DESIGN, CONSTRUCTION AND PERFORMANCE EVALUATION OF A SOLAR-POWERED CASSAVA GRATING MACHINE

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ABSTRACT

A solar powered cassava grating machine was designed and fabricated to solve the problem of unreliable power supply from the conventional power sources (National Grid) to operate food processing machines. The machine was fabricated using galvanize metal sheet for feeder hopper and grating mesh. The cassava tubers were fed through the hopper into the grating unit which rotates at constant speed of 412 revolutions per minute (rpm). The performance of the machine was found to be throughput capacity 131.1kg/hr and grating efficiency of 89.1%. While the solar power source for the machine was designed considering the array size of the photovoltaic modules and number of batteries. The appropriate size of charge controller and inverter were selected.

Keywords: Design, Construction, Solar-Power, Cassava, Grater

1 INTRODUCTION

Solar energy is the utilization of radiant energy from the sun. It is often used interchangeably with solar power but refers more specifically to the conversion of sun light into electricity, either by photovoltaic and concentrating solar thermal devices or by one of several experimental technologies such as thermoelectric converters, solar chimneys or solar ponds. Solar photovoltaic (PV) is the direct conversion of sunlight into direct electric power through use of solar collectors. The solar photovoltaic application includes solar homes system (SHS), solar pumps and solar power appliance like refrigerators, air conditioners and street light. Solar lighting involves the direct collection and distribution of sunlight to provide interior illumination. They system is often applied for day lighting but recent technology has provided enhanced form of application called hybrid solar lighting which provide interior illumination both during the day and night. The advantages of PV technology include direct room temperature conversion of solar radiation to electricity, absence of moving parts, less maintenance cost, high reliability and long effective life [1]. Cassava is typically grown by small scale farmers using traditional methods, and often on land that is not suitable for other crops. It is a major food crop in Nigeria [1]. It supplies about 70% of the daily calorie of over 50 million people and about 500million people in the world [3]. Some cassava varieties show high resistance to drought and mosaic disease, high yield, even in agro ecological conditions where other starch bearing crops do not thrive. The prevailing climate change, the threatening global warming and the expected negative impact on the yield of less hardy crops highlight further advantages of cassava as the crop of the century. Traditionally, cassava is cultivated by farmers at subsistence levels as the "poor man's food". Currently, semi-commercial and commercial farmers are available due to increasing awareness and proof of functional versatility of cassava flour especially in the food manufacturing sector [4].

Cassava is process into garri, lafun, tapioca kokote, fufu and ackhe. Cassava has several advantages compared with other carbohydrate sources, especially other root crops. It has a high productivity under marginal climatic conditions, which results in a low-cost raw material. Root dry matter content is higher than other root crops at 35-40%, giving optimum rates of 25:1 or better. Over 85% consists of highly digestible starch. Cassava starch has excellent agglutinant properties which make it especially suitable for shrimps and fish feeds, replacing expensive artificial agglutinants. The need to mechanized cassava processing is enormous. The traditional method of cassava processing has a number of undesirable attributes. This has drawn the attention of national agricultural research to devote utmost interest and resources to engineering research. The highest share female labour in cassava processing called for an urgent need to appropriate gender sensitive machines and equipment for cassava processing. In gari production, peeling and frying constitute a substantial percentage of the total cost of production. Mechanization of cassava production and processing will enhance human capacity in the rural areas, leading to intensification and increase productivity as a result of harvesting, handling and appropriate machinery. More importantly, it reduces drudgery, making the food processing an attractive enterprise. It therefore, has the potential for national economic growth, food self-sufficiency, industrial growth and employment leading to poverty reduction, [5] designed a dual-operating cassava grater, the cassava is fed into the hopper and a piece of wood was used to press the cassava against the grating drum to prevent the scattering of cassava cause by the machine vibration. The discharge chute is inclined for effective discharge of the pulp. They machine have an efficiency of 92.4% manually and 91.9% using electric power. The circumferential-type cassava grater with cylindrical blade is made of punctured metal plates. It is driven by a 746W electric motor; it transforms fresh cassava into pulp at more than 200 kg/hour. Hammer mill is another option considered to grate the cassava. The hammer mill uses a screen and spinning cylinder that has blades. The blades would grind the cassava until the pieces are small enough to fit through the screen. Research into the hammer mill showed that the machine is heavy and requires a large amount of power to operate. In addition to these difficulties, a hammer mill involves many blades that swing around a shaft, each one similar to the spinning blade previously. [6] fabricated a cassava lump breaker with locally available materials such as mild steel, stainless steel, etc. but they failed to carry out a comprehensive performance evaluation in terms of the efficiency and throughput capacity of the machine. They recommended that the machine should be constructed with stainless steel materials to prevents corrosion and allow hygienic operation. [7] developed a cassava siever, he carried out a performance evaluation on the machine with an efficiency of 76% and output capacity of 69.12kg/hr, he suggested that the machine can be improved upon so as to increase the efficiency and capacity, to lessen the hectic aspect of the sieving operation. [8] developed a motorized cassava lump breaker and sifting machine but recommended that an outlet provision should be made for unshifted materials, cover for the hopper, and also a cover should be made for the pulley and electric motor for the protection of the operator. [9] Developed a cassava grater and tested in Nigeria. The machine uses a grating drum assembly at high speed for the grating operation. The grater can be manually-operated or power-driven. The average output is 22 kg/h using the manually-operated machine and 93 kg/h when power-driven. The grating efficiency is in the range 86.1 to 87.5%. The grated pulp obtained by using this machine consists of medium fine to very fine (powdery) particles. Most of the cassava graters used electrical power which is no more feasible as is used to be, and continuous using of small engine involved high cost of maintenance and also there is an increase in environmental pollution as well as global warming. Hence there is a need to design a solar power system that will power cassava graters that will sustain the gari processing industries in Nigeria. The objective of this study was to design, construct and evaluate the performance of a solar powered grating machine. Solar power is an environmentally friendly, maintenance free, and can be use everywhere even in the remote rural setting. Nigeria is blessed with abundant sunshine all year round which can be harness to power our agricultural processing machines. The need to design a solar power system to power cassava graters to sustain the garri processing industries in Nigeria cannot be over emphasized. Hence, the study to designed, construct and evaluate the performance of a solar powered grating machine.

2 MATERIALS AND METHODS

The main features of the grater include; the loading and unloading chute, grating unit, electric motor, pulley, v-belt, bearing and supporting frame. The cassava tuber was fed into the grating unit through the loading chute. The grating unit consisting of a perforated sheet of metal raps round the

cylinder by riveting pin; it will grate the cassava against the housing; the grated cassava will be collected and unloaded through the discharge chute. The various components (listed above) of the machine were fabricated in stages before assembling into complete functional unit. The machine has the following components as shown Figures 1 and 2. Hopper: it is the receptacle through which cassava is admitted into the machine for grating, it has a rectangular plan which was taper gradually forming a trapezoidal cross-sectional area. Grating Unit: this unit consists of the shaft, perforated mesh, rolled sheet circular discs and rivet pin. The drum was formed by the shaft passing through the rolled cylindrical sheet and it was welded in place by circular discs. This drum was then wrapped with the perforated mesh which was attached by riveting pins.

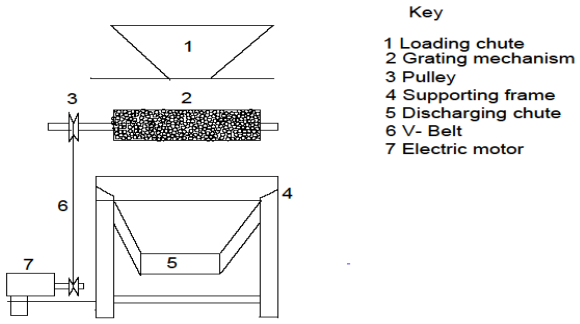

Fig. 1 EXPLODED VIEW OF THE SOLAR POWER CASSAVA GRATER

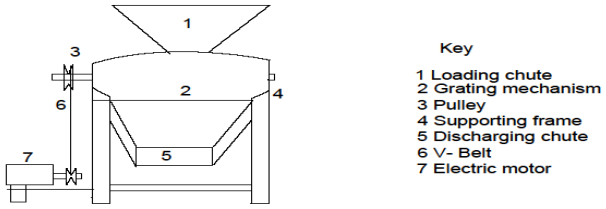

Fig. 2 ASSEMBLY OF THE SOLAR POWER CASSAVA GRATER

Discharge Unit: This is a continuation of the grater's frame connected to the hopper. It directs the flow of the grated cassava to a storage pit or receptacle. Shaft: it is a rotating machine element used to transmit power from one point of the machine to the other; the power was provided by a tangential force which was then transfer to the various machine element linked up to the shaft. Electric motor: An AC electric motor was used to power the machine; the motor utilizes solar energy obtained directly from the sunlight and invert it from DC to AC current. A PVC technology was employed to convert sunlight directly into electrical energy. The solar cells system of the PVC technology response linearly to the flux. Pulleys System: to reduce the speed, pulley system was used to transmit power to the grating drum at reduced speed and high torque. This provides the rotary motion required for grating the cassava. The general considerations in designing grating machine was, to produce a machine that can be easily assemble and dismantling, A machine in which the hopper allows the material to pass through effectively with minimum damage. The grating drum is made of a metal so as to increase its durability, the chute sloppy to allow the grating pulp to slide downward and get discharge by gravity.

Hopper

The hopper with trapezoidal cross section was used and was able to take 10kg of cassava at full capacity. The average bulk density of cassava is 362.15Kg/m^3. The volume was determined from equation 1.

$$V = \left(\frac{1}{2}(A + B)\, H\right) L \quad (1)$$

Where, A=Upper length = 0.4m, B=Lower length = 0.2m, H= height = 0.3m. Mass of the hopper was determined from equation 2.

$$M = \rho v \quad (2)$$

Grating drum design

This was in form of cylinder and made of metal sheet with a punched surface as a grating unit. The diameter of the drum was determined by the lower width of the hopper. The volume of the drum was equal to volume of the circular plate + rolled steel sheet + perforated mesh and this was estimated from equation 3, from which the mass of the drum was estimated. The load to be carried by the shaft was estimated to be 586.05N.

$$V = \pi r2l\ \frac{\pi d2L}{4} \quad (3)$$

Selection of electric motor

An electric motor of the following specifications was selected: Power, P = 746W; Rotational speed, N = 1400 rpm; Phase: single and Frequency = 50Hz. The power transmission drive used for the machine was belt and pulley, with dimensions as shown below.

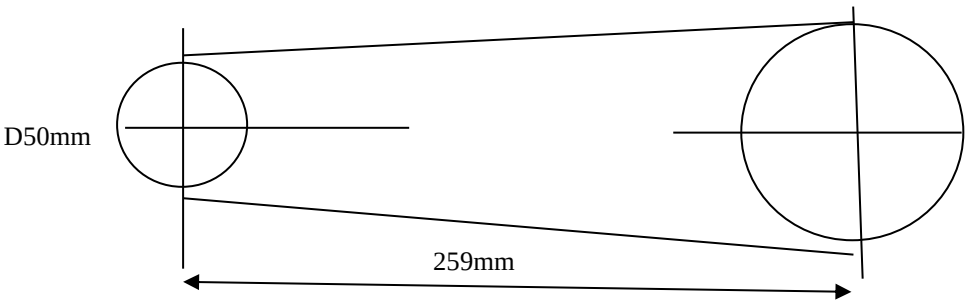

Figure 3. the power transmission drive used for the machine was belt and pulley

The speed ratio of the larger pulley on the machine shaft to the smaller pulley on the electric motor is given equation 4.

$$N_1D_1 = N_2D_2 \quad (4)$$

Where N_1 =Speed of electric motor = 1400rpm, D_1 = Diameter of motor pulley =50 mm, D_2 = Diameter of machine pulley =170 mm. The speed of the pulley was calculated to be 412rpm.

Shaft design

For satisfactory performance, the shaft was made rigid enough while transmitting load under various operating condition. Solid circular shaft was considered for the analysis of combined effect of torsion and bending. For solid shaft having little or no axial load, the diameter was determined using the recommended values of the maximum working stress and the maximum shear stress of 84MPa and 42MPa. The Power (746W) transmitted via a pulley of diameter 170mm (0.17m). The torque was determined from equation 5 [10].

$$T = \frac{p \times 60}{2\pi n} \quad (5)$$

The force on the pulley (Fp) was estimated from equation 6, from which the radius (r) of the pulley was determined.

$$Fp = \frac{T}{r} \quad (6)$$

This force acting at an angle of 45° to the vertical, therefore the vertical force of the pulley on the shaft (F_s) was estimated from equation 7.

$$F_P = Fp\cos 45° \quad (7)$$

This weight constituted a uniformly distributed load over the length of the shaft and therefore assumed to act at the centre. The highest bending moment was determined from bending moment diagram (Figure 4). The power transmission drive used for the machine was belt and pulley.

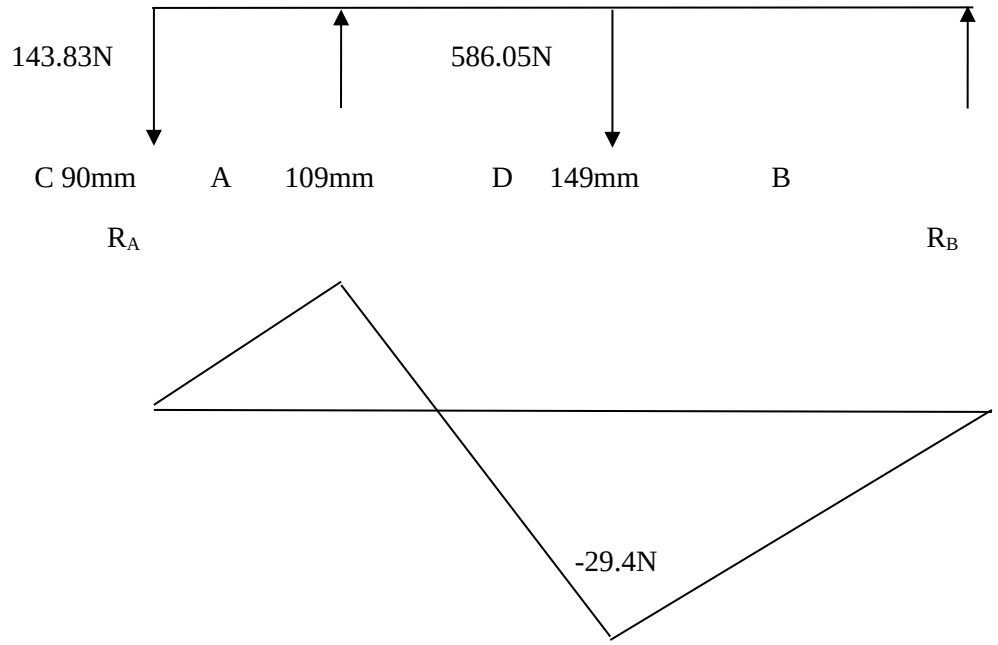

Figure 4. Bending Moment Diagram

The value for equivalent twisting moment of rotating shaft with steady or gradually applied load was estimated from equation 8 [10].

$$\text{Te} = \sqrt{(K_m \times M)^2 + (K_e \times T)^2} \quad (8)$$

The shaft diameter based on strength was determined from equation 9.

$$\text{d3} = \frac{Te \times 16}{\pi \times \mathcal{T}} \quad (9)$$

Where D_3 = diameter of the shaft (mm), $\mathcal{T}$ = maximum shear stress (MPa). The value for equivalent bending moment of rotating shaft with steady or gradually applied load was determined from equation 10.

$$\text{Me} = \frac{1}{2}\left[Km\ xM + \sqrt{(Km\ xM)^2 + (Ke\ xT)^2}\right] \quad (10)$$

The shaft diameter based on rigidity was estimated from equation 11.

$$\text{Me} = \frac{\pi}{16}\ \text{x}\ \sigma\ \text{x}\ \text{d3} \quad (11)$$

Where σ = 84 MPa [10]. The calculated shaft diameter was 29.90mm; shaft diameter of 25mm was selected. The maximum cross-sectional area, maximum allowable stress of belt and peripheral velocity of belt were estimated from equations 12, 13 and 14 respectively.

$$\text{A} = \text{b x t} A = \text{b x t} \quad (12)$$

$$\text{For maximum tension T} = \delta \text{a} \quad (13)$$

Where δ =maximum allowable stress of belt =2.8 N/mm^2 [10].

$$\text{Peripheral velocity V} = \frac{\pi d1N1}{60} \quad (14)$$

V is less than 10 m/s therefore centrifugal tension (T_c) is negligible. Therefore T= T_1= 291.2N. The power transmitted by the belt was determined from equation 15.

$$\text{Power transmitted P} = (\text{T1} - \text{T2})\text{v} \quad (15)$$

Number of belts required (n) required. The number of belts required to transmit 746 kW power from the electric motor was determined from equation 16 [10].

$$n = \frac{Motor\ power}{power\ per\ belt} \quad (16)$$

Determination of length belt

The length of belt was determined from equation 17 and A44 belt type was selected.

$$L = \pi\,(r2 + r1) + 2x + (r^2 - r^1)^2 \quad (17)$$

Selection of bearing

Ball rolling contact bearing of standard designation 307 with bore inside diameter of 25 mm was selected [10].

2.1 Design of Solar power

Electrical loads

a. 745w @ 240 volts.

b. Total load wattages =746W

c. Total current was estimated from equation (18).

$$\text{Total current} = \frac{Wattage}{Voltage} \quad (18)$$

Daily energy requirement

Energy loss is estimated to be 25%. Therefore, the total daily energy use was estimated from equation 19.

$$\text{Total daily energy used} = W - h \text{ x losses} \quad (19)$$

Ampere hour's requirement (Ah)

The ampere-hour requirement which is the charge to be generated by the modules was determined from equation 20. The system voltage was 12V.

$$Ah = \frac{w-h}{system\ voltages} \quad (20)$$

2.2 Sizing of the modules

The charging current (I_C) was estimated from equation 21 using a peak sunshine hour of 7hr for Makurdi location.

a. $$= \frac{A-h}{peak\ sunshine\ \ hrs} \quad (21)$$

Module specification.

a. Modules of 80W@17V were used. The module current (I_M) was determined from equation 22.

b. $$I_m = \frac{W}{V} \quad (22)$$

The number of modules in parallel (Mp) was estimated from equation 23.

$$Mp = \frac{Ic}{Im}, \quad (23)$$

The number of modules in series (Ms) was estimated from equation 24.

$$Ms = \frac{\text{system voltages}}{\text{module specification}} \quad (24)$$

The array sizing was estimated from equation 25.

a. Mp x Ms = number of modules (25)

2.3 Require system battery capacity (Bc)

The battery capacity (B_C) was estimated from equation 26 considering (2) days of cloudiness environment a battery depth of discharge of 0.6 was used.

$$Bc = \frac{\mathbf{Ah \times autonomous\ day}}{\mathbf{D\ O\ D}} \quad (26)$$

Number of batteries in series was determined from equation 27, using a battery capacity of 100Ah

$$B_N = \frac{Bc}{\text{selected battery capacity}} \quad (27)$$

2.4 Charge controller

A charge controller of 12/24V specification was chosen.

2.5 Inverter

An inverter of 3.5KVA@48V specification was chosen.

2.6 Performance Evaluation

Performance of the fabricated cassava grater was evaluated. The evaluation was carried out in two phases; the machine was first evaluated by running it without any load to determine the correction of the fabrication. The second phase, 3.8kg, 4.8kg, and 7.2kg of cassava tubers were fed into the machine and grated to determine the throughput capacity and grating efficiency. The time taken for grating the various quantities of cassava was recorded from a stop watch. The throughput capacity of the machine was calculated from equation 28 and the grating efficiency was calculated from equation 29.

Throughput capacity

$$Q_C = \frac{Wc}{T} \quad (28)$$

Where, Q_C = throughput capacity (kg/hr), W_C = weight of the grated cassava (kg), T= Time taken (hr).

Grating efficiency

$$\eta_G = \frac{W2}{W1} \text{ x } 100\% \quad (29)$$

Where, W_2 = weight of the grated cassava (kg), W1 = initial weight of the cassava (kg). Three samples have been used to evaluate the throughput capacity and grating efficiency of the machine.

3 RESULTS AND DISCUSSION

Table 1 shows the performance evaluation of the machine. The throughput capacity of the machine was 131kg/h with the grating efficiency of 89%. This capacity compares well with Odigbo grating machine, which has a throughput capacity of 135kg/h [12]. The throughput capacities of other grating machines are 158kg/h [13], 158kg/h [10] and 93.0kg/h [9]. The machine grating efficiency 89% also compares well with 91% [5], 80% [10], 87% [9]. This compare well with the existing cassava graters despite its solar power source.

Table 1. Measured Performance Parameters of the Grating Machine

	Replicates			Mean
Performance parameter	1	2	3	
Throughput capacity (kg/hr)	127.5	126	139.8	131.1
Grating efficiency (%}	89.5	87.5	90.3	89.1

4 CONCLUSIONS

Solar powered cassava grating machine was successfully designed, constructed, and evaluated. It is reasonable to state that the aim and objective of the undertaken project has been achieved. This

can solve the problem of erratic in power supply and environmental pollution. The throughput capacity of the machine was 131kg/h with a grating efficiency of 91%.

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