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Development of a Sugarcane Juice Extractor for Small Scale Industries

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Abstract*—A motorized sugarcane juice extractor was developed, constructed and tested to assist the small and medium sugarcane crusher to extract juice from sugarcane. The machine grinds the vertically loaded sugarcane stem and presses the macerated stem against the cylindrical cone to extract the juice from the wet baggasse. The machine consists of the housing, shaft, bearings, keys, pulleys, rollers, hopper, v-belt, adjusters and gears electric motor etc. The performance tests carried out on the developed machine showed an efficiency of 65%. This machine can be produced in small machine shops in the sugarcane producing areas instead of depending on the imported ones.

***Keywords*—Sugarcane, developed, motorized, baggasse, extract, juice**

Introduction

Sugarcane is any of the six to thirty-seven species (depending on taxonomic system) of tall perennial grasses (Naturland, 2000). Sugarcane is a tropical grass belonging to the same family as sorghum, Johnsongrass, and corn – also known as maize (Midwest Research Institute, 1997). Most of the several types of sugarcane planted are cross-fertilised between *Saccharum officinarum* (high sugar content), *Saccharum .sinensis* (adaptable), *Saccharum. spontaneum* and *Saccharum robustum* (disease resistant). The most common clones are octaploid and are propagated vegetatively (Natureland, 2000).

Due to the favourable climate of Nigeria, the sugarcane plant has growing well and one would have expected Nigeria to be a huge exporter of sugar by reason of high production of sugarcane stalk but this is not so at present, (Makinde-Ojo, 2010). Sugarcane is the main source of obtaining sugar, the extraction of sugar from sugarcane is done through certain processes, which have undergone immense improvement. However, two processes are commonly used which are the milling and the diffusion processes, (Rika, 2010).

In the milling process, the sugarcane first go through a washer before being fed to a cane cutler consisting of cylindrical shaft, revolving at 400-500 rpm fitted with knives. The knives cut the cane either into small pieces, which are shredded, or not before moving to the crushers. The crushing is done as the sugarcane stalks pass between series of grooved horizontal metal rollers results in separating the juice that contains the sugar from the fibre otherwise known as bagasse.

Methodology

With the successful completion and assembly of the developed machine, it was connected to power source and switched on and allows to run for some minutes. Thereafter, 1kg of unshredded sugarcane was first weighed and fed into the machine. The time for crushing and squeezing was noted. This was repeated for different weight of 2kg, 3kg, 4kg and 5kg respectively.

1.0 Design Analysis

Maximum force of failure = 110 N

Safety factor of 1.7

Crushing force for the design $F_c = M_f \times S_f$ (1)

F_c = 110 x 1.7 = 187N

M_s= 130 g = 0.13 kg

1.1 Design of Roller Size

$F_c = Ms_{\omega r}{}^2$ (2)

But $\omega = \frac{2\pi Ns}{60}$ (3)

And $r = \frac{F}{M_{\omega r}2}$ (4)

$r = 0.06504m$

Diameter of roller, $D = 2\,x\,r$ = = 0.13 m

1.2 *Power Selection for Motor*

Torque transmitted to the crusher,

$T = F\,x\,r$ (5)

$= 12.155\ Nm$

Power required P = Tω (6)

= 1807.6916 w = 1.8077 kw

= 2.4244 Hp

Hence, a 3.0Hp motor of 1420 rpm is chosen.

1.3 *Permissible Angle of Twist for Crusher*

$\theta = \frac{584\ ml}{G\ (do^4 - di^4)}$ (for hollow circular shaft) (7)

$\theta = \frac{584\ MtL}{Gd^4}$ (for solid circular shaft) (8)

But,

$M_t = \frac{P\ x\ 9550}{N}$ (Nm) (9)

$M_t = \frac{2.2368\ x\ 9550\ x\ 1000}{1420}$ = 15043.3Nm

Length of roller, L = 0.283m

For steel, modulus of rigidity, G = 80 x 10^9 N/m^2

Applying equation 8

$\theta = \frac{584\ x\ 15043.3\ x\ 0.283m}{80\ x\ 10^9\ x\ (0.1301)^4}$ = 0.108^o

1.4 *Axial Deflection of Crusher*

δL = $\frac{FL}{AE}$ (10)

Area of crusher, $A = \frac{\pi D^2}{4}$

= 0.0133m2

Therefore, δL = 1.922 x 10^{-8}m

1.5 *Determination of Actual Motor Pulley Power*

Motor power = 2.2368 Kw

The efficiency of motor speed selected from table = 96% (Chernilevsky, 1984)

Actual power due to efficiency = 96% (P_m)

P_m = 0.96 x 2.2368 $Kw\ =\ 2.14733\ kW$

1.6 *Determination of Actual Motor Torque*

The angular velocity of motor,

ω = 148.72 rad/s

Motor torque, $T_m = \frac{motor\ power\ (P_m)}{angular\ velocity(\omega)}$

= 14.438Nm

1.7 *Design of Pulley Diameter*

Applying equation

D_m = 58T$_m$^{1}/$_3$$(mm)$ (11)

D_m = 141.233mm

Rounding off to the nearest standard value for cast iron pulleys, D_m = 140mm

1.8 *Selection of Roller Shaft Pulley*

A velocity ratio of 2.5 is chosen to provide for speed reduction of the 1420 rpm 3.0hp motor selected for a suitable speed for the crushing roller

1.9 *Angular Velocity of Crushing Shaft*

From $\frac{D_2}{D_1} = \frac{\omega_1}{\omega_2}$

ω_2=D_1 x ω_1

But ω_1 = 148 .72 rad/s

$\omega_2 = \frac{140}{400}$ x 148.72 = 52.05 rad/s

1.10 *Designs for Belt Drive*

$V = \omega\ r = \frac{\omega D}{2} = \frac{\pi DN}{60}$ (12)

For motor pulley,

$V_1 = \frac{\omega_1 D_1}{2}$ = 10.4104 m/s

For crushing shaft pulley,

$V_2 = \frac{\omega_1 D_1}{2}$ = 10.410 m/s

$V\ =\ V_1\ =\ V_2\ =\ 10.41\ m/c$

1.11 *Determination of Belt Length*

For an open vee-belt drive, the length of the belt is given by:

L= $\pi(r_1 + r_2)$ + 2c+$\left(\frac{r_1 + r_2}{c}\right)^2$ (13)

Or 2c + $\frac{\pi}{2}$ $(D_1 + D_2)$ + $\left(\frac{D_2 + D_1}{4c}\right)^2$ (Khurmi and Guiper) (14)

For a vee-belt, the center distance, C, is given by:

C = 0.55 $(D_2$+$D_1)$ + t_b (15)

"B" belt is chosen and its corresponding belt thickness, 11mm is chosen.

D_1 = 140mm and D_2 = 400mm

$\therefore\ C\ =\ 0.55\ (140\ +\ 400)\ +\ 11\ =\ 308mm$

Hence, length of belt required to connect the motor and roller shaft pulleys is $(L)\ =\ 1.52m$

1.12 *Design of Angle of Contact or Wrap between the Belt and Each Pulley*

For an open belt drive, the angle of contact is given by:

Sinβ = $\frac{r_2 - r_1}{c}$ (16)

Also angle of wrap α_1= 180 – 2 β

=180-2sin^{-1} $\frac{r_2 - r_1}{c}$ (17)

α_2 = 180 + 2β (reflex angle)

=180 + 2sin^{-1} $\frac{r_2 - r_1}{c}$ (18)

r_1= 70mm, r_2= 200mm, c = 308mm

α_1 and α_2 are the angles of wrap for the smaller and larger pulleys respectively

Thus from equation (16)

$\beta\ =\ 27.74^o$

For the smaller pulley (motor pulley)

$\alpha_1\ =\ 124.52^o$

Similar, for the larger pulley, (Crushing shaft pulley)

$\alpha_2\ =\ 235.480235.48^o$

1.13 *Design of Belt Tension*

Power transmitted by a belt drive:

$P = (T_1 – T_2)$ (19)

Power developed by the machine

$P = \frac{2\pi N_t}{60}$ (watt) (20)

But torque developed $T = F_r$ (21)

1.14 *Maximum Belt Tension*

$T = S_1 \, x \, A$ (22)

$S_1 \, x \, b \, x \, t_b$ (23)

If the width of the belt is unknown, the required cross-sectional areas of the belt can be determined from the relation $\frac{T_1 - T_2}{S_1 - S_2}$ = A

$B = \frac{Area}{Thickness} = \frac{A}{t}$ (24)

Where S_2 = stress in slack side 0 belt, (N/m^2)

The values of $(T_1 - T_2)$ can be determined from the power transmitted

The mass of the belt per meter is given by the expression

$M = b \, x \, tb \, x \, \rho$ (25)

Belt tension could be calculated using equation

$\frac{T_1 - my^2}{T_2 - my^2}$ = e^fa/sin1/20 (Doughtic**)** (26)

For a pair of pulley, density is based on the pulley with the smaller value of $e^{fA/\sin ½ 0}$(Mc-graw hill 1982)

But β = 27.74°

α_1= 124.52°

α_2= 235.48°

t_b = 11mm

b = 14mm

Motor pulley capacity = $e^{(124.5211)0.25/\sin 1/240)}$

= $e^{0.5434/0.3420}$

= 4.8977

Since the motor pulley is expected to give a smaller value of $e^{: fa/\sin 1/20}$ it governs the design.

Recalling equation 26

$\frac{T_1 - mV^2}{T_2 - mV^2}$ = 4.8977

$M = 0.014 \, x \, 0.011 \, x \, 1250 = 0.1925 kg/m$

But power transmitted,$P = (T_1 – T_2)V$ (27)

Power selected, $p = 2.2368kw \ (3.0HP), and \ belt \ speed \ V = 10.41mls$

Applying equation (27)

2236.8 = $(T_1 – T_2)$ 10.41

$T_1 – T_2$ = 214.87

T_1= 214.87 + T_2 (28)

And $MV^2 = 0.1925 \, x \, (10.41)2$

$= 20.86N$

T_2 = 75.988N

þ $T_1 = 290.86$

1.15 *Designs for Shaft*

$M_t = \frac{P \, x \, 9550}{N}$ (N_m) (29)

For a belt drive, the torque is found from:

$M_t (T_1 – T_2)$R (30)

M_t = 42.97 Nm

For a gear drive, the torque is found from:

M_t= $f_t R$ (31)

But,

F_s = f_t tan ψ (32)

Measured weight of crusher and shaft = 80 N

Measured weight of pulley= 26 N

Effective weight of pulley acting vertical down on the shaft:

T_e = weight of pulley + total belt tension

$T_e = 26 + (T_1 + T_2) = 392.85N$

Diameter of gear selected = 140mm. for gear drive,

Torsional moment M_t = F_tR and F_s = $F_t$tan

Where ψ = 20° (involute angle)

But, $M_t = \frac{P \, x \, 9550}{N}$

Substitution for P and N gives

Mt =15.04Nm

From equation 32

Ft = $\frac{M_t}{R}$

But R = $\frac{140}{2}$ mm = 70mm = 0.07m

Ft = $\frac{15.04}{0.07}$ = 214.86N

F_s = 214.56 x tan 20° = 78.20N

$D^3 = \frac{16}{\pi \, x \, 40 \, x \, 10^6}$ x $(42.07 \text{ x } 1.6)^2 + (1.5 \text{ x } 39.285)^2$

Kt = 1.0 and Kb = 1.5 (Hall *et al*, 1982)

D_3 = 9.284 x 10-5

D = 0.0453m

D = 45.3mm

Shaft diameter required, d = 45mm

1.16 Design of Key

B = d/4 (33)

L=1.18d (34)

Where:

L = length of key

d = diameter of shaft

Applying equation (33) where d = 45mm

B = 45/4 = 11.25mm

Length of key is obtained by equation 34

L = 1.18 x 45

L = 53.1mm

Length of key selected, L = 53mm

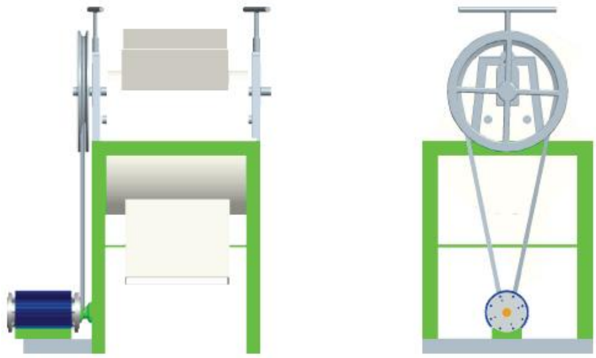
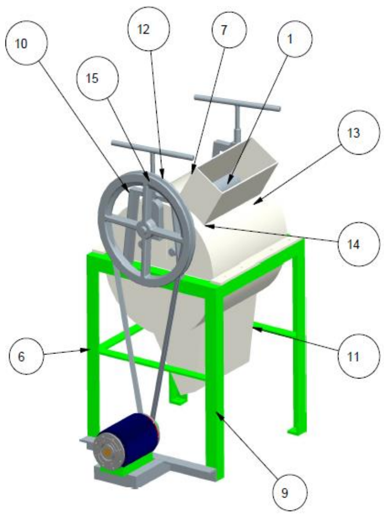


Figure 1: *Side view of sugarcane juice extractor*



S/N	PARTS DESCRIPTION	QTY
1	ADJUSTABLE_ROLLER	1
2	ADJUSTER	2
3	BASE	1
4	BASE1	1
5	BELT	1
6	BRACE	1
7	COVER_PLATE	1
8	ELECTRIC-MOTOR	1
9	FRAME	1
10	HOLDER	2
11	LOWER_COVER	1
12	PULLEY	1
13	ROLLER_1	1
14	ROLLER_2	1
15	ROLLER_ADJUSTER	2

Fig 2: *Assembly Drawing of Sugar cane juice Extractor*

Performance Evaluation

The machine was tested using a given sample of cane stalks (500); the results of the test are as shown in the graph below.

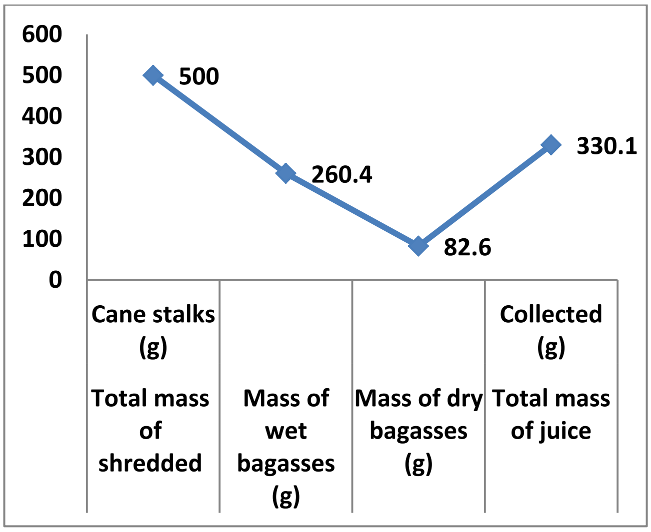


Figure 3: ***Result of machine test using a given sample of cane stalks***

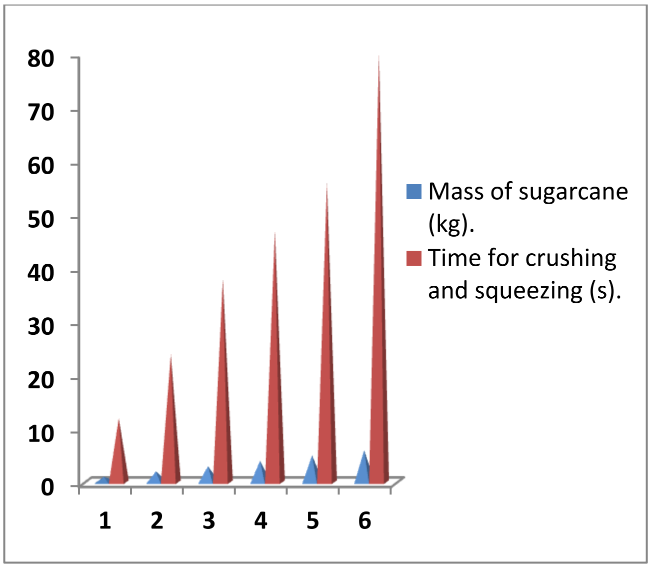


Figure 4: Result of different masses of ***sugarcane and time***

Results and Discussion

From the data obtained, the efficiency of the machine was calculated from the formula:

$$\text{Efficiency} = \frac{mass\ of\ extracted\ juice}{Total\ mass\ of\ juice\ in\ the\ stalk}\ x\ 100 \quad (35)$$

Total mass of juice in stalks is given by (mass of shredded stalks – mass of dry bagasse)

$$\text{Efficiency} = \frac{330.1}{590.5-82.6}\ x\ 100 = 65\%$$

It can be seen that the efficiency of the machine was not as high as expected. This is due to the fact that the single set of roller arrangement cannot effectively extract the juice in one pass. In standard sugar mills, the effective extraction of the juice is done by sets of rollers. This ensures a higher efficiency.

CONCLUSION

A sugarcane crushing and squeezing machine with a capacity of 360 kg/hr was developed and tested; the production cost of the machine is $520 at an exchange rate of #197:00 to a dollar. The development machine possess simplicity in operation and maintenance, as well as being affordable with low running and maintenance costs and with reliable efficiency. If commercialized, the machine could go a long way in solving the problem of sugarcane juice extraction domestically, for the local use thereby meeting the sugar requirement of the nation

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