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Development and Testing of Sugarcane Juice Extractor

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A Sugarcane juice extractor having 3340.95-4635.3kg per day cane crushing capacity was designed and fabricated as one of the equipment of the indigenous sugar processing plant recently developed in Nigeria by the National Cereals Research Institute, Badeggi. The equipment is made up of the juice extractor units, cane inlet and baggasse discharge chutes, juice collector, power transmission unit, covers and frame. The machine was fabricated with about 95% local materials in the Agricultural Engineering workshop of the Institute. Test results of the machine using sugarcane varieties BD 95-030, BD 96-009 and local chewing cane indicates juice extraction efficiency of 72.53-83.9%. It was also found suitable for extracting juice from varying cane sizes and simple to operate and maintain.

KEYWORDS : Sugarcane, juice extractor, design, fabricate and efficiency

INTRODUCTION

Sugarcane is one of the most important crops from which sugar is produced. It accounts for about 62% of the total world's sugar while only 38% is produced from beet (Naidu 1998; Fry 1997) which is the second crop from which sugar is conventionally obtained. Unlike sugar beet which grows best in temperate climates, sugarcane does better in the tropics (Kaplinsky 1984). 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, 2000).

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% fibre (Mathur, 1993).

Similar to other crops, the cane is processed in order to extract the sucrose content. The machines used for processing sugarcane includes cane juice extractor, juice evaporator/pan boilers, cystalizers, centrifuge and dryer (Amonsun *et al.*, 2000). Among these, the juice extractor plays a very significant role in sugar manufacturing since it is one of the equipment that greatly determines the efficiency of the whole processing plant.

Sugar cane juice extractors are classified into advanced, intermediate and small scale levels according to the scale of operation. The advance and intermediate juice extractors usually are composed of two to three sets of rollers with shredders. Also warm water is sprayed on the fibre between the rollers aimed at extracting maximum juice from the cane (Anon, 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 equipments are imported from developed countries and always require complex maintenance procedures in addition to lack of spare parts within the locality. The only alternative was for us to design and fabricate cane juice extractors that would be suitable to our local conditions. This paper discusses the development and testing of a Cane juice extractor which is one of the major equipment in the indigenous brown sugar processing plant that was recently developed in Nigeria.

MACHINE DESCRIPTION

The machine is composed of the following components as described in Figs 1-5.

Juice Extraction Unit

This is made up of three V-grooved mild steel rollers having 8mm pitch and 6mm depth. Two of these rollers (D) have diameter and length of 150mm and 270mm, respectively each and arranged horizontally on the same plane on a frame. The third roller (C) having size 240mm diameter and 300mm long is incorporated on top of the center of the two lower rollers. Clearance adjustment device (F) were also provided to enable

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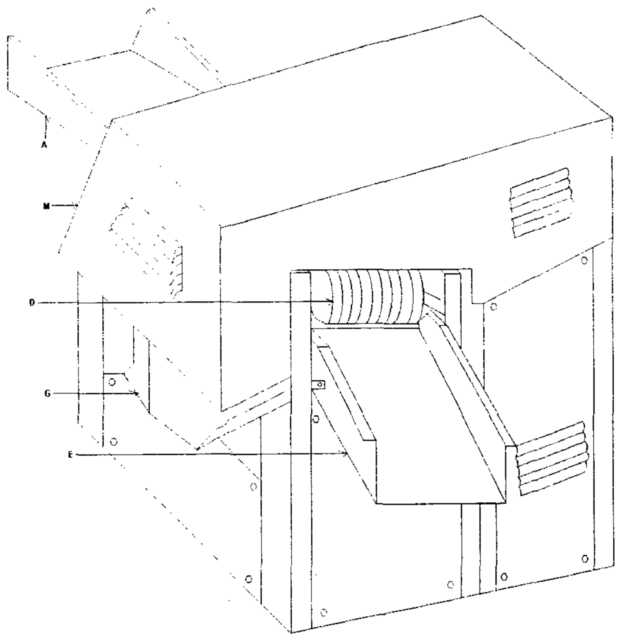

Fig. 1 : Isometric view

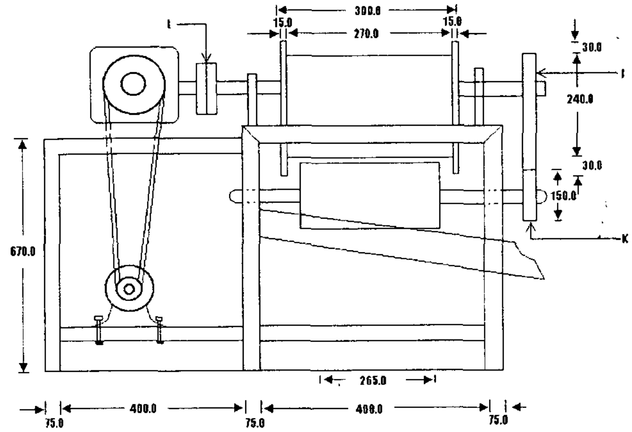

Fig. 4 : Right hand side view

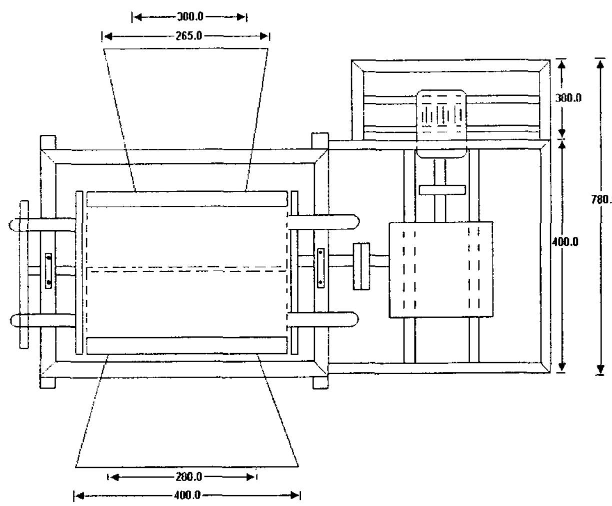

Fig. 2 : Plan

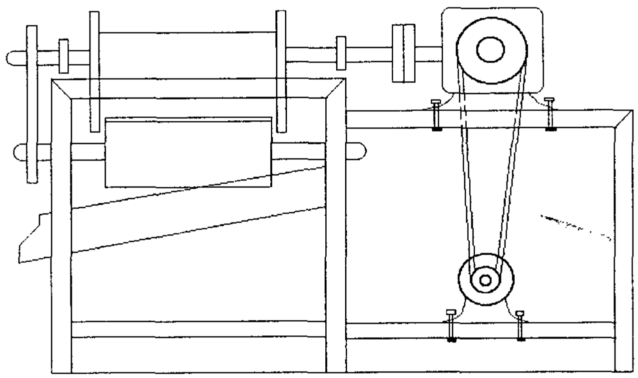

Fig. 5 : Left hand side view

LEGEND

All dimensions in mm

A : Feed Chute
B : Gear Box
C : Upper Roller
D : Lower Roller
E : Delivery Chute
F : Clearance Adjustment Device
G : Juice Collection Tray
H : Electric Motor
I : Belt Interconnecting Elect Motor and Gear Box
J : Upper Roller Gear
K : Lower Roller Gear
L : Flange Connecting Gear Box and Upper Roller
M : Roller Cover
D_1 : Diameter of motor pulley
D_2 : Diameter of gear box pulley
C_{Mg} : Center to center distance between motor and gear box pulleys
G_b : Gear box
F_l : Flanges
S_r : Shaft from gear box to top roller

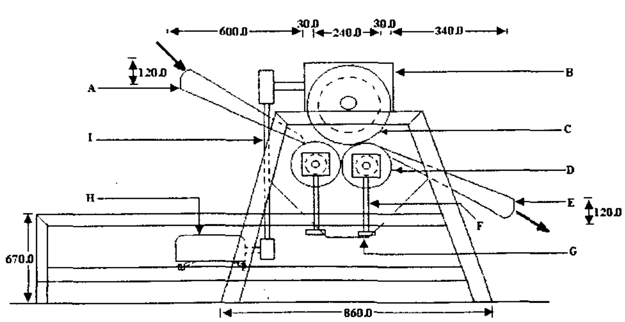

Fig. 3 : Front view

sugarcane of varying sizes to be accommodated between the top and lower rollers. A 240mm and 150mm diameters gears are fixed to the top and the lower roller shafts respectively in order to transmit power from the 15HP electric motor through two flanges (I).

Inlet and discharge chutes : These chutes (A and E) are trapezoidal troughs made of mild steel sheets. The inlet chute guides and direct sugarcane fed to the rollers. It also prevents loss of sugarcane juice resulting from the crushing action of the rollers.

The discharge chute is fixed at the opposite 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.

Juice Collector : The juice collector (G) is also a trapezoidal trough placed directly below the lower rollers to collect the extracted juice .It is included at an angle 25^0 from the horizontal plane to enable the juice to flow towards the spout.

Power Transmission Unit : This is composed of a 15HP electric motor, 15hp speed reduction unit having speed reduction ratio of 1:20, pulleys and belts. The electric motor and speed reduction units are interconnected with the belt and pulleys while the speed reduction unit is connected to the top roller with a 200mm diameter flange.

Frame and Covers : The frame of the machine is fabricated with mild steel angle iron while the machine covers were made from mild steel sheets.

WORK MODE OF THE MACHINE

The machine is put on with the aid of an electric switch connected to the electric motor. It is left to run for 2 minutes before it is loaded with sugarcane by feeding manually with about three canes at a time. The shredding, shearing and pressing action of the rollers on the sugarcane results in extraction of the juice, which drains down to the collector and finally transferred to the evaporator through pipes.

DESIGN THOREMS

(i) Power requirement

The power required to drive the machine is a function of the total mass of the rollers and the gears and is obtained from the generally established equation:

$$P = F_T V_e \quad \text{.................... (1)}$$

Substituting $F_T = Mg$ and $V = pd\,N$ in equation (1)

$$P = Mg\ pd_r\ N \quad \text{.................... (2)}$$

Substituting $M = r_s\ v$ in equation (3)

$$P = r_s vgpd\ N \quad \text{.................... (4)}$$

$$= r_s\ [v_U\ gpd_U\ N\ _U + 2(v_L gpd_L N_u)]$$

where

r_s = Density of mild steel (780kg/m^3)

v_u = Volume of upper roller, shaft and gear (m^3)

v_L = Volume of each of the lower rollers, shaft and gears (m^3)

g = acceleration due to gravity (m/sec^2)

D_u = Diameter of upper roller (m)

N_u = Required speed of upper rollers (rpm)

N_u = Required speed of lower rollers (rpm)

Number of lowers rollers = 2

(ii) Diameter of shafts of rollers.

The diameter of each of the shaft of the rollers was determined using the equation below (web 1982):

$$d = \frac{16\ M_T g\ d_r}{2\pi\rho_s}$$

Where M_T = Total mass of rollers and gears (kg)

g = Acceleration due to gravity (m/sec^2)

d_r = Diameter of rollers (m)

r_s = shear stress of street = 115 × 10 N/M2 (Juvinal, 1989)

(iii) Radial deformation

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

$$\phi = \frac{\Upsilon L}{G}$$

Where ϕ is the radial deformation or angle of twist (radians)

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

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

(iv) Speed reduction ratio of gear box

The speed reduction ratio of the gear box is a function of the electric motor, recommended speed of the top roller connected to the gear box and the diameter the pulley of the electric motor and the gear box. Thus, it is computed from established relation:

$$N_m\ D_m = N_g D_g \quad \text{.................... (6)}$$

$$\frac{N_g = N_m D_m}{D_g} \quad \text{.................... (7)}$$

Substituting $N_g = G_r \times N_r$ in equation (7)

$$\frac{G_r = N_m D_m}{D_g} \times N_r^{\bullet} \quad \text{.................... (8)}$$

Where G_r = the expected gear ratio of the gearbox

N_m = Speed of the pulley of the electric motor (rpm)

D_m = Diameter of the pulley of the motor (m)

N_r = Recommended speed of the top roller (rpm)

SPEED OF LOWER ROLLERS

The speed of the lower rollers are the same and inter-related with that of the top roller. It is computed based on the following equation:

$$N_T T_T = N_L L_T \quad \text{.................... (9)}$$

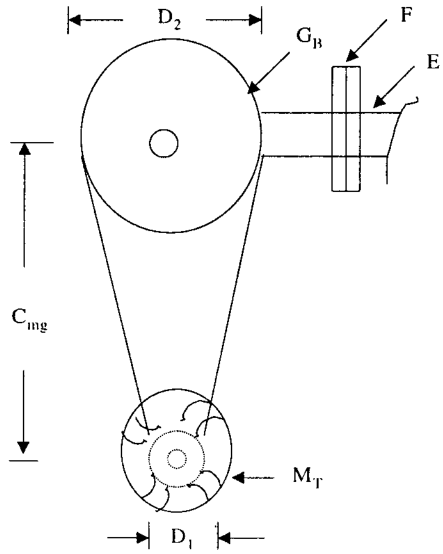

Fig. 6 : Belt connection between electric motor and top roller through the gear box

$$N_L = \frac{N_T T_T}{L_T} \quad \text{.................... (10)}$$

Where N_L is speed of each of the lower rollers (rpm).

N_T is speed of the top roller (rpm).

T_T is no. of Teeth of the top roller

L_T is no. of teeth of each of the lower rollers.

(v) Belt Lengths

Three B V – belts of equal lengths were used to transmit power from the electric motor to the speed reduction unit as shown in Fig 6. Their lengths were compared using the following equation. (Gbabo 1991):

$$L_T = \pi/2\ (D_2 + D_1) + 2C + \frac{(D_2 + D_1)_2}{4} \quad \text{.................... (11)}$$

where,

D_1 = Diameter of motor pulley

D_2 = Diameter of gear box

C = Centre to center distance between gearbox and motor pulley.

TESTING

The machine was tested to assess its throughput and efficiency.

MATERIALS AND METHODS

Three samples of sugarcane varieties: BD 95-030 BD 96-009 and local chewing cane were used for the experiment. The samples were weighed and crushed with the juice extractor. The same extraction pressure provided by a 10mm clearance between the top and intake roller with the aid of the adjustment mechanism was used for all the samples of the industrial canes. The clearance between the delivery top and delivery rollers were maintained at the same level of 0.005m for both the industrial and local cane varieties. These adjustments were obtained as optimum clearances during series of previous test running.

The weight of the extracted juice, baggasse, brix of the juice and time taken to extract the juice were recorded. The baggasse were initially sun-dried for 2 days and later oven dried for 4h. The weight of the dried baggasse was also noted. The moisture left in the baggasse, machine throughput and juice extraction efficiency were computed and values recorded in table 1 as follows :

(i) Moisture left in the baggasse,

$$W_{wb} = W_w - W_d \quad \text{.................... (12)}$$

Where W_w = Weight of wet baggasse (kg)

W_d = Weight of dried baggasse (kg)

Table 1 : Juice extraction data

Cane variety	Repli-cation	Wt. of cane kg	Brix of juice	Wt. of juice (kg)	Wt. of wet baggasse (kg)	Wt. of dried baggasse (kg)	Wt. of moisture Wm (kg)	Wt. of sugar in baggasse (kg)	Time Sec	Juice extr. effici-ency, %	Machine through put (capacity) kg/day
Bd 95-030	1	15.0	23	6.3	7.7	4.6	1.70	0.39	124	75.4	3483.9
	2	14.5	24	6.7	7.6	4.5	2.2	0.53	122	71.05	3422.9
	3	13.2	23	5.75	7.1	4.0	1.75	0.40	122	72.15	3116.06
Bd 96-009	1	20.5	19	8.3	11.9	8.7	2.5	0.48	130	73.58	4541.5
	2	18.6	21	7.1	11.0	8.2	2.2	0.46	125	72.75	4285.4
	3	19.0	20	7.5	10.8	8.0	2.4	0.48	125	72.25	4377.6
Local chewing cane	1	22.2	16	9.4	11.2	7.7	1.5	0.24	132	84.3	4843.6
	2	19.6	14	9.1	10.0	8.7	1.3	0.18	128	86.0	44100
	3	21.0	14	9.0	11.7	9.9	1.8	0.25	130	81.45	4652.3

Mean Juice extraction efficiencies (%) :
BD 95 – 030 = 72.53
BD 96 – 009 = 72.86
Local chewing cane = 83.9

Mean Throughput (capacity) kg/day :
BD 95 – 030 = 3340.9
BD 96 – 009 = 4401.5
Local chewing cane = 4635.3

(ii) Juice Extraction efficiency (h_{cy}) =

$$\frac{W_i}{W_j + W_m + W_s} \% \qquad \text{.................... (13)}$$

Where,

h_{cy} = Efficiency of juice extractor

W_i = Weight of juice (kg)

W_j = Weight of extracted juice (kg)

W_m = Weight of moisture left in the baggasse (kg)

W_s = Weight of sugar left in the baggasse (kg)

(iii) Capacity of machine

$$C_m = \frac{W_c}{t} \qquad \text{.................... (14)}$$

where C_m = machine capacity (tons/day)

W_c = weight of cane crushed

t = Time taken to crush the sugarcane

Weight of sugar left in the baggasse (W_s) =

$$\frac{B_j}{100} \times W_{mb} \qquad \text{.................... (15)}$$

Where B_j = Brix of juice

W_{mb} = Moisture left in the baggasse.

Machine Performance Assessment and Conclusion

The result of the cane juice extraction test using three sugarcane varieties as shown in table1 shows variation in juice extraction efficiency between the local chewing cane and the other two, BD95-030 and BD96-009. The efficiency of the machine when the chewing cane variety was used is 83.9% which is higher than the other two varieties. This variation could be as a result of the fact that the local chewing cane contains more juice than fibre compared to those of the exotic cane varieties meant for industrial uses. Accordingly, the weight of moisture and sugar left in the baggasse after juice extraction is more for BD95-030 and BD 96-009. The throughout (capacity) of the machine also varies (3340 .9 kg/day- 4635.3kg/day) for different cane varieties. The machine is also simple, easy to operate and maintain. Within the period it was used in the sugar plant, it worked continually without much interruptions from mechanical failures. These results indicates that the design of the machine suits its purpose as one of the equipment for processing sugar in developing countries like Nigeria.

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