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Development of a sugarcane juice extractor for small scale industries

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The major areas of need in the cane industry are identified along the plant process as cane preparation, milling, juice extraction, sugar boiling and separation of crystal. Mechanical power is the most essential need in these areas, except for juice concentration and sugar boiling that requires heat. The milling of sugarcane is a unit operation that crucial for making sugarcane juice available for various applications. The currently available sugarcane juice extractors require high energy and sophisticated mills, driven mechanically. These are out of the reach of small scale and rural farmers that are presently involved in processing of cane juice into ethanol, brown sugar and other related products in Nigeria. The development of a small scale sugarcane juice extractor was therefore to meet the needs of the small scale farmers who cannot afford the high capacity and complex cane crushers. This successfully project designed and constructed a simple mechanical device for extraction of sugarcane juice. The functional performance and economics operations of the machine were evaluated. The output capacities of 10.50, 12.00 and 14.25 kg/ hr were obtained at operating speeds of 0.25, 0.3 and 0.36 m/s. The extraction efficiency of the machine ranged between 40 and 61 % at operating speeds of 0.25 and 0.36 m/s. It was observed that this optimum performance of the machine cannot be sustained over a long processing period due to the bluntness development of the perforated grating drum over time. However, conditions that enhanced in maximum operating performance were enumerated.

Keywords: Sugarcane, Juice Extraction, Grater, Maceration, Milling, Crushing

Introduction

The major areas of needs in the cane industry are identified along the plant process as cane preparation, milling, juice extraction, sugar boiling and separation of crystal. Mechanical power is the most essential need in these identified areas except for juice concentration and sugar boiling that requires heat (FAO, 1995, Robotham and Chappell. 1998). The milling of sugarcane is a unit operation that is crucial and necessary for making sugarcane juice available for various applications. The currently available sugarcane juice extractors

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require high energy and are application of more sophisticated mill driven mechanically (Muchow et al. 2000, Ou et al., 2002). Some of the available cane crushers are of high capacity mainly for industrial applications. These are out of reach of small scale and rural farmers that are presently involved in processing of cane juice into ethanol, brown sugar and other related products at small scale level. The problems associated with processing of sugarcane include small size of farms and farm fragmentation as a result of land ownership by inheritance. Poor storage facilities and practices to preserve harvested canes or extracted juice from being refined to sugar (Mello and Harris, 2000; Wegener, 1996). In addition to the above problems using the same carriage capacity/medium, it will further reduce production cost to transport extracted sugarcane juice from the farm to the factory for refining into sugar than transporting harvested sugarcane to the factory for processing. This is because the extracted juice from a trailer load of sugarcane many not be up to 30% of a trailer load of juice.

The major cane processing stages in converting sugarcane to its essential derivatives was shown in Fig 1. It was clearly indicated that processing of sugarcane starts with the extraction of juice from sugarcane stalk. Several methods of juice extraction were in used. These methods included boiling the cane to extract the juice, use of wooden presses and application of more sophisticated mills driven mechanically or by bullocks (Okogie, 1980). The high power requirements during processing of sugarcane constitute the major constrain in the development of small scale sugar processing plants. This also explains why natural sugar juice is not generally available. The average power distributions for a medium size sugar factory powered by electricity or steam turbine at crushing rate of 170 tons/hour is presented in Table 1. The recent upsurge of interest in generation of biofuels from plant material has necessitated current waves of interest in the partial mechanization of cane juice extraction and coupled with the production of bio ethanol for domestic and industrial application (Galitsky et al., 2007). The development of a small scale sugarcane juice extractor was therefore to meet the needs of the small scale farmers who cannot avoid high capacity and complex cane crushers. The main objectives of this study were to design and construct a simple mechanical device for extraction of sugarcane juice. The functional performance and economics of operation of the machine were evaluated.

Table 1. Average power distribution of Medium Size Sugar factory crushing at 170 tons / hour

Processing Stages	Cane Preparation and Milling			
	Using Steam Turbine		Totally Electrified	
	Power (kW)	% of Total Load	Power (kW)	% of Total Load
Cane Preparation and Handling	110	5.0	410	10.0
Milling	120	5.5	1700	41.7
Clarification	190	8.6	190	4.7
Pan Boiling and Concentration	552	25.1	552	13.5
Centrifugal	472	21.5	472	11.6
Steam generation	656	29.5	652	16.1
Lighting and Various Uses	100	4.5	100	2.4

Methodology

Basic Design and Construction

The principal components of the sugarcane juice extractor were performed as a framework, grating surface, drive system, hopper and cane stalk clapper. The relationship between design considerations was done as Grating Cylinder. Punched metal sheet was perforated to create grating medium and size reduction of the whole cane stalk. The grating surface was systematically positioned above a crushing chamber and at the lower base of hopper. The front view of the machine was shown in Fig.2. The perforated grating cylinder macerated the stalks into fine chips. The trapped liquid like sponge in the cane fibre was finally discharged and separated from the other plant materials in a crushing chamber. The speed of operating the grating cylinder was crucial. The peripheral speed was determined using Equation 1 and the expression of power requirement from Equation 2 (Khurm and Gupta,2008).

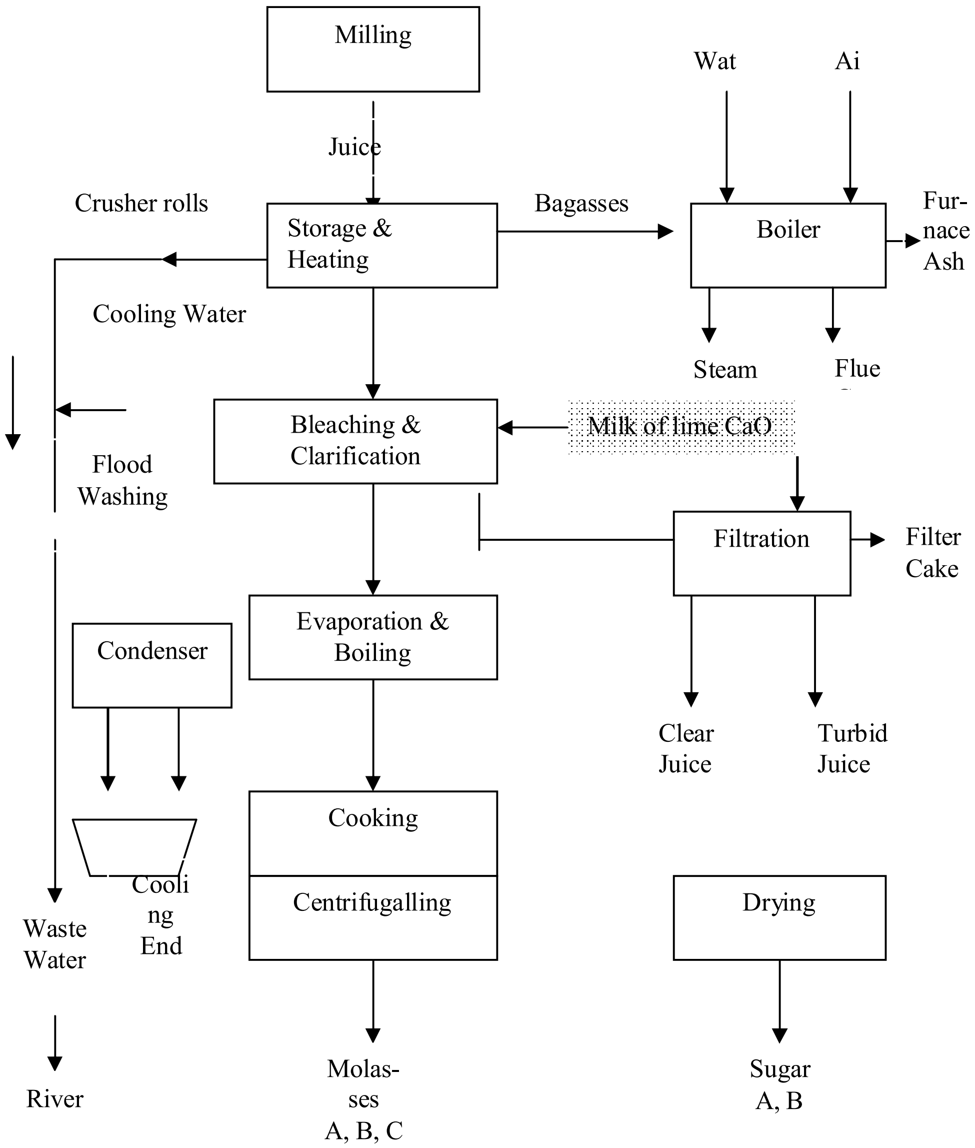

Fig. 1. Outline of Major Cane Processing Stages

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$$V_s = \frac{\pi d N}{60} \quad (1)$$

where, V_S = Peripheral Speed (m/s)
d = Grating drum Diameter (m)
N = Speed of Operating the drum (rpm)

The operating peripheral speeds vary between 0.25 m/s and 0.36 m/s. The diameter of the grating drum was chosen as 120 mm.

$$P = \frac{2 \pi N T}{60 \; x \; 75} \quad (2)$$

where, P = Power required (kW)
T = Torque on the Drum (N)

b) Diameter of the Main Shaft

The diameter of the main shaft that carries the grating drum, hopper and other accessories was determined using the expression presented in Equation 3.

$$d = \sqrt[3]{\frac{16 T}{\pi \tau}} \quad (3)$$

Where, τ = Torsional shear stress MPa
T = Twisting moment or Torque acting on the Shaft, Nm

The diameter of 25 mm stainless steel was chosen for the main shaft.

c) Gravimetric Capacity and Volume of a Crushing Chamber

The gravimetric capacity of the crushing chamber is related to the volumetric capacity and storage capacity of the chamber using Equations 4 and 5.

$$G_v = V_v \; x \; \rho_b \quad (4)$$

where, G_v = Gravimetric Capacity
V_v = Volumetric capacity

ρ_b = Nominal density of the plant material in the crushing chamber

$$V_v = \frac{\pi D^2}{4} LH \qquad (5)$$

where, D = diameter of the cylinder
LH= Stuck level at the maximum dead end of the compressing bar
= H – 2%H
H = Overall height of the cylinder

The machine was constructed using the available facilities at the Department of Agricultural Engineering, University of Ilorin. The pictorial view of the machine is presented as shown in Fig. 3.

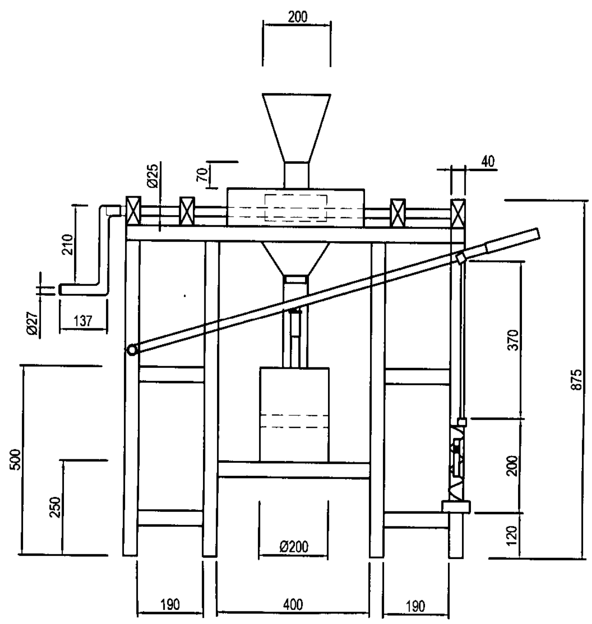

Fig.2. Front View of of the Sugarcane Juice Extractor

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Machine Testing

The preliminary machine testing was undertaken to assess the effective performance of the machine components and to investigate the machine efficiency. Stalks of sugarcane were collected from the University of Ilorin Sugar Research Farm. Long section of sugarcane is loaded through the hopper and then press against the grating surface. The grated sugarcane and juice are directed to the compression chamber where there is a pressing lever that brings about the extraction of juice. The extracted juice is collected through the tap as shown in Fig 1.

The material employed in machine testing includes stalks of sugarcane, a collector to receive the extracted juice from the discharge outlet, Venier Caliper, Stop Watch, Weighing Balance and three categories of operators. The operators are categorized as an average man, average woman and child. A Tachometer was used to establish the average speed of operating the machine by each of the classified operators as 58, 48 and 40 rpm respectively. The diameters of the sugarcane are grouped into 3 sizes, 28, 24 and 20 mm with the aid of a Venier Caliper.

Three levels of the peripheral speeds of the machine were determined using Eqn. 1 as 0.36, 0.30 and 0.25 m/s, respectively. The three distinct cane sizes were 28 mm, 24 mm and 20 mm. The moisture content of each cane stalk was determined following method described by Jenkins (1966). Eqn. 6 was used to evaluate the exact moisture content of each cane stalk.

$$m_{cwb} = \frac{Wet\,Cane - Dried\,Cane\,Fibre}{Wet\,Cane} \qquad (6)$$

Each of the sizes of the sugarcane stalks is loaded vertically into the hopper and press against the grating drums effort is applied at the rotating handle to bring about the crushing of the canes. The mass of the juice extracted and time taken for the grating were recorded. Weight of the fibre of the crushed cane was recorded independently.

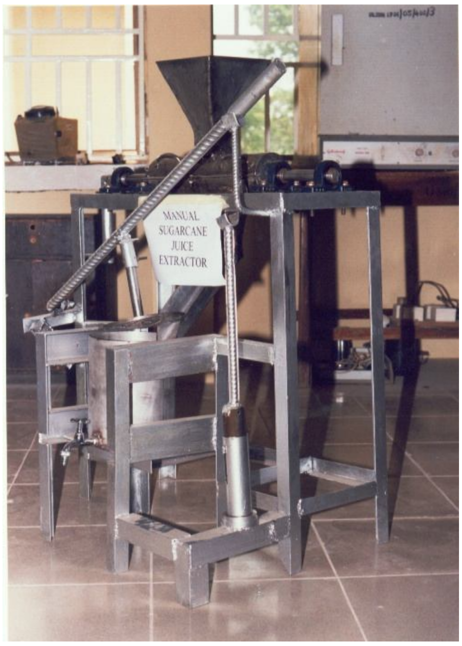

Fig. 3. Pictorial View of the Sugarcane Juice Extractor

The output capacity and extraction efficiency of the extractor were evaluated using Equations 7, 8 and 9 as described by Jenkins (1966), Hugot and Jenkins (1960), Rein et al. (2007) and Meade (1977).

$$C_o = \frac{W_j}{T} \quad (7)$$

where, C_o = Output Capacity (kg / hr)
W_j = Weight of juice extracted (kg)
T = Total time taken for extraction (hr)

$$J_p = \frac{W\, M_{cwb}}{100} \quad (8)$$

where, J_p = W - W_d = Juice present (kg)
W = Weight of wet sample (kg)
W_d = Weight of dry sample (kg)
M_{cwb} = Moisture content wet basis

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$$E_{ef} = \frac{W_j}{J_p} \ x \ 100 \qquad (9)$$

where, E_{ef} = Extraction Efficiency (%)
W_j = Weight of juice extracted (g)

Results and Discussion

The classified physical dimensions and the values of the moisture content for the sets of cane stalks that were used for the experiment. The values of the extracted juice in kilogramme were presented in Tables 2 and 3. 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 amount of extracted juice with reference to moisture content and variation in cane stalk sizes were as presented in Figs. 4 and 5 that presented the effects of the cane size and operating speed of the machine on the extractor efficiency of the cane juice.

Effects of Stalk Size and Moisture Content on the Quantity of Cane Juice
The extracted juice increased with increase in moisture content washown in Fig.4. The amount of extracted juice also decreases as the size of cane stalk decreases. The presence of high moisture content was an indication of high quantity of cane juice in the stalk accoeding to the report of Mathur (1995). 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 wall thereby realizing small quantity of the juice. This is explaination for the reason of low juice extraction in smaller cane sizes while operating the machine at either low or high peripheral speed (Table2). The output capacity was determined using expression presented in Eqn. 5. The output capacity ranges between 5.32 kg/hr and 12.75 kg/hr. At operating speed of 0.36 m/s about 12.75 kg can be extracted in 1 hour. At high operating speed, higher energy is developed resulting in effective maceration and crushing of cane stalk to release more cane juice. The various sizes of cane stalks the extraction of juice followed the same trend of increase of juice extraction at higher peripheral speed while higher juice was recovered with an increase in cane stalk (Fig.5). The machine efficiency increased with an increase in peripheral speed (Fig.4). The juice extractor operated at 60 % of cane juice extraction at operating peripheral speed of 0.36 m/s and the machine developed higher energy that was sufficient to cause effective crushing and extraction of

cane juice. Result indicated that low extraction efficiency of 41 % is experienced at low operating peripheral speed of 0.25 m/s (Fig.6).

The quantity of juice presented in the whole cane juice was determined by Eqn. 6 and presented in Table 2. It is clearly shown that further processing conditions can be imposed on the macerated cane stalk before subsequent expression for recovery of the cane juice from the enclosed cane fibre without prejudice to the ability of the cane juice extractor from expressing juice from the entrapped cane fibre. Chen, *et al.* (1993) highlighted some of the factors that affect effective sugarcane juice extraction. Therefore, further investigation of some of these factors may be considered for future studies.

The amount of extracted juice decreased in the size of cane stalk decreases. The presence of high moisture content was indicated high quantity of cane juice in the stalk. 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. This confirms the observed phenomenon in Tromp (1949) and Okogie (1980).

The output capacity was determined using expression that presented in Eqn. 5. The output capacity ranges between 5.32 kg/hr and 12.75 kg/hr. At operating speed of 0.36 m/s about 12.75 kg can be extracted in 1 hour. At high operating speed, higher energy is developed resulting in effective maceration and crushing of cane stalk to release more cane juice.

A sugarcane juice extractor was well-designed and constructed. The output capacities of 10.50, 12.00 and 14.25 kg/ hr were obtained at operating speeds of 0.25, 0.3 and 0.36 m/s, respectively. The extraction efficiencies ranged between 40 and 61 % at operating speed of 0.25 and 0.36 m/s. It was observed that the optimum performance that cannot be sustained over a long processing period because of the observed bluntness in the perforated grating drum over time of use and this reduces the extraction efficiency of the machine. Further work would be carried out on the arrangement of the grating drum, crushing chamber and effects of some processing factors on expression of juice from cane fibre in a compression chamber.

Table 2. Moisture Content and other Measured Values of the Cane Stalks

Cane size (mm)	Peripheral Speed Vs (m/s)	Moisture content Mcwb (%)	Extracted Juice Wj (kg)	Weight of wet Material W (kg)	Duration T (hr)	Juice Present Jp (kg)	Weight of Dry Material Wd = W - Jp (kg)
28	0.36	80.2	0.32	0.68	0.027	0.55	0.13
		80.6	0.36	0.74	0.030	0.60	0.14
		84.2	0.38	0.74	0.027	0.62	0.12
	0.3	80.2	0.26	0.6	0.027	0.48	0.12
		81.6	0.28	0.66	0.025	0.54	0.12
		84.2	0.3	0.68	0.025	0.57	0.11
	0.25	80.4	0.26	0.6	0.030	0.48	0.12
		82.2	0.27	0.64	0.030	0.53	0.11
		84.4	0.28	0.66	0.027	0.56	0.10
24	0.36	76.6	0.24	0.6	0.032	0.46	0.14
		80.2	0.25	0.68	0.033	0.55	0.13
		81.6	0.26	0.7	0.032	0.57	0.13
	0.3	78.4	0.22	0.6	0.030	0.47	0.13
		80.2	0.23	0.62	0.032	0.50	0.12
		82	0.24	0.64	0.032	0.52	0.12
	0.25	74.6	0.19	0.54	0.027	0.40	0.14
		78.8	0.2	0.54	0.028	0.43	0.11
		80.2	0.21	0.58	0.030	0.47	0.11
20	0.36	72.6	0.19	0.6	0.028	0.44	0.16
		74.2	0.2	0.62	0.030	0.46	0.16
		78.2	0.22	0.64	0.032	0.50	0.14
	0.3	78	0.18	0.54	0.028	0.42	0.12
		78.8	0.2	0.58	0.030	0.46	0.12
		80.4	0.21	0.62	0.032	0.50	0.12
	0.25	72.4	0.14	0.48	0.030	0.35	0.13
		75.4	0.15	0.5	0.028	0.38	0.12
		78.8	0.18	0.52	0.030	0.41	0.11

Table 3. The effects of cane size and peripheral speed on the extraction efficiency and machine output capacity

Size of cane (mm)	Peripheral Speed Vs (m/s)	Moisture Content Mcwb (%)	Duration T (hr)	Efficiency (%)	Output Capacity Pc (kg/hr)
28	0.36	80.2	0.027	59	12.00
		80.6	0.030	60	12.00
		84.2	0.027	61	14.25
	0.3	80.2	0.027	54	9.75
		81.6	0.025	52	11.20
		84.2	0.025	52	12.00
	0.25	80.4	0.030	54	8.67
		82.2	0.030	51	9.00
		84.4	0.027	50	10.50
26	0.36	76.6	0.032	52	7.58
		80.2	0.033	46	7.50
		81.6	0.032	46	8.21
	0.3	78.4	0.030	47	7.33
		80.2	0.032	46	7.26
		82	0.032	46	7.58
	0.25	74.6	0.027	47	7.13
		78.8	0.028	47	7.06
		80.2	0.030	45	7.00
22	0.36	72.6	0.028	44	6.71
		74.2	0.030	43	6.67
		78.2	0.032	44	6.95
	0.3	78	0.028	43	6.35
		78.8	0.030	44	6.67
		80.4	0.032	42	6.63
	0.25	72.4	0.030	40	4.67
		75.4	0.028	40	5.29
		78.8	0.030	44	6.00

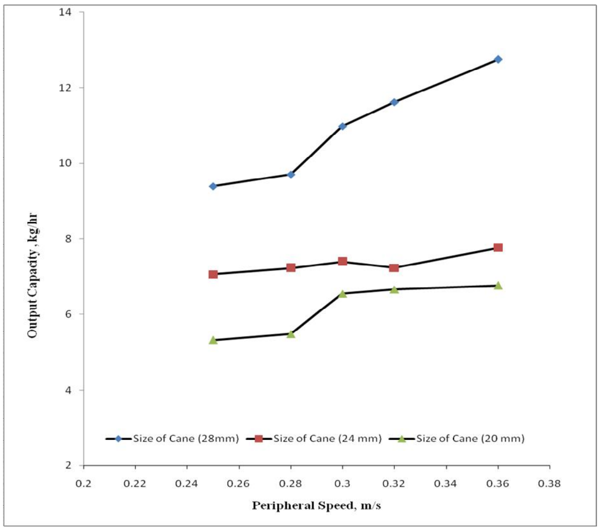

Fig. 4. Effects of the Cane Size and Operating Speed of the machine on the Output Capacity of the Cane Juice Extractor

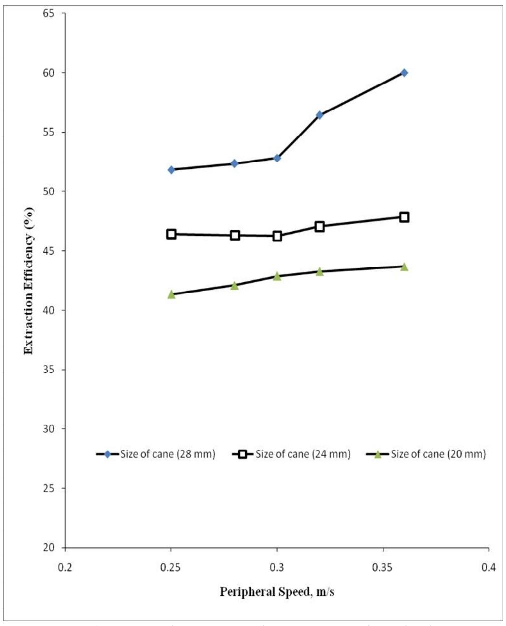

Fig. 5. Effects of the Cane Size and Operating Speed of the Machine on the Extractor Efficiency of the Cane Juice

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