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Design and Performance Evaluation of a Corn De-Cobbing and Separating Machine

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Abstract: - Agricultural products like maize, soya bean, millet and rice, when processed into quality forms not only prolongs the useful life of these products, but increases the net profit farmers make from mechanization technologies of such products. One of the most important processing operations done to bring out the quality of maize is de-cobbing or threshing of maize. Consequently, a de-cobbing and separation machine was designed, fabricated and its performance evaluated. Corn at moisture content of 15.14% db sourced locally was used in the experiment and the data collected were analyzed. Results showed that for a total 20kg of sample tested, the average feed and threshing time were 2.37 and 2.95 minutes respectively. The average feed and threshing rates were 2.06 and 1.65 kg/min with an average threshing efficiency of 78.93 %. The average separation efficiency was 56.06 %. These results indicate that threshing and separation can be performed out satisfactorily with the designed machine and it can be used to process about 1 tonne of maize per nine-hour shift.

Keywords: *- Maize, Separation, Efficiency, De-cobbing, Design*

I. INTRODUCTION

Maize, the American Indian word for corn, means literally that which sustains life. It is, after wheat and rice, the most important cereal grain in the world, providing nutrients for humans and animals and serving as a basic raw material for the production of starch, oil and protein, alcoholic beverages, food sweeteners and, more recently, fuel. In Africa, maize has become a staple food crop that is known to the poorest family. It is used in various forms to alleviate hunger, and such forms include pap or ogi, maize flour etc. It is because of the importance of maize that it's processing and preservation to an optimum condition must be analyzed. The major steps involved in the processing of maize are harvesting, drying, de-husking, shelling, storing, and milling. For the rural farmers to maximize profit from their maize, appropriate technology that suites their needs must be used. The processing of agricultural products like maize into quality forms not only prolongs the useful life of these products, but increases the net profit farmers make from mechanization technologies of such products. One of the most important processing operations done to bring out the quality of maize is shelling or threshing of maize.

In Nigeria maize constitute the staple food of large chunk of the populace. It is also responsible for about 60% by weight of most of livestock feed formulations. Peasant farmers are responsible for more than 70% of the maize produced annually while large scale commercial farmers constitute the remaining 30% (Adewumi, 2004). The problems of post harvest processing and storage of agricultural produce are well documented and various approaches are being employed in tackling it. For maize one of its post harvest challenges is shelling. Kaul and Egbo, 1985 reported that maize harvested are traditionally shelled by hand or by beating sacs stuffed with maize cobs with wooden flails. These traditional methods of shelling maize are time wasting, hazardous and associated with lots of drudgery. They also described shelling as a process of repeated pounding or dragging of plant mass over a surface through an aperture. Akubuo, 2003 described the use of pestle and mortar as a process by which the dry maize is put into the mortar and pestle is used to hit the maize with impact forces. A considerable quantity of shelling is achieved per time but the amount of grain damage is high with low cleaning efficiency (Ologunagba, 2003).

There have been various means of shelling starting from the traditional pestle and mortar to the various mechanical and electro-mechanical devices. The use of 'cone' sheller was reported by Kaul and Egbo, (1985), the sheller consists of a cone with three to four lines of serrated ribs. The dehusked cob is rotated in the cone by one hand while the Sheller is held in the other hand rotating the cob against the internal rib of the Sheller to detach the grain from the cob. Adewale, et al (2002) and Adegbulugbe, (2000) established that shelling process is a function of moisture content. It is easier to shell maize dry than wet. Adewale et al (2002) also reported that the local techniques of shelling and winnowing of shelled maize is grossly inefficient judging by the serious bruises encountered by the crops. There are many types of maize shellers, but the motorized shellers are either imported or locally fabricated by local welders who have no knowledge of both the machine and crop parameters suitable for optimum performance of the shelling machines (Adewumi, 2004). Maize can also be dehusked and shelled but this is with a lot of kernel damage at the end of the processing operation (Adesuyi, 1983). Other types of devices used for shelling mechanism are cross flow rasp bar, axial flow rasp bar and spike tooth cylinder. A spike tooth cylinder is more positive in feeding than rasp bar cylinders with the added advantage that, it does not plug in easily. While rasp bars are easier to adjust and monitor and are relatively simple to operate and durable. The efficiency of shelling machines varies from one machine to the other as affected by some factors like the crop moisture content, feeding rate, shelling mechanism and the concave cylinder clearance (Adewale et al, 2002).

II. MATERIALS AND METHODS

Machine Description: the designed machine consists of the following components namely:

- Peforated de-cobbing barrel
- Shaft with spikes
- Bearings
- Barrel cover
- Inlet hopper
- Maize discharge spout
- Cob discharge spout
- Blower
- Blower mounting
- Structural frame work
- Electric motor
- Pulleys
- V-belts
- Keys and key sets
- Body cover
- Belt cover
- Air flow channel
- Bolts and nuts
- Hinges: locking device

The shaft carrying the spikes is suspended on two ball bearings. The spikes are arranged in spiral form (like a screw conveyor) with a uniform pitch. The bearings carrying the shaft are mounted on the structural frame work. The barrel cover carrying the inlet hopper houses the de-cobbing cylinder. The throat of the inlet hopper fits into a square hole created at one end of the de-cobbing cylinder. Both the barrel cover and de-cobbing barrel are static. The barrel is split into two halves but held at one side with hinges so that it can be opened and closed. The free end of the cover is provided with a locking device. The electric motor is mounted at one lower end of the structural frame. The assembled blower is mounted opposite to the electric motor. The air exit channel of the blower is connected against the maize exit spout. V-belts are used to connect the shaft carrying the spikes, the blower shaft to electric motor shaft via pulleys. All the components of the machine are mounted on a rigid structural frame work. The surface area of the de-cobbing barrel is perforated with a 12mm hole so that the de-cobbed maize grains and chaff can escape through them and fall to the collector that channels them to the maize exit spout. The assembled machine has the following dimensions: overall length = 1.28m; width = 0.92m; height = 1.39m; diameter of barrel cover = 0.32m; length of barrel cover = 1m; diameter and length of de-cobbing barrel = 0.21m and 0.95m respectively

2.1 Principle of operation;

The electric motor provides the primary motion required to power the machine. The motion and torque are transmitted via pulleys, v-belt and bearings to the shaft carrying the spikes and blower shaft connected to the impeller. Both the de-cobing spikes and blower impeller rotate in a clockwise direction. The whole maize (together with the cobs) are introduced into the machine through the inlet hopper. They reach the rotating spikes inside the de-cobing barrel by gravity. The spikes give continuous impact force on the whole maize, thereby removing the grains and chaff. Because the spikes are arranged in a spiral form, the whole maize moves along the length of the barrel in the forward direction until they reach the cob exit spout. Before the whole maize reaches this point, almost all the grains (seeds) are removed thereby letting the cob go out of the machine clean. Due to the impact of the spikes some of the cobs may be broken, though both broken and whole exit through the exit spout. The air generated by the blower impeller is channeled to flow against the maize grain exit spout via a wire mesh. The air blows off unwanted chaff that exit together with the maize grains thereby keeping the maize

grains very clean. The clean maize then run into the receiver where they are collected for further processing operations.
Advantages:

- The machine is portable, simple to operate and requires only one operator.
- Materials of construction are locally sourced and it is inexpensive
- Power requirement is low (1.5 – 2.5 hp)
- Its output is higher than the output of several persons put together.
- It de-cobs and separates simultaneously
- Grain damage is almost eliminated

III. DESIGN PRINCIPLES

The design consideration of this machine is based on three principles namely:

- The gravitational dropping of the whole maize through the inlet hopper to the rotating spikes and exit of the grains to the receiver.
- The impact force delivered by the rotating spikes to the whole maize and motion of this whole maize along the length of the de-cobing barrel
- The air generation and supply by the blower

The dropping of the whole maize through the hopper to the rotating spikes is governed by gravitational force (f_g) which is given as; (Ryder and Bennet, 1982)

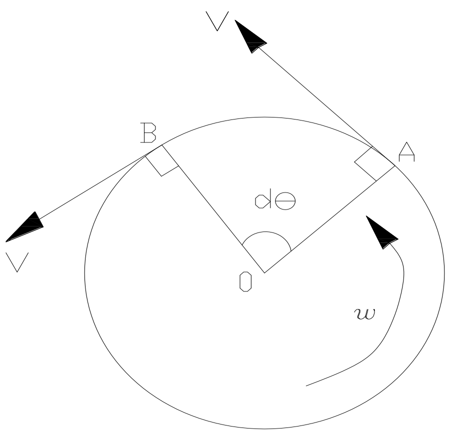
F= mg

Where: m = mass of whole maize g = acceleration due to gravity

The impact principle and air generation by the blower is achieved through the dynamics of the machine components namely: pulleys, belt, bearings and shaft. Circular motion of these components and gravitational motion of the whole maize through the inlet hopper and exit of grains through the exit spouts are employed to achieve the desired result.

3.1 Rotational motion and centrifugal force (F_C):

The rotational motion from the shaft of the prime mover (electric motor shaft) is transmitted to the driven shaft carrying the rotary spikes.



(Hannah & Stephens 1984)

Fig 1: Body experiencing circular motion

For any object of mass M moving in a circular motion, its acceleration is directed towards the centre of the body and its linear velocity is tangential to the radius of the object. The displacement which starts from point A, then to B and continues is in terms of θ. The angular velocity is designated ω. The acceleration (a) of the rotary body is given as

$$a = \omega^2 r. \qquad (1)$$

Where r = radius of the object. The acceleration is centripetal. The radially inward, or centripetal force required to produce acceleration is given as

$$F_c = Ma = M\omega^2 r = \frac{MV^2}{r} \qquad (2)$$ (Hannah and Stephens, 1984)

If a body rotates at the end of an arm, this force is provided by the tension on the arm, the reaction to this force acts at the centre of rotation and is centrifugal force. It represents the inertia of the body resisting the change in the direction of motion. A common concept of centrifugal force in engineering problems is to regard it as radially outward force which must be applied to a body to convert the dynamical condition to the equivalent static condition.

3.2 Rotational Torque (T):

The value of torque developed by a rotational body is given as the product of the force causing the motion multiplied by the radius of rotation

$\mathbf{T = F_C \times r}$ (3)

3.3 Work done by a torque:

If a constant torque T moves through an angle θ

Work done = T * θ (4)

If the torque varies linearly from zero to a maximum value T

Work done = $^1/_2$ T*θ (5)

In general case where **T = f (θ)** (6)

Work done = $\int f(\theta)\, d\theta$ (7)

The power (P) developed by a torque T (N.M) moving at ω rad/sec is

$\mathbf{P = T\omega = 2\pi NT}$ **(watts)** (8)

Where N is the speed in rev/min and

$\omega = \frac{2\pi N}{60}$ (9)

3.4 Pulley and Belt Drive:

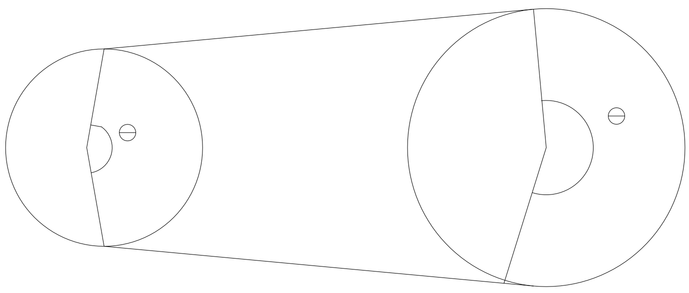


Fig 2: Diagram showing two pulleys connected by a belt.

The velocity ratio between two pulleys transmitting torque is given as (Avallone and Baumeister, 1997);

$\omega_1/\ \omega_2 = N_1/N_2 = D_2/D_1$ (10)

Where: ω_1 = angular velocity of driver pulley

ω_2 = angular velocity of driven pulley

N_1 = rpm of driver pulley

N_2 = rpm of driven pulley

D_1 = diameter of driver pulley

D_2 = diameter of driven pulley

Θ = angle of lap between belt and pulley

3.5 Tensions on Belt (T_1 and T_2):-

For belt transmission between two pulleys, the following equations by Hall et al., 1961 are used

$T_1/T_2 = e^{\mu\Theta}$ (11)

Also

$\frac{T_1 - T_c}{T_2 - T_c} = e^{\mu\Theta}$ (12)

And $T_c = mv^2$ (13)

$T_c = T_1/3$ i.e. $3T_c = T_1$ (14)

The power transmitted with the belt is given as

$P = (T_1 - T_2)\ v$ (15)

In this equation the power (P) is in watts, when T_1 and T_2 are in Newton and belt velocity is in metre per second.

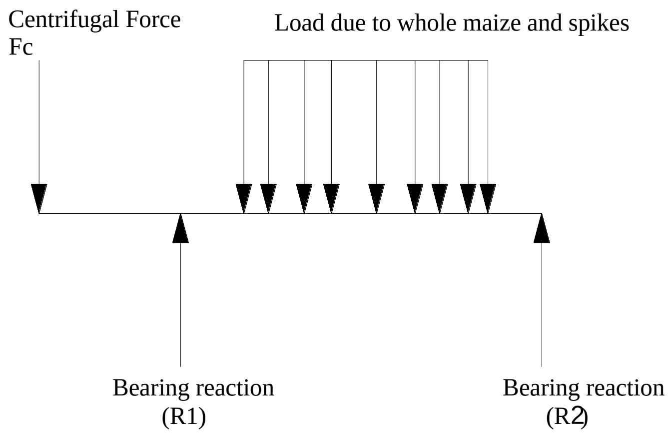
3.6 Belt Length (L):-

The belt length equation is given as (Avallone and Baumeister, 1997):

$$L = \frac{\pi}{2}\left(D_1 + D_2\right) + \frac{\left(D_1 - D_2\right)^2}{4C} + 2\,C \tag{16}$$

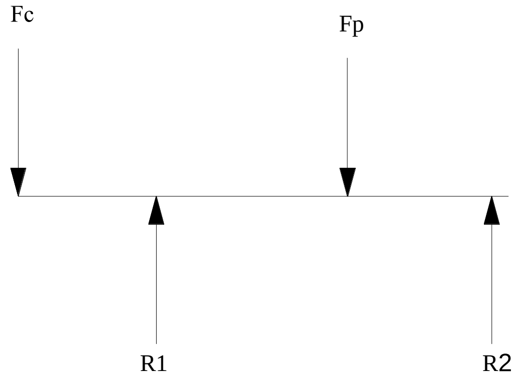
Where C = centre distance between two pulleys

3.7 Design of de-cobbing Shaft: - The shafts with the forces acting on it is represented schematically



(a)

For ease of calculations, the uniformly distributed load is made a point load as shown below



(b)

Fig 3 a & b: Schematic representation of loads on shaft

From the evaluation of the forces and determination of the bearing reactions, the maximum bending moments (Mmax) for the shaft is evaluated. The shaft diameter (D) is calculated using the ASME code standard for shafting. The ASME code equation for shafting is given as

$$D = \left\{\frac{5.1}{\tau_d}\left[\left(C_m \times M_{max}\right)^2 + \left(C_t \times T\right)^2\right]^{\frac{1}{2}}\right\}^{\frac{1}{3}} \tag{17}$$

For ASME code standard, $\tau_d = 0.3\sigma_y$ or $0.18\sigma_u$

The smaller of the two values is chosen as τ_d. The presence of key sit on the shaft reduces the value of τ_d by 75%. For rotating shafts, $C_m = 1.5$, $C_t = 1$

Definition of terms:

D = Diameter of shaft

τ_d = Allowable shear stress

C_m = Moment factor

C_t = Torque factor

M_{max} = Maximum bending moment

σ_y = Yield stress of shaft materials

σ_u = Ultimate stress of shaft material

Material used for the shafting is Stainless steel AISI 304

IV. SAMPLE PREPARATION

Already preserved corn was purchased from New market and Eke-Agbani markets in Enugu state. The samples were cleaned to remove dirt and any other foreign materials. Whole undamaged corn with cobs were selected and weighed in batches of 2kg. Some samples were collected and used to determine the moisture content of the corn. Samples of weight 2kg, 4kg, 6kg and 8kg were fed into the machine and feed time recorded. The shelled corn was collected through the exit chute and the cobs also collected through the cob exit. The collected shelled corn and the cobs were weighed and the weights recorded. The experiment was repeated twice and average values noted.

Fig 1 a) Whole Corn cob samples after cleaning b) Shelled corn collected form exit chute

c) Separated corn and cob after shelling

V. RESULTS

The results obtained from the experiment was recorded and shown in Table 1. The feed rate and threshing rate were obtained as a function of time while the separation efficiency was found by subtracting the weight of cobs collected at the exit spout form total sample collected and multiplying by 100 %. Threshing efficiency was obtained using the equation (Hamada et al, 2008). All the results obtained were analyzed to obtain their best fit mathematical models and their attendant coefficients of determination (R^2) values.

$$E_{th} = \frac{M_s - M_{ut}}{M_s} \times 100\%$$

Where; E_{th} = Efficiency of threshing (%)
M_s = Total mass of sample (kg)
M_{ut} = Mass of un-threshed seeds (kg)

Table 1: Data obtained from designed machine test

Wgt of corn	Feed time (min)	Threshing time (min)	Feed rate (kg/min)	Threshing rate (kg/min)	Threshing efficiency (%)	Separation Efficiency (%)
2kg	1.05	1.34	1.90	1.49	79.79	68.1
4kg	2.03	2.47	1.97	1.62	80.17	52.6
6kg	3.09	3.55	1.94	1.69	78.42	50.6
8kg	3.29	4.45	2.43	1.80	77.32	52.93

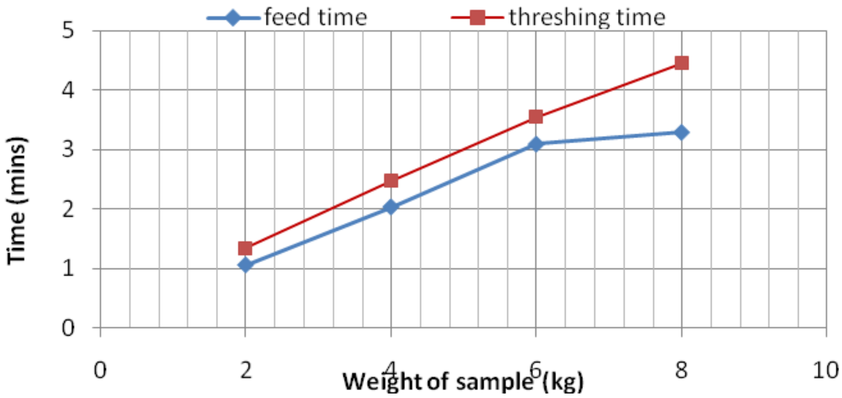


Fig 2: Feed time versus weight of sample

The plot above gives the trend observed for feed time and threshing time with respect to weight of sample. Both showed linear relationships indicating that they both increased with increase in weight of sample. Their best fit mathematical model equations are given below.

$$Y_f = 0.389\,x + 0.42 \qquad (R^2 = 0.939) \qquad (18)$$

$$Y_T = 0.520\,x + 0.35 \qquad (R^2 = 0.997) \qquad (19)$$

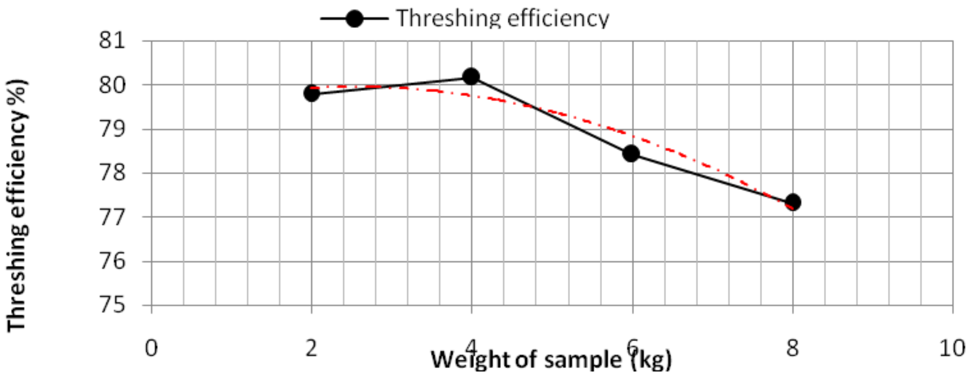


Fig 3: Threshing efficiency versus weight of sample

$$Y = -0.092x^2 + 0.467x + 79.36 \qquad (R^2 = 0.924) \quad (20)$$

Fig 3 shows threshing efficiency also had a quadratic relationship with weight of sample used. However, there was a slight increase before decreases started to occur. This is an indication that the more samples of materials fed into the machine the higher the probability of some not being threshed. The observed decrease was gradual as load increased.

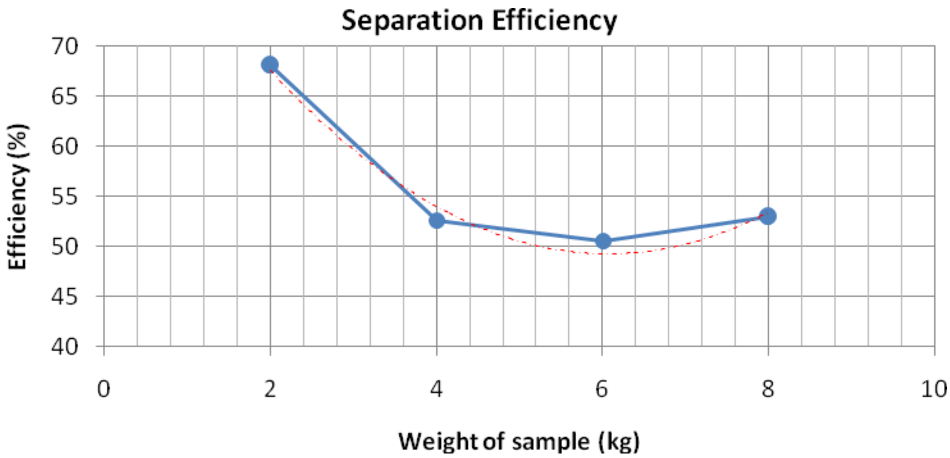


Fig 4: Separation efficiency versus weight of sample

$$Y = 1.114x^2 - 13.51x + 90.22 \qquad (R^2 = 0.978) \qquad (21)$$

Fig 4 showed that separation efficiency decreased as weight of samples increased. This can be attributed to the design of the machine which enabled separation to occur simultaneously with threshing. As samples increased, threshing rate increased and more materials were pushed towards the exit spout. Separation efficiency followed a quadratic trend with the model equation given in equation 21. The feed rate and threshing rate showed differing relationships to sample weight. While feed rate had a quadratic relationship, threshing rate exhibited a linear relationship. Their best fit model equations were also obtained and stated below (22 & 23). Threshing rate was on the other hand found to have a linear relationship with feed time (Fig. 6). Its best fit mathematical model is given in equation 24.

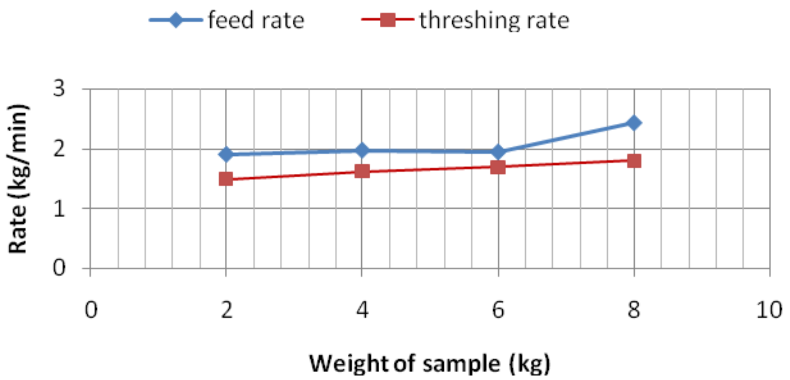


Fig 5: Separation efficiency versus weight of sample

$$Y_f = 0.026x^2 - 0.184x + 2.195 \qquad (R^2 = 0.896) \qquad (22)$$

$$Y_{th} = 0.05x + 1.4 \qquad (R^2 = 0.988) \qquad (23)$$

$$Y_{th} = 0.120x + 1.365 \qquad (R^2 = 0.924) \qquad (24)$$

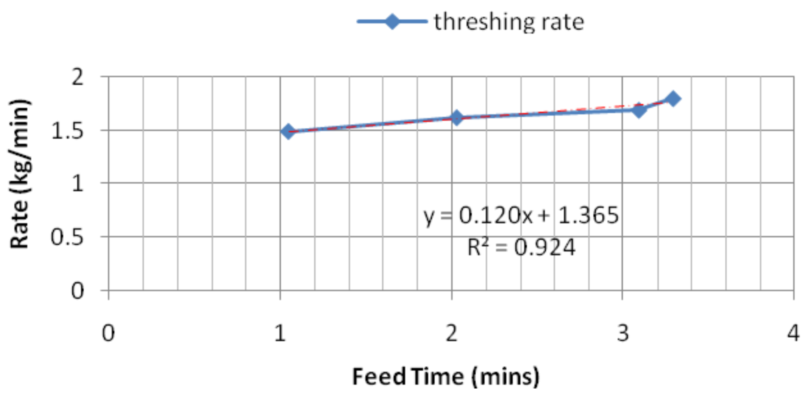


Fig 6: Threshing rate versus Feed time

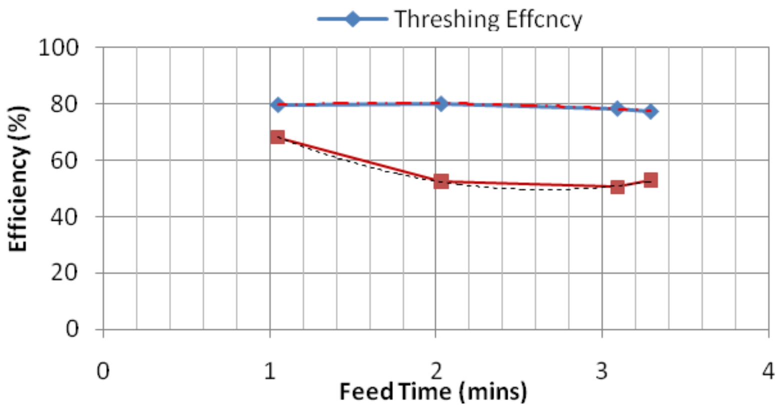


Fig 7: Threshing and Separation efficiency versus Feed time

$$Y = 7.195x^2 - 38.17x + 100.2 \qquad (R^2 = 0.998) \qquad (25)$$

$$Y = -1.192x^2 + 4.161x + 76.71 \qquad (R^2 = 0.982) \qquad (26)$$

From Fig 7, it can be observed that threshing efficiency seemed to be almost constant with respect to feed time while separation efficiency tended to decrease with increase in feed time. Both operations had quadratic functions as best mathematical models describing the relationship. However, it is important to note that the designed machine performed well in threshing but not so well in separation as more sample materials were fed. Projecting mathematically the points obtained, we see (Fig 8) that both processes diverged further. This implies that if more sample materials are fed into the machine continuously threshing efficiency will decrease slightly but separation efficiency will decrease greatly. This can result in clogging and necessitates adequate feed time regulation.

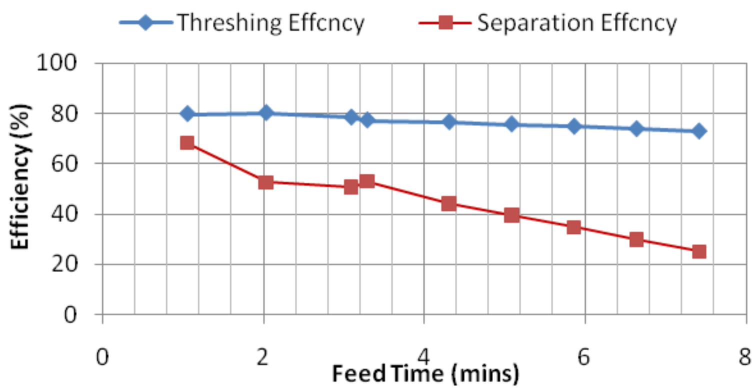


Fig 8: Projected Threshing and Separation efficiency versus Feed time

Fig 9: Photograph of designed machine

VI. CONCLUSION

From the results of the experiments carried out, the average feed rate of the designed machine was found to be 2.06 kg/min. This implies a value of 123.6 kg/hr while average threshing efficiency was obtained as 1.65 kg/min (99 kg/hr). The average threshing efficiency was found to be 78.93 % while the average separation efficiency was 56.06 %. These values were an improvement on the values obtained for human labour (as reported by Nwakire *et al*, 2011) where human mechanical efficiency was determined to be 45% at the biomaterial test weight of 20 kg with actually shelled grain weight of 15.8 kg. They also reported that human throughput capacity was 26.67 kg/hr and actual grain handling capacity of 21.1 kg/hr at a shelling time of 45 minutes or 0.75 hr. this shows clearly that the designed machine would perform satisfactorily and can process about 1 tonne of maize in 9 hrs. The design can be modified in order to find ways to improve the separation efficiency of the machine.

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