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Design and Fabrication of Sugarcane Juice Extractor Machine for Small Scale Industries

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ABSTRACT
Sugarcane milling is a unit operation that is fundamental for making sugarcane juice available for different purpose. The present existing sugarcane juice extractors require high energy and complicated mills, driven mechanically. These are out of the reach of small scale and rural farmers that are currently involved in processing of sugarcane juice into ethanol, brown sugar and other related products in Nigeria. This research work is aimed at designing, fabricating and carrying out performance evaluation of a small scale sugarcane juice extraction machine, taking into consideration the small and micro scale farmers, and juice processors who are the target end users of the machine. The machine was constructed with materials being available locally at affordable costs, the functional parts of the machine included extraction unit, pulley, transmission belts, bearings and frame, powered by 5 hp single-phase electric motor. The machine was evaluated with two varieties of sugarcane and results show that the average extraction efficiencies for the two varieties are 64.97 % and 56.90 % respectively. The machine can be used for small scale sugarcane juice extraction in the rural and urban communities.

Keywords: *Crushing, Juice Extraction, Machine and Sugarcane.*

1 INTRODUCTION

Sugarcane belongs to a class of permanent grass of the group Saccharum belonging to the tribe of Andropogoneae, mostly found in humid regions of Southern Asian and been utilized for the production of sugar. It accounts for about 62 % of the total world's sugar while only 38 % is produced from beet (Naidu 1981). This makes it the second crop from which sugar is normally obtained. The mature sugarcane itself is composed of 69-75 % water, 8-16 % sucrose, 0.2-3.0 % reducing sugar, 0.5- 1.0 % other organic matter, 0.2-0.6 % inorganic compounds, 0.5-1.0 % nitrogenous bodies, 0.3-0.8 % ash and 10.0-16.0% fiber (Gbabo, 2002). Unlike sugar beet which grows best in temperate climates, sugarcane does better in the tropics. As a result, Nigeria which is located within the tropical zone has enormous potentials for sugarcane cultivation. As at the year 2000, over sixty (60) potential sugarcane estate sites were identified across the country (Busari, 1999).

The most areas of request in sugarcane industries are recognized along with plant process as cane preparation for milling, juice extraction, sugar boiling and separation of crystal (Olaoye, 2011). Mechanical energy is the most identified areas in these requests except for sugar boiling and juice concentration that requires heat (Robotham and Chappell, 1998). The milling of sugarcane is a unit operation that is vital for making sugarcane juice available for diverse applications. Sugarcane .juice extractors are classified into small scale, intermediate and advanced levels with respect to the degree of operation. The intermediate and advanced juice extractors generally composed of 2 to 3 set of rollers by means of shredders. As well warm water is sprayed on the fiber between the rollers meant at extracting highest juice from the cane (Anonymous, 1999). Alternatively, the small scale juice extractor uses only a single set of rollers to extract the juice without imbibition. It is the type of juice extractor that is found useful for developing countries like Nigeria where sugarcane farming is not yet practiced on extensive scale despite the huge production potentials. Also, the complex large equipment are imported from developed countries and always require complex maintenance procedures in addition to lack of spare parts within the locality (Gbabo, 2002).

The problems that are related to sugarcane production and processing in Nigeria include small scale farms and farm disintegration, land tenure system, inadequate transportation infrastructure and lack of appropriate technologies for micro, small and medium scale processing. Other problems include poor storage facilities for harvested canes and extracted juice prior to further processing to sugar (Olaniyan and Babatunde, 2012). In view of this, a simple small scale machine to process sugarcane into juice is highly essential for the small scale farmer in order to make him thrive well in the business and consolidate his income. Such machine should be of low cost, portable, devoid of technical complexity and can easily be operated and maintained by small scale farmers in the rural communities. This will go a long way in alleviating the problems of small scale sugarcane farmers while ensuring a regular supply of sugarcane juice to cottage sugar factory and also provide employment for rural dwellers. Hence the objective of this research is to design, fabricate and evaluate the performance of a sugarcane juice extracting machine for small scale industries.

2 METHODOLOGY

2.1 DESCRIPTION OF MACHINE

The main component of the machine includes the extraction unit and juice collector unit; extraction unit is made up of two hollow mild steel rollers having thickness of 5 mm. The two rollers have inner and outer diameter of 100 mm and 115 mm respectively, each are arranged vertically on the same plane in the frame, while the length of the rollers are 500 mm. Adjuster device were also provided to enable sugarcane of varying sizes to be accommodated between the top and lower roller while the collector unit is a cylindrical trough placed directly below the lower roller to collect the extracted juice. The trough was situated at an angle of 180^{o} from the vertical plane to enable the juice flow towards the spout. Inlet and outer discharge chutes are trapezoidal troughs that is been made of mild steel sheets. The inlet chute direct and controlled the sugarcane fed to the rollers. It also prevents loss of sugarcane juice resulting from the crushing action of the rollers. The discharge chute is placed at the reverse end of the inlet chutes to discharge sugarcane baggasse after extracting the juice. A clearance is provided between the rollers and the chutes to prevent them from making contact with each other. The frame of the machine is made up of mild steel iron while the cover is made up of mild steel sheet.

2.2 PRINCIPLE OF OPERATION OF THE MACHINE

The sugarcane juice extracting machine is shown in Figs. 1-3.

The machine was powered with the aid of 5 hp electric motor. It was allowed to run for about 5 minute before it was loaded manually with two sugarcanes at the same time. The pressing, shredding and shearing action of the rollers on the cane result to extraction of the juice which was drained down to the collecting unit.

Fig. 1. The fabricated Machine Side view

Fig. 2. The fabricated Machine

Fig. 3. The fabricated Machine Top view

2.3 DESIGN COMPUTATIONS

1. **Speed of the driven pulley**

It is the ratio between the velocities of the driving pulley (driver) and the driven pulley (follower). It is obtained from the general established equation 1, (Khurmi and Gupta, 2005).

$$\frac{X_2}{X_1} = \frac{D_1}{D_2} \quad (1)$$

Where

X1 = speed of the Driver (D.C motor 1480rpm)

X2 = speed of the Follower

D1 = Diameter of the Driving pulley

D2 = Diameter of the driven pulley

2. Velocity Ratio

This is defined as the ratio of speed of the motor and the speed of the pulley, it can be determined from the given equation 2 (Bernard *et al.,* 2012).

$$\text{Velocity Ratio} = \frac{\textit{speed of the motor}}{\textit{speed of the pulley}} \quad 2$$

3. Radial Deformation

The radial deformation is the tendency of the shaft to dependent on the modules of rigidity, length and torsional stress. (Ryder, 1982)

$$\delta = \frac{\gamma L}{G} \quad 3$$

Where

δ is the radial deformation or angle of twist (radians)

γ is the allowable torsional stress in the shaft = 9.89 x 10^7 N/ m^2 (Juvinal, 1989)

G is modulus of rigidity of the shaft = 8.0 x 10^{10} N/ m^2 (Juvinal, 1989)

4. Speed of Lower Roller

The speed of the lower roller is equal to speed of the top roller. It is computed based on the following equation:

$$N_l L_t = N_t T_t \quad 4$$

$$N_l = \frac{N_t T_t}{L_t} \quad 5$$

Where N_l is the speed of the lower roller (rpm).

N_t is the speed of the top roller (rpm).

T_t is the number of Teeth of the top roller

L_t is the number of teeth of the lower rollers.

5. Belt Design

The total length of the belt was determined using the design equation given by Shigley and Mitchell (1983) equation 6 as:

$$L_q = 2C + 1.57(D_1 + D_2) + \frac{(D_2 - D_1)}{4C} \quad 6$$

Where, L_q is the total length of belt and C is the centre to centre distance between the two pulley C = 500; hence L_q= 1518.4mm.

6. Determination of Belt Tension

The belt tension is the pulling force that arises as a result of the movement of the belt over the pulleys. The tension on the slack and tight belt (W) was determined with Equation (5) as given by Balami *et al* (2016);

7. Power Requirement

The power required by the machine to crush the sugarcane is determined by using equation 8 given by Khurmi and Gupta, (2005).

$$p = \frac{2\pi NT}{60} \quad 7$$

Where

p = power required (watts)

N = speed of the rotating shaft = 250 rpm

T = Torque transmitted

Bastian and Shridar (2014) reported in their study that the average crushing strength of sugarcane is 1.14kNm.

2.4 THROUGHPUT CAPACITY OF SUGARCANE EXTRACTING MACHINE

Throughput capacity is the mass/weight/quantity of sugarcane that can be extracting by the machine per unit time. The throughput capacity (Tc) as given by Balami et al. (2016) in Equation (8);

$$T_C\ (g/sec) = \frac{W_t}{t} \quad 8$$

Where:

Wt = weight of sugarcane fed into the machine (g) and

t = time taken for the sugarcane and its extract to completely leave the machine (sec)

2.5 MACHINE TESTING PROCEDURE

Two Preliminary machine testing was carryout to evaluate the performance of the machine components and to investigate the machine efficiency. Two samples of sugarcane varieties (*Saccharum sinence* and *Saccharum spotaneum*) were obtained from Kure Market of Minna, Niger State Nigeria. The samples were weighed and crushed with the juice extractor. Equal extraction .pressure was provided by a 10 mm clearance between the top and intake roller with the help of the adjuster mechanism was used for all the samples of the sugarcanes varieties.

The weight of the extracted juice, baggasse, and juice loss were also recorded. The baggasse were sun-dried and oven dried according to Gbabo (2002). From the values obtained, extraction efficiency was calculated using Tressler and Joslyn (1961) Equation 8 as:

$$E_l(\%) = \frac{100W_{Je}}{J_y} \quad 8$$

Where

W_{je} =Weight of juice extracted (g)

$J_y = W - W_d$ = Weight of juice presents (g)

W_d =Weight of dry samples (g)

W = Weight of wet samples (g)

3 RESULTS AND DISCUSSION

The results of the sugarcane juice extraction machine using two sugarcane varieties is presented in Table 1 which shows variance in juice extraction efficiency. The actual juice present in each of the cane stalk was determined for comparison with the extracted juice in order to calculate the extraction efficiency of the machine.

The average extraction efficiency of the machine when SS1 and SS2 variety were used is 64.97 % and 56.90 % respectively. These values were lower than the value in a research carried out by Gbabo (2002). SS1 variety has higher efficiency than SS2 variety, this variance may be as a result of SS1 variety contained more juice than fiber compared to the SS2 variety. The ability of the machine to crush and expel the juice from the plant fibre was determined by its effect on the total collapsing of the cell wall that entraps the juice. The extracted juice showed that cane size of smaller sizes that were more difficult to break its cell walls thereby realizing small quantity of the juice. This confirms the observed phenomenon by Olaniyan and Babatunde (2012). This explained for the reason of low juice extraction in smaller cane sizes while operating the machine at constant peripheral speed.

The throughput capacity was determined using the expression presented in Eqn. 9. The throughput capacity ranges between 17.39 g/sec and 37.51 g/sec. At operating speed of 0.131 m/s about 37.51 g can be extracted in 1 sec. The initial weight of sugarcane fed into the machine before and after extraction stood at 2700 g and 1850 g with a difference of 850 g. The efficiency and throughput of 68.6% and 23.57 g/sec respectively were obtained for SS1 variety while SS2 variety the weights of sugarcane before and after extraction were determined to be 3150 g and 2350 g with a difference of 1700 g. This result shows an efficiency and throughput capacity of 60% and 37.51 g/sec respectively. From this, it could be observed that, the SS2 variety was adequate with minimum juice loss. A cottage sugarcane juice processing plant based on this technology can provide employment for three persons at the same time providing fresh sugarcane juice at affordable costs for rural dwellers. An improvement in the design, analysis and optimization of the roller shaft and press cage is expected to improve the extraction efficiency; hence, this is highly recommended.

4 CONCLUSION

A small scale sugarcane juice extracting machine was successfully designed, fabricated and evaluated. The machine is simple for easy operation and maintenance, repair and suitable for local production. It was powered by 5 hp single phase electric motor. The average extraction efficiency of 64.97 % was obtained. The machine can be used for small scale sugarcane juice extraction in the rural and urban communities.

TABLE 1: JUICE EXTRACTION MACHINE EVALUATION PARAMETER

Sugarcane variety	Replication	Length (mm)	Initial Weight of sugarcane (g)	Initial Weight of baggasse (g)	Dried Weight of baggasse (g)	Loss juice (g)	Weight of juice (g)	Juice extraction efficiency (%)
SS1	1	1960	2500	1600	1100	500	900	64.3
	2	2010	2400	1700	1000	700	700	62.0
	3	2070	2700	1850	850	900	850	61.6
SS2	1	1970	3150	2350	1700	650	800	55.2
	2	2020	2600	2000	1475	525	600	53.3
	3	1600	1600	1250	785	465	550	54.2

SS1: *Saccharum sinence*
SS2: *Saccharum spotaneum*

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