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## **White and Refined Sugar Production from Cane Sugar Factories**

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### **Introduction**

Sugar from sugar cane is extracted today much the same as it was 40 years ago. Sugar extracted from sugar cane is processed to become raw sugar at sugar mills and then further purified to refined white sugar in a sugar refinery, using energy intensive processes. However, sugar from beet is processed to refined white sugar directly in a beet factory. Volumes of research have been conducted on nature of colorants, polysaccharide and inorganic profile of sugar process streams over the past thirty (30) years. However very few research priority have been directed to develop a sugar process that will produce the same quality sugar at cane sugar factories that is currently provided at sugar refineries at a significant reduction in energy consumption.

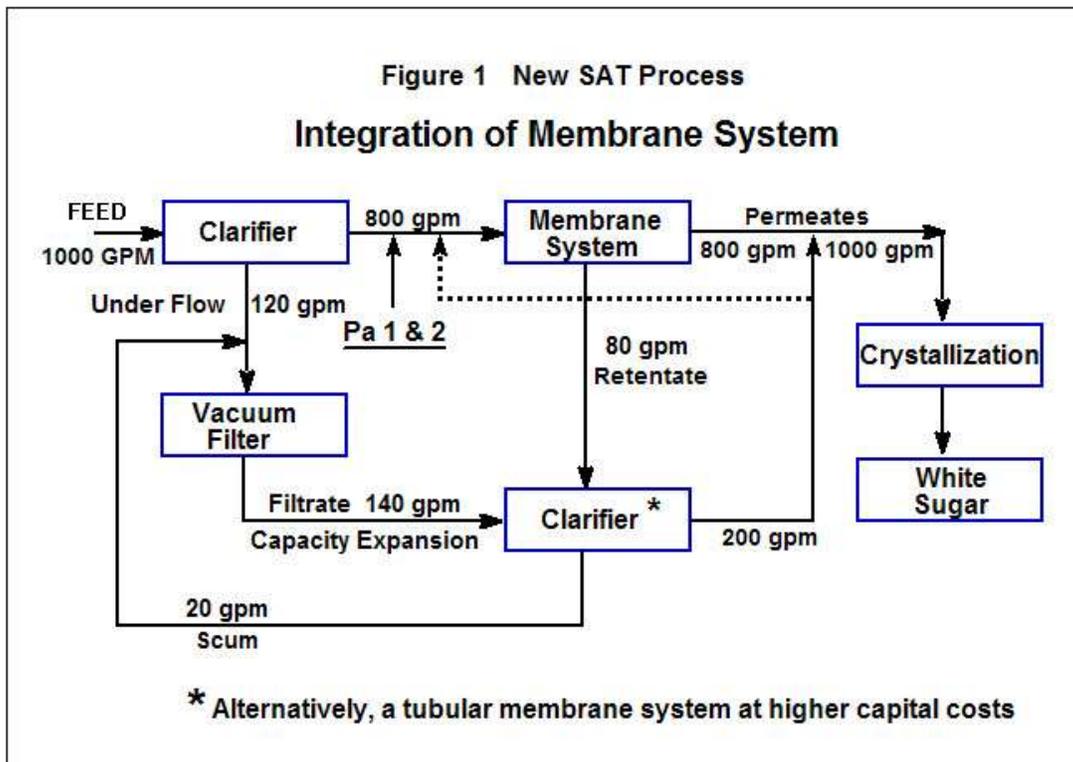
Dr. Chung Chi Chou, while he was the managing director of Sugar Processing Research Institute (SPRI) during 1999 / 2000, organized and directed a team to conduct a research project with the objective specifically to produce white/refined sugar directly in sugar factories. The team succeeded in their effort and developed the "SAT" process to produce white sugar using clarified juices from Sterling sugar factory in Louisiana. Both the bench scale boiling pan at SPRI and pilot scale boiling pan at Audubon Sugar Institute of Louisiana State University were used for this study.

The "SAT" process involves the addition of processing aids to clarified raw juice followed by UF membrane filtration to produce refined quality sugar with color ranging from 80 to 200 ICU. The sugar can further be crystallized, using existing pans, to give a color of 10 to 20 ICU depending on customer requirement (1).

### **The SAT process**

The following flow chart, figure 1, describes the SAT process. A conventional raw sugar mill clarifier is used to treat the mixed juice first. The clarified juice is then subject to SAT process treatment as follow: two processing aids are added separately to the clarified juice with at least five minutes apart between the additions to facilitate the reaction. The treated clarified juice is

then filtered through a cross flow UF membrane system which produces at least 90% of permeate and a maximum of 10 % retentate. The permeate fraction is sent forward for evaporation. The retentate fraction is further subject to secondary clarification together with the under flow from the drum filters to remove highly concentrated suspended matter and macromolecules such as polysaccharides, waxes and gums etc. By clarifying the vacuum drum filtrate together with retentate and sending forward, the capacity of the primary clarifier would increase by about 15%. The clear effluent from the secondary clarifier can either be sent forward for evaporation or sent to the UF system for filtration. The “scum” from the clarifier is sent back to the drum filters for removal of suspended matter. The two processing aids meet the US regulatory requirements.



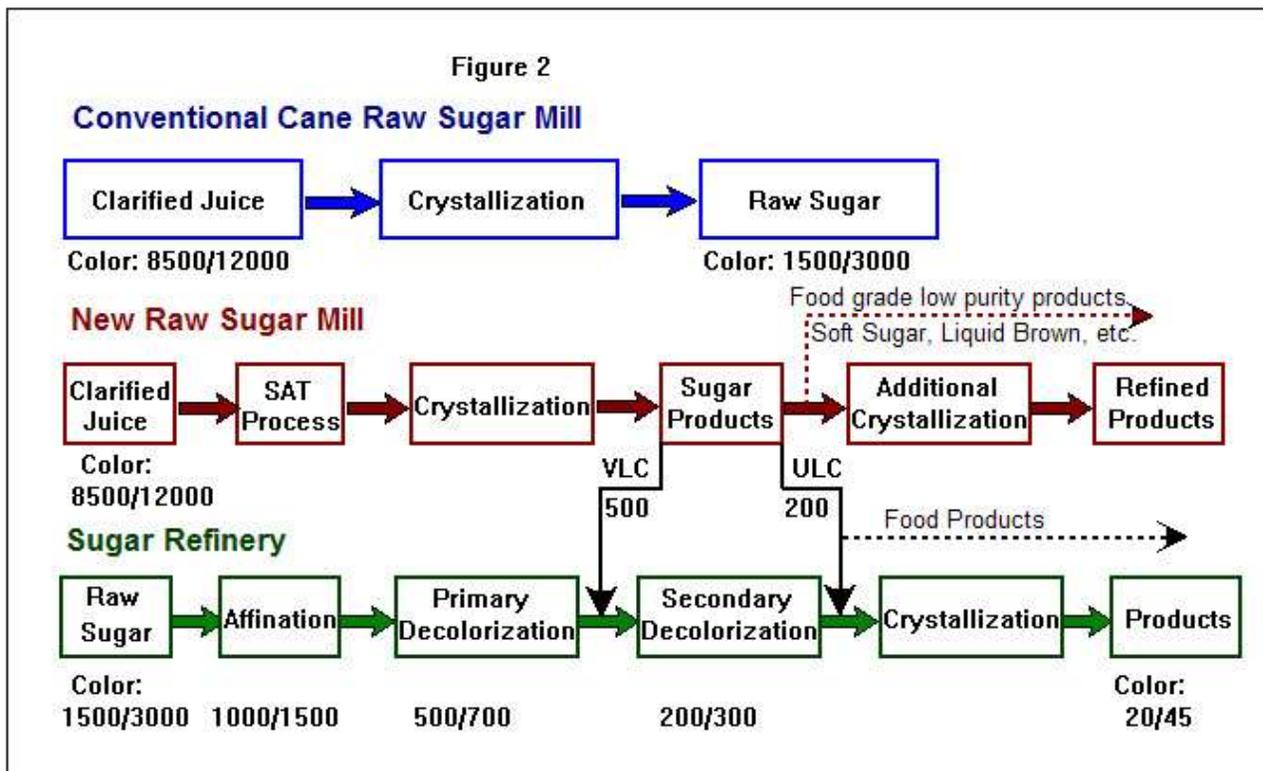
The SAT process is a “perfect” replacement of carbonation and / or sulfitation processes for production of plantation white sugar. Carbonation involves an environmental issue for disposal of carbonate cake, particularly for long term consideration. Sulfitation has been known for its serious problems with respect to process instability, operational difficulties, low sucrose yield due to high sucrose loss and poor product quality, including, but not limited to, high SO<sub>2</sub> contents and storage problems.

With the SAT process a raw sugar mill can easily produce Very Low Color (VLC) sugar with color of 400 to 600 ICU and Ultra Low Color (ULC) sugar with color of 100 to 200 ICU. When VLC “raw sugar” is shipped for further refining, A refinery can eliminate affination and carbonation/ phosphatation processes. For ULC sugar, a refinery can eliminate all the processes before pan boiling with considerable operating cost saving. These advantages are illustrated in the following figure 2.

The illustration clearly shows that refined sugar can also easily produce in a sugar mill by boiling ULC sugar one more time. As to be shown later in this presentation, a raw sugar mill can produce about 30% of its product as refined sugar without additional capital investment in boiling pans.

The SAT process will be perfect for a refinery attached to a raw sugar mill. In fact, when a ULC sugar is produced by the SAT process only some additional pans and drying equipment are needed to produce 100 % of refined sugar in the attached refinery.

### Integration of sugar mill with refinery operation with SAT process (Figure 2)



### Selection of a membrane system for the SAT process

From technical and process view point the pore size of membranes, based on molecular weight cut off limit, is the most important factor to be considered. For the SAT process to successfully remove sufficient fine particles, macro-molecules, such as polysaccharides, dextrans, starches, gums, waxes, color and the complexes of these constituents, the membrane selected should have a maximum molecular weight cut off limit of 300,000. However, a molecular weight cut off limit of 75,000 to 100,000 is preferred.

For the design and engineering of a membrane system, and most importantly for economic justification, many factors need to be considered such as those listed in the table below. The table is a text book case of a membrane project. For a given objective/function of the project, four membrane vendors, after extensive pilot testing, submitted the design as shown in the table. It should be noted that power consumption varies as much as twofold and one system

requires as many as five heat exchangers for the same application. It is obvious that each vendor has different types of membranes with diverse design criteria. It is up to the user to select the best technically and economically justifiable system for applications. It goes without saying that both operating and capital cost greatly depend on the design and engineering of the system.

### Design of membrane systems

Vendor	Membranes pore size	Flux (lmh) rating	Surface area (M2) needed	No. of modules	No. of stages	No. of heat exch required	Recirc pump HP	Footprint & height	Total weight	Power consumption per day	Operating pressure (bar)
1	0.05μ	1	302	34	5	5	5 x125 HP	39'L x 22'W x 11'H	14 tons (wet)	9000	3 - 5
2	0.02μ	2	288	12	2	2	1 x 200 HP	36'L x 36'W x 15'H	15 tons (wet)	4750	3 - 5
							1 x 100 HP		7 tons (dry)		
3	0.1μ	3	322	3	3	none	3 x 75HP	15'L x 25'W x 25'H	10 tons (wet)	3800	5 - 7
4	0.2μ	3	448	40	2	2	2 x 200 HP	40'L x 40'W x 20' H	36 tons (dry)	6800	2 - 4

### Principle, Experiments, and Results

Factors affecting the color of white/refined sugar includes: purity and color of pan feed liquor, color types, polysaccharides, ash constituents, sugar crystal size and distribution, and boiling time. SAT process is designed/developed to reduce/minimize and improve or change these effect in order to produce white/refined sugar.

**Purity and color of feed liquor**--The crystal sugar color is greatly affected by the color and purity of pan feed liquor. Generally crystallization removes between 90 to 96 % of color. The lower the color of feed liquor the better the sugar color. Sugar refining processes use affination (mechanical separation of color), carbonation, phosphatation, bone char, granular carbon and ion exchange resin to remove color before sugar boiling (crystallization) to produce white/refined sugar. Any or combination of above processes selected should perform the highest net color removal with minimum environmental problems. Unfortunately, except affination and crystallization, all other processes create environmental issue.

The UF membranes used in the SAT process remove color with minimal effect on environmental quality as shown in the table below. The color removal ranges from 48% for raw sugar to 58% for affination syrup. The ability of SAT to remove color is essential to make white sugar from sugar mill. The maximum color of clarified cane juice entering the SAT system should not exceed 12,000 ICU.

## Syrup color and purity improvement by the SAT process

Run No.	Samples	Color (ICUMSA)	Purity
Run 1	Affination syrup 30 BX	40572	80.36
	SAT treated	16940	84.03
Run 2	Affination syrup 30 BX	39244	84.09
	SAT treated	17024	88.47
Run 3	Raw sugar solution 30 BX	7877	98.62
	SAT treated	4042	98.78

The above data also indicate considerable improvement in purity due to non-sucrose removal by the SAT process. The increase in purity is as high as four points for affination syrup used in the study, most likely due to the presence of large quantity of macro-molecules and well dispersed fine particulates. The increase in clarified cane juice is expected to be less. The higher the purity of cane juice the easier it is to make white sugar. For the SAT process the cane juice should have a minimum purity of 85. Cane juice with low purity would contain large percentage of invert sugar, which would not only create color but also induce significant sucrose loss, particularly at low PH as practiced in sulfitation processes for production of plantation white. The following data evidences the tremendous sucrose loss due to sulfitation, up to 5%, due to low PH and high invert in the cane juice.

### % Sucrose loss at 80 °C, pH 5.0 of 65 brix sucrose solution spiked with Fructose

% fructose	1.5 hr heating	3 hr heating	6 hr heating
0	0.263%	0.834%	2.36%
1.5	0.392	0.969	3.43
3.0	0.512	1.36	5.51

**Color Types**—To produce white/refined sugar, in addition to lessen the color of feed liquor, a survey of literature suggests a need for removal of colorants preferentially occluded in the crystal. Donovan and his coworker have concluded, in their study on preferential color occlusion in sugar crystal, that the higher molecular weight colorants, which can be separated by membrane, give much high color transfer into sugar crystal (2). Clarke and her coworkers has proposed that polysaccharide is part of the very high molecular weight color complex and is preferentially occluded in sugar crystal (3). Removal of these high molecular weight color and polysaccharide by a membrane system, which is part of the SAT system, should facilitate production of white/refined sugar from sugar mill. The following table shows the color and polysaccharide removal as a function of membrane molecular weight cut off limits. It should be noted that in general the % removal increase as the pore size of membrane decrease. Chou also reported similar findings (4).

### Color and polysaccharide removal as a function of membrane pore size

Membrane Molecular weight cut-off	% removal Turbidity	% removal Color	% removal Polysaccharide
10,000	99.5	89	90.8
35,000	100	85.3	84
75,000	88.5	60.8	81

**Ash types**—Carpenter reported (5) that ionic constituents in sugar solution would greatly influence the degree of color adsorption by adsorbents such as bone char and granular carbon. Colorants in a sugar solution with excess polyanions (EPA) has much less tendency to be adsorbed or picked up by adsorbents, particularly as the degree of conjugated double bond decrease as shown in his data. He did not advance his explanation for the phenomenon. Chou (4) advanced his reasoning in term of ionic strength of the solution and the degree of conjugated double bond of the adsorbents. Since the sugar crystal has no conjugated double bond, the adsorption/occlusion of colorants into the crystal should be minimal as the EPA is increased by addition of polyanions as processing aids. Some other reasonings can be found in the literature (6, 7). In the SAT process, polyanions are added as processing aids to increase EPA, and therefore minimize color occlusion into sugar crystals.

**Sugar crystal size and distribution**— the sugar color, for a given weight of sugar product, increases with surface area due to the fact that about 15 to 30% of total color are on the outside of the crystal. To minimize sugar color, the SAT process requires a minimum of 0.65mm average sugar crystal size (MA) and a maximum of 35 coefficient of variation (CV) for its sugar products.

**Boiling time**--It is generally stated in the literature that ultrafiltration (UF.) treatment of sugar containing solutions improves the crystallization rate during boiling and therefore will subsequently increase vacuum pan capacities. However, there is little specific data available in the literature on the subject. Too many parameters affect sugar boil, for instance, boiling schemes. The table below shows the increased rate of crystal growth achieved with juice treatment by the SAT process.

### Crystal growth rate improvement with SAT process

Samples	Sugar crystal growth rate (u/min)		
	1st hr.	2nd hr.	3rd hr.
Affination	4.7	3.4	2.7
SAT treated	7	4.7	3.7
% Increase	49%	38%	37%

The SAT process provides benefits, in addition to color reduction, in the form of polysaccharide and other non-sucrose impurities removal.

For example, the treatment of affination syrup using the SAT process removed impurities as previously shown. It can be seen (see above table) that removal of polysaccharides and other impurities, which affect the rate of crystallization, did indeed improve the crystal growth rate by up to 49 %, 38 %, and 37 % for the first hour, second hour, and third hour, respectively. The subsequent increase in crystal growth rate will increase the factory/plant capacity, reduce sucrose loss, and increase yield.

The increased crystal growth rate can be attributed to a reduction in viscosity caused by the membrane ultrafiltration along with processing aid treatment. It is well known that treating juice with U.F. and processing aids will give reduced viscosity. The table below shows the reduction in viscosity up to 19% due to the SAT treatment. Since the viscosity is difficult to measure at 85 brix, they were measured at about 75 Brix. It is expected that viscosity reduction would be significantly higher at 85 Brix, which is closer to the actual conditions in sugar boiling.

**Syrup viscosity improvement with the SAT treatment**

Run No.	Viscosity cps			
	Run # 1 (74.3 Bx)		Run #2 (74.5 Bx)	
Temperature	60 C	22 C	60 C	22 C
Clarified juice	128	1622	150	1820
SAT treated	108	1348	122	1568
% Reduction	16%	17%	19%	14%

**Pilot plant testing**-- In essence, The SAT process uses (a) the membrane with right pore size to remove color, polysaccharide, and their complexes, after addition of processing aids, in order to reduce both feed liquor color and color transfer coefficient, and (b) processing aids to increase EPA and to change the nature of colorants in order to reduce occlusion of sugar color into sugar crystal.

The experiment involved five scientists and engineers on three shifts/day basis for about two months. The clarified juice were first treated with processing aids and membrane filtered using a two gpm membrane pilot unit on site in Sterling Sugar Company of Louisiana. The treated clarified juice was then evaporated to 65 brix using an pilot evaporator on loan from ASI of Louisiana University of Louisiana (LSU). The concentrated syrup were then trucked to ASI of LSU and boiled/ crystallized using a pilot vacuum pan with nominal capacity of twenty gallons. The results are shown below. The data clearly indicate that white sugar with color ranging from 80 to 200 ICU can be produced from cane sugar factories.

### White sugar produced with SAT process

Sugar boiling using ASI (LSU) pilot vacuum pan					
Run No.	Samples	Syrup color	Sugar color (ICUMSA)		
			10 sec. Washing	20 sec. Washing	30 sec. Washing
Run 1	Clarified syrup	11406	687	442	335
Dec. 1999	SAT treated	6590	239	152	85
Run 2	Clarified syrup	11443	567	422	340
Jan. 2000	SAT treated	8384	217	125	80

**Benefits of the SAT process is shown in the following list**

- 1) Sparkling sugar with color of 85 minimum (ICU) meeting U. S. Food grade standard**
- 2) SO<sub>2</sub> less than 6 ppm**
- 3) Increase vacuum pan capacity by 30%**
- 4) Increase clarifier capacity by 15%**
- 5) Reduce evaporator scale by up to 75%**
- 6) Reduce sucrose loss by up to 2%**
- 7) Excellent stability in storage**
- 8) Up to 90% Dextran removal**
- 9) An automated process**
- 10) No conventional sulfitation/carbonation/ flotation process facilitating automation of mills to reduce manning, and consistent high process efficiency and products quality**
- 11) Ability to produce 30% of refined sugar without additional vacuum pan**
- 12) Operate in conjunction with the Cti process to produce white/refined sugar and value added sugarcane extract (antioxidant etc.)**

## CONCLUSIONS

Reported here is a new sugar processing method (SAT) providing an energy efficient and environmentally friendly process for production of white/refined sugar from cane sugar factories. The SAT process is a direct replacement of the sulfitation, carbonation, and Blanco Directo processes for plantation white sugar productions.

The SAT process will: a) minimize color occlusion into sugar crystal during sugar boiling producing sugar product with color ranging from 80 to 200 ICU depending the need of the market ; b) reduce scale formation in the evaporation process by up to 75%; c) increase pan boiling capacity by 30%; d) increase primary clarifier capacity of 15 % by elimination of vacuum drum filtrate recycle; e) reduce sucrose loss by up to 2%; f) reduce sulfate/sulfite content of the sugar; and g) improve the storage stability of sugar products.

The crystallized ULC and VLC sugar products from the SAT process in raw sugar mills/factories can be used as food grade products for direct consumption as refined sugar, plantation white sugar, and other low purity refined sugar. Application of the SAT process in raw sugar mills in conjunction with a sugar refinery can eliminate one or more of the various refining processes such as affination, carbonation, phosphatation, and/or granular carbon/bone char/ion exchange for decolorization.

In summary, the environmentally friendly SAT process can produce high quality food grade sugar products meeting customers' needs with considerable savings in both capital and operating costs.

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