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Development and Evaluation of an Improved Inclined Belt for Separating Palm Kernel and Shell

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Research Article

Abstract

An improved inclined kernel and shell separating machine was developed based on the principle of angle of repose and factors influencing the separation technique investigated. The difference in frictional characteristics of the kernel and shell was exploited in the design and the developed machine was evaluated for separating efficiency using the roller speed, feeding point, and surface roughness of the inclined belt as determining factors. A predetermined angle of 19^o, above angle of repose of kernel but below that of shell was used for the inclined surface enabling free fall of kernel. Results from the evaluation revealed that maximum separating efficiency of 97% was attained at optimal settings of roller speed of 58.3rpm, feeding distance of 500mm along the plane and using fabric material surface (Rug). Hence, the three factors were critical in improving the separating efficiency of the adopted technique for high kernel recovery and thereby enhancing the quality of palm kernel oil production with insignificant 3% shell contaminations.

Keywords
Angle of repose; feeding distance' frictional surface; palm kernel/shell separation; roller speed.

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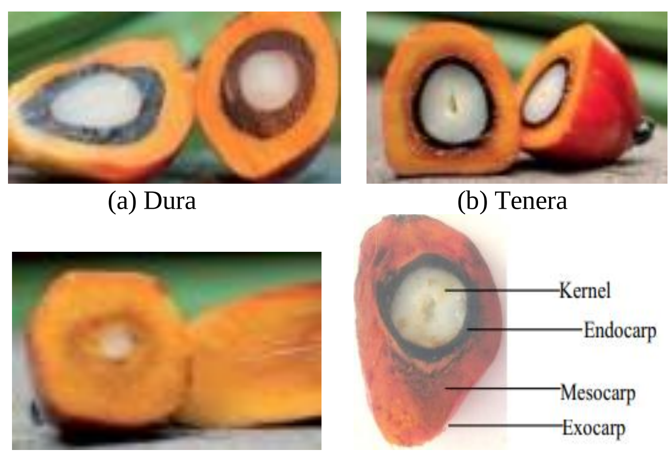
1. Introduction

Palm nut is an essential product of oil palm fruit, *Elaeis guineensis*, from the tribe of *ceoxylimae* and of the *palmaceae* family. When harnessed, the nut consists of small embryo (kernel) encapsulated in mass of hard oily endosperm, bounded by a tough black integument called; the testa. The kernel and the cracked shells are of great potentials for wealth creation in Nigeria. While the kernels and its' derivatives have wide applications in cosmetics, soap making, vegetable oil industries, medicine and agriculture (livestock feeds); the shells are exploited in foundry, civil works and even as source of energy. The nut is classified from its oil palm fruit origin based on the pericarp thickness as dura, tenera and pisifera (Figure 1). Dura has kernel size usually larger than other varieties, having shell thickness of about 2 - 5 mm. Tenera has a thick pericarp of about 60% fruit weight containing very high oil and shell thickness of 1 -2.5 mm which promotes easy cracking while pisifera has the thickest pericarp with higher oil yield but little or no nut/kernel (Nwankwojike *et al.*, 2011). These varying physical characteristics impose design challenges on the palm kernel processing equipment such as nut cracker and kernel/shell separating machine (Eric *et al.*, 2009; Akinoso and Raji, 2011; Ezeoha, 2011). Although, efficient nut cracking has been realized, pure kernel recovery from the mixture of kernels and shells for high quality kernel oil production is yet to be achieved satisfactorily. Thus, the target to develop and evaluate an improved kernel and shell separating machine for increased palm kernel production in meeting the huge demand of agro based industries.



(a) Dura (b) Tenera

(c) Pisifera (d) Structure

Figure 1: Types and structure of oil palm fruit (Edet *et al.*, 2022)

Cracking of palm nuts in the ancient times began with the use of stone to impact on the nut, leading to breaking of the shell and release of the kernel inside. This age long practice was bedeviled with drudgery and low output hence giving way to a technologically driven and mechanized system of cracking using the palm kernel-cracking machine. The machine was generally designed to impart force on the nut against an anvil (hard wall of metal) causing breakage of the shell and release of the kernel seed. The product from nut-cracking operation is a mixture of kernel and wrecked shell of irregular shapes but comparable sizes. Subsequent to cracking is the separating/sorting operation, during which the kernels are separated from the shells. The requirements for kernel cleanliness and quality present a major challenge in the palm kernel oil extraction process for other downstream industrial applications. Consequently, sufficient progress has not been made in mechanization of kernel and shell separating technology that guarantees distinct separations.

Traditional hand-picking method was initially common though with huge attendant drudgery, time consuming, clamp and fatigue in addition to very low output. At present, methods employed in the separation of the mixture (kernel and shell) are broadly classified based on the medium and techniques used. The media are of 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. For the dry method, no liquid medium is involved. Kernels recovered in wet systems requires sterilization against molds' growth and re-drying (with extended toasting time) of 14 – 16 hrs in silos to remove moisture absorbed during the separation process (Akubuo and Eje, 2002). This inadvertently affects the quality of the palm kernel oil produced. Oriaku *et al.*,(2010) also classified separation as air medium (traditional winnowing, pneumatic separator, specific gravity table separator), liquid medium (clay and salt baths), screening process (indented cylinder, spiral separator, screen or sieve separators), frictional process and separation by angle of projection.

Realization of efficient separation was found to be largely dependent on the choice of the separation techniques informed by differences in certain characteristics of the kernel and shell. Studies in developing suitable kernel and shell separating machines are ongoing with attempts on integration of both cracking and separating operations. Ismail *et al*., (2015) developed an improved palm kernel shelling and sorting machine with a shelling and sorting efficiency of 90%, and throughput of 59 kg/h. The whole kernel recovery was 70 percent. Adejugbe *et al.* (2017) designed an improved palm kernel shelling and sorting machine that cracks palm nut of all sizes with an incorporated sorting unit for separation. The efficiency of the machine was reported to be over 90% with processing rate of 95 nuts per second. A comparison was made with an existing palm kernel machine of 90% efficiency and 87 nuts per second processing rate without separation. Oriaku *et al*.,(2010) had earlier developed a palm nut cracker separator machine that uses angle of projection principle to achieve separation. Though, they reported separating efficiency of 87%, the design requires large installation space to account for range of throw during separation. A recently optimized palm kernel cracker machine (Udo *et al*.,2015) recorded efficiency of cracking up to 95% and ability to crack about 10-20 kernels at a time depending on the impact velocity and cracking surface area of the anvil. This machine demonstrating high production capacity, however, only cracks the nut; thus automatically creating the need for an efficient kernel and shell separation. Reviews conducted on separating techniques showed frictional process based on the angle of repose principle as more promising. The angle of repose/coefficient of friction of materials on various surfaces was found to be very important in predicting the movement of the materials in the processing equipment (Nwankwojike 2012). Thus, separation technique based on the coefficient of friction of a modified inclined plane was suitable for separating palm kernel and shell.

In general, the coefficient of friction (μ) of any surface in contact with another is related to angle of repose (θ) as in (1).

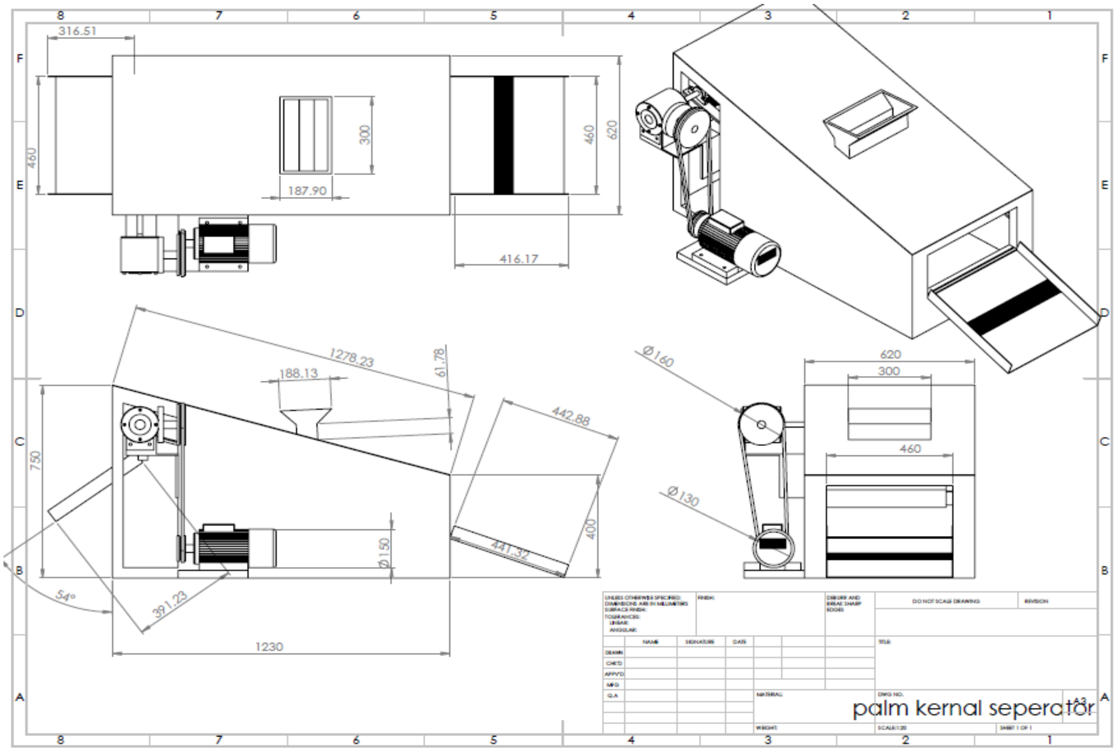
$$\mu = \tan\theta \qquad (1)$$

2. Materials and Methods

The materials used in the production of the kernel shell separation machine includes mild steel metal sheet/ plates, galvanized circular hollow rod (pipe), mild steel angle bar, pulleys, bearings, bolts and nuts, metallic rollers, V-Belts, wooden brush, fabric (rug) material, electric motor, speed reducer. A 100 kg of cracked palm nuts (kernel and shell mixture) gotten from a palm kernel processing plant at Dozy way Umuahia, Abia State, Nigeria was used for the developed machine performance evaluation. A digital weighing balance was used in weighing the mixture of kernel and shell, tachometer was used to measure the output speed of the roller and meter rule for measurement of distances along the plane. The assembled design of the developed machine is shown in Figure 2.

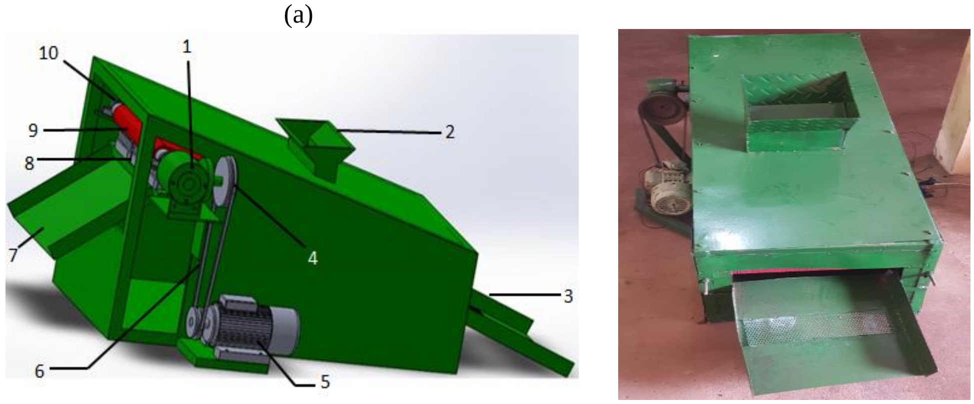
2.1 Description of the machine

The palm kernel shell separator machine consists of the hopper with top and bottom having rectangular forms mounted on the top side of the machine. The hopper enables the free fall of the kernel and shell mixture to the rotating inclined rug due to gravity. The framework of the outlined dimension (750 mm high by 1250 mm long and 620 mm wide) was formed with angular bars covered with mild steel plate concealing the mechanism of the machine. Another part of the machine is the rug with thickness 0.3 mm and length 2100 mm that is attached end to end on the rollers inclined at angle of 19^o to enable effective separation of the kernel from the mixture of kernel and shell. The roller brush that is in octagonal shape that brushes off the shell or other rough particles that stick to the surface of the rug after dropping the shell through the exit channel. A speed reducer was mounted at the upper roller with speed ratio of 15:1 to achieve a suitable speed for effective separation. Two pulleys, 100 mm diameter mounted on the electric motor and 160 mm diameter mounted on the speed reducer were used with an open belt arrangement for power transmission. Two collectors were installed (the first collector mounted at the upper exit of the machine for the shell collection and the second collector mounted at the low exit of the machine for the kernel collection). Lastly, a sieve was introduced at the lower exit of the kernel to enable the fibers/small particles of the mixture drop through it and thereby allowing only kernels to roll to the collector.



(a)

No.	Machine components
1.	Speed reducer
2.	Feeding Hopper
3.	Kernel exit chute
4.	Pulley
5.	Electric motor
6.	Belt
7.	Shell exit chute
8.	Brush
9.	Fabric Material (Rug)
10.	Roller



(b)

Figure 2: (a) Design drawing (b) Assembled Kernel/shell separating machine

2.2 Design Considerations and Analysis

The considerations on the design and selection of the components of the machine were based on functional requirement, strength, availability and cost implications. Modification for improved performance was conducted. The design improvement of existing stand-alone separator was done based on the following considerations:

i. To improve the separation efficiency of the machine by properly determining the best/ suitable angle between the angles of repose of the kernel and the shell.
ii. Selecting a frictional surface with adequate frictional characteristics (surface roughness) as a conveyor to properly separate the kernel from the shell.
iii. To determine optimum speed for maximum separation efficiency.

2.2.1 Design of the rollers

The roller was locally fabricated with a galvanized circular hollow rod with light weight property to enable the separating surface (belt) move freely as they rotate along with the bearings. The roller has a total length of 600 mm and 50 mm diameter.

2.2.2 Selection of inclined surface

The separation of the kernel and shell through different exit channels was possible through the ability of the rug to retain the shell due to its frictional property inclined at an angle which is below the angle of repose of the shell and drops off the kernel as its angle of repose is attained. The total length and width of the rug are 2100mm and 440mm respectively, selected based on distance between rollers and machine proposed capacity

2.2.3 Determination of the machine angle of inclination

The angle of repose, θ of the kernel/shell was determined using Equation 2.

$$Tan\ \theta = \frac{h}{d} \tag{2}$$

where, h = height of pile of kernel or shell (inclined plane)
d = fixed horizontal distance of the inclined plane just before the specimen slides.

The height of the pile of kernel/shell was taken and the distance made by the piled kernel/shell was taken. Then, the values were substituted into Equation 1.
The angle of repose of the kernel was found to be 14.57°. Similarly, the angle of repose of the shell was found using same procedure as 34°. Using these two angles of repose as extremes, experimental interpolation was carried out to determine the suitable angle of inclination of the separator machine that enables free fall of the kernel and retain the shell on the rug while transported through the shell exit channel. Angle of inclination of 19^o favored high kernel recoveries and therefore was selected.

2.2.4 Speed determination and variation

The speed of the electric motor is 1400 rpm, while the speed ratio of the reducer is 1:15 input speed to output speed since separation is a low-speed operation. Pulleys were further used to vary the input speed of the speed reducer from the electric motor using velocity ratio relation of Equation 3.

$$\frac{N_1}{N_2} = \frac{D_2}{D_1} \tag{3}$$

Therefore, $N_2 = \frac{N_1 \times D_1}{D_2}$

Where: N_1 = speed of the electric motor (rpm), D_1 = diameter of pulley on the motor(mm), N_2 = input speed of the reducer (rpm) and D_2 = diameter of the pulley on the reducer (mm)
With speed reducer output ratio (1:15) the roller speed, N_R was determined as

$$N_R = \frac{N_2}{15} \tag{4}$$

$$\omega = \frac{2\pi N_R}{60} \tag{5}$$

Where ω is the angular velocity of the roller
The peripheral velocity of the fabric material was determined using Equation 6

$$V_p = \omega R_r \tag{6}$$

Where V_p is the velocity of the fabric surface and R_r is the radius of the roller (25mm).

With the diameter of the roller as 50mm, (R_r=25mm), the power requirement (P) was determined as

$$P = (T_1 - T_2) R_r \omega \tag{7}$$

Where T_1 and T_2 are tensions at the tight and slack sides of the belt separator respectively.
The design settings of the machine were D_1=100mm, D_2= 160mm, N_1=1400, N_2=875 N_R =58.3, ω=6.1rad/s, R_r=25mm and V_p = 0.1525m/s, 1 HP electric motor.

2.3 Performance Evaluation Procedure

The developed inclined belt separator was evaluated at different speeds (N), different feeding point (y) and the use of different frictional surfaces (nylon, leather, polypropylene and rug) for the separating inclined surface. These input parameters were chosen to evaluate the separating efficiency of this machine and it was performed at an angle of inclination of 19°. The machine performance parameter: separating efficiency (SE) as posited by Alade *et al.* (2019) is the product of kernel recovery and shell recovery per a cent; thus Equation 8.

$$SE = \frac{Kr\ Sr}{100} \tag{8}$$

Where Kr is the kernel recovery efficiency and Sr is shell recovery efficiency

$$Kr = \frac{M_{sk}}{M_{sk} + M_{lk}} \times 100 \tag{9}$$

Where M_{sk} is the mass of separated kernels and M_{lk} is the mass of kernel apparently discharged with the shell.

$$Sr = \frac{M_{ss}}{M_{ss} + M_{ls}} \times 100 \tag{10}$$

Where M_{ss} is the separated shells and M_{ls} is the mass of shell discharged with the kernels
Performance evaluation was conducted subject to varying the output speed of the speed reducer (Roller speed, N_R) as determined in section 2.3 for varying D_2 shown in Table 1.

Table 1: Machine speed variation using V.R relation

D_1(mm)	**N_1(Rpm)**	**D_2 (mm)**	**N_2 (Rpm)**	**N_R(Rpm)**
100	1400	120	1166.7	77.8
100	1400	140	1000	66.7
100	1400	160	875	58.3
100	1400	180	777.8	51.85
100	1400	200	700	46.7

It was also done with respect to the feeding point on the inclined rotating plane, y. Different distances were chosen. Letting L be the total length of the inclined separator plane and x, the distance from the upper side of the machine to the position of the hopper while y is the distance from the lower end to the hopper along the plane, thus:

$$L = y + x \tag{11}$$

The total distance (L) of the separating inclined plane is 1050 mm

Therefore, y was varied at different location (y = 800 mm, 650 mm, 500mm, 350 mm and 300 mm) to determine the position of the hopper with the best separating efficiency while keeping other factors constant.

Performance evaluations with respect to the material surfaces as the separating mechanism were carried out. Nylon, Leather, Polypropylene and Fabric (rug) materials were used as the separating surface which provided different separating efficiency. 10kg of kernel/shell mixture was used in each test.

2.5 Cost Evaluation

Table 2: Bill of Engineering Measurement and Evaluation as at 10th September, 2021 ($1/N525)

S/N	Items	Quantity	Unit	Rate	Cost (N)
1	Pulley	2	mm	7000	14000
2	Bearing	4	mm	500	2000
3	Roller	2	mm	2000	4000
4	Speed reducer	1	mm	25000	25000
5	Metal sheet	1	mm	15000	15000
6	Bolts and nuts	28	mm	200	5600
7	Mild steel angular bar	1	mm	7000	7000
8	Belt	1	mm	1000	1000
9	Electric motor	1	HP	30000	30000
	Total				N103,600.00

3. Results and Discussion

3.1 Effect of Speed Variation on Separating Efficiency

Table 3 shows the effect of the speed variation on the separation efficiency.

Table 3: Effect of the speed variation on the separation efficiency.

S/N	Speed(rpm)	Separating efficiency (%)
1	93.30	89.10
2	77.80	91.59
3	66.70	93.80
4	58.30	94.67
5	51.85	87.70
6	46.70	73.13

As the roller speed of the inclined plane separator is altered, the kernel and shell recoveries varied, thereby affecting the separation efficiency of the machine. From the table, the result showed that at high speed, the separation was poor but peaked at 58.3rpm with an indication that it is the optimal operating speed for best separating efficiency. The implication was that at high speed, there was no resident time for kernels to attain its' angle of repose as they were quickly carried together with the shell to the shell discharge spout thus reducing the kernel recovery. Conversely, when the speed drops below 58 rpm, the low speed of the roller (resulting in slow speed of inclined plane) will increase the resident time of the shell on the fabric material thus allowing agitation and shake off of the sticking shells down the plane along with the kernels thereby reducing shell recovery with increased kernel contamination.

3.2 Effect of Feeding Point Variation on Separating Efficiency

While evaluating the machine with varying positions of the feeding point, it was noticed that as the feeding point increases up the inclined plane (at constant speed of 58.3rpm), the kernel recovery rate drops significantly, but moving the feeding point toward the lower side of the machine, an increase in the kernel recovery was observed as the shell recovery remained constant. From Table 4, the result showed that the feeding point affects the separation efficiency. When the feeding point was positioned at 800mm from the lower end of the machine, the separation efficiency was poor because the kernel recovery rate was low. This showed that the position of the feeding hopper affects the resident time required in the free fall of kernels.

Table 4: Effect of feeding point variation on the separating efficiency

S/N	Y(mm)	Separating efficiency (%)
1	800	74.70
2	650	92.00
3	500	96.34
4	350	93.12
5	300	86.07

When the feeding point was positioned at 650mm from the lower end of the machine, it was observed that the separation efficiency increases significantly, then getting to 500 mm distance, a very high kernel recovery rate that improved separation efficiency of the machine was observed.

When the feeding point was moved further down to a distance of 350mm from the lower end of the machine, shells recovery rate dropped thereby reducing the separating efficiency of the machine. Going further down to 300mm from the lower end of the machine almost same effect at 350mm was observed. Therefore, at feeding point distance of 500mm from the end of the machine proved to provide the best separating efficiency.

3.3 Effect of Inclined Surface Material on Separating Efficiency

Table 5 shows the effect of frictional surface on the separating efficiency

Table 5: Effect of frictional surface on the separating efficiency

S/N	Materials	Coefficient of friction (μ)	Separating efficiency (%)
1	Nylon	0.44	39.00
2	Leather	0.48	78.46
3	Polypropylene	0.71	86.00
4	Fabric (Rug)	0.82	95.89

It shows how different materials used at the inclined separating plane affects the separation efficiency of the machine due to the varying frictional characteristics (coefficient of friction). Nylon material was used for the first experiment, and it was observed that the separation efficiency was poor due to the low frictional property of the nylon material. When leather material was used the separation efficiency increased though the kernel recovery rate was poor and affected the separation efficiency of the machine. The next material used was polypropylene which gave a good separating efficiency due to its high frictional property.

However, when a fabric material (rug) was used, a higher separating efficiency was observed as high coefficient of friction enhances sticking of the shells (with high angle of repose) to the material for high shell and kernel recoveries hence its adoption in fabricating the machine.

At the roller speed of 58.3rpm, feeding point of 500mm and with surface of rug (Fabric material), a maximum separating efficiency of 97.04 % was obtained with the separated kernel and shell shown in Figures 3 and 4 respectively.

Figure 3: Separated kernel

Figure 4: Separated Shell

4. Conclusion

The improved kernel/shell separating machine was developed and tested at Michael Okpara University of Agriculture, Umudike. The performance evaluation test conducted revealed that the separating efficiency of the machine improved at optimal settings of machine and operational parameters of 500mm of the feeding point along the plane, the roller output speed of 58.3rpm and the fabric material (rug) of friction coefficient of 0.82 used in the fabrication of the machine. With the improvement, the machine was observed to provide a separating efficiency of over 97%, which is greater than the existing separating machines and projected inclined belt separating efficiency of 70%. The improved inclined plane separating machine has improved the quality of the processed kernel oil as the shell contamination of kernel is significantly reduced to 3%. It is recommended that this machine be optimized with respect to the various capacities and integrated with a nutcracker for adoption by small and medium scale palm kernel oil millers to help eliminate drudgery and increase quality kernel oil production.

Acknowledgment

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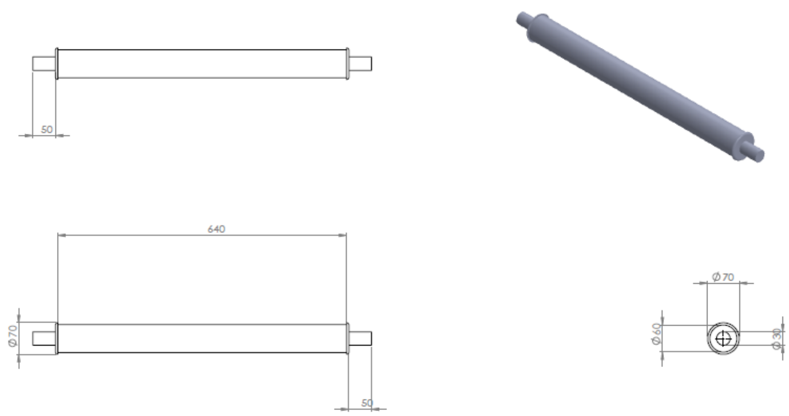
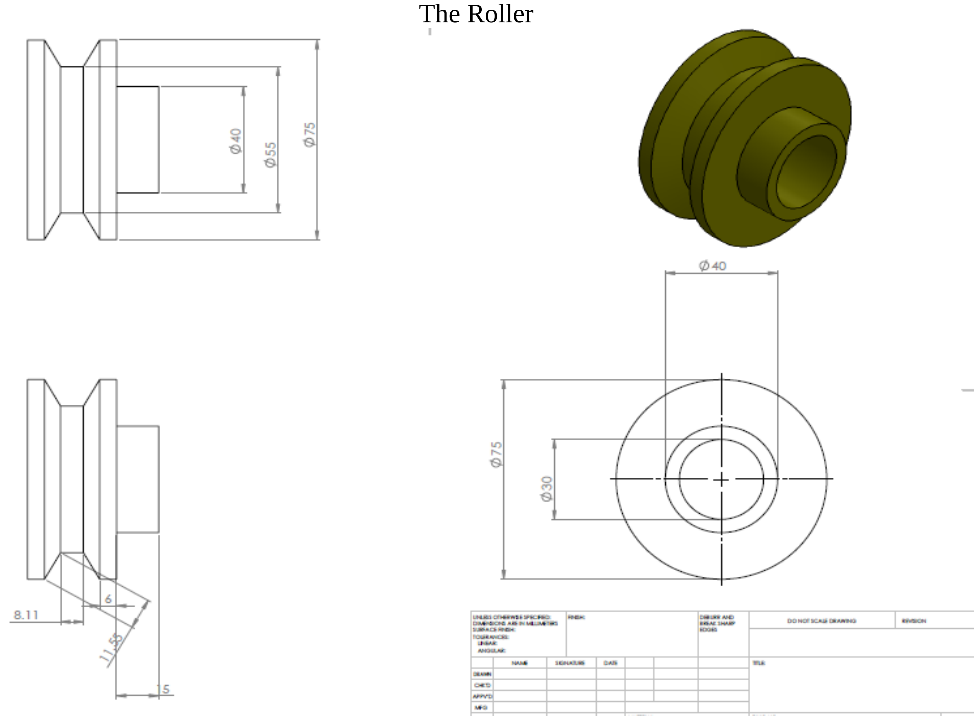
APPENDIX: Components



The Roller



The smaller Pulley