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# PERFORMANCE CHARACTERISTICS OF INTEGRATED COCONUT GRATING AND MILK EXTRACTING DEVICE

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## ABSTRACT

***Coconut milk extraction from the kernel is usually done in two processes and with two different machines. First, the coconut meat is crushed into smaller pieces using a grater and then the grated meat is taken to an extracting device where the milk will be removed from the meat. This makes the process a bit cumbersome and time consuming. Hence, this work develops a suitable device with a simple design and easy to operate mechanism efficiently grating the coconut meat and extracting the milk in a single operation. The system is made up of a hopper, rolling grater, screw press, sieve, and an electric motor, all assembled on a metallic frame. The capacity of the grater was determined to be 299 kg/h. Three phases, 3 horse power electric gear motor was employed in running the machine with the speed of 750rpm during the performance evaluation of the device. The experimental machine gave the highest milk yield of 39.22% and an average milk yield of 36.04% which is about 81% of the moisture content of the coconut kernel. Also, the average milk extraction efficiency was 35.15%, showing that the machine can produce about 105 kg of milk per hour.***

**Keywords:** *Coconut, Milk Extraction, Grating, Screw Press*

## INTRODUCTION

The Coconut palm (*Cocos Nucifera L.*) from the palm family (*Arecaceae*) and class Liliopsida (mono-cotyledon plant) have proven for the past years to be a gift of nature to mankind for its usefulness both in its immature and mature forms. The trees provide materials for buildings and food for both man and animals. Some hold the belief that they could be good materials for medicine. It is popularly referred to as the tree of life because of its large variety of useful products to man and as the support to the economy (Pham, 2016). The coconut palm can be categorized into two groups, the tall and dwarf varieties. The tall palms can live for about 70 years and produce between 100 to 140 nuts per year whereas the dwarf palms live a shorter life span of between 30 to 40 years and produce about 100 to 150 nuts per year (Henrietta, *et al*, 2022)

Various hybrids of the coconut species have been developed over the years by cross breeding the dwarf and tall palms (Henrietta, 2022). Coconut milk is the aqueous extract from the coconut kernel usually gotten by grating and mechanically compressing the kernel (Henrietta, 2022). The coconut milk is very rich in fat, proteins, vitamins, minerals and sugar. Coconut milk production can be divided into three basic stages: pre-processing, processing and post-processing. The pre-processing stage comprises of all necessary activities carried out before the coconut milking. This includes the harvesting of the coconut, transportation, de-husking and de-shelling of nuts. The processing stage is the actual process of grating and pressing to extract the milk while the post-processing stage involves all additional steps taken either to make the coconut milk of highest quality or to produce other products from it.

Coconut grating is done to reduce the particle size of the coconut meat to enable efficient extraction of the coconut milk. There are various types and designs of graters used over the years for coconut grating. These are the traditional graters, hand graters, rotatory graters and the industrial graters (Raj *et al.*, 2016). Pressing and de-watering is the process of pressing or squeezing the grated coconut to obtain the milk. The traditional way of expelling coconut milk is done in a muslin cloth and the hand squeezed (Raj *et al.*, 2016). Modern expellers are majorly of two types as classified by (UNIFEM, 1987). They are the hydraulic presses and the screw presses. A screw press is used in the separation of liquids from solids or for the extraction of liquids in a solid. The liquid is expelled through a screen that surrounds a compression screw (Firdaus *et al.,* 2017).

The experimental coconut grating and milk extracting machine, as a system is made up of a hopper, rolling grater, screw conveyor, conveyor tube, sieve, and an electric motor, all assembled on a metallic frame. The electric motor drives the grater and the screw press simultaneously. Broken coconut kernel is poured in the hopper and grated by the turning action of the grater. Kernel was conveyed by gravity into the barrel of the screw press. As the screw press rotated, it conveyed and compressed the grated kernel thus extracting the milk out of it. The extracted milk is filtered off the barrel and collected through the tap and the cake is expelled at the end of the barrel.

## DESIGN CONSIDERATIONS

The grater and press srew were synchronized to make the machine work efficiently.

### *The grater*

The grater is made of up of stainless sheet metal with closely packed and randomly arranged teeth and then wrapped around a cylindrical disk. A transmission shaft is inserted through the cylindrical disc and driven by an electric motor. The size of the grater teeth is made to a size of 0.002 m in diameter and with an average tooth spacing of 0.008 m randomly distributed over the grating drum. This was reported by (Edem and Elijah, 2016) to produce the required particle size of 1300 µm for optimal yield of coconut milk. The capacity of any grater can be defined as the amount of material the grater can process at a particular time, usually expressed in kg/h. The capacity of a grater is a function of its size, teeth orientation and speed.

Fresh coconut fruits were obtained, deshelled, broken and weighed. The grater, powered by an electric motor with a speed of 750 rpm was put on. The speed of the grating drum was determined using equation 7, by calculating the ratios of the speed and size of the motor and grater pulleys. The weighed coconut kernel was introduced to the grater and a stopwatch was used in determining the time taken for the grating. Five runs of the experiment were carried out and for each run, the grating time and the mass of coconut after grating obtained were recorded. The loss and grating efficiency were also calculated using Equations 1 and 2:

$$L = f - d \qquad 1$$

$$\eta = \frac{d}{f} 100\% \qquad 2$$

Where $L$ is the loss in mass during grating, $f$ and $d$ represent the mass of feed of the coconut samples and mass of the grated.

About 500 g of hand broken coconut kernel were washed and fed into the coconut grating device. The grating time and mass of grated kernel were determined using a weighing balance and a stopwatch. The experiment was repeated six times with the loss in mass and efficiency calculated.

***The Screw Press***

The principle of differential pressure applied to the grated coconut along the screw length is the working mechanism of the device. The design used is a helical screw flight of uniform pitch fixed on a conical shaped shaft, supported by two bearings and enclosed in a barrel (Oyinlola, et al, 2004). The smaller end of the cone is placed under the hopper to receive the grated coconut. As the screw press rotates, it conveys the grated coconut towards the bigger end of the cone with reducing volume, thus compressing it against the inner wall of the barrel resulting in milk extraction by frictional, torsion and compressive forces. The cake is then discharged at the end of the screw. From a preliminary experiment carried out to determine the compression ratio of the grated coconut, a 3:1 compression ratio was observed satisfactory for the expulsion of the coconut milk. Equations 3 and 4 were used in the design of the screw press to achieve the required compression ratio (CR).

$$C.R = \frac{Volume\ displaced\ at\ the\ feed\ section}{volume\ displaced\ at\ the\ discharge\ section} \quad 3$$

$$C.R = \frac{D_1^2 - d_1^2}{D_1^2 - d_2^2} \quad 4$$

$D_1$ is the barrel diameter, $d_1$ is the diameter of the smaller end of the cone, $d_2$ is the diameter of the larger end of the cone. Taking, $D_1$ = 90 mm, $d_1$ = 40 mm, $d_2$ = 80 mm.

The screw flight is made of stainless steel welded to the conical shaft. The helix angle of the screw was determined using Equation 5 (Hall *et al.*, 1961)

$$tan \propto = \frac{Pitc}{\pi D} \quad 5$$

Where $\propto$ is the helix angle, D is the diameter of the screw. The screw clearance is therefore approximated to be 3 mm, the screw diameter 90 mm, the pitch 50 mm and the helix angle $10^o$.

The theoretical capacity of material that can be displaced by the auger flight can be determined using Equation 6 by Adetola *et al.*, (2014):

$$Q_e = 60\frac{\pi}{4}(D_2^2 - d_1^2)PN\varphi\rho \quad 6$$

where $D_2$ is the outer diameter of screw flight, $d_1$ is the diameter of the conical shaft at the feed section, P is the pitch of the screw, N is the rotational speed of the screw, ρ is the bulk density of coconut and $\varphi$ is the filling factor

The capacity of the screw press has to be equal to the capacity of the designed grater, therefore other parameters were designed to produce the predetermined grater capacity. $D_2 = 90\ mm, d_1 = 40\ mm,\ P = 50mm,\ N = 60\ rpm,\ \varphi = 0.8,$ $\rho = 401\ kg/m^3$. The theoretical capacity of the press $Q_e$, is therefore 294.8 kg/hr.

**The Pulley**

Olarewaju *et al.*, (2015) and Bello *et al.*, (2014) in their analysis reported that for a high yield of coconut milk, low rotation speed and moderate extraction time is advised. A 2hp gear reduction, motor operating at a speed of 750 rpm is used. The power was transmitted to the screw expeller using a V-belt and from the expeller to the grater using another V-belt (Kadurumba and Ogundu, 2020). Since the rotational speed of the screw press is 60 rpm, the screw expeller has to have six pitches. This means that it will take six turns for the screw to move materials from the beginning to the end of the conveyor. So, to achieve the required timing, the right size combination of pulleys is necessary. The speed of the shafts for the screw expeller and grater can be determined using Equation 7 (Gupta and Khurmi, 2004)

$$\frac{N_a}{N_b} = \frac{D_b}{D_a} \quad 7$$

where: $N_a$ is the speed of the motor (rpm), $N_b$ is the speed of screw shaft (rpm), $D_a$ is the diameter of the motor pulley (mm), $D_b$ is the Diameter of screw shaft pulley (mm)

Given that, $N_a = 750$ rpm, $N_b = 60$ rpm, $D_a = 30$ mm then $D_b = 375$ mm

From the preliminary experiment to determine the capacity of the grater, the grater was operated at a speed of 1500 rpm. Using the same motor with the screw press with a speed of 750 rpm, the pulley of the grater will thus be half the size of its driver motor pulley. The ratio of the pulley of the electric motor to that of the grater can be determined using equation 7.

Let $D_d$ be the diameter of motor pulley to be connected to the grater, $D_c$ be the diameter of grater pulley, $N_c$ is the speed of grater pulley, $N_b = 750$ rpm, $D_d = 60$ mm, $N_c = 1500$ rpm then $D_c = 30$ mm.

**The load capacity of the auger**

The amount of load the auger could lift was determined using the relationship between turning moment and axial load from Hall *et al.*, (1961) as shown in Equation 8.

$$W_e = T\frac{\frac{D_m}{2}tan\theta + \frac{f}{cos\propto}}{1 - ftan\theta cos\propto} \quad 8$$

where: T is the screw torque (Nm), $W_e$ is the load that can be lifted by the auger, $D_m$ is the mean thread diameter (mm) and f is the coefficient of friction for stainless

Using the calculated torque of 159 Nm, the maximum load the auger can lift is calculated to be 9352.9 kg. This is far beyond what the grated coconut can produce.

**Determination of the auger delivery pressure**

From Hall *et al.*, (1961), to determine the auger delivery pressure Pr, the pressing area Ap needs to first be determined. Equation 9 was used to determine the pressing area while Equation 10 was used to calculate the delivering pressure.

$$A_p = \pi D_m nh \quad 9$$

Then $$P_r = \frac{W_e}{A_p} \quad 10$$

where: $D_m$ is the mean diameter of the screw thread, n is the number of screw turns and h is the screw depth at the point of maximum pressure (the outlet)

The area was calculated to be 0.008 $m^2$. Thus, a pressure of about 1.165 MPa will be developed in the auger at its maximum weight.

**Power Requirement for the Machine**

The total power required to drive the device is the summation of the power required for the grater and the screw press. The grater has already been designed to a power of 1hp. The power required to drive the auger can be affected by the auger's pitch, diameter, rotational speed, grain properties and gravity (Cole, 2002). It can be determined using Equation 11 Adetola *et al.*, *(2014).*

$$P_s = 4.5Q_v I_s \rho g F \quad 11$$

where: $P_s$ is the Power to drive the auger, $Q_v$ is the volumetric capacity of the worm shaft, $I_s$ is the length of the worm shaft, g is the acceleration due to gravity, F is the material factor (0.4) and $\rho$ is the bulk density of grated coconut (401 kg/$m^3$)

$$P_T = P_g + P_s \quad 12$$

where: $P_T$ is the total power, $P_g$ is the power of grater and $P_s$ is the power of screw press

An estimate of the power of the electric motor needed to drive the device can be gotten from Equation 13,

$$P_m = \frac{P_T}{\eta} \quad 13$$

$P_m$ is the power of the electric motor and $\eta$ is the efficiency (75%). The exploded view of the machine is shown in figure 1 and figure 2 shows the pictorial.

Table 1 depicted the bill of measurements and materials required for the assembly of the device.

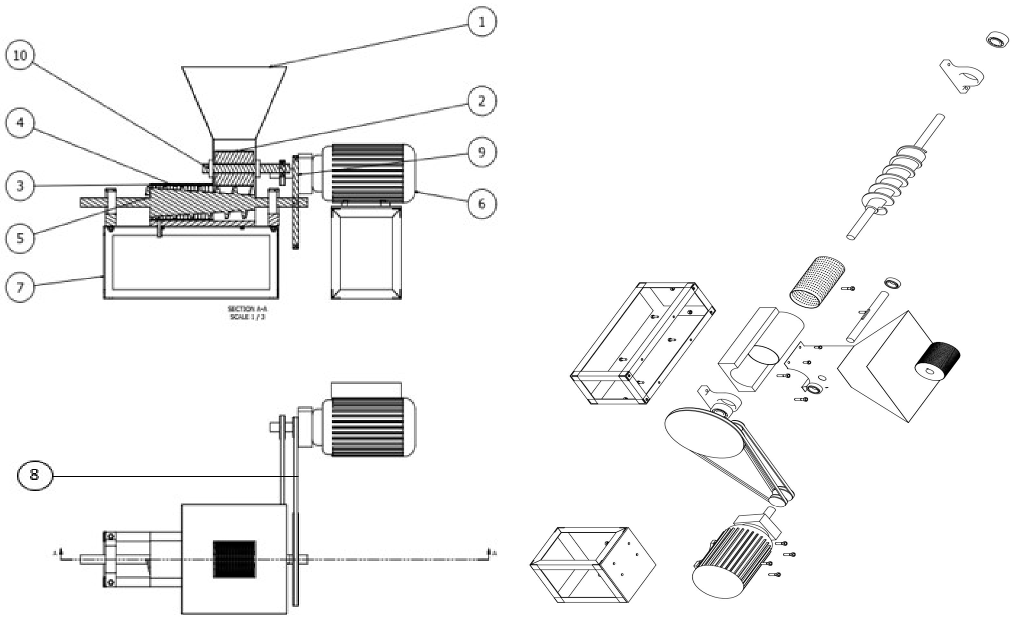


**Figure 1: Exploded view of the machine**

**<u>Legend</u>**

1. Hopper 2. Grater 3. Pressing tube 4. Sieve 5. Screw conveyor 6. Electric motor 7. Frame 8. Belt drive 9. Pulley 10. Bearing

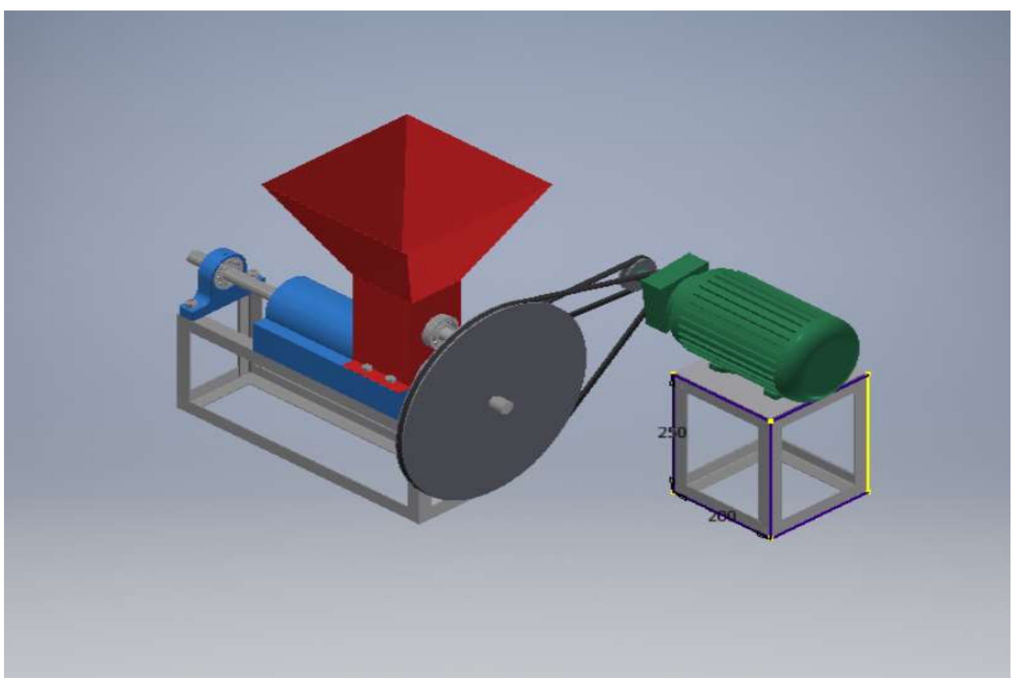


Figure 2: Pictorial view of the machine

Table 1: Bill of Engineering Measurements and Evaluation (BEME)

| Item | Part Number | QTY | Description | Cost ₦ |
|---|---|---|---|---|
| 1 | Frame 2 (AISC - L 1 x 1 x 1/8 ) | 1 | Angle Steel | 5000 |
| 2 | Small frame (AISC - L 1 x 1 x 1/8) | 1 | Angle Steel | 5000 |
| 3 | Barrel 2 | 1 | 1.5 mm Stainless Steel | 10000 |
| 4 | Strainer | 1 | Stainless Steel | 7000 |
| 5 | Auger | 1 | Stainless Steel, tapered shaft equal pitch | 10000 |
| 6 | Hopper | 1 | 1.5 mm Stainless Steel | 10000 |
| 7 | Grater | 1 | Stainless Steel | 5000 |
| 8 | Motor | 1 | 3 phase 3 hp electric gear motor | - |
| 9 | Rolling bearing B70000AC 146305 GB/T 292-94 | 2 | Rolling bearings - Angular contact ball bearings - Boundary dimensions | 12000 |
| 10 | V-Belt | 2 | V-Belt DIN 2215 | 1400 |
| 11 | Grooved Pulley1 | 2 | 30 mm and 375 mm circular diameter | 3000 |
| 12 | Grooved Pulley2 | 2 | 30 mm and 60 mm circular diameter | 2500 |
| 13 | AS 1112 - M8 Type 5 | 4 | ISO metric hexagon nuts, including thin nuts, slotted nuts and castle nuts | 750 |
| 14 | AS 1427 - M8 x 25 | 4 | ISO metric machine screws | 250 |
| 15 | AS B194 - 3/8x7/16-H AB | 8 | Tapping and metallic drive screws (inch series) | 200 |
| 16 | Bearing (BS 290 SKF - SKF 2305) | 2 | Self-Aligning Ball Bearings Double Row with Cylindrical Bore SKF | 4500 |
| 17 | AS 1427 - M10 x 35 | 4 | ISO metric machine screws | 180 |
| 18 | ISO 4161 - M10 | 4 | Hexagon nuts with flange-coarse thread | 420 |

Note: The three phases, three horse power electric motor was available in the Department

**Performance Evaluation of the Machine**

Fresh coconut fruits were obtained, de-shelled, broken to smaller pieces and washed. The machine was set in force and a measured quantity of the coconut was introduced into it through the hopper. The turning motion of the grater crushes the coconut kernel and drops the particles by gravity into the extractor where the milk was mechanically expressed. Both the expressed milk and the discharged cake were collected and weighed separately. From the values obtained, juice yield, expression efficiency and machine throughput capacity were computed.

**Milk yield**

Mathematically, milk yield $M_y$, is expressed in Equation 14 according to Olaniyan and Oje (2011)

$$M_y = \frac{W_{ME}}{W_{ME}+W_{RC}} \times 100\% \quad 14$$

The milk extraction efficiency $M_E$, can be expressed as the ratio of the mass of milk extracted to the mass of feed samples. Equation 15 applies.

$$M_E = \frac{W_{ME}}{W_{FS}} \times 100\% \quad 15$$

The extraction loss $(E_L)$, the expected milk yield $(E_p)$ and the deficit of milk yield $(D_f)$ can also be determined by the following mathematical relations in equations 16 to 18.

$$E_L = \frac{W_{FS} - (W_{ME} + W_{RC})}{W_{FS}} \times 100\% \quad 16$$

$$E_p = XW_{FS} \quad 17$$

$$D_f = E_p - E_A \quad 18$$

where: $W_{ME}$ is the Mass of milk extracted, $W_{FS}$ is the Mass of feed samples, $W_{RC}$ is the Mass of coconut cake after extraction, $X$ is the moisture content of coconut used for the experiment (in decimals), $E_A$ is the Actual milk yield.

## RESULTS AND DISCUSSION

There were eight experimental runs to test the performance of the device. A constant mass of 500g of cococnut was used throughout the runs. Figure 3 shows the coconut cake and figure 4 shiws the milk extracted from the coconut. The machine performance evaluation results were depicted in Table 2. The mean and standard deviation (SD) were calculated for each of the important parameters and were presented in the Table 2. The result showed that an average of 175.75 g of milk was extracted and 311.88 g of cake discharged. This tells us that at least 36% of the total mass of fresh coconut meat was made up of extractable milk. This was 9.35% less than the expected milk yield which was about 81% of the total moisture content of the coconut kernel. The results also showed that the machine was about 35.15% efficient with an extraction loss of about 2.48%.

**Table 2: Machine Performance Evaluation Results**

| | $W_{FS}$ (g) | $W_{ME}$ (g) | $W_{RC}$ (g) | $X$ | $E_A$ (g) | $E_L$ (%) | $E_p$ (g) | $D_f$ (g) | $M_y$ (%) | $M_E$ (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 500 | 166 | 309 | 0.45 | 166 | 5.00 | 222.5 | 56.5 | 34.95 | 33.2 |
| **2** | 500 | 168 | 313 | 0.45 | 168 | 3.80 | 222.5 | 54.5 | 34.93 | 33.6 |
| **3** | 500 | 174 | 318 | 0.45 | 174 | 1.60 | 222.5 | 48.5 | 35.37 | 34.8 |
| **4** | 500 | 173 | 319 | 0.45 | 173 | 1.60 | 222.5 | 49.5 | 35.16 | 34.6 |
| **5** | 500 | 171 | 322 | 0.45 | 171 | 1.40 | 222.5 | 51.5 | 34.69 | 34.2 |
| **6** | 500 | 176 | 312 | 0.45 | 176 | 2.40 | 222.5 | 46.5 | 36.07 | 35.2 |
| **7** | 500 | 187 | 306 | 0.45 | 187 | 1.40 | 222.5 | 35.5 | 37.93 | 37.4 |
| **8** | 500 | 191 | 296 | 0.45 | 191 | 2.60 | 222.5 | 31.5 | 39.22 | 38.2 |
| **Mean** | 500. | 175.75 | 311.88 | 0.45 | 175.75 | 2.48 | 222.5 | 46.75 | 36.04 | 35.15 |
| **SD** | 0.00 | 8.84 | 8.34 | 0.00 | 8.84 | 1.31 | 0.00 | 8.84 | 1.66 | 1.77 |

Figure 3: Cococnut cake


Figure 4: Milk Extracted

## CONCLUSION

A simple and portable device for grating coconut and extracting its milk was successfully developed. The designed grater's capacity was observed to be 299 kg/h. and the pressing unit was also designed to about that same capacity for a synchronized running of the grater and the pressing unit. The experimental machine gave the highest milk yield of 39% and an average milk yield of 36% which is about 81% of the milk content of the coconut kernel. Also, the average milk extraction efficiency was 35.15%, showing that the machine can produce about 105 kg of milk per hour.

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