Design and Operation of a USDA-ARS Pilot-Plant for the Processing of Sugarcane Juice into Sugar at the Southern Regional Research Center in Louisiana

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A pilot-plant facility to process sugarcane juice into sugar and molasses has been developed under a limited budget at the Southern Regional Research Center of the United States Department of Agriculture in New Orleans, Louisiana. The batch plant (27.9 m²) includes juice heating, clarification, evaporation, vacuum pan boiling, and centrifugation equipment. Juice is collected from factories or other research facilities, transported to the pilot-plant and processed. A walk-in cooler is available close to the pilot plant to store juices, factory products or pilot plant products at refrigerated or freezing temperatures, if necessary. Design characteristics and operational procedures are discussed. This pilot-plant will be used to conduct research projects, complement factory research trials, as well as research processing innovations. Juices from other sugar crops, including sugar beet, sweet sorghum, and tropical maize can also be processed.

Postharvest Deterioration in Sweet Sorghum

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Sweet sorghum is a potential feedstock for sugar-based biofuel production in sugarcane growing areas, since high concentrations of sugars accumulate in the stalk, and it can be processed using existing sugarcane factories. To better understand how harvesting options influence processing parameters, sweet sorghum was hand-cut and stripped, and cut into four sizes: shredded, 20-cm billets, 40-cm billets, or whole stalks. The sorghum was then stored for up to 4 days at ambient temperature before processing to extract the juice. Quality parameters measured included juice pH, titratable acidity, Brix, and simple sugars. Juice pH and titratable acidity were the most rapid and easiest measures of juice deterioration. Juice pH dropped from 5.5 to 3.5 within 24 h after harvest in the shredded treatment, while titratable acidity increased from 3 mL to 18 mL 0.1 N NaOH per 10 mL juice in the same time period. Measurement of juice Brix was not a good measure of deterioration, since it either increased or remained the same during the 4-day storage period. Sucrose decreased with storage, while glucose and fructose increased in juice from billets and whole-stalks. In freshly harvested juice, glucose concentrations were about twice the
fructose concentrations. However, in deteriorated juice, glucose and sucrose disappeared, while a residue of fructose remained. There were no significant differences in sugars among the two sizes of billets and whole stalks.

How Harvesting Cane with Different Levels of Trash Affects Field Yields, Delivered Cane Quality, Factory Operations, and Processing to Sugar

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New refineries in Louisiana (LA) are requesting LA sugarcane factories to deliver VHP/VLC raw sugar with low ash concentrations. The higher quality raw sugar will allow both growers and factory processors to gain economic premiums from the new refinery. A very large factory trash trial was conducted at Cora Texas Manufacturing Co. factory at White Castle, LA to determine how different speeds of the extractor fans on two combine harvesters (Cameco/John Deere 3500 and 3510 models) affect trash levels of L 99-226 commercial sugarcane variety (ripener treated) as well as upstream and downstream processing. Fan speeds of 1050, 850 and 650 rpm were studied on days 1, 2, and 3 (20-22 Nov, 2010), respectively, and the ground speed was kept constant at 3.5 mph. There was sufficient cane of each treatment (24-27 truck loads) harvested and processed each day to purge the tandem mill of other cane and to process the selected cane for ~30 min. Trash tissues, prepared cane, and bagasse samples in the front end were collected and analyzed. Extraction and processing rates were calculated. A bulk sample of mixed juice was transported to the USDA-ARS-SRRC pilot plant in New Orleans to produce clarified juice, syrup, A-massacuites, A-molasses, A-sugar, and affined sugar. Total trash levels (GPR or top stalk + green leaves + brown leaves) were 12.1, 18.9 and 22.7% for the 1050, 850, and 650 rpm fan speeds, respectively. There was extra trash than the hand-cut field cane at 850 and 650 rpm because of slight layers of mud on the trash adding to the weight as well as weed plant material. Most quality and processing parameters, including sucrose, color, ash, starch, extraction and processing rate became progressively worse with increased trash levels and decreased fan speed. For every 1% increase in total trash between 1050 and 850 rpm there was an increase of 182 color units (CU at pH 8.5) of mixed juice, and from 850 to 650 rpm this increase was much worse at 944 CU. Furthermore, purity (based on pol) of MJ and subsequent raw sugar became progressively worse with increased trash levels. This progressive decrease was even worse when sucrose was measured by the more accurate GC method. Overall, at 650 rpm fan speed, VHP sugar (<2200 CU) cannot be commercially attained for L 99-226 in late
November. A fan speed of 850 rpm was optimum for both growers and processors, but more data is still needed for L 99-226 and other varieties, early in the LA processing season when trash levels are considerably higher.

**Extent of Seasonal Sucrose Losses in Louisiana Sugarcane Factories**

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Factory staff must consider all costs to make sound economic decisions on how to improve the performance of unit processes, which includes knowing the cost of sucrose losses across the factory. Large, seasonal studies were conducted at two factories in Louisiana across the 2009 processing season. At Factory A, crusher juice, recycled juice, mixed juice (MJ), filtrate juice and incubator juice were collected taking into account retention times $R_t$. Samples were taken every 30 min for 2.5 hours, and this sampling period was repeated seven times across the season (Oct to Dec). At Factory B, first expressed crusher juice, mixed juice in, filtrate juice, mixed juice out, flash, heated limed juice (FHLJ), clarified juice, juice exiting the Pre1 evaporator, and final evaporator syrup were collected taking into account $R_s$. Samples were taken every 30 min for 2.5 hours, and this sampling period was repeated six times across the season. Gas chromatography was used to determine glucose, fructose and sucrose concentration. Sucrose losses were determined by two methods: (1) as a decrease in the % sucrose on a Brix basis and (2) as a change ($\Delta$) in %glucose/% sucrose ratios on a Brix basis. At Factory A, glucose/fructose (G/F) ratios of the juices were greater than 1.0 on the 5 and 9 Oct. For the rest of the season, they were below and 1.0. Thus, the factory suffered from dextran problems on numerous occasions across the 2009 season. The G/F ratios were a more sensitive indicator of dextran problems than the haze dextran method used at the factory. High G/F values, i.e., greater than 1.04, are a sensitive indicator of the inversion of sucrose. For factory A, in the juices studied most sucrose losses occurred in the MJ and incubator tanks. At Factory B, G/F ratios were only below 1.0 on the 24 Nov and 15 Dec. Thus Factory B suffered less dextran problems than Factory A. Sucrose losses (<0.19%) occurred in the MJ tank only in early season (Oct) most likely because of the influence of the high trash levels, i.e., high invertase and ash contents catalyzing the degradation of sucrose. The highest sucrose losses occurred in the clarification tank and across the evaporation station, particularly the pre-evaporators where juice temperatures are high and Brix is low. Total sucrose losses were much higher in early season and decreased across the season. Season average sucrose losses were 2.57% or 5.64 lbs sucrose lost per ton cane per day. Overall, when actual sucrose losses are greater than ~0.5-0.6%, the $\Delta$%glucose/% sucrose ratio measurement underestimates expensive sucrose losses and a decrease in % sucrose concentration should be used. Conversely, decreases in sucrose concentrations are not able to detect sucrose losses when they are less than ~0.5-0.6% and $\Delta$%glucose/% sucrose ratio should be used instead.
The Flash Tank. Suggestions to Design or Modify Existing Tanks

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The flash tank is the midpoint for any alkalization procedure, and complex processes occur inside it that are stable and continuous, to condition the juice properly before being fed to the clarifiers. Thus, all aspects of the flash tank, including construction, design and of course the operation are all crucial for the clarification of cane juices. The information about the flashing process is poor; references to indices of capacity, retention time, as well as the diameter and height relationship for the most common designs are found in the literature, although how they relate to the alkalization and clarification processes is not. Discussion will focus on the mechanisms that occur during the process of flashing. A simple and secure method would be a valuable tool for any modification, improvements, or solving of operation troubles as well as to make the clarification process of sugarcane juice more efficient.

Measuring Starch in the Raw Sugar Factory

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Starch is a polysaccharide that arrives at the raw sugar factory in the sugarcane plant. It is released from the plant during the milling or diffusion stage of sugarcane processing. After release into cane juice, starch in high concentrations can cause problems inside the raw factory as well as being carried into the raw sugar and subsequently into the refinery process. If starch is present in raw sugar in concentrations of approximately 250 ppm or higher, problems arise during refining. These include filterability issues, higher phosphate levels in clarified liquor using phosphatation refining, and poor filterability after clarification in carbonatation refining. Many methods exist for measuring starch in raw sugars, but no standard method is in use throughout the international sugar industry. These methods, while oftentimes very accurate, are not rapid and not well suited for use in the raw sugar factory laboratory. Sugar Processing Research Institute (SPRI) has developed a simple, rapid, and quantitative starch test for use with cane juice and raw cane sugar samples. The time required to complete the analysis of the SPRI Rapid Starch Method is 15-20 minutes, and multiple samples can be analyzed at once. Very small amounts of reagents are required, and the equipment needed is usually readily available in most mill laboratories. This paper will discuss starch and problems it can cause in cane sugar processing from raw sugar factory and refinery perspectives, the SPRI rapid starch method details, equipment requirements, and the analysis of mixed cane juice, clarified cane juice, and raw sugar samples.

Seasonal Variations in Starch Delivered to Factories and Optimized Applications of Intermediate Temperature Stable α-Amylase
In recent years, starch being delivered to and processed in U.S. factories has risen for various reasons: (1) the increased production of green (unburnt) and combine-harvested (billed) sugarcane, (2) the introduction of new sugarcane varieties with higher starch content, and (3) varying environmental conditions. To prevent carry-over α−amylase activity in molasses and raw sugar in the U.S., commercial α-amylases used to control starch are intermediate temperature (IT) stable and sourced from Bacillus subtilis bacteria. A wide range of activity exists for IT α-amylases (59.0 to 545.3 KNU/ml) that do not reflect their comparative unit costs, i.e., activity per U.S. dollar only differed 4-fold from 40.7 to 161.8 KNU/ml/$. α-Amylases have been typically applied to syrup in last evaporators where starch is solubilized and gelatinized, syrup temperatures are ~60-65 °C, and ~18 min retention time (Rt) is available. As IT stable α-amylases are effective up to 85 °C, they could be more effective and economical if applied to next-to-the-last evaporators where syrup temperatures are ~77 °C. Factory α-amylase trials were conducted across LA processing seasons (Oct-Dec). Application of a working solution (diluted 3-fold in water at the factory) of IT stable α−amylase of high activity per unit cost (118.3 KNU/ml/$) to the next-to-the-last evaporator provided significantly (P<.05) greater starch hydrolysis (up to 78.0% at a 5 ppm/cane wt dose) than applying it to the last evaporator alone (only up to 59.8% at a 5 ppm/cane wt dose). Reasons for the improved starch hydrolysis in the next-to-the-last than the last evaporator are multi-fold: (i) the lower Brix levels in the next-to-the-last evaporator improve α-amylase action, (ii) more water is available as a reactant for the hydrolysis reaction, and (iii) there is more time for the hydrolysis reaction to occur. Starch hydrolysis, generally, increased polynomially with increasing initial concentrations of starch in syrups. Seasonal variations in starch concentrations affected the application of α-amylase to next-to-the-last evaporator more than to the last evaporator alone. Significantly (P<0.05) less starch was hydrolyzed with lower precision when starch concentrations were <1000 ppm/Brix in late season (Dec), because of lower contact between the starch and α-amylase. Fluctuating starch concentrations across the season make standardized application of α-amylase impossible. Successful factory applications and final recommendations are provided.

**LLT Clarifier Optimization and Performance**

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In the 2009 harvesting season, a new concept of trayless clarifier with patent pending turbulence reduction devices has been tested in a Louisiana sugar mill. Reduced turbidity of clarified juice at shorter residence times have been demonstrated compared to Graver and Rapidorr clarifiers operated in the same plant. The initial design has been modified and a 20 ft. diameter clarifier
has been constructed and operated during 2010 season in parallel with an existing short residence time (SRT) clarifier. The new clarifier design called LLT (Louisiana Low Turbulence) with about 30 minutes residence time averaged 18% less turbidity as compared to the SRT over the course of the season. Residence time in the SRT clarifier was maintained between 40-50 minutes. Tests results and performance comparison data will be discussed.

**Observations of Evaporator Condensate Carryover**

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During the 2010/2011 grinding period, the condensate water from the evaporators of a raw sugar mill was examined for sugar carryover which could adversely affect the boilers (corrosion and scaling). The study involved testing of the pH, conductivity and sugar in the continuous composite condensate samples from the pre and first evaporators. These measurements would then be compared to the “Mill Lost Time Report” in an attempt to correlate a cause and affect relation and therefore eliminate the sugar carryover. It was hoped that these measurements would give an indication as to when sugar carried over into the condensate system which in turn causes corrosion and scaling in the boilers. The relationship between the four parameters did not seem to correlate. Therefore, it was thought to examine the sugar separately and using the other measurements to indicate the general operating process of the sugar house.

**Progress Towards a New Color Method for Determining Trash Levels in Pressed Juice**

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New refineries in Louisiana have requested LA factories to start manufacturing very high pol VHP/very low color VLC raw sugar with low ash content. The higher quality raw sugar will allow both growers and factory processors to gain economic premiums from the new refineries. One of the main keys to manufacturing VHP/VLC sugar is lowering color. It is known that high levels of trash (growing point region or top stalk, green leaves, and brown leaves) in sugarcane delivered to the factory will result in more color, lower purity, and higher ash content in the final raw sugar product. Currently, there is no inexpensive and simple method for determining the amount of trash delivered to the sugarcane factories. By examining the spectra of various sugarcane plant stalk and trash tissues taken from different varieties we hope to elucidate a readily observable parameter at a set wavelength for different trash levels. In addition, we are
examining the effects on the UV-visible spectra by various additives and contaminants commonly found in sugarcane deliveries such as soil.

**Importance of In-line Color Measurement of Sugar for Product Quality and Factory Performance**

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Process control and process automation is becoming more and more important in the sugar industry. During the last 25 years the online monitoring of almost every part of the process has been improved continuously. By the help of intelligent sensors and measurement devices the operators can nowadays see the details of each process step online on the screen. Due to this development many processes that were earlier manually controlled can now be controlled automatically. One example is the automation of the boiling process in the sugar house of a sugar factory. Due to online measurements of pressure, level, density, and temperature the process can be run by a computer program, eliminating quality variations due to personal influence on the process. However, in many sugar factories the process control stops after the massecuite has left the pan. The most important parameter to be controlled in the sugar factory is doubtless the quality of the final product. However, many factories still do not have an on-line quality control of the sugar after the centrifugals, and rely on samples analyzed in the laboratory at the most every 2 hours. A factory producing 2400 t of sugar per day sends 200 t of sugar to the silo within 2 hours. For the color measurement in the laboratory a sample of 50 g is used to evaluate the quality of the sugar. This is less than 0.000025% of the total sugar produced during the sample interval. The most modern real-time color measuring instrument gives the color value of the sugar every 2 seconds. Due to this abundance of results, the instrument presents graphs clearly showing the origin of color variations, whether in a single centrifugal, in the boiling process or by a change in the quality of the raw material. With this information the operator can identify the cause of a problem and act accordingly. The Neltec ColourQ instrument gives scientific proven accuracy, excellent troubleshooting and process optimizing features. This paper discusses the accuracy of the ColourQ measurement against laboratory analyses done by sugar factories as well as by scientific institutes. It also describes the additional benefits the factories get besides the color indication.

**Raw Sugar Quality Improvement as a Route to Sustaining a Reliable Supply of Purified Industrial Sugar Feed Stocks**

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Demand for purified sugar in many countries of the world is increasing while energy costs for a sustainable level of this product outstrips manufacturing technology. Agricultural commodity delivery of sugar in a number of markets, as an adequately refined raw material for manufacturing value-added goods, demands that the highest quality sugar be realized to be competitive in manufactured end-products. This report shares with the U.S. cane sugar industries some accumulated experience in on-site remediation of raw sugar applications where final liquid sugar can be utilized. Components in raw juice inhibiting the color upgrade of sugar must be defined to achieve very low colorant values with highest pol of the product. Micro- and nanoparticulate materials can foul sensitive surface properties of adsorbents such as activated carbons or resins. Improved approaches to clarification, such as combined centrifugation/microfiltration or nanofiltration of sugar juices or syrups permit more efficient decolorizing with solid adsorbents. Lower quality sugars can thus be upgraded to permit isolation of acceptable product while sustaining more favorable energy utilization. Studies are reported combining filtration and activated carbon treatments to improve sugar technology for upgrading raw sugars from experience in global markets where these remelted and purified liquid sugars are widely used.

Heat Release from Raw Sugar Piles

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Investigation of color increase during long-term storage of raw sugar established that temperature rise in the core of the piles may cause enhanced color formation. Heat generated as a result of the exothermic decomposition reactions does not escape the pile, which leads to further temperature increase. A system has been designed to cool and dehumidify raw sugar stored in a warehouse with a goal to minimize color rise during long-term storage. The system was installed in a commercial warehouse in October 2010 and operated until February 2011. The study is ongoing, with temperature and humidity sensors continually monitoring cross-sectional profiles of two sections of sugar pile - one control, and one experimental - consisting of 2.5 million pounds each. A positive displacement blower aerated the experimental section of the pile using ambient air under specific conditions that maintained no heat or moisture would be added to the pile. A control system based on monitoring dew point of ambient air allowed the system to operate only when the air would reduce temperature and humidity within the pile. Operating parameters necessary for scale-up were identified in the course of study including volumetric flow rate of air required as well as pressure drop and temperature rise across the blower. During 4 months of operation, the temperature in the core of the experimental section reduced by 9 °F compared to an increase of 1 °F in the control section. Absolute humidity was also reduced in the experimental section. The latest results will be discussed in the presentation.