

## Design and Fabrication of a Medium Scale Ginger Pulverizing Machine for Rural Dwellers

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**Abstract:** The goal of the millennium is to conserve energy. Medium scale machines are known to possess a better overall energy efficiency utilization particularly in rural areas in comparison to the full blown commercial ones. Thus a 120kg /hr (medium/intermediate scale) ginger pulverizer was designed and fabricated with about 80% of materials of construction locally sourced. The machine design was empirical, which involved the use of information from handbooks, experience and scientific principles. The performance of the machine was evaluated in terms of throughput capacity, pulverizing efficiency, energy coefficient, losses and size reduction ratio as 96 kg/hr; 80%, 0.032ton/hp-hr; 24.63% and 21:1 respectively.

**Key words:** Energy, pulverizer, ginger, capacity and performance

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### INTRODUCTION

Ginger (*Zingiber officinale* Roscoe) belongs to the plant family of *Zingiberaceae*. It is an erect herbaceous plant which produces underground tuberous stems characterized by its strong essence (Erinle, I.D., 1987; Dafwang, I.I., 1999; Benjamin, A., 2001; Arene, O.B., G.C. Orkwor, 1986). It is cultivated vegetatively as an annual crop (Arene, O.B., G.C. Orkwor, 1986; Ebewe, R.O. and A.A. Jimoh, 1988).

This agricultural crop has a lot of economic importance. Among which is its use for food in the production of drinks; beverages; spices; tea; peppermint; beer; wines; sausages; biscuits; bread; etc. It's used medicinally because of its active biological components which have the ability of reducing cholesterol in the body; warm the body to liberate stagnant fluids; aids digestion; quickens the body of general weakness; ensure easy menstrual flow; reduces high blood pressure, amongst others (Arene, O.B., G.C. Orkwor, 1986).

The value derived from ginger is a function of the level to which it is processed. Pulverization is generally a limiting unit operation in ginger processing. Pulverization is a physical unit operation whose phenomenon involves size reduction or crushing of the cells and separation of granules from other insoluble matter. This is to aid the extraction of constituents from a composite structure (Earle, R.L., 2003).

There are two major methods of crushing namely: traditional and modern methods.

Traditional method (mortar and pestle) employed in ginger crushing is quite primitive, favours low capacity output and susceptible to increase in microbial load on the crushed ginger, while modern method even though offers higher capacity output, requires skilled manpower to operate and maintain, in addition it often suffers from underutilization/redundancy due to limited ginger availability within a given locality (Guwo, A.N., V.I.O. Ndirika, and U.S. Mohammed, 2006).

Therefore, it is the aim of this publication to develop an intermediate capacity crushing machine that will bridge the gap between local and the commonly available commercial ginger crushing machines to solve this societal need especially for communities where ginger is produced and processed.

### MATERIALS AND METHODS

#### *Design Considerations:*

In order to develop an efficient pulverizer, the following considerations were taken into account during the design stage.

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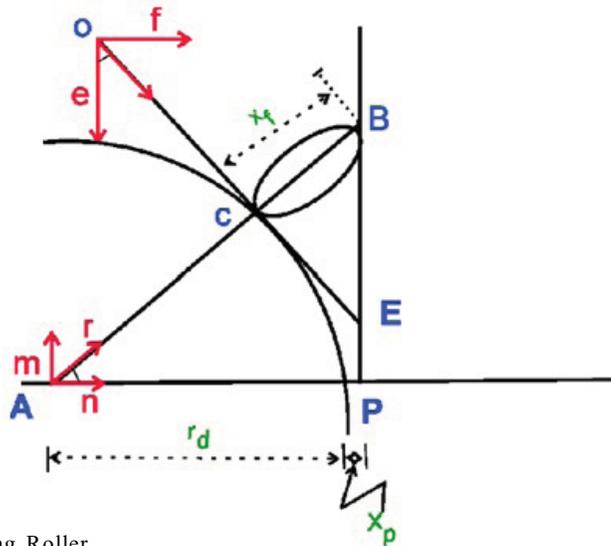
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1. The Pulverizer developed consisted of two basic operational units: grating (rasping unit) and pulping (rotor/stator unit).
2. To ensure flow of ginger in the hopper, the average angle of repose on stainless steel was 35.2° (see Table 2).
3. The rasper design was based on a recommended (Grace, M.R., 1988) linear velocity of 10m/s .
4. The axial dimension of the ginger was considered in determining the feed parameters.
5. At moisture content of 75.32% a shearing mechanism was chosen for the machine. The shear stress was determined to be 0.373N/mm<sup>2</sup> while the compressive stress was 1 7.5kN/mm<sup>2</sup> at the same moisture content.
6. All static and dynamic stresses resulting from direct loading, bending and torsion were considered in shaft design.
7. The capacity of machine is 120 kg/hr

**Design Equations:**

**Raspier Ssizing:**

There is a definite relationship between the rasping drum diameter (AC), feed (X<sup>f</sup>) and product (X<sup>p</sup>) of the rhizome as shown in Fig. 1.



**Fig. 1:** Action of Rasping Roller.

In  $\triangle ABP$

$$AB = r_d + X_p$$

$$AP = r_d + X_f$$

Where

$r_d$  = radius of rasper

$X_f$  = size of feed particle

$X_p$  = size of product particle

$$\cos \alpha = \frac{r_d + X_p}{r_d + X_f} \tag{1}$$

The drum diameter is determined from the feed size and expected product size using equation 1.

**Power Requirement:**

The power required to drive the shaft and its load is given by Hannah and Stephens (Hannah, J.P. and R.C. Stephens, 1984)

$$P = 2 \pi N_{sh} \tau / 60 \tag{2}$$

Where

$$\begin{aligned} \tau &= \text{Torque} \\ &= F_{sh} \cdot r_p \end{aligned} \tag{3}$$

Nsh = shaft speed, rpm

$$= \frac{60 u}{\pi D_d} \tag{4}$$

u = linear (peripheral speed, 10 m/s), as recommended by Grace (1988).

**Shaft Sizing:**

The diameter of a solid shaft having little or no axial loading is given by

$$D_{sh}^3 = \frac{16}{\Lambda S_s} \sqrt{(K_b M_b)^2 + (K_t M_t)^2} \tag{5}$$

Where

M<sub>b</sub> = Resultant moment, Nm

$$= \sqrt{[M_v^2 + M_h^2]} \tag{6}$$

M<sub>t</sub> = torsional moment

$$= \frac{9500, xkW}{rev / min} \text{ Nm} \tag{7}$$

kW = power transmitted by belt

K<sub>b</sub> = combined and fatigue factor applied to bending moment

K<sub>t</sub> = combined and fatigue factor applied to torsional moment

S<sub>s</sub> = allowable shear stress for types of shaft.

The American Standard of Mechanical Engineers (ASME) Code states for commercial steel shafting:

S<sub>s</sub> (allowable) = 6000 psi for shaft with key way (40 MN/m<sup>2</sup>)

K<sub>b</sub> = 1.5, K<sub>t</sub> = 1.0 for gradually applied load on rotating shaft (Hannah, J.P. and R.C. Stephens, 1984).

**Rotor- Stator Design:**

*Rotor-stator technology and high shear mixing theory:* Mixers that utilize a rotor and a stationary stator typically operate at high rotational speed that produces high rotor tip speeds. The speed between the rotor and the stator impacts extremely high shear in the gap between the rotor and stator. Therefore, the tip speed is a very important factor when considering the amount of shear input into the product.

The equation of the tip speed (Harnby, N., M.F. Edwards, 1992) is

$$\text{Tip speed, } V = \rho_{ginger} DN \text{ m/s} \tag{8}$$

Where

ρ<sub>ginger</sub> = density of ginger, kg/m<sup>3</sup>

D=diameter of rotor (m), and

N = rotational speed of rotor (rev/sec)

Additionally the gap distance between the rotor and the stator will contribute to the amount of shear. The equation used for calculating the shear in the gap between rotor and stator is:

$$\text{Shear rate: } \tau = \frac{V}{g} \text{ (S}^{-1}\text{)} \quad 9$$

Where V = tip speed of rotor (m/s) and g =gap distance

**Selection of Materials of Construction:**

Some of the basic materials of construction for the ginger pulverizer may include wood, glass, galvanized iron, mild steel and stainless steel. The factors for choice of material are as indicated in Table 1.

The frame work was sized by considering the entire forces acting on the machine as a point load distributed on the four support legs of the machine using Newton’s third law of motion.

**Table 1:** Characteristic of Pulverizer Common Fabrication Materials

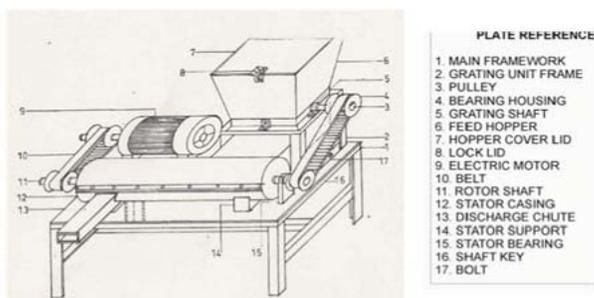
Material	Strength	Formability	Weldability	Corrosion Resistance	Product Contamination	Vibration
Wood	Bad	Good	Bad	Good	Bad	Good
Glass	Bad	Bad	Bad	Good	Good	Bad
Mild steel	Good	Good	Good	Bad	Bad	Good
Galvanized Iron	Good	Good	Good	Fair	Fair	Good
Stainless steel	Good	Good	Good	Good	Good	Good

**Machine Description and Working Principles:**

The various components of the pulverizer include, frame assembly, feed hopper (rectangular frustum), power drive (electric motor), rasping unit and the pulping unit (a rotor –stator consisting of cutting knives attached to a fast rotating shaft).

The fresh ginger rhizomes fed into the hopper will be grated in the rasping unit, a stainless steel (SS) serrated drum after which it will finally be pulped in the pulverizing unit (rotor-stator) via sharp fast moving blades and transported by same to the outlet chute.

The framework of the pulverizer is fabricated of 37.5mm x 37.5mm MS (mild steel), with an overall dimension of 100mm x 750mm x 900mm. The complete machine drawing is as shown in Figure 2.



**Fig. 2:** Complete Machine Drawing

**RESULTS AND DISCUSSION**

The results obtained from the design are as follow:

The estimated cost of the machine was one hundred and thirty nine thousand, three hundred and eighty two naira forty kobo only (Nigerian Currency). The capacity and price of the machine makes it compatible and affordable to local farmers or their cooperative societies as an intermediate technology (Shumacher, E.F., 1973; Ndirika, V.I.O. and A.J. Buys, 2006).

Table 2 shows the physical and mechanical values of ginger at 75.32% moisture content which is the average storage condition for post harvest ginger (Francois, M., R. Alexandra,, 2007). The average thickness of 24.30mm governed the feed particle size which signified the clearance required for a rhizome particle to pass from the hopper to the rasping unit.

**Table 2:** Statistical Analysis of Measured Values of Ginger Physical /Mechanical properties at 75.32% Moisture Content

Parameter	Replicate	Mean, $\bar{x}$	Standard Deviation $\bar{s}$	COV, %
Length, mm	50	90.00	15.51	17.24
Width, mm	50	61.90	11.86	19.16
Thickness, mm	50	24.30	4.14	17.68
Weight, g	50	75.72	28.81	38.04
Moisture, %	06	75.32	0.42	0.56
Angle of Repose, %	06	35.20	0.08	0.23
Tensile Stress, N/mm <sup>2</sup>	07	0.37	1.28	34.21
Compressive Stress, N/cm <sup>2</sup>	07	0.175	0.015	8.410

The energy required to tear up the roots was derived from the momentum of the rasping drum, a certain minimum kinetic energy was found necessary to obtain rasping effect. Above a certain speed of the rasping drum, however, it was expected that no further increase in rasping effect will be obtained. Thus, there exists an optimum speed for the rasping effect on the one hand, and with the economy of power supply on the other hand. In this connection it should be remembered that only the linear velocity of the rasping surface counts. To this effect, 1.0m/s peripheral speed recommended by Grace (1988) was used.

**Particle Size Distribution:**

Table 3 shows the particle size distribution of the experimental ginger pulverizing machine. The peak size 1.18mm from the experimental machine occurred at 40.58% distribution. The particle size (1.18mm) obtained in this work is suitable for extraction of water soluble and extracts from ginger. Reducing it further will make it suitable for ginger tea production and ginger spice. Over 80% of 60µm to 80µm particle size have been reported of ultra – fine modern mills (Perry, H.R., D.W. Green, 1989).

**Table 3:** Particle Size Distribution of Pulverized Ginger

S/No.	Sieve size (mm)	Weigh, g	Distribution, %
1	10.00	1.7949	9.50
2	6.30	2.5400	13.42
3	5.60	3.3380	17.68
4	4.00	3.5535	18.82
5	1.18	7.6651	40.58
Total		18.8855	100.00

A comparative performance indexes between the designed values and the experimental ginger pulverizing machine is shown in Table 4. The mechanical efficiency of the experimental machine was 80% with a throughput capacity of 96kg/hr, while the work index was 0.03 2ton/hphr which correspond to that of Ball mill (0.02 to 0.1 ton/hp-hr) of hard material as reported in literature (Perry et al, 1989).

**Table 4:** Material/Energy Balance of the Designed and Experimental Mills

Parameter	Designed	Experimental
Capacity, kg/hr	120.00	96.00
Power, hp	2.78	3.00
Energy Coeff. (ton/hp.hr)	0.043	0.032
Machine Efficiency, %	100.00	80.00

**Conclusions:**

Within the limits of resources the following conclusions can be made:

1. The experimental machine capacity was 96kg/hr with a mechanical efficiency of 80%.
2. The material losses, 24.63% observed were as a result of leakages
3. The machine is an appropriate intermediate technology in terms of improvement in quantity and quality of output, reduction of drudgery and time of operation.

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