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Trends in the Development of Engineering Technologies for Sugarcane and Sugar Production in Nigeria

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***Abstract*— Research on sugarcane started effectively in Nigeria in 1986 when the National Cereals Research Institute (NCRI), Badeggi was mandated by the Federal Government to undertake research into sugarcane genetic improvement, crop production techniques and sugar production. In line with this mandate, the Sugarcane Research Programme set up a processing technology for sustainable sugar production at the cottage level in 1986. Accordingly, the Agricultural engineering department of the Institute in collaboration with other relevant organizations developed and commissioned the first proto type Sugar Processing Plant in 1988. Also, a heat treatment system for treating sugar cane setts before planting for smut control in the field was designed and fabricated. The components of the sugar prototype plant include cane juice extractor, cane juice clarifier /boiling system, crystallizer, centrifuge and dryer. From 1988 to date, further research activities on these machineries have resulted to the development of more efficient systems, thereby improving the overall output and performance of the plant. The various trends followed in the development of the NCRI sugar processing plant and the heat treatment machineries from their prototype stages to the current stages are discussed in this paper.**

***Keywords: Bagasse, crystallizer, juice extraction, massecuite, sugarcane*.**

I. Introduction

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 [1].

Unlike other countries such as India, Cuba and Brazil who were at the same level of development in the 1960s, Nigeria has not effectively harnessed her potential for producing sugar in spite of the availability of huge natural resources in form of land, suitable climate, market and manpower. At present, Nigeria has a population of over 150 million people and occupies a land area of 98.3 million hectares out of which 71.2 million hectares are suitable for agriculture [2]. Out of the cultivable land area, 800, 000 ha are suitable for sugar cane cultivation, where up to 30 million metric tons of sugarcane can be harvested and processed into 3.0 million metric tons of sugar annually if fully utilized [3, 4]. However, the overall sugar production capacity of the country is less than 1% as almost 100% of the sugar requirement is imported thereby spending several billions of dollars annually to meet up with the domestic consumption requirement.

Before the country plunged into this abysmal level of sugar production, efforts were made by past governments to establish two sugar factories at different times. These were the Nigerian sugar company Ltd. Bacita in 1961 and the Savannah Sugar Company Ltd. Numan in 1977 [5]. The total average sugar production capacities of these two companies were about 30,000 tonnes per annum from 1978-1995 [6]. This production figure only represented 5% of the annual national sugar requirement leaving room for importation of about 95% [3]. These sugar factories were privatized by the federal government in 2002 and 2005 due to their inability to sustain themselves economically because of corruption and undue government interference on their management systems.

However, the establishment of the first sugar factory at Bacita in the 60’s spurred research activities on sugar cane which is the only viable source of sugar production in the country. At that period, research was centred mainly on crop protection at the request of the sugar company at Bacita [7]. In the mid 70’s the need for the establishment of sugarcane breeding and variety testing station arose after a government delegation visited West- Indies Sugar cane Breading Station in Barbados. Consequently, the sugar cane research programme was established in the National Cereals Research Institute (NCRI) Badeggi in 1981 with research mandate on variety breeding, agronomic practices, crop protection and utilization/processing [8].

Thus, at present, over 700 sugar cane accessions have been assembled in a national germplasm at the National Cereals Research Institute. Proven parents are being indentified and used in hybridization schemes annually thereby generating over 10,000 seedlings (sugarcane hybrids) from different crosses. Also, some best agronomic practices for the crop have been indentified and recommended for famers to utilize [3].

Similarly the research and development efforts of the engineering department of the NCRI resulted in the development of the first prototype cottage level Brown Sugar Processing technology in 1988 with a view to augmenting the production capacities of the two giant industries. The plant which had a processing capacity of 2tons cane per day (tcd) was made up of a roller cane juice extractor, juice evaporation system; crystallizer, centrifuge and platform dryer. The efficiency of the plant was very low (with a sugar recovery of 5.5%) compared with similar plants in countries like India and Cuba with 8-10% sugar recovery [2].

Since then several researches aimed at improving the efficiency and capacity of the technology have resulted in the development of a mini 10 tons cane per day capacity plant [9, 10]. Functional units of this model plant have been established at different geopolitical sugarcane growing locations of the country namely Sara in Jigawa state in 1999, Kona- Mada in FCT, Abuja in 2004, Babangida Village – Zaria in Kaduna State in 2008, Omor- Anambra in 2008 and Ibba - Rivers State in 2005 with financial support from the National Office for Technology Acquisition and Promotion (NOTAP) and the Jigawa state government.

II. TRENDS IN THE DEVELOPMENT OF MACHINERIES/EQUIPMENT

A. Sugar Cane Setts Heat Treatment Systems

This equipment was developed by the engineering department in response to a request by the sugar cane programme to heat treat sugar cane setts before planting with a view to controlling sugarcane whip smut disease (Ustilago scitaminea, Syd.). Two models were developed:

i. Direct Convectional Steam Treatment Chamber:

This was the first model developed. It is a simple rectangular insulated chamber which has a false bottom made of sieve located 15cm above the bottom of the chamber. Four electric heaters with 2.75kw each were incorporated below the false bottom to heat water to 54oC (Fig. 1). The warm humid and moisture laden air was then allowed to rise convectionally through the sieve and the sugar cane setts for 45minutes before the cane setts were discharged.

The system was found to be efficient in treating small quantities (250kg) of cane setts as shown in Table I. Problems such as overheating of the setts at the bottom were observed for quantities above 250kg as time spent by the humid air to rise through the cane setts took significantly longer duration to travel to the top of the chamber.

Fig. 1: Direct Convectional Steam Treatment Chamber for Whip Smut Control.

ii. Indirect Forced Air Steam Treatment Chamber:

This system was designed and fabricated in order to overcome the problems of uneven heat distribution in the chamber resulting to low system efficiency (Fig 2).

The new system is basically made up of three units: Heating, cane holding and blower units. The heating unit is an insulated rectangular tank having simple four (4) electric heaters of 2.75kw each to raise the temperature of water to 54oC thereby producing humid moisture laden warm air in the chamber. The axial flow blower transports ambient air across the hot moisture laden air and exchanges heat with it before releasing it into the cane setts holding chamber of 250-500kg capacity for 45minutes before they are discharged gravitationally with the aid of sloppy false bottoms through two gates located at opposite sides of the chamber. The efficiency of this system is over 92% as obtained from preliminary tests.

Fig. 2: Indirect Forced Air Steam Treatment Chamber for whip Smut Disease Control in Sugar Cane

B. Developing of Engineering Technology for Cane Processing Into Sugar

i. Juice Extraction

Two models of cane juice extraction system have been developed.

a. Roller Juice Extractor

The roller juice extractor (Fig. 3) was the first model of juice extraction system which was designed and fabricated to extract sugar cane juice at NCRI. It has an average juice extraction efficiency of about 60% which subsequently leads to low sugar recovery of about 5% (Table II). It is mainly made of three grooved rollers suspended on bearings. They are arranged triangularly with two rollers of dimensions 300m (length) and 180mm (diameter) each which are placed below a top roller with dimensions 300mm (length) and 300mm (width). A minimum clearance of about 1mm is maintained between the grooves when the top and lower rollers are in meshed position. A 15 hp electric motor or 16 hp diesel engine depending on location, supplies power to the rollers through belts, pulleys and gears to actuate the movement of the rollers at 60 revolutions per minute (rpm) for the top roller and 70 rpm for the lower set of rollers. About 4 to 5 cane stalks are fed into the clearance between the top and lower rollers at a time.

Fig. 3: Roller Juice Extractor

Fig. 5: Cane Juice Expeller

b. Cane Cutter/Juice Expeller

The cane cutter/juice expeller (Figs. 4 and 5) was developed in order to improve on the juice extraction efficiency and sugar recovery, thereby making the technology to be economically viable. The system is made up of two units: cane cutter and juice extraction assemblies.

The cane cutter is made up of horizontal knife assembly having 75 knives that rotate at a speed of 1,650 rpm within a concave sieve placed at the bottom and upper solid stainless iron casing. A grasshopper conveyor is also incorporated directly under the sieve to transport cut and fragmented canes into the cane juice expeller.

The juice extraction unit is an expeller which extracts the juice from the fragmented canes. It is made up of a conical worm with conveying attachments that convey the cane fragments from the anterior to the posterior end within a cage barrel made of square iron bars placed at pre-determined clearances.

About 3-4 cane stalks are thrown into the hopper of the cane cutter and are cut into fragments of about 3-7 mm sizes. These fragments pass through the sieve on to the grasshopper conveyor by gravity as they are brushed against the sieve by the rotating knives. They are then transported by and fed into the expeller through the cane fragments and are subject to compressive forces as they are forced to pass through diminishing clearance in the cage barrel. These compressive forces on the cane fragments result in the squeezing out of the juice from them which is released through the barrel clearances while the bagasse is forced out through the posterior end of the barrel.

Fig. 4: Cane Cutter

The juice extraction efficiency of this system was observed to be 98.7% with corresponding higher sugar recovery of 9.0 as given in Table 2.

ii. Juice Evaporation

Two types of juice evaporation systems have been developed since the establishment of the prototype plant in 1988.

a. Rectangular Surface Evaporator

This was a rectangular evaporation system fabricated from 2 mm thick stainless steel whose dimensions were 1.6 m length, 1.2 m breadth and 0.25 m height. It was placed over a bricks firing chamber on the earth's surface. It was able to concentrate about 500 litres of juice in 8hrs using sugar cane baggasse as source of heat energy.

Problems such as long evaporation duration and sugar calamerization were frequently observed which led to the development of an underground firing evaporation system.

b. Underground Firing Evaporation System

In order to solve the problems of long juice evaporation duration leading to frequent calamerization of sugar, the underground firing open pan evaporation system was developed (Gbabo 2004). It is made up of six (6) cylindrical evaporation pans of 1.2 m diameter having slight cone at the bottom aimed at preventing sugar calamerization (Fig 6).

The pans are installed in two sets of 3 each in series. Although each pan has a juice holding capacity of about 420 litres they are filled with juice to only about half of the capacity in order to create space for frothing over in the process of boiling. The first pan in each set takes about 20 minutes to start boiling and about 2 hours to complete the boiling process, while the juice from subsequent pans take between 30-42 minutes as shown in Table III. The lower boiling duration for the same quantity of juice compared to the surface open pan boiler was due to higher heat utilization efficiency of the underground furnace, which provided room for pre-heating the juice in the second and third pans. About 4,800 litres of raw juice of 20^{o} brix is evaporated daily by the 2 units open pan boilers to yield 1200 litres of syrup at 80^{o} brix (Table III)

Fig. 6: Underground Firing Evaporation System

iii. Crystallization

Two types of crystallizers have been designed and fabricated.

a. Air Cool system

The air cool crystallizer is the oldest model which uses air at ambient conditions to cool the syrup contained in a U-Shaped trough (Fig. 7). The crystallizer which has baffles has a total volume of 1,000 litres and is powered by a 10hp electric motor through a speed reduction mechanism that makes the stirrer to rotate at 5 rpm. Appreciable crystallization rate of about 75% was recorded but the crystal sizes were small (about 0.05 mm diameter) size and took a long period for total crystallization to be achieved.

Fig. 7: Air Cool Crystallizer System

b. Combined Air and water cool system

This crystallizer was designed to use air and water as medium to cool the hot syrup during the crystallization process. It is a double compartment U-shaped metal trough with inner and outer vessels (Fig.8). The baffles were constructed with 2 inches diameter pipe that allows water to circulate between an overhead water storage system and the crystallizer as it rotates at a speed of 2 rpm with the aid of a 5 horse power electric motor and gearbox.

Fig. 8: Combined Air/Water Cool Crystallizer System

iv. Centrifugation

a. Engine Driven Centrifuge

This centrifuge was designed and fabricated using an 8 horse power diesel engine as source of power (Fig. 9). It was developed in order to make it adaptable in rural areas where electricity is not available. The equipment is basically made up of inner perforated rotary basket which rotates at 1,500 npm within an external solid basket. This machine had problems of frequent breakdown and inefficient massecuite separation due to complexity of the drive connection using differential from used- motor vehicle to transmit power at ninety degrees (900) and dynamic in balance of the rotary basket. These problems also led to longer massecuite separation time of about 4-5 minutes depending on the physical properties of the massecuite.

b. Electric Motor Driven Centrifuge

This centrifuge was designed and fabricated in order to overcome the problems of dynamic in balance and long massecuite separation time. A 20 horsepower electric motor was used to transmit power on the same plane to the inner rotary basket designed to rotate at a speed of 1,500 rpm. A hand speed breaking system is incorporated at the upper end of the shaft connected to the rotary basket also assist in stopping the machine at desired time of operation.

Fig. 9: Electricity Driven Centrifuge

Average massecuite separation time of 60 seconds per cycle for 12 kg load was achieved thereby enabling the machine to have an output of 920 kg of sugar of 80 cycles per day (Table IV).

The relatively shorter duration of separation was achieved because of the elimination of problems of instability of the rotary basket and the speed hand breaking system.

v. Drying

Two types of dryers have been developed.

a. Platform Dryer

A 150 kg capacity per batch platform dryer was designed and fabricated as the first model of dryer (Fig. 10). It is made up of a platform drying chamber having series of trays containing sugar crystals. Heat is provided by electric heaters while a centrifugal fan conveys the hot air at 65 oC generated by the heater to dry the sugar in the drying chamber. Drying is accomplished in 1 hour 30 minutes which is a relatively long period compared to other conventional sugar drying systems. Other problems such as caking of the dried sugar crystals and manual evacuation of the sugar were encountered.

Fig. 10: Platform Sugar Dryer

b. Rotary Dryer

A rotary dryer having capacity to dry 1000 kg of sugar per day was developed in order to solve the problems of sugar aggregation and manual discharge after drying (Fig. 11). It comprised a rotary drum with louvers that convey sugar crystals and drop at varying heights as the drum rotates at 10 rpm. Hot air is blown into the rotary drum assembly to dry the sugar with the aid of electric heaters and centrifugal fan.

Tests conducted with the dryer indicated average sugar granulation efficiency of about 95.0%. Drying time was also observed to be about 30 minutes for 65kg of sugar while sugar discharge was easily done automatically with the aid of the rotary drum [10].

Fig. 11: Rotary Sugar Dryer

III. FURTHER AREAS OF RESEARCH

Research activities are expected to be undertaken in the future to improve the efficiency and sugar recovery of the sugar production technology in the following areas.

- Cane Juice Extraction

Development of high capacity juice expeller with necessary ancillaries that can be used to process sugar cane at medium scale.

- Cane Juice Evaporation System:

Application of the underground baggasse firing furnace to boil large volume of juice with the introduction of automated stirring mechanism.

- Centrifugation:

Incorporation of mechanical scrapper and gravitational discharge mechanism into the centrifuge

Improvement in the dynamic balance and ability to accommodate more loads per cycle of operation.

- Drying:

Utilization of baggasse as source of heat through steam heat exchangers to dry the sugar processed.

IV. CONCLUSION

Research into the development of technologies for sugarcane production and processing in Nigeria is still at abysmal level in spite of the conducive natural conditions available in form of land and climate. This is due generally to inadequate funding of research in this sector of the economy of Nigeria. However, remarkable progress has been made in the development of indigenous technology for processing sugarcane into sugar as highlighted in the paper.

Similarly, the heat treatment technology for whip smut management has also received improvement. The improvement achieved, especially on increased juice extraction efficiency of the juice expeller, boiling, crystallization and centrifugation systems are favourable indications for setting up cottage sugar processing plants, using this technology in cane growing communities of Nigeria and elsewhere [11].

Table I
Effect of heat therapy on smut incidence in infected sugarcane under glass house and field conditions at Badeggi, 2000

Treatment	% Establishment at 42 DAP		Smut incidence (%)	
	Glass house	Field	Glass house	Field
Inoculated canes not heat-treated	75.1	26.0	43.7	49.9a
Inoculated canes heat-treated at 52^{0}C for 30min.	75.0	25.6	15.1	7.1b
Inoculated canes heat-treated at 54^{0}C for 45min.	80.3	23.0	18.4	6.5b
Inoculated canes heat-treated at 56^{0}C for 60min.	80.2	24.7	15.4	6.2b
No head treatment and No inoculation (control)	76.3	26.4	18.9	23.6ab
Heat treated at 52^{0}C for 30 min. followed by inoculation	75.1	21.7	25.4	15.1b
Heat treated at 54^{0}C for 45 min. followed by inoculation	76.3	15.3	28.4	13.1b
Heat treated at 56^{0}C for 60 min. followed by inoculation	73.3	22.7	36.6	12.7b

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Table II
Comparison of performance of Roller Juice Extractor with Cane Cutter/Juice Expeller system

Process parameters	Roller model Replications			Average	Cane Cutter/juice expeller model Replications			Average
	1	2	3		1	2	3	
Weight of sugar cane bagasse (kg)	100.5	999.2	1005.0	1001.6	1010.1	1000.8	998.0	1003.0
Brix of Juice	19.5	18.6	20.1	19.4	18.4	19.2	19.7	19.1
Quantity of extracted juice (litres, kg)	457.5lits (549.0kg)	450.0lits (540.0kg)	462.0lits (554.4kg)	456.5lits (547.8kg)	758.5lits (910.2kg)	760.1lits (912.12kg)	762.0lits (914.4kg)	760.2lits (912.24kg)
Weight of wet Bagasse (kg)	540.7	548.0	550.2	546.3	250.0	248.3	249.2	245.7
Weight of dried Bagasse (kg)	241.0	242.3	240.5	241.3	239.1	340.0	238.8	273.4
Weight of moisture in Bagasse (kg)	302.0	300.0	305.5	302.5	9.8	9.9	10.2	10.0
Weight of sugar left in Bagasse (kg)	58.9	55.8	61.4	58.7	1.8	1.9	2.0	1.9
Juice extraction time (minutes)	120	122	119	120.3	130	135	125	130
Percentage juice extraction from totaling cane (%)	54.8	54.0	55.4	54.7	69.0	76.0	76.3	73.8
Machine input capacity (kg/hr)	500.2	91.4	506.7	499.4	507.7	444.8	479.0	477.2
Juice Extraction Efficiency (%)	60.3	60.0	60.2	60.2	98.7	98.7	98.7	98.7
Sugar recovery (%)	5.0	5.5	5.2	5.23	9.0	8.8	8.9	9.2
Average Bagasse Temperature (^{0}C)	28	27	29.5	28.2	65.0	65.0	67.0	65.0

Table III

Data Generated from Cane Juice Evaporation System

Sets of Evaporation pans	Evaporation pans Juice	Volume of fresh cane (litres)	Brix of fresh Juice (degree)	Evaporation time to reach 80^0 brix (min.)	Volume of Juice after evaporation (litres)	Volume of scum (degree)	Brix Scum (degree)	Evaporation rate (lit/min)
1	1st pan	180	23	125	65	18.6	30	0.92
	2nd pan	180	22	35	60	19.0	23	3.43
	3rd pan	180	23	32	68	21.3	25	3.5
2	1st pan	192	23.5	115	71	19.5	24.0	1.05
	2nd pan	192	23.0	42	62	22.1	27.5	3.10
	3rd pan	192	23.0	30	68	18.4	29.4	4.13
3	1st pan	210	22	120	74.0	26.1	23.5	1.13
	2nd pan	210	22.8	38	72.5	23.6	25.0	3.6
	3rd pan	210	21.0	30	75.7	24.3	27.2	4.5

Table IV

Average Values of Centrifugation Data and Machine Efficiency of the Centrifuge

S/No	Mass of Massecuite (Kg)	Mass of Moist sugar (kg)	Mass of Molasses (kg)	Mass of dried sugar (kg)	Sugar discharge period (secs)	Mass of Evaporated sugar (kg)	Total mass of molasses
1	8.0	4.03	3.77	3.6	48	4.08	92.4
2	10.0	5.43	4.4	4.9	53	4.93	89.25
3	12.0	7.13	4.7	6.0	60	5.83	80.62
4	14.0	8.96	4.8	7.2	94	6.64	73.3

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