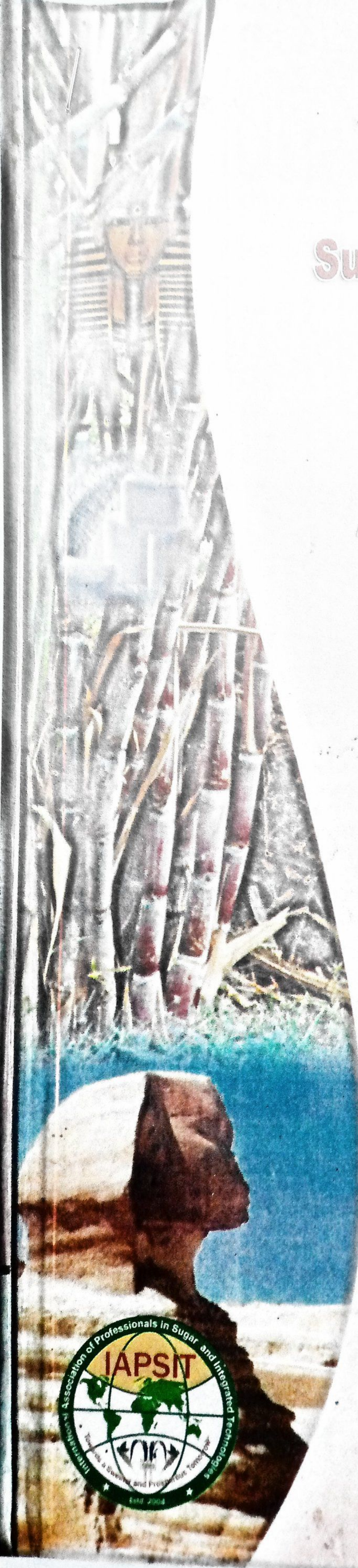

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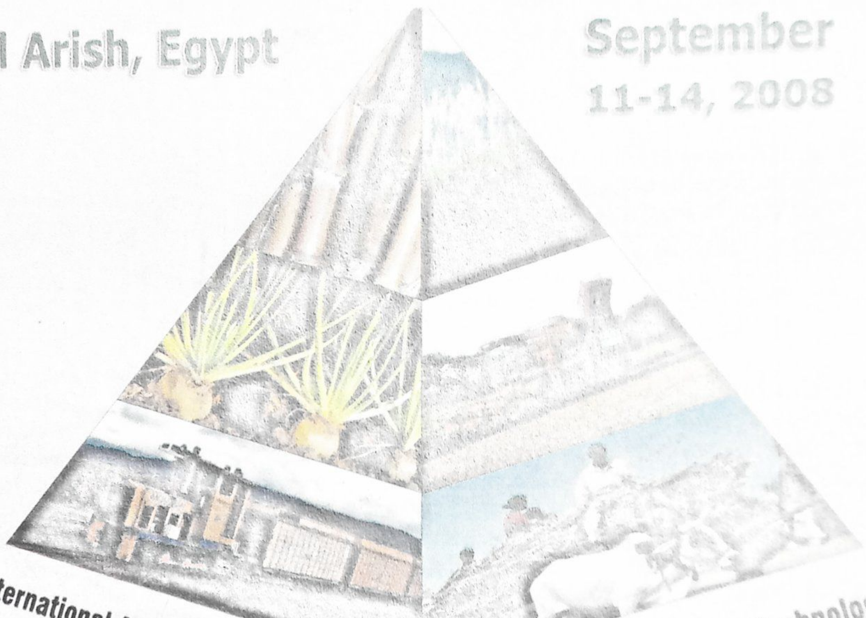
Meeting the Challenges of Sugar Crops & Integrated Industries in Developing Countries

Proceedings of the International Conference IS-2008

Al Arish, Egypt

September 11-14, 2008



International Association of Professionals in Sugar and Integrated Technologies

Editors-in-Chief

Yang-Rui Li, M.I. Nasr, S. Solomon and G.P. Rao

Sponsored by

International Association of Professionals in Sugar and Integrated Technologies IAPSIT and Dr. Hassan Rateb, Sinai University

Engineering House Press Co.

6, October . Egypt

جامعة سيناء

Sinai University

Meeting the Challenges of Sugar Crops & Integrated Industries in Developing Countries, Al Arish, Egypt, pp 683-688 (2008)

DEVELOPMENT AND TESTING OF SUGARCANE CUTTER AND JUICE EXPELLER FOR COTTAGE LEVEL SUGAR FACTORIES IN NIGERIA

GBABO AGIDI A.C. WADA and A.A. OCHIGBO

National Cereals Research Institute, Badeggi, Niger State, Nigeria

Summary

Aims: A system to extract sugarcane juice was designed and fabricated in order to replace the older and conventional method of cane juice extraction by using roller model machines.

Methods and Results: The present work was carried out at Agricultural Engineering workshop, National Cereals Research Institute, Badeggi, Nigeria. The development of the new system was initiated to increase juice extraction percent as it was only 50-60% with traditional roller method of juice extraction. The Cane Cutter/ Juice expeller system is basically made up of a trapezoidal hopper, cane cutting assembly having series of rotating knives, a grasshopper reciprocatory conveyor; a frustrum hopper, a screw worm, a cage of iron bars, pressure adjustment device, cane juice and baggase outlets. A 10hP electric motor provided power to the cane cutter while a 25hP electric motor which drive the expeller through a gearbox. Result obtained from testing the system indicates that the cane cutter has an average input Capacity of 1287kg/h with minimal losses ranging from 0.8kg-2.0kg sugarcane/ton. These losses are even recoverable by gathering and feeding them into the expeller. For the cane Juice Expeller, about 98% juice extraction efficiency was obtained for all the Sugarcane varieties *viz.*, BD 95-030, BD96-001 and BD 96-009. The average machine capacity was 327kg/h. The high extraction Efficiency of the system was evidenced by the high temperature (70-75^{0}C) of the discharged bagasse.

Significance of study: The sugarcane crushing system showed 98% juice extraction efficiency and is quite easy to operate and maintain, hence it is very suitable for economical use even in rural communities.

Key words: Sugarcane cutter, juice expeller, capacity, efficiency, rural communities.

INTRODUCTION

Sugarcane juice extraction is the major process in the manufacture of sugar from Sugarcane. It is basically the separation of the juice with its constituents from the fibrous portions. Over the years, mechanical means involving the application of pressure through grooved rollers are commonly utilized. The simplest of this system is a 3 roller model in which 3-4 sugarcane stalks are fed directly into the machine. Another model of the roller type juice extractor is the multiple sets, of roller system having 2 – 6 sets of grooved roller (Rapheal, 1983). In this system, sugarcane stalks were shredded into multi-dimensional fragments by heavy rotating knives are fed into these sets of rollers simultaneously with the aid of belt conveyors. In order to maximize juice extraction rate, a process of spraying hot water into the shredded mass of sugarcane was provided in between adjacent sets of rollers (Gbabo, 2004).

In the sugar industry, the simple 3 roller vertical or horizontal models are widely used by small scale sugar producers due to simplicity of operation and maintenance while the later model of multiple 2-6 sets roller juice extractors are utilized by large scale manufacturers. It has been established that although higher juice extraction efficiencies of about 75% was recorded for the multiple roller juice extractors compared to the simple 3-roller models which has about 60% efficiency, the additional heat energy requirement to evaporate the water added to the juice during the imbibition process also requires additional running cost (Amosun *et al.*, 2000).

This cost is easily offset by the large sugar factories with the aid of the Vacuum Pan Boilers which evaporate the water at lower pressures and correspondingly lower temperature. This system is devoid of sugar calmerization which usually leads to higher sugar recovery. Since, the small scale sugar factories evaporate their juice with an open Pan system at normal atmospheric temperature and pressure, sugar calmerization usually takes place which results in lower sugar recovery. Therefore, the development of an efficient juice extraction system was required in order to offset the loss of sugar during the evaporation stage (using the Open Pan Boiling System) through calmerization. As a result the expeller cane juice extraction model was developed by the National Cereals Research Institute, Badeggi which has the National mandate on Sugarcane and sugar Research in Nigeria.

MACHINE DESCRIPTION

The sugarcane cutter and juice expeller system is made up of the following basic components (Fig. 1-4).

Cane Cutter

The function of the cane cutter is to cut sugarcane transversely into small fragments of 30- 50mm lengthwise. It is composed of a horizontal shaft (5) carrying 75 knives (k1-k75) fabricated with stainless steel flat bar. Each of the blade is 23mm long, 50mm wide and 5mm thick. The shaft with its knives is suspended by two 2 bearings (B_1 and B_2) over a screen concave (Cs) constructed with 5mm rods that are spaced 50mm apart. A trapezoidal hopper (H) capable of accommodating sugarcane lengths of 1800 mm is provided at the top end of a stainless solid upper concave (Cu). A grasshopper conveyor assembly (Gc) which transports the cut fragments of cane that pass through the concave screen is incorporated with the aid of solid stainless sheet housing, suspended by four (4) spring flat iron bars and hinged to an eccentric reciprocatory unit. A 10hP electric motor supplies power to the rotating knife assembly at 1,850 rpm and the grasshopper conveyor unit at 0.35m/sec. with the aid of appropriate pulleys (Pe, Pg and Pc) and belts (Bc and Bg) (Fig. 1 and 2).

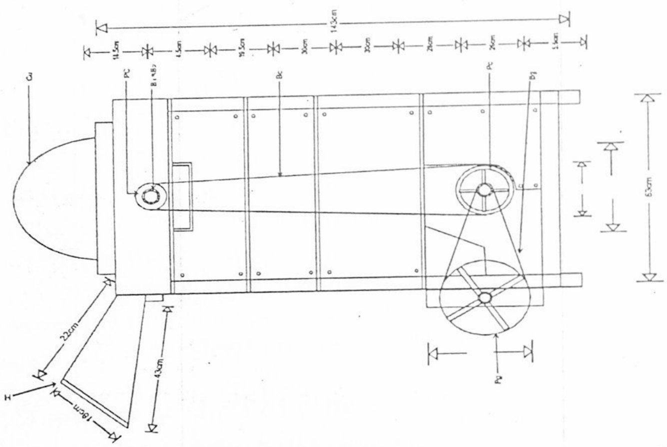


Fig.1. Left hand side view of sugarcane cutter

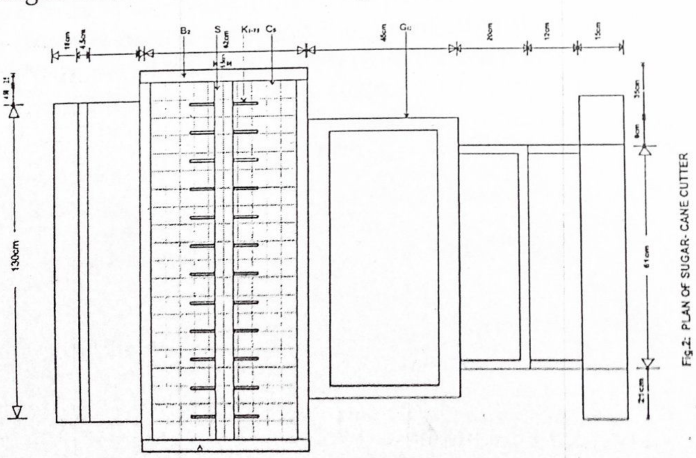


Fig.2. Plan of sugarcane cutter

The Juice Expeller

This is essentially made up of a screw worm (Sw) tapering from a diameter of 80-150 mm. It rotates at 50 rpm and housed in a barrel (ba) constructed with 16mm stainless square rods. A 3.5mm clearance is maintained between adjacent rods to allow free flow of extracted juice. A rotary pressure adjustment (Pa) device is attached to the rear of the worm while the front of the worm is connected to a 25hP electric motor through a speed reduction gear mechanism, Pulleys, and belts (Fig. 3 and 4).

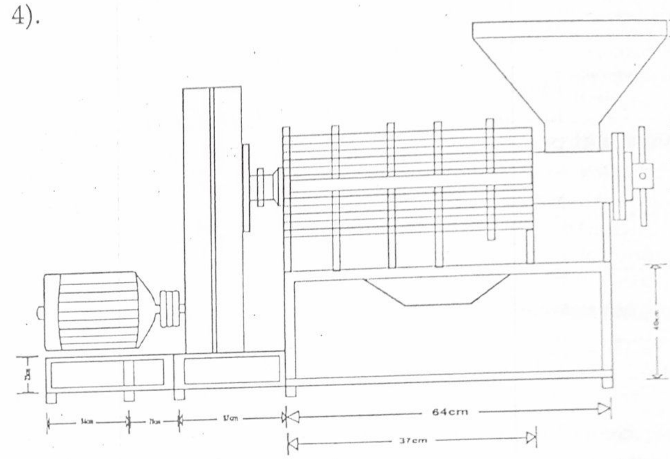


Fig.3. Right hand side view of sugarcane juice expeller

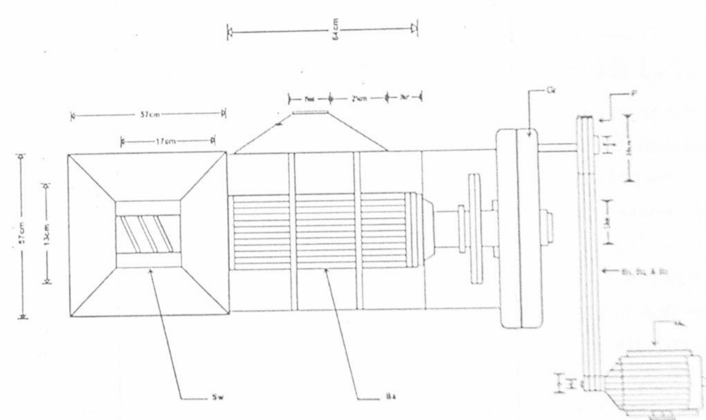


Fig.4: PLAN OF SUGAR-CANE JUICE EXPELLER

Fig.4. Plan of sugarcane juice expeller

MODE OF OPERATION

The Sugarcane Cutter is put on with aid of the switch and left to run without load for about 2 minutes before feeding it with materials. Three to four Sugarcane stalks measuring about 1200mm or fewer sizes are thrown intermittently into the machine through the hopper at interval of about 10 seconds. The high speed rotating knives cut the canes into fragments of 30-50mm lengthwise where they were swept through the concave screen that is placed below the blade assembly onto the inclined tray platform of the reciprocating unit. The fragments of the cane are transported downwards and discharged through the spout into the hopper of the expeller.

The fragments are automatically conveyed and subjected to very high pressure with the aid of the rotating worm (screw) and barrel assembly. The juice from the fragmented canes is squeezed out due to the high pressure and passed through the clearance between the bars of the barrel into a collector and channeled into the pans of the open pan evaporator while the bagasse are pushed further and discharged at the front opening of the barrel.

DESIGN ANALYSIS

Power requirement

The power required to drive the cane Cutter was computed from established equation as follows:

Cane Cutter

$P = F_T V_C$ ....(1)

Substituting $F_T = Mg$

And $V = pDN$ in equ. (1)

$P = Mg\,\pi DN$.......................................(2)

Substituting $M. = \lambda \rho_s V_s$ in equ. (2)

$P = \pi \rho_s V_s g D_k N$..................................(3)

Where P= The power requirement of the cane Cutter (watts); ρ_s=the density of stainless steel = 8,500kg/m^3 (Gbabo 2005); V_s = Total volume of the stainless steel used for the construction of the cane Cutting knife assembly (m^3); D_k = Diameter of cane cutting knife assembly (m); N = Speed of cane cutting knife assembly (rpm); G = Acceleration due to gravity (m/sec^2)

Diameter of shaft of cane Cutter

The diameter of the shaft to transmit power to the cutting knives is dependent on the expected twisting moment (torque) on the shaft and the permissible shear stress of the material (stainless steel) used for the construction of the shaft as shown (Web 1982).

$$Ds = \left\{\frac{16M_t}{\pi S_s}\right\}^{0.333} \qquad \text{.......................(4)}$$

Substituting $M_t = F_T \frac{D_c}{2}$ in equ. (4)

And $F_T = mg$

$$M_t = \left\{\frac{Mg\, d_c}{2}\right\}$$

$$Ds = \left\{\frac{8M_T D_c}{\pi S_s}\right\}^{0.333} \qquad \text{.......................(5)}$$

Where M_t=Twisting moment (N_m); g =Acceleration due to gravity (m/sec^2); d_c =Diameter of cane cutting knife assembly (m); Ss=Shear stress of stainless Steel = 115 x 10^{6}N/m^2 (Juvinal 1989); D_s=Diameter of shaft of cane cutter

Pulley Size Selection

The pulley sizes for transmission of power from the electric motor to the cane cutting knife assembly and reciprocatory unit of the Cane cutter is a function of the speed of the electric motor, the selected pulley size of the motor, the selected speeds of the cane cutting knife assembly and the reciprocating unit. The selection of the pulley sizes were made as follows:

Diameter of Cane Cutter pulley

As shown in Fig 5

$$D_c N_c = D_m N_m \qquad \text{.......................(6)}$$

$$D_c = \frac{D_m N_m}{N_c}$$

Where D_c=Diameter of Cane cutter Pulley (m); D_m=Diameter of electric motor pulley (m); N_m=Speed of electric motor=1450 rpm; N_c=is expected speed of cane cutting unit (rpm)

Diameter of reciprocatory unit pulley:

$$D_r N_r = D_m N_m \qquad \text{.......................(7)}$$

$$\therefore D_r = \frac{D_m N_m}{N_r} \qquad \text{.......................(8)}$$

Where D_r = Diameter of reciprocatory unit pulley (m); D_m =Diameter of electric motor pulley (m); N_m = speed of electric motor = 1450rpm; N_r = Expected speed of the reciprotary unit

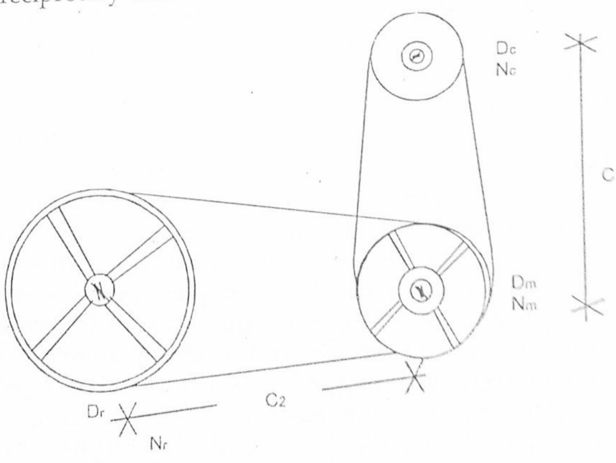


Fig.5. Derive connection for sugarcane cutter

Cane Juice Expeller

Power Requirement

The power requirement of the Cane Juice Expeller is a function of the total weight of the screw worm and the expected designed speed of the expeller:

$$P_e = F_e V_e \quad \ldots(9)$$

Substituting $F_e = M_e g$ and $V_e = \pi D_e N_e$ in equation (9)

$$P_e = \pi M_e g D_e N_e$$

$$= \pi \rho V_e g D_e N_e$$

Where P_e = Expected power requirement of the expeller (watts); Where M_e = mass of expeller (kg); g = acceleration due to gravity 9.81m/sec²; D_e = biggest diameter of shaft (m); N_e = Rev. per minute of worm screw (m/sec); V_e = volume of expeller (m³); ρ = density of stainless steel = 8750kg / m³ (Ryder 1982)

Speed reduction ratio of gearbox

A gear box was used to reduce the speed of the electric motor (1450rpm) to the recommended speed of the cane Juice Expeller (60rpm). The speed reduction ratio of the gearbox that was selected is dependent on the recommended speed of the cane juice expeller, the speed of the electric motor, the pulley diameters of the gearbox and the electric motor (Fig. 6). The following conventional equation relating to these parameters was used to determine the speed reduction ratio of the gearbox.

$$N_g D_g = N_m D_m \quad \ldots(10)$$

$$N_g = \frac{N_m D_m}{D_g} \quad \ldots(11)$$

Substituting $N_g = G_r \times N_r$ in equation ...(12)

$$G_r = \frac{N_m D_m}{D_g} \times N_r \quad \ldots(13)$$

Where G_r=The expected gear ratio of the gear box; N_m=Speed of the electric motor (rpm); D_m = Diameter of the electric motor pulley (m); N_r=Recommended speed of the Cane juice expeller.

Dimensions of Key to transmit power from the gear box to the expeller

As shown in fig. 6 two keys were provided to transmit power from the gearbox to the shaft (screw worm) of the expeller through two flanges. Since the expeller is expected to exert great pressure on the fragments of Sugarcane introduced into the expeller, the dimensions of the two keys were appropriately determine from the equation expressed in BS 4235 (1987).

$$\sigma_s = \frac{F}{wL} \quad \ldots(14)$$

$$\therefore L = \frac{F}{\sigma_s W} \quad \ldots(15)$$

considering a 20% factor of safety level

$$L = \frac{F}{\sigma_s W} + 0.2\left(\frac{F}{\sigma_s W}\right) \quad \ldots(16)$$

Where L = The expected length of the key (m); W = width of the key selected to be 0.012m; ós = shear stress exerted on the key (N/m²); F = is the force exerted on the keys (N)

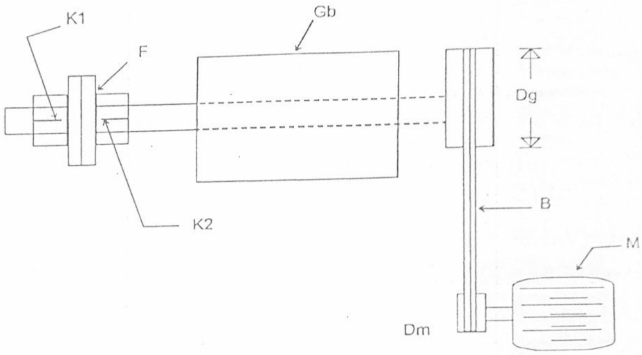


Fig. 6. Derive connection for sugarcane juice expeller

Testing

The cane Cutter and Juice Expeller system was tested to assess its Efficiency, throughout (Capacity), and other parameters as follows.

MATERIALS AND METHODS:

Four samples of Sugarcane varieties: BD95-030, BD96-009 and BD 96-001 of approximately the same weight (1000kg) were used for the testing.

Approximate weights of Sugarcane were used because it was impossible to measure the exact weight of 1000kg of the Sugarcane. Each sample was replicated three times.

Three to four stalks of Sugarcane were thrown into the cane Cutter intermittently at intervals of 10-15 seconds. The cut and fragmented pieces of Sugarcane being automatically conveyed by the grasshopper conveyor located beneath the Cane cutter knife assembly was collected with a stainless trough having an open end measuring 1.2m length, 0.8m width and 0.3m high. They were then scooped manually and fed into the hopper after adjusting the pressure device to a predetermined degree. This level of pressure adjustment was obtained as optimum standard during series of test-running in the engineering workshop. The juice which oozes out of the clearance between the bars of the cage assembly are collected through the juice collector with graduated buckets in litres and weighed in a hanging spring balance. The baggasse which discharged through the posterior end of the expeller were also collected and weighed with the same hanging spring balance. The samples were then dried in an oven and weighed again in order to compute the juice extraction efficiency of the expeller. The following parameters were computed from established formula as follows (Gbabo 2002) and presented in Table 1 and 2.

Input Capacity of cane Cutter.

$$C_c = \frac{Wt}{t} \times 60 \text{ mins/hr} \quad \text{.................(17)}$$

Where C_c = The input Capacity of the cane Cutter (kg/hr); W_t = The weight of sugar cut by the machine (kg); t = The time taken to cut the Sugarcane (min.).

Operation loss of cane Cutter:

$$L_c = W_t - W_f \quad \text{..................................(18)}$$

Where L_c = The weight of loss Sugarcane after cutting (kg); W_t = Initial weight of Sugarcane sample; W_f = Total and final weight of Sugarcane after cutting (kg)

Table 1. Cane Cutting Data

Weight of cane stalks	Time (mins)	Weight of fragmented canes	Losses (kg)	Input Capacity of machine kg/hr
1000.5	45	999.1	1.4	1334.0
998.7	48	997.6	1.1	1248.4
1001.0	43	999.5	1.5	1396.7
1002.4	49	1001.3	1.1	1227.4
1000.8	43	1000.0	0.8	1396.5
1000.0	50	998.0	2.0	1200.0
1000.4	47	999.7	0.7	1277.1
1001.0	48	998.9	2.1	1251.3
1002.0	48	1001.2	0.8	1252.5

Average input Capacity = 1287kg/hr

Approximate sizes of Sugarcane fragments = 7.5cm x 2.0cm

Average loss of Sugarcane = 0.13%

Weight of moisture left in the baggasse of the expeller:

$$W_{wb} = W_w - W_d \quad \text{..(19)}$$

Where W_{wb} = Weight of moisture in baggasse (kg); W_w = Weight of wet baggasse (k); W_d = Weight of dried baggasse (kg)

Weight of sugar left in the baggasse

$$W_s = \frac{B_r}{100} \times W_{wb} \quad \text{.....................(20)}$$

Where W_s = Weight of sugar left in the baggasse (kg); B_r = Brix of juice (kg); W_b = Wet weight of baggasse (kg)

Juice Extraction Efficiency of Expeller

$$\wp_{cy} = \frac{W_j}{W_j + W_m + W_s} \quad \text{.....................(21)}$$

Where $\wp_{cy}$ = Effeiciency of juice extraction (%); 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.

Capacity of Expeller

$$C_e = \frac{Wt}{t} x 60 \text{mins/hr} \quad \text{..................(22)}$$

Where C_e = Input Capacity of the machine (kg/hr); W_t = weight of Sugarcane crushed in the expeller (kg); t = Time taken to crush the Sugarcane (kg).

RESULTS AND CONCLUSION

The result of the field test carried out on the Cane cutter and juice expeller system indicates that the Cane cutter was very efficient because the sizes of the fragments measuring approximately 12.0cm x 5.5cm were adequately suitable for feeding the expeller.

The recorded average input Capacity of 1287 kg/hr

Table 2. Sugarcane juice extraction

Sugarcane variety	Weight of Sugarcane (kg)	Vol. Of extracted juice (litres)	Weight of extracted juice (litres)	Brix of juice (%)	Weight of Wet baggasse (kg)	Weight of dried baggasse (kg)	Weight of moisture (kg)	Weight of sugar left in baggasse (kg)	Juice extraction time (mins.)	Machine input Capacity (kg/hr)	Machine Efficiency (%)	Percentage juice extraction from total Weight of cane
BD 95-030	1000.5	657.8	750.8	19.5	249.0	239.1	9.9	1.9	184	324	98.5	75.0
	998.7	651.1	742.3	19.0	253.8	241.5	12.3	2.3	190	312	98.1	74.3
	1001.0	643.9	734.1	19.8	265.6	254.2	11.4	2.3	176	342	98.2	73.3
BD 96-001	1002.4	641.1	731.7	19.5	269.4	257.5	11.9	2.3	178	336	98.1	73.0
	1000.8	641.1	730.8	18.7	270.0	258.9	10.8	2.0	192	312	98.3	73.0
	1000.0	639.0	728.5	19.0	270.0	258.0	12.0	2.3	180	336	98.1	72.9
BD 96-009	1002.0	663.4	656.3	18.0	242.9	230.3	12.6	2.3	195	306	98.1	75.6
	1001.0	654.1	745.7	19.5	243.3	243.3	12.0	2.3	177	342	98.1	74.5
	1002.0	666.2	759.5	18.5	241.2	228.0	13.2	2.4	181	330	98.0	75.8

(Table 1) is very suitable for cottage sugar factories. Also, the average 0.13% loss of Sugarcane fragment is very insignificant. This loss is even recovered by gathering them on the floor and feeding them into the expeller.

The Efficiency of 98.2% of the expeller is very high. This high expeller efficiency was evidenced in the extreme dryness of the baggasse after juice extraction. The baggasse were so dried that they were used to heat the open pan evaporation system immediately without further drying process unlike the baggasse from the roller model juice extractor as they had temperatures of 70-75% depending on the degree of adjustment of the pressure device. The percentage juice extraction from total weight of cane is 73-76%. This value is very desirable compared to the expected maximum juice to total weight of cane value of 72 – 76% as expressed by Chen and Chou (2004).

A thorough assessment of the whole process indicates that it is superior to the roller model juice extraction system due to its high juice extraction Efficiency of over 98.2% which is almost twice the value (50-65%) of the roller model juice extractor. Also, less frequent breakdown of machine arising from overfeeding was observed for the expeller model. The expeller can work continuously for 10hours once it has been set to the recommended pressure; Whereas, in the case of the roller juice extractor, frequent breakdowns and interruptions are recorded due to the involvement of many mechanical systems in the machine. As a result, the operation of the expeller is less tedious, simple and easy to maintain compared to the roller juice extractor. As the advantages of the expeller models outweigh those of the roller juice extractor, it is highly recommended in cottage sugar industries since the high juice recovery of the expeller system can offset the losses incurrend in the open pan evaporation system usually adopted in cottage sugar industries due to sugar calmerization that is associated with such system.

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