (Akubuo and Eje, 2002; Koya and Faborode, 2005). Therefore, the difference in the motion of particles of different shapes was contemplated as a basis for the separation of kernels and shells. The same postulation was considered in the analysis of kernel-shell separation on a spinning disc (Koya and Faborode, 2006), but the hardware for the realization of the theory requires series of discs, and the material handling capacity may be quite low. Therefore, it was considered that the use of a rotating drum would provide a more practical solution; viewing the drum as an integration of evenly spaced series of discs. The analysis of the corresponding theory formed the subject of an earlier report (Olasumboye, 2012).

Consequently, the objectives of this work were to investigate the difference in the dispatch angles and the trajectories of palm kernel and shell of comparable sizes, when placed inside a rotating drum. This was with the view to separating the mixture and, to propose a suitable proprietary machine. It is expected that the machine will incorporate a pre-cleaning section to eliminate dirt, immature kernels, and smaller shell particles.

2. Background Theory

Palm kernel and shell were considered as disconnected, segregated granular particles, so that inter-particle collision is negligible. And, based on the differences in their shapes, it was assumed that shells will slide down the drum surface while the kernel will either roll or slide off the drum surface. It has been shown (Olasumboye, 2012) that:

(i) The dispatch angle for the particle which slides is given by,

$$\theta_s = \sin^{-1}\left(\frac{\mu\omega^2 R}{g\sqrt{1+\mu^2}}\right) + \tan^{-1}(\mu) \qquad (1)$$

And,

(ii) For the particle which rolls,

$$\theta_r > \cos^{-1}\left(1 - \frac{5\omega^2 R}{4g}\right) \qquad (2)$$

where, θ_r and θ_s are the dispatch angles for rolling and sliding particles, respectively; μ is the static coefficient of friction of the particle on the drum surface; ω is the angular velocity of the drum; R is the radius of the drum (assuming that the height of the rolling particle is far smaller than the radius of the drum), and g is acceleration due to gravity.

In the present study, the analysis was taken further, recognizing the product $\omega^2 R$ as machine radial acceleration. Hence, the dispatch angles are rewritten as follow:

For particle which slides,

$$\theta_s = \sin^{-1}\left(\frac{\mu M_a}{g\sqrt{1+\mu^2}}\right) + \tan^{-1}(\mu) \qquad (3)$$

And, for particle which rolls,

$$\theta_r \geq \cos^{-1}\left(1 - \frac{5M_a}{4g}\right) \qquad (4)$$

where, M_a is the product of the square of the rotational speed and the radius of the drum.

Typical friction coefficients are 0.65 for kernel and 1.95 for shell on expanded steel wire, as reported in the literature (Koya *et al.*, 2004). Therefore, the motion of the shells, assumed to slide because of its shape, is given by

$$\theta_{ss} = \sin^{-1}\left(\frac{M_a}{11.0}\right) + 62.8^o \qquad (5)$$

So that, for practical values, the machine parameter M_a must lay between 0 and 11.0 m/s^2; and shell will slide at θ_{ss} between 62.8 and 152.8^o. At higher values of M_a, the shell sticks perpetually to the wall of the drum. Similarly, the kernel, whose motion is given by,

$$\theta_{sk} = \sin^{-1}\left(\frac{M_a}{18.0}\right) + 33.0^o \qquad (6)$$

may slide for M_a lying between 0 and 18.0 m/s^2 and θ_{sk} between 33 and 123^o. However, this has very limited chances because of its shape, which may stimulate spinning and once it begins to roll, it will continue to roll with increasing angular velocity. Therefore, the separation is governed primarily by the difference in the motion of sliding shell and rolling kernel. On the basis of Eqn. 4 kernel rolls when

$$\theta_{rk} < \cos^{-1}\left(1 - \frac{M_a}{8}\right) \qquad (7)$$

resulting in θ_{rk} lying between 0 to 90^o and M_a between 0 and 7.8 m/s^2. Therefore, if conveniently conveyed along the length of the drum, the kernel will be taken up and roll back intermittently, within 0 to 90^o, as it travels from the feed point to point of discharge from the drum. In summary, the theory suggests that, shells only will be dislodged between 90 and 152^o; while, the mixture contained between 62 and 90^o may be re-circulated, as it passes along the length of the drum. Once the shell is dislodged from contacting the drum surface, it behaves as a projectile until it impinges the wall of the drum, or is intercepted by a suitably located collector. The trajectory of such particles is well discussed in standard literature on mechanics of particles (Meriam and Craige, 1998).

3. Experimental Procedure

The theoretical dispatch angles for the shells (assumed to slide) and for the kernels (sliding or rolling) was plotted for the different values of machine radial acceleration, to obtain the value providing the best promise for the separation of the mixture. An experimental facility (Plate 1) was then fabricated to evaluate the theory. The unit consists of a drum, 500 mm in diameter, opened at one end; while the other end is covered with a transparent screen, to observe the particle during experimentation. The drum was driven by a variable speed electric motor, and its speed was monitored using an electronic tachometer with accuracy of $\pm$ 0.001 rpm.

Plate 1: Experimental facility for investigating the dispatch angle of kernel and shell in a rotating drum

Dried palm nuts (at 13.4% moisture content, wet basis) were cracked, and the mixture was screened using a set of standard BS 410 sieves (Endecotts Ltd., London), to obtain kernels and shells of the same size grade for the experiment. Samples of the kernel and shell were then fed in sequence into the drum, whose speed was increased gradually until the sample began to either slide downward against the direction of rotation, or was dislodged from the surface of the drum. The motion of the particle was recorded with a digital video camera (Steady Shot™, Model DSC W310, SONY) and the recording, integrated with a computer for magnification, was played back in slow motion in order to estimate the dispatch angle. The results of the experimental investigations were then compared with the predictions from theory. Based on the result, a practical device was then proposed, integrating the concept of the conventional trammel and the investigated technique for the future development of a single unit separator for the dry palm kernel and shell mixture.

4. Results and Discussion

The theoretical dispatch angles for the shell, which slides; kernel, which slides and kernel, which roll, are shown in Figure 1. It is interesting to note that the intercepts of the curves with the ordinate represent the least inclinations of a plane to initiate free sliding of the representative particle on the plane. Clearly, because the difference in these angles is marginal, separation of the mixture on an inclined plane may not be quite promising. Such limitation had been reported by previous researchers (Olie and Tjeng, 1974). It is however obvious from the plots that separation is most feasible for a system driven with machine parameters between 8.0 and 9.8 m/s^2 where kernels are dispatched below 90^o and shells above 120^o of drum rotation. Ideally, the

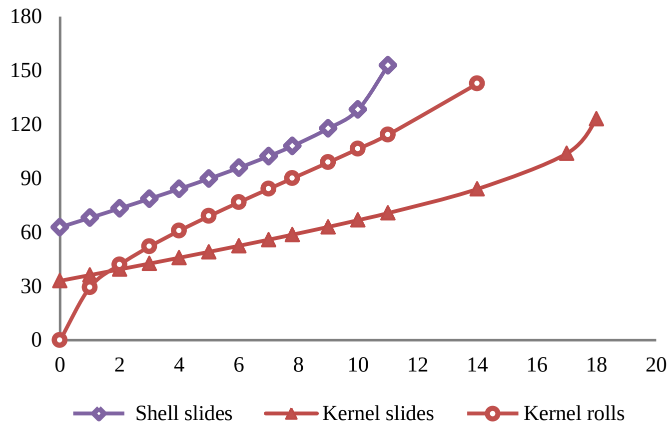

Fig. 1: Dispatch angles for kernel and shell based on the theory of particle dynamics in a rotating drum

kernel and shell would adhere fixedly to the drum if driven above 9.8 m/s^2, the acceleration due to gravity. In comparison, kernels were dislodged below 90^o, and shells between 130 and 180^o (Plate 2) using the experimental facility, with the drum rotating at 62 rpm (corresponding to machine radial acceleration of 10.5 m/s^2). In view of deviations in the shapes of kernel and shell from the assumptions of regular geometric shapes in the theory and within the limits of experimental errors, the results may be judged to be reasonably congruent with the theory. Therefore, based on the theory, a prototype of the proprietary mechanical separator shown in Figure 2 is proposed for future implementation.


(a)


(b)

Plate 2: Snapshots of the test rig during experimental validation of the theory; a – Shell, b – Kernel

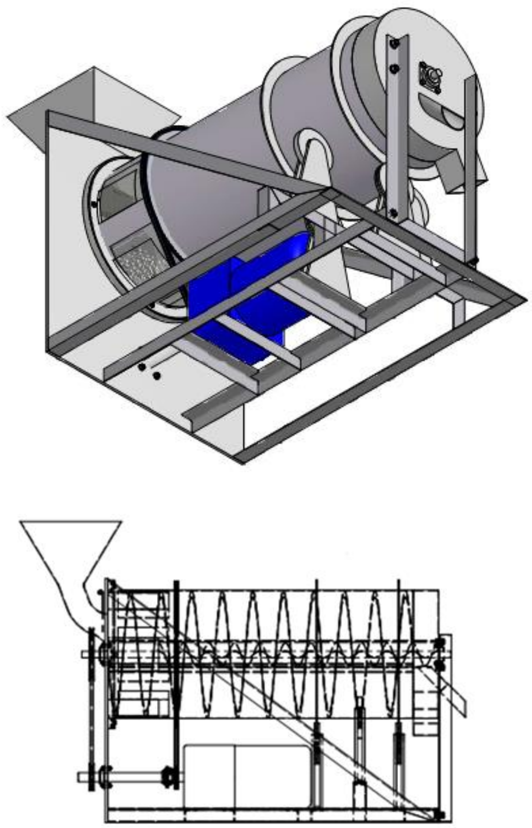

Fig. 2: An outline of the proposed mechanical separator for the dry palm kernel and shell mixture

5. Conclusions

The study examined the separation of dry palm kernel and shell mixture in a rotating drum based on an established theory. It was shown by experiment and the theory that the technique is superior to the use of inclined plane and the existing sieving method, such as employed in the conventional trammel. Machine operating radial acceleration for a practical design employing the new technique with a drum whose product of its radius (in meters) and the square of its rotational speed (in radians per second) is 8 m/s^2. In the experiment, palm kernel shells were dislodged at less than 90^o of the drum rotation, and the shell at above 120^o. The study therefore, established the viability of the technique and proposed a prototype of the proprietary machine for future implementation

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