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Design And Performance Evaluation Of A Solar Powered Melon (Citrullus Species) Shelling Machine

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***Abstract*—Manual shelling of melon is slow, strenuous, inefficient and unhygienic. A Melon shelling machine powered with solar energy was designed and tested. It is an impeller-type which applies centrifugal force to crack the melon seed shell, thereby freeing the cotyledon from the outer shell. A separation shell was also introduced in a separation chamber to effect the separation of the chaff from the seeds. The machine is powered by a 12V, 100Ah D.C. battery which is charged by a 130W solar panel. It has a hopper made of stainless steel (150 x 150 x 80) mm connected to a Shelling chamber made up of the same stainless steel material (230 x 130) mm. An impeller made up of reinforced plastic material for cracking the melon seeds is placed inside the shelling chamber, attached below shelling chamber is the separation chamber (200 x 600) mm which has a fan of 200 mm diameter made up of reinforced plastic material installed into it. Results of performance tests conducted for the two days showed that on the first day of test, the highest shelling efficiency of 67.99% was obtained at an average solar radiation of 650.87 W/m^2, an output voltage of 13.7 V. It was observed that the quantity of fully shelled seeds is higher as global solar radiation is high hence the output voltage from the panel. The same thing applies on the second performance test; the highest shelling efficiency recorded was 66.10% at an average solar radiation of 655.3 W/m^2 with an output voltage of 13.9 V. These results indicate that the solar Melon shelling machine will only be effective when there is a clear blue sky.**

Keywords—Design, Solar Energy, Melon seeds, Shelling chamber, Separation chamber, shelling machine

I. INTRODUCTION

Melon seeds are popular in the sub-Saharan Africa and Asia. Egusi as it is called is a popular fruit in Nigeria because of the edible seeds, which are commonly used in the preparation of local soup or stew and snacks. It is a tendril climbing herbaceous annual crop which grows better in some parts of the savannah belt region of Nigeria. Nigeria as an agricultural nation grows a lot of melon among other seedlings during the planting season of the year. Several tones of this melon seeds are gathered each harvesting period of the year. Farmers and other users of melon perform melon shelling through the cumbersome and wasteful manual methods. The main cultivars of the crop are Bara and Serewe in Nigeria. Bara is characterised by large brown seeds, thick black edges, and a mean dimension of 16 x 9.5 mm. It is dominantly found in the Northern and western regions of Nigeria. Serewe seeds are smooth, light brown; unthicken whitish edge with 15 x 9 mm mean dimension. The cultivar is mainly found in the Eastern part of Nigeria [1].

[2] Shows that melon seeds consist of about 50% oil by weight, 37.4% protein, 2.6% fibre, 3.6% ash and 6.4% moisture. The oil content of melon seeds constitute 50% unsaturated fatty acids (35% Linolelic, and 15% Oleic) and 50% saturated fatty acid (Stearic and Palmitic acid) [1]. According to Norton [3], the average protein and oil content value of melon seeds are relatively higher than the values in some oil-bearing seeds such as cotton with 20.2% protein, 21.2% oil, and groundnut with 23.2% protein, and 44.8% oil. In [1], the presence of unsaturated fatty acids makes melon nutritionally desirable due to its hypocholestroleric (blood cholesterol lowering) effect. Research has shown that the consumption of melon seed and its products reduces the chances of developing terra-arterial or heart disease [2]. Melon has amino acid profile that compares favourably with that of soya beans and even white of egg [4]. The nutritional values of melon per 100g are: 7.6g carbohydrate, 0.4g dietary fibre, 0.2g fats, 0.6g protein, and 8mg vitamin C [1]. Shelled melon seeds are used for the production of soup, margarine, salad cream, livestock feeds, local pomade and soap [5].

The most challenging aspect of postharvest processing of melon is the mechanical shelling of seeds and separation of the kernels from the shells. The traditional method of shelling melon is tedious, time consuming and inefficient [6]. The drudgery and fatigue associated with melon shelling affects the market supply of shelled melon seeds thus, hindering the industrialization of melon oil production and other end products. This necessitates the development of an easy and affordable machine for this operation.

The machine which is powered by a solar panel and a D.C. battery consists of a hopper, shelling chamber, separation chamber, and the power system. The shelling action is achieved by a rotating impeller which throws the melon seeds by centrifugal force against the walls of the shelling chamber, thereby freeing the seeds from the shells as a result of the impact. The shelled seeds and chaff fall directly into the separation chamber where an installed fan introduces an airstream to separate the chaff from the seeds.

[7] (2009) developed and evaluated a mutually powered motorized melon shelling machine, also using impact technique. The machine was made up of three sections; the feed hopper, the shelling chamber, and the gear system. The working principle of the machine was based on the principle of energy absorbed by a seed as a result of impact (collision) between the seed and a stationary wall which cracked and removed the shell. Analysis of tests carried out on the machine showed that 7.5% of the total melon seeds shelled were broken during the motorized shelling, but less than 40% in manual shelling.

[8] (2001) design and fabricate a melon shelling machine that uses the principle of Impact method. A separation chamber was included where an installed fan introduced air stream which blew away the chaff, and the shelled seeds were collected directly through an opening below the shelling chamber. Tests were carried out at speeds of 750rpm, 950rpm, 1200 rpm, and moisture contents of 7% and 10% wet basis (wb), the researchers tried to determine if the moisture content of melon seeds and the shelling speed had any significant effect on the shelling capacity, separation capacity, and efficiency. Results of the analyses showed that increase in the shelling speed increases the shelling capacity of the machine, but also increase breakage of the seeds thereby reducing efficiency. They concluded that melon seeds should not be shelled at moisture content less than 6.5% wet basis (wb), and the optimum shelling speeds range from 900 - 1200 rpm.

Rubbing action was used by [9] to design a melon sheller based on the principle of frictional force between two plates, one stationary and the other rotary. His design was constructed and tested by [10]. Analyses of tests performed on the machine showed that 50% of the number of shelled seeds was broken, making the machine uneconomical. [11] (1993) replaced the metal disc shellers with ones made of seasoned wood, observed that the percentage of broken seeds was reduced to about 42%, but the shelling capacity decreased. He concluded that rubbing action is efficient for shelling melon due to the thinness of the seeds (about 2.22mm thickness).

II. DESIGN OF THE MACHINE COMPONENTS

A. Power Requirement

The power required to operate the machine at a maximum speed of 1200 rpm was determined thus. According to [12],

Power,

$$P = T\omega \quad (1)$$

Where,

$T = Torque\ generated\ by\ the\ impeller,$

$\omega = Angular\ velocity$

The values of Torque generated by the impeller, T and angular velocity, ω were obtained by using equations (2) and (3).

$Torque\ generated\ by\ the\ impeller,$

$$T = F_c r \quad (2)$$

Where,

$F_c = \text{Centrifugal force developed by the impeller} = \text{mr}\omega^2, \text{r} = \text{impeller radius.}$

m =Mass of a seed

And,

$Angular\ velocity,$

$$\omega = \frac{2\pi N}{60} \quad (3)$$

According to [13], the impeller speeds for effective shelling ranges from 950-1200 rpm.

B. Design of the Impeller Shaft

The design of impeller shaft was done using parameters listed in tables 1 – 3.

Table 1: Some Physical Properties of Melon (Citrullus Species) Seeds at 6.25%

Properties	Number of Samples	Mean Values
Length, mm	100	12.81
Width, mm	100	7.02
Thickness, mm	100	2.22
One thousand unit mass, g	50	94.0
Arithmetic mean diameter, mm	100	7.36
Geometric mean diameter, mm	100	5.84
Sphericity	100	0.47
Surface area, mm^2	50	134.64
Volume, mm^3	100	154.83

Source: [14], 2016

Table 2: Some Gravimetric Properties of Melon (Citrullus Species) Seeds at 6.25% (D.B.)

Properties	Mean Values
Bulk density, kg/m^3	405
True density, kg/m^3	816.29
Porosity, %	53.7
Angle of repose	36

Source: [14], 2016

Table 3: Some Frictional Properties of Melon (Citrullus Species) Seeds at 6.25% (D.B.)

Properties	Mean Values
Coefficient of static friction:	
Glass	0.35
Plywood	0.51
Galvanized metal	0.43

Source: [14], 2016

The required shaft diameter was determined by using the ASME code equation for solid shafts as in [18].

$$d^3 = \frac{16}{\pi \tau_{max}} \sqrt{M^2 + T^2} \qquad (4)$$

Where,

$\sqrt{M^2 + T^2} = Equivalent\ twisting\ moment$

C. Equivalent Static Force Required to Crack a Melon Seed

According to [15], the equivalent static force required to crack a melon seeds in an impeller-type machine are given as

$$F = \sqrt{E\rho \frac{m}{M} \omega r A} \qquad (5)$$

Where;

E = Young Modulus of elasticity of the seed (N/m^2),

ρ = density of the seed (kg/m^3),

m = mass of the seed (kg),

M = mass of impeller impacting the seed (kg),

ω = impeller rotational speed (rad/s),

r = impeller radius (m),

A = cross-sectional area of the seed (m^2).

D. Terminal Velocity

Pneumatic separation of grains involves the separation of foreign materials from the grain with the aid of an air stream. The air is made to pass through the disposed materials to effect their separation. In free fall, the shelled seeds and chaff attain a constant velocity (V_t), at which the net gravitational force (F_g) equals the resisting drag force (F_t). The design of the fan for effective grain separation takes advantage of the variation in aerodynamic properties of the grain [11]. Terminal velocity of the shelled seeds and chaff was determined with the following equation

$$mg = \frac{1}{2}\rho V_t C_d A \qquad (6)$$

Where;

m = mass of the object (kg),

g = gravitational acceleration (m/s^2),

C_d = drag coefficient,

ρ = air density (kg/m^3),

A = projected area (m^2),

V_t = terminal velocity (m/s).

E. Pulley and Belt Design

A suitable pulley size and belt length was determined by using equation (7) and equation (8) respectively as reported by [14].

$$N_1 D_1 = N_2 D_2 \qquad (7)$$

$$L = \frac{2C + 1.57(D_2 + D_1) + (D_2 - D_1)}{4C} \qquad (8)$$

Where,

$N_1 = speed\ of\ the\ driven\ pulley, rpm$

$N_2 = speed\ of\ the\ driving\ pulley, rpm$

$D_1 =$ Diameter of the driven pulley, mm

$D_2 =$ Diameter of the driving pulley, mm

$L = Length\ of\ the\ Belt, mm$

$C = Distance\ between\ driving\ and$

$driven\ pulley, mm$

F. Design of Solar PV System

Design of the solar PV system for Melon shelling machine was undertaken to determine:

1. Energy requirement of the machine
2. Array sizing of the modules
3. Required numbers of batteries
4. Selection of charge controller

1. Energy requirement of the machine

An electric motor of 373 Watts (0.5HP), 240V was used.

The current of the electric motor *IM* was determined from equation (9) as reported by [16].

$$P_m = I_m V_m \qquad (9)$$

where,

$P_m =$ power of the electric motor (W)

$V_m =$ Voltage of the electric motor (V)

$I_m =$ Curent of the electric motor (A)

The hours of use (h) is estimated to be 8 hours daily. The daily energy use *DE* was estimated from equation (10).

$$D_E = hP_m \quad (10)$$

Energy loss in PV system is usually estimated to be 25% to correct for inverter loss and battery efficiency.

Taking this into account the daily energy use becomes *Daily energy use x Energy loss.* The daily energy requirement (*DE*) was therefore estimated from equation (11) as reported by [16].

$$D_E = 1.25D_E \quad (11)$$

The *Ah* requirement of the machine is the charge to generate by the module and is estimated from equation (12) as reported by [16].

$$Ah = \frac{D_E}{V_S} \quad (12)$$

2. Array sizing of the modules

Peak sunshine hour for Modibbo Adama University of Technology, Yola location is 8h (Dasin et al, 2015). The charging current (*Ig*) was determined from equation (13) as reported by [16].

$$I_g = \frac{Ah}{P_{sh}} \quad (13)$$

The module to be used is 130W, 12V therefore the module current *Im* is 11.67 A. The number of modules in parallel (*Mp*) was determined from equation (14) as reported by [16].

$$M_P = \frac{I_g}{I_M} \quad (14)$$

The number of modules in series (*Ms*) was determined from equation (15) as reported by [16].

$$M_S = \frac{V_S}{12V} \quad (15)$$

3. Required Number of Batteries

1. Maximum number of days of cloudiness (*dc*) for the location during peak period is 1 day.

2. Depth of discharge of battery (*DOD*) is 0.8.

3. Capacity of selected batteries (*bc*) is 100Ah

4. The battery capacity (*Bc*) was determined from equation (16)

$$B_C \quad (16)$$

No. of batteries was determined from equation (17).

$$B_N = \frac{B_C}{b_c} \quad (17)$$

G. Moisture Content

According to [11], percentage moisture content was determined using equation (18).

$$\% \text{ moisture content, } m_c = \frac{m_w - m_d}{m_w} \times 100 \quad (18)$$

Where,

m_w = wet/final mass, (g)

m_d = dry mass/initial mass, (g)

III.DISCUSSION OF RESULTS

The performance evaluation of the melon shelling machine was carried out with 0.5 hp electric motor. Prior to shelling, seeds preparation was done by soaking the seeds in water for a few minutes, and allowing them to dry for some time before feeding them into the machine. This softens the shell thereby making shelling easier, and makes the seeds ductile so as to reduce breakages during shelling The unshelled melon seeds were weighed, sprinkled with water and partially dried with natural air so that the skin coat became slightly softened so as to make shelling more efficient. The melon shelling machine was fed with different quantity of melon seeds and the shelling operation carried out in successions as shown in Tables 4 and 5 below. The shelled, partly shelled, unshelled and broken were counted separately in the the operations carried out.

Table 4; First Performance Tests Results

Time Interval	Global Radiation (W/m^2)	PV Voltage (V)	System Output (V)	Fully Shelled (g)	Partly Shelled (g)	Unshelled (g)	Broken (g)	Shelling Efficiency (%)	Time Taken (sec)
11:00	639.05	13.4	12.9	66.5	9.51	10.6	19.01	62.96	11
12:00	650.87	13.7	13.1	71.83	7.4	9.51	16.9	67.99	9
16:00	143.58	8.5	7.8	23.24	19.01	12.68	50.70	22.00	20

Table 5; Second Performance Tests Results

Time Interval	Global Radiation (W/m^2)	PV Voltage (V)	System Output (V)	Fully Shelled (g)	Partly Shelled (g)	Unshelled (g)	Broken (g)	Shelling Efficiency (%)	Time Taken (sec)
11:00	549.3	13.2	12.6	63.81	8.40	8.63	16.71	65.41	13
12:00	655.3	13.9	13.2	66.24	8.48	9.03	16.15	66.10	10
16:00	260.4	6.9	5.7	16.84	20.0	52.27	15.8	16.05	21

From figures 1 and 2, it is observed that during peak sunshine hours, the panel receives the highest solar radiations, resulting in the panel generating its highest voltage output and system output voltage.

Global solar radiation recorded was highest at midday (12:00) at 655W/m^2, generating highest panel voltage output of 13.9V and system voltage output of 13.2V. This is in line with what Terhemba et al (2016) reported.

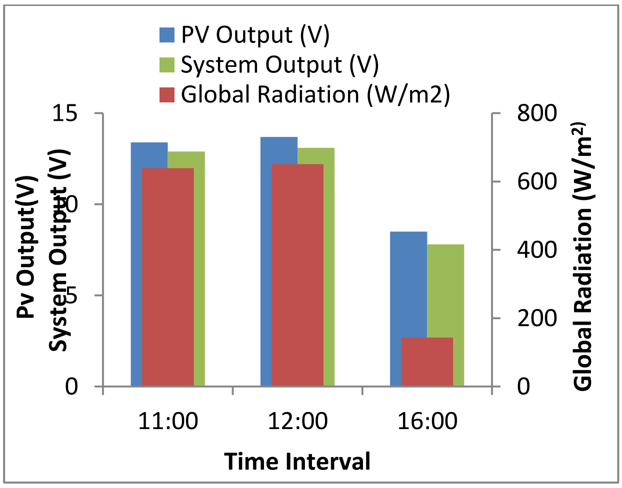

Figure 1; Variation of generated voltage, global radiation and system output from solar panel with the time of day for the machine test on 03/2/2018

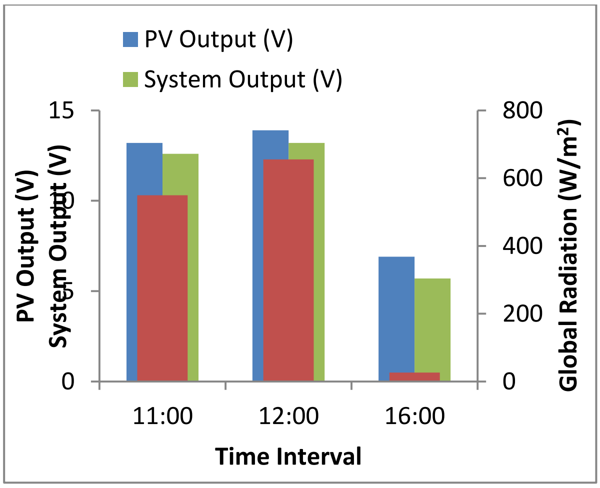

Figure 2; Variation of generated voltage, global radiation and system output from solar panel with the time of day for the machine test on 04/2/2018

From figures 3 and 4, it was observed that the global solar radiation recorded were 650.8 W/m^2 and 655.3 W/m^2 respectively, giving the highest shelling efficiencies of 68% and 66.1% recorded for the tests conducted. At (16:00) when there is no abundant solar radiation, the shelling efficiency of the machine dropped to as low as 22% and 16.05% which result into high percentage of the seeds went unshelled.

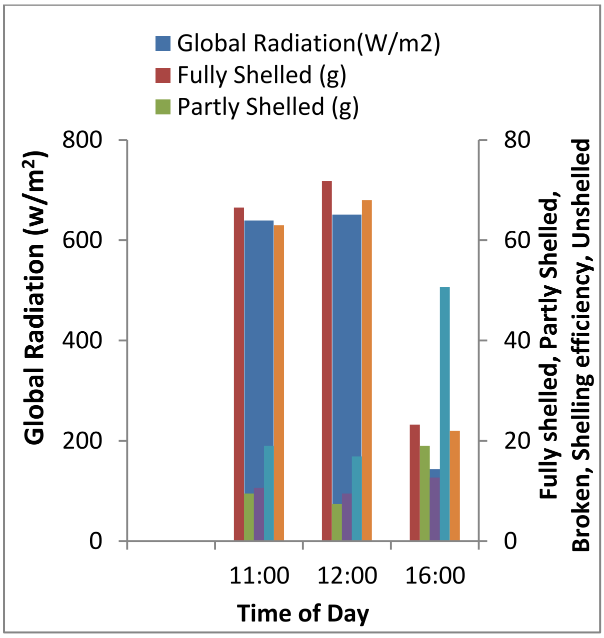

Figure 4; Variation of Shelling Efficiency of fully shelled, partly shelled and unshelled with global radiation and time of day for machine test

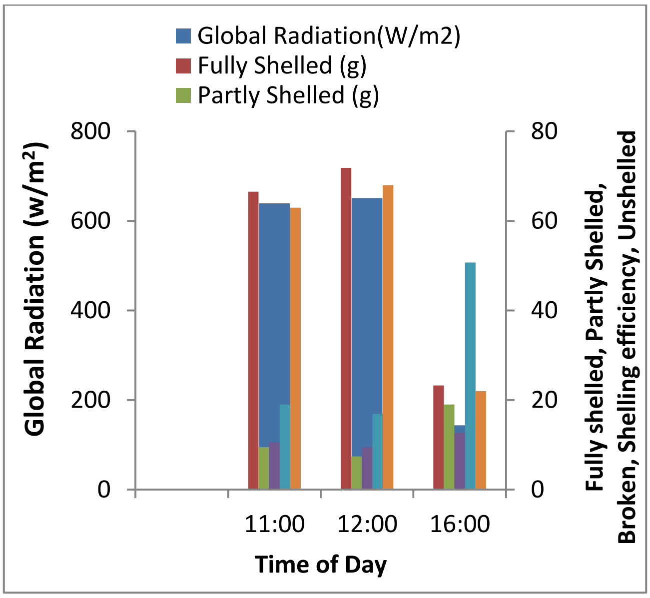

Figure 5; Variation of Shelling Efficiency of fully shelled, partly shelled and unshelled with global radiation and time of day for machine test

All figures indicate that peak sunshine hours play an important role in the efficiency of a solar powered machine. At noon (12:00) which is about the highest peak all the parameters, solar radiation, PV output and shelling efficiency were high and at 16:00 about the time the sun begins its proper descend lower solar radiation, PV output and shelling efficiency were recorded. Therefore when operating a solar powered household melon shelling machine, the higher the solar radiation, the better and more efficient the machine will perform.

IV. CONCLUSION

A solar powered melon shelling machine was designed, constructed and tested. The machine is an impeller-type machine which applies impact force to crack the melon seed shell, thereby freeing the cotyledon from the outer shell. A separation shell was also introduced in a separation chamber to effect the separation of the chaff from the seeds. The machine was designed for domestic use at home, and so is portable, easy to operate, and can be powered by a 12V, 100Ah D.C battery which is charged by a 130W solar panel. Results of performance tests conducted for the two days showed that the highest shelling efficiency of 68% and 66.1% was obtained at high solar radiation, PV voltage output and highest peak time (12:00). Therefore, the machine is reasonably efficient and fast in melon shelling.

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