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Sweet Sorghum Juice and Syrup Production Using Conventional Sugarcane Mill and Evaporator

ABSTRACT

In light of heightened discussions regarding food vs. fuel issue, different feedstocks have emerged to compromise in meeting the desired volumetric requirement of bioethanol in the country. Sweet sorghum is considered as one of the promising feedstocks taking into account its remarkable characteristics such as shorter crop duration, less water and fertilizer requirement and its compatibility in terms of planting in idle lands. This study focused on the prospect of producing sweet sorghum juice and syrup using conventional sugarcane mills and evaporators. Parameters vital in juice extraction and evaporation sections have been determined to assess its qualities and compared with that of sugarcane. For the milling station, the first expressed juice obtained a Polarity of 6.54 %, apparent purity of 50.97 % and 12.83° Brix. For the mixed juice, same parameters were determined (Polarity of 4.76%, apparent purity of 46.21%, Brix of 10.26°). Lastly, the bagasse contained 1.66% Pol, 50.11% moisture and 48.23% fiber. Pol extraction was also calculated as 88.29%. In terms of syrup production, a Brix of 65° and Polarity of 50.05% were achieved. To assess the performance of the evaporators, % evaporation was computed and a value of 83.87% was obtained.

Key words: *evaporator, juice extraction, sweet sorghum, syrup production, three-roller tandem mill*

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INTRODUCTION

The need for clean locally available fuel for transport has drawn attention to biofuels. In the later years, this concern result to another aim of looking for second generation biofuels when the food vs. fuel issue was raised. The non-food-based biofuel feedstocks are cultivated to complement if not replace the first generation biofuels (i.e. sugarcane for bioethanol and coconut for biodiesel) specific for the country. In the Philippines, the enactment of RA 9367 or the “Biofuels Law of 2007” addressed these issues by providing incentives to encourage investments not only in the production of biofuel, but also in the distribution of mandated blends as well. On the other hand, with regards to competition on land use for food and feedstocks for biofuels, the “Guidelines Governing the Biofuel Feedstock Production, and Biofuels and Biofuel Blends Production, Distribution and Sale under Republic Act No. 9367” or JAO 2008-1 required certifications and provided restrictions and limitations in the conversion of land for biofuel feedstock plantation. In line with this, rice, corn, and other cereals cannot be used as biofuel resources, and irrigated lands and lands with firm commitments cannot be used for biofuel production. To address the need of agencies and players opting to invest on alternative feedstock, an approximation of 2 M ha of idle land suitable for feedstock expansion was identified by the Department of Agriculture of the Philippines.

Several studies on biofuels have been conducted by Chemical Engineering Department UPLB-CEAT in collaboration with different agencies and biofuel plants such as DA-BAR (Department of Agriculture-Bureau of Agricultural Research), BIOTECH (National Institute of Microbiology and Biotechnology), OPTION-MPC (Organic Producers in the Island of Negros-Muscovado Plant Cooperative) and SCBI (San Carlos Bioenergy, Inc.) to name a few. From a pool of second and third generation bioethanol feedstocks (i.e., corn, cassava, sweet sorghum, lignocellulosic materials and macroalgae), sweet sorghum [*Sorghum bicolor* L. Moench] has been viewed as a competitive alternative feedstock for sugarcane in the Philippines. According to *Reddy et. al.* (*200*8), this crop has sugar-rich stalks and is water efficient. In addition, sweet sorghum is an early maturing crop, has high yield in biomass and requires less fertilizer; characteristics of which may translate to good economic and energy returns and decrease on production cost (*Gnansounou et al. 2005*; *Woods 2001*). Sweet sorghum has shorter crop duration unlike sugarcane and can be harvested 3-4 months after planting with 2-3 croppings annually. Moreover, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) discussed the ability of sweet sorghum to resist drought, saline and alkaline soils, and water logging has been proven by its wide prevalence in various regions of the world. Also known as the "sugarcane of the desert", sweet sorghum is considered a potential marginal land crop. Another remarkable characteristic of sweet sorghum is its low water requirement of only about 4,000 cm^3 of water per plant as compared to that of sugarcane which amounts to 36,000 cm^3 (*ICRISAT 2011*). Having this low water requirement, the crop can rely on rain-fed agricultural practice. However, if the crop experience dry season, it can go into dormancy and resume its growth upon intake of sufficient moisture. While investors eyed this crop for ethanol and power production, the residue known as bagasse may also be used as fodder and additive for fertilizer.

Based on the Philippine agronomic data provided by the Department of Agriculture (DA), sweet sorghum has an agricultural yield of about 50 t ha^{-1} per cropping with approximately 19° Brix producing approximately 5,000 l of ethanol ha^{-1} for two croppings (*ICRISAT 2011*). In terms of the economic viability of the crop, the study of *Demafelis et al.* (*2013*) included an estimated amount of PhP 51,600.00 and PhP 46,400.00 for the seed crop and ratoon crop production cost per ha, respectively. Also, selling price per kilogram of seed is at PhP 13.00 while cane selling price per ton is at PhP 1,000.00. Given these approximation, an annual net income of PhP 80,000.00 can be obtained by farmers for every hectare of sweet sorghum.

Since liquid biofuel (bioethanol in this case) is the desired product, the process starting from the mills should have a relatively high efficiency. According to *Bernal* (*2013*), most of the operation cost is due to the preparation and extraction of juice. To be able to level off this high processing cost, high juice recovery from extraction must be done. Another production concern is the need to concentrate the juice once extracted from the mills. Due to more invert sugar (i.e., glucose and fructose) in sweet sorghum juice compared to sugarcane juice, the storability index is expected to decrease. One way to reduce possible degradation is to concentrate the juice right after the extraction, from about 10°Brix of juice to a quality syrup with 60-65° Brix. Prior to processing in distillation columns, the juice is heated in an evaporation system to produce the desired Brix.

This study is conducted to investigate the effect of using conventional sugarcane equipment such as mills and evaporators for the production of sweet sorghum juice and syrup, respectively. Specifically, this study determined the possible causes and explanation to validate the results obtained with regards to quality of juice and syrup (Brix, Pol and efficiency) and cited recommendations to obtain high quality juice and syrup which may aid bioethanol key players.

MATERIALS AND METHODS

The general process of OPTION-MPC starts from cane receiving up to syrup production (**Figure 1**). For the cane receiving proper and intermediate preparations (**Figure 2**), the stalks were delivered to the contracted miller (OPTION-MPC) using a hauling truck. Sweet sorghum SPV 422 stalks were harvested from a plantation study site in Sagay City, Philippines. The weight of the stalks was determined by difference method wherein the trucks loaded with canes pass the weighbridge (Holbright-scale) and after unloading, the trucks were weighed again. The weights of delivered sorghum canes were noted. Canes were dumped in the receiving pit and the auxiliary cane carriers convey them to pass through the cane leveller which has a variable speed

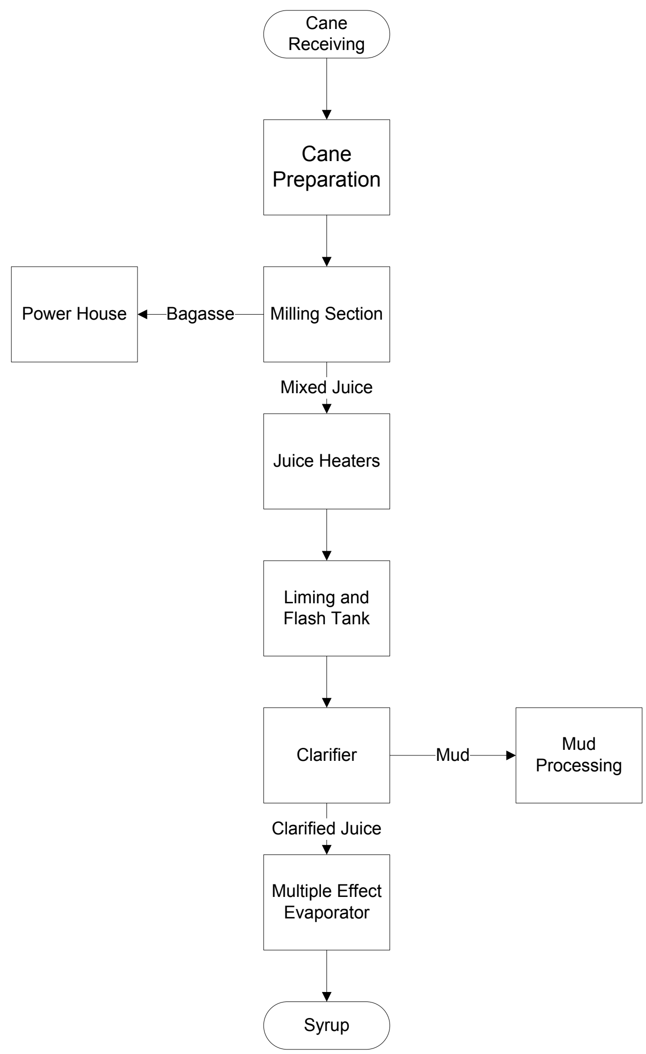

Figure 1. General process flowchart of OPTION-MPC for syrup production.

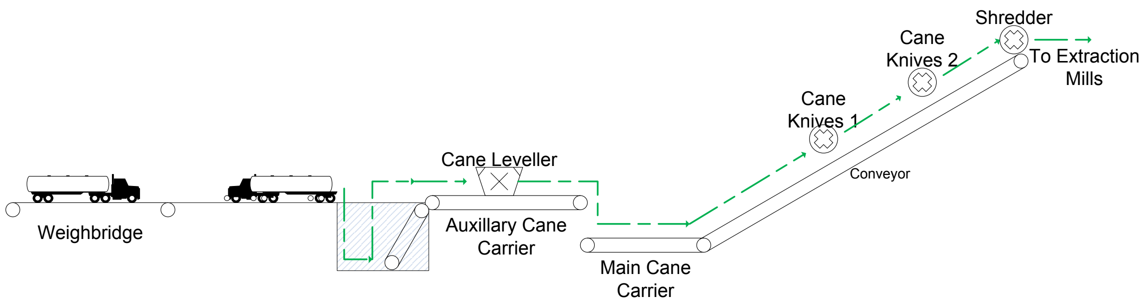

Figure 2. Schematic overview of the cane handling and preparation of OPTION-MPC.

drive rated at 600 rpm. Designated operators manually estimated if the amount of canes entering the mills would not choke as it pass through the main cane carrier. If the canes are already sufficient, the auxiliary cane carrier will be shut off and will be turned on again when the main carrier is unrestrained. The conveyor going to shredder was inclined to further ensure no choking will occur. For size reduction purposes, the two sets of cane knives were also installed in the inclined conveyor prior to the shredder.

Extraction of the juice from the stalks in OPTION-MPC has an efficiency of 95%. Four three-roller tandem mills were used (**Figure 3**). Compound maceration is practiced for the extraction of juice. Hot water of about 80°C was used as imbibition water for the fourth mill. Imbibition for the second and third mill is the juice extracted from the third and fourth mill, respectively. During start-up, when no juice was extracted yet, only water was used for imbibition for the mills. The bagasse, with 48-50% moisture, that left the fourth mill was fed to the boiler. The juice was strained using cush-cush conveyors while the bagasse was conveyed through a slat-type bagasse elevator. Parameters such as Brix, Pol and apparent purity for first expressed juice and mixed juice were recorded in an hourly basis. On the other hand, moisture content and Pol of the bagasse (fibrous residue) were logged.

Boiling house in OPTION-MPC started with heating of the juice (**Figure 4**). After the juice was extracted, it was then heated to about 103-105°C. The plant used three horizontal shell-and-tube heat exchangers to heat the juice to this temperature. The same type of heat exchanger was used to heat the water that is used for imbibition.

The hot mixed juice then entered the flash tank. Milk of lime (MoL) was added to the juice for defecation before entering the tank. The pH of the clarified juice was monitored to determine if the amount of lime added is enough. If the pH is too high, the amount of MoL is decreased and increased if otherwise. Clarified juice was maintained at a pH of 6.8 to 7.2. After the flash tank, the defecated juice was then clarified. Chemical flocculants were added in the clarifier to ensure the separation of solids in the juice. Clarifier used in OPTION-MPC is a 4-tray type. Aside from Pol, Brix and apparent purity, clarity and pH of the clarified juice were also noted.

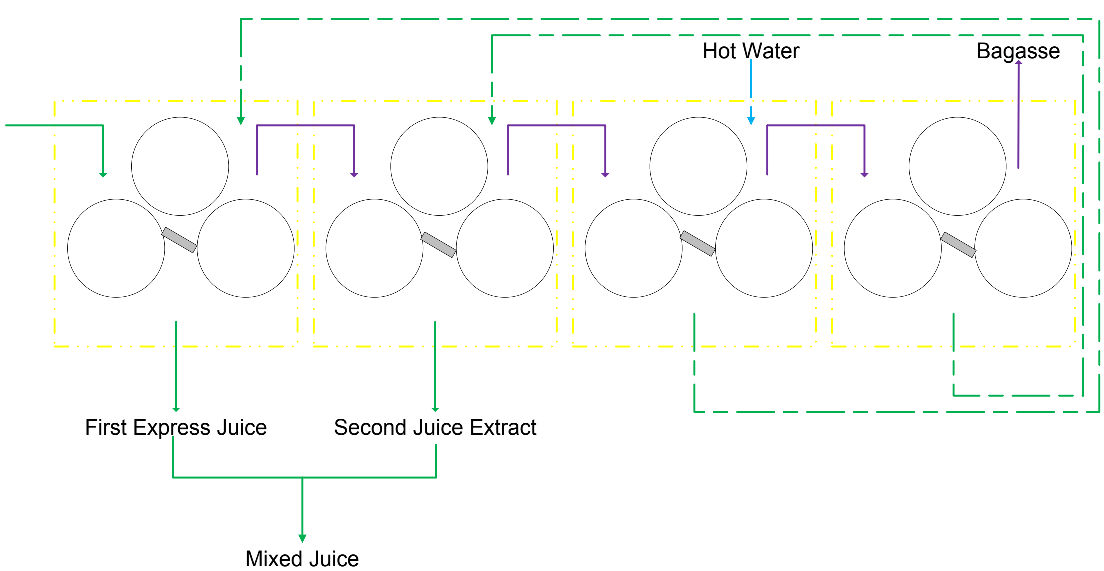

Figure 3. Schematic overview and material flow for the three-roller tandem mill used in OPTION-MPC.

The mud obtained from the clarifier was fed to the rotary vacuum filter (RVF). The solids acquired were conveyed through screw conveyors for further mud processing to be used as organic fertilizer. On the other hand, the liquid part was recycled back to the mixed juice tank.

Multiple effect evaporator was used to concentrate the juice to 60-65 Brix. OPTION-MPC was operating at quadruple effect with pre-evaporation/preheater. Each unit is of calandria-type (**Figure 5**). Same as for the streams in milling, the Pol, Brix and apparent purity of syrup were logged.

The actual milling started at 1:36 PM of May 23, 2012 and ended at 11:00 PM of May 24, 2012.

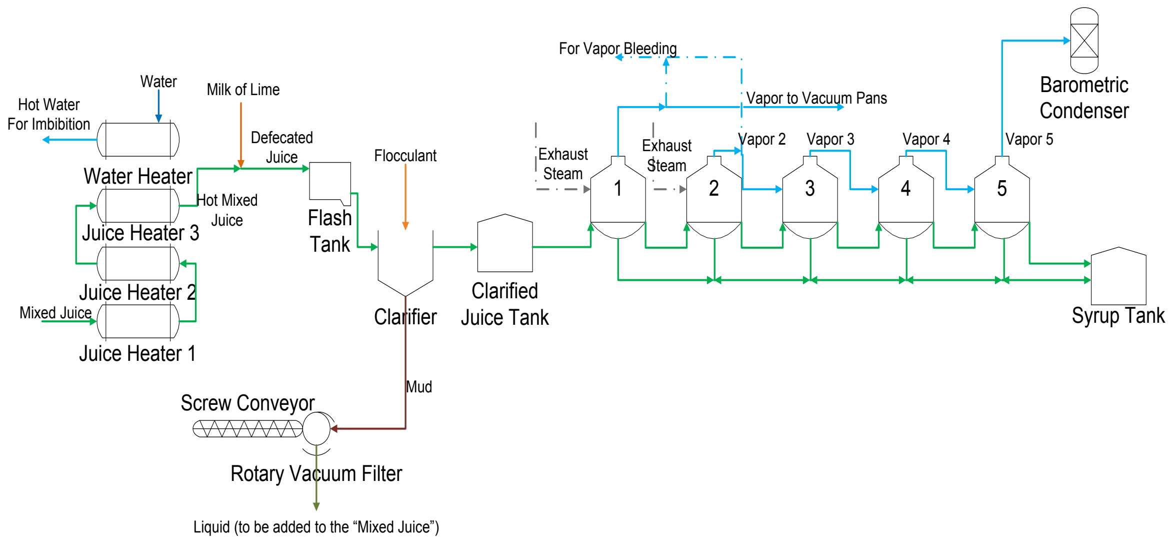

Figure 4. Schematic overview and process flow chart of the Boiling House in OPTION-MPC.

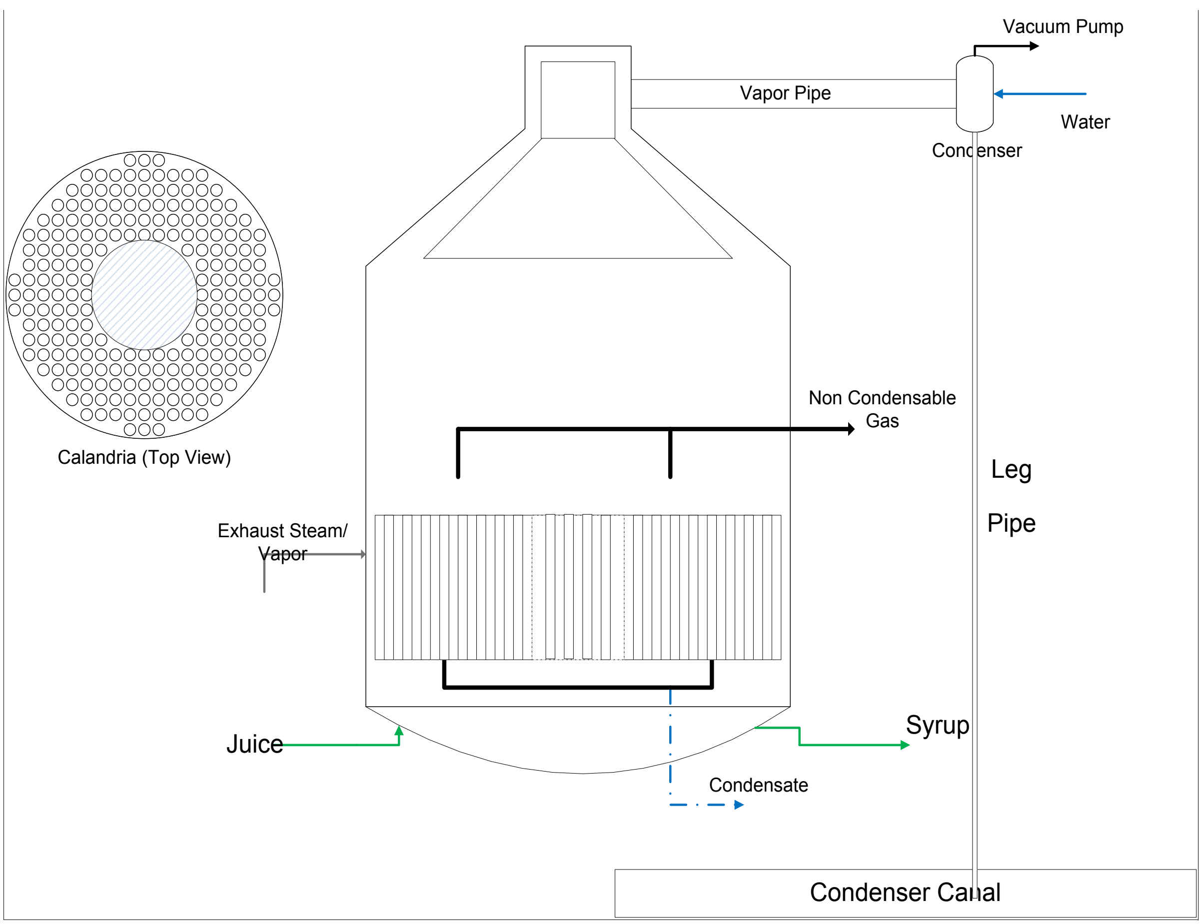

Figure 5. Parts of the calandria type evaporator in OPTION-MPC.

RESULTS AND DISCUSSION

Milling of Sweet Sorghum Stalks

Juice extraction involves milling of sweet sorghum stalks using a set of rollers. This station follows the intermediate process wherein stalks passed through levelers, carrier and knives or cutters for further size reduction to ease the extraction of juice (**Figure 6**). In this study, four three-roller tandem mills were used. For this station, vital parameters needed such as Pol, Brix, apparent purity for first expressed juice and mixed juice and moisture content, Pol and fiber of bagasse were noted (**Table 1**). Since standard values of these parameters are available for sugarcane only, this study compared the obtained values from the standard values of sugarcane processing. For the apparent purity of first expressed juice, the obtained value of 50.97% is considered low for purity of juice. In sugar manufacture, canes with this value of Pol are usually rejected by the Chief Chemist for further processing; however, since the produced juice is intended for bioethanol production, this value may be considered. Low apparent purity (46.21%) of sweet sorghum as compared to the standard range of 80 to 85% may be attributed to three days of holding period of stalks in the cane yard. This may have caused deterioration of stalks. As for the % fiber of bagasse, the typical standard value is 47 to 50%. The value obtained for sweet sorghum bagasse is 48.23% and may be considered acceptable and close to the range for the sugarcane bagasse. Pol of bagasse for sugarcane ranges from 1.5 to 3%. Though % losses cannot be avoided, this range with small amount of sucrose in the bagasse is desirable since producers want to extract almost all the sucrose. The Pol in bagasse of sorghum is at 1.66% which falls between the range making it acceptable for bioethanol producers.

Table 1. Parameters obtained from milling of sweet sorghum stalks.

Parameter	First Expressed Juice	Mixed Juice	Bagasse
%Pol	6.54	4.76	1.66
Apparent Purity	50.97	46.21	-
Brix	12.83	10.26	-
%Moisture	-	-	50.11
%Fiber	-	-	48.23

At OPTION-MPC, the efficiency of the mills is established at 95%. No data was provided during the run of sweet sorghum milling. However, the Pol extraction may be calculated using Equation 1:

$$Pol\ Extraction = \frac{weight\ of\ pol\ in\ mixed\ juice}{weight\ of\ pol\ in\ stalks} \quad \text{(Equation 1)}$$

By substituting the values from **Table 2** (given that weight of Pol in stalks is equivalent to weight of Pol in mixed juice added to weight of Pol in bagasse), Pol extraction efficiency is equal to 88.29%. This obtained figure may be considered low. Slight altering of the mill settings to account for high fiber content of sweet sorghum could possibly increase extraction percentage. In addition, since the diameter of sweet sorghum stalks were generally smaller compared to that of sugarcane, it is expected that the extraction percentage is lower. The mill settings in OPTION-MPC were not altered such that it is set for sugarcane milling. Given this scenario, the rollers may not fully extract the juice from sweet sorghum stalks due to larger clearance of rollers. *Bernal* (*2013*) also discussed in her study that juice extraction of stalks with small diameter is lower than from medium or large stalks. In the experiment of *Olaoye* (*2011*), the

Figure 6. Sweet sorghum stalks at the (a) cane yard, (b) cane leveller and (c) cane carrier.

Table 2. Pol tonnage values for the determination of Pol extraction in milling.

	Weight (tons)	Weight of Pol (tons)
Mixed Juice	385.07	18.33
Bagasse	146.15	2.43
Stalks	531.22	20.76

author explained that lower volume of extracted juice from cane of smaller sizes were expected since rollers will have a difficulty in breaking the cell wall of smaller stalks. However, this observation does not deduce that more fermentable sugars can be recovered from medium and large stalks as compared to small-sized diameter stalks. Also, the operators deduced that milling of sweet sorghum is easier than sugarcane since the former has softer stalks.

During the milling proper, it must be noted that mill stops happen due to worn out bearing in some intermediate conveyors, choke up at intermediate conveyor, cane cutter and cane carrier and detached bearing in bagasse conveyor. Total stoppage time due to maintenance is 7 hrs and 54 min and the total milling time is about 34 hrs and 24 min. With this amount of time and malfunction of some equipment, the extraction percentage may also be affected. Furthermore, *Bernal* (*2013*) cited *Hugot* (*1986*) for the discussion of factors that may affect the juice extraction efficiency. Aside from the variety of cane, the quality and level of cane preparation must also be considered. Holding period of cane for more than 24 hr is not recommended since this may cause deterioration. Also, intermediate processing or size reduction is suggested for ease of extraction. Due to stoppage experienced in this area of processing, this is a vital factor in the extraction efficiency obtained. Crucial operating parameters in milling efficiency also includes mill settings, hydraulic pressure, mill speed, condition of roll grooves, juice drainage from the rolls, extent of imbibition and sanitation.

Bagasse produced from milling of sweet sorghum is smaller and has lower heating value as compared to that of sugarcane, thus the operators have to add more supplemental bagasse to the boiler. In practice, wood chips or sugarcane bagasse are utilized for power generation in the boiler. Fibrous residue such as bagasse becomes essential for steam and power generation (cogeneration) in any plant may it be sugar or bioethanol plant since it may be accounted as savings. Instead of buying electric power from the grid, the plant may utilize whatever power it may need. In this study, sweet sorghum bagasse became insufficient since this is the first round of milling. In fact, during start up, the boiler is first operated until the obtainedpower is at least 80% of the needed electricity for operation. It must also be noted that the boiler in OPTION usually has shortage for bagasse, thus the need to use wood chips for additional heating value. Moreover, the *Environmental Protection Agency* (*1996*) considered factors that may affect the composition, consistency and heating value of bagasse; some of which include the climate, type of soil where the cane is grown, variety of cane, harvesting method, amount of cane washing and efficiency of milling plant. Usually, bagasse with moisture content of 45 to 55% by weight is being fed to the boilers, the process also known as wet fired-based. Since the moisture of the bagasse obtained after milling contained 50.11% moisture, this value may be regarded as acceptable. However, the milling efficiency might still be improved to acquire good quality for both bagasse and mixed juice.

Clarified Juice Production

Clarification process involves addition of milk of lime (MoL) to the juice. This process preceded heating of mixed juice to a temperature of 103 to 105°C using three horizontal shell-and-tube heat exchangers. After the addition of MoL, the pH of clarified juice is monitored and maintained between values of 6.8 and 7.2. The average pH is approximately at 6.86 which is considered suitable for clarifying purposes (**Table 3**). This pH is desired to coagulate and precipitate unwanted solids and at the same time, to minimize the inversion of sucrose to glucose and fructose (*Doherty et al. 2002*). For sugarcane clarified juice the quality of Brix is between 15º and 16º. Same goes for the apparent purity of 48.95% which should be above 70%. Based also from the clarity (as measured in Kopke), it may be deduced that clarification is poor. This may be accounted from the dark pigments of sweet sorghum. In this area, it is recommended that the retention time in the clarifier be increased to two to three hours to permit the settling of coagulates.

Another part of the process to be compared is the lime dosage for every ton of sweet sorghum. For this study, 1.67 kg of lime t^{-1} of stalks were used; a higher value compared to that applied to sugarcane (0.60 to 0.90 kg CaO ton^{-1} cane).

Syrup Production

To concentrate the clarified juice, evaporators are

Table 3. Parameters measured for clarification of sweet sorghum juice.

pH	6.86
Clarity (Kopke)	12.71
Brix	9.56
Pol	4.68
AP	48.50

being utilized to produce the desired product known as the syrup. OPTION installed a quadruple effect evaporator wherein each evaporator is of calandria type. For this section, two parameters are monitored (AP and Pol). Standard Brix and apparent purity for sugarcane syrup ranges from 60 to 65% and 80 to 82%, respectively. From these values, the standard Pol for cane syrup is between 48 and 54%.

When the sweet sorghum syrup was tested for its Brix, a value of 65° was obtained. Likewise, a desirable value for Pol was achieved (50.05). It is vital to have good quality syrup as this will next undergo a crucial process for production of bioethanol (fermentation).Though the quality of syrup depends on the variety of sweet sorghum, the type of soil and the amount of fertilizer used, it might also be influenced by the equipment and processed used (*Mask and Morris 1991*).

The primary objective of evaporation is to remove the water from the clarified juice (*Hugot 1986*). With this in mind, the calculation for the % evaporation is a simple equation (Equation 2):

$$\%\ Evaporation = \frac{Brix\ of\ syrup - Brix\ of\ clarified\ juice}{Brix\ of\ syrup} \times 100 \quad \text{(Equation 2)}$$

The calculated % evaporation for this study is 83.87%. This value is higher compared to evaporation in sugarcane with a desirable value of 70%. With this, the evaporators will have to “boil” this amount of water which may cause additional operation cost. Time and steam may be reduced in the evaporation section when appropriate amount of water is supplied to the mills for imbibition or maceration. In terms of equipment cost, it may be reduced once the evaporators are downsized and in the long run, consume less steam for its operation.

Lastly, the final product (in this case, syrup) is delivered in three batches to SCBI for fermentation and distillation. The first tanker has a net weight of 26.980 tons which was dispatched at around 9 AM of May 24. The second and third tanker were delivered at 1:55 AM on May 25 (syrup weight of 17.945 tons) 5:18 AM (approximate weight of 17 tons), respectively. Therefore, a total of 611.93 tons syrup was collected from the evaporation station.

CONCLUSION AND RECOMMENDATIONS

Attaining good quality sweet sorghum juice and syrup became a challenge while utilizing conventional sugarcane equipment such as mills and evaporators.

In the milling station, a value of 88.29% Pol extraction was obtained and this value was considered low given that the efficiency of the mills was set at 95%. Different factors were determined to justify the said value of which the mill stops. The mill stops were caused by malfunction of intermediate equipment such as cutters and conveyors that are noted as vital for the size reduction of stalks. Once the recommended size of stalks was not reached, difficulty of milling may be experienced. Also, the smaller diameter of the sorghum stalks compared to sugarcane might be another element. Since the mill clearances were not adjusted, efficient milling was hindered as operators cannot guarantee that the stalks were fully crushed. Lastly, the stalks were left in the receiving cane yard for three days, causing some deterioration on the quality of juice and the cane itself. It is recommended that the canes be processed within 24 hrs after the canes are delivered to the plant. In this sense, the canes may still be considered fresh. Maintenance of the milling station and intermediate equipment should also be done prior to operation to avoid any mill stops and malfunction which in turn, saves time and does not alter the efficiency of the succeeding equipment. When it comes to the rollers settings, the clearances may be altered or adjusted to make sure that the rollers have efficient direct contact with the stalks.

Ample amount of lime and temperature of the heaters must also be supplied and monitored to avoid alterations in clarified juice quality. Aside from these parameters, the pH must also be maintained at the desirable range of 6.8 to 7.2 to reach the effective coagulation and precipitation of unwanted particles. The retention time must also be longer (about 2 to 3 hrs) since clarification of sweet sorghum juice was poor due to the presence of pigments. Hot liming was also recommended to aid in faster contact of mixed juice and MoL.

Lastly, for the process of syrup production, the preferred Brix of 65° was achieved; a standard for sugarcane syrup production. However, the % evaporation was at 83.87%, a high value considering the desired value of 70%.

Although sugarcane conventional equipment were used from sweet sorghum stalk milling to syrup production, the parameters obtained such as Pol, Brix, apparent purity, moisture and fiber content and pH were still acceptable for the next process of bioethanol production (fermentation). The bagasse produced was also used as feed for boilers, therefore producing its own steam and power for the plant.

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