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Simplified refining process for the 21st century

by

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(I) Introduction

As we entered the 21st century, the sugar industry found itself at a cross road facing many challenges and opportunities: limited energy supply, diminishing other resources (food, water, etc.), environmental pressure, health and safety issues, regulatory compliance, nutritional values of refined sugar under attack, global competition (WTO); and a global economy in which the only **Constant** is "**change**". We sugar technologists must be more innovative and creative in our approach to reduce the sugar production cost to a minimum possible.

The best way, economically, technically, and environmentally, to produce refined sugar in the 21st century's economy is to (a) attach a simplified refinery to a sugar mill with matching capacity and (b) for an autonomous refinery, use VHP raw sugar with maximum color of 1000 ICU as the refinery input to simplified the refining process.

This paper describes the development of ***a simplified refining process*** employing only phospatation with addition of purifying aids when the input VHP raw color is 1000 ICU max. **When the input VHP raw sugar is less than 600 ICU color, ONLY** press filtration with addition of purifying aids is needed. No Ion exchange process (therefore no dark brine regenerant waste disposal problems) and No UF- and nano-membrane systems are used in the process. Also No sulfitation (air pollutant and health hazard) and No conventional sugar silo for sugar conditioning are needed.

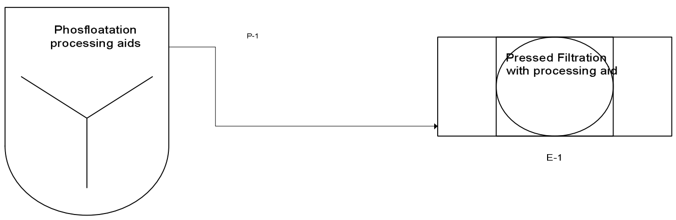
In an attached simplified refinery, bagasse is the only fuel needed to produce refined sugar. No other source of energy, such as coal, gas, or oil should be needed.

(II) Autonomous Simplified refinery

In USA sugar refineries, the average liquor color going to the pan floor for boiling refined white sugar ranges from 175 to 275 ICU. The average combined sugar color of the 1st strike (R1), 2nd strike (R2), and 3rd strike (R3) is around 35 meeting all industrial and grocery product requirements.

Any process selected for a simplified refinery should be able to produce pan feed liquor color of less then 275 ICU. It has been demonstrated that when the VHP raw sugar color is less than 1000 ICU, all a simplified refinery needs is Phosphatation plus press filtration as shown in figure 1:

Figure 1 depicts the simplified refining process selected:



(II a) Color of input raw sugar exceeds 600 ICU. In this case, phosphatation process is definitely needed to decolorize the liquor to be less than 275 ICU using various FDA approved purifying aids as shown below. It should be noted that all processing aids used meet US government regulatory requirements.

Decolorization test I

All PuriAids products comply with US FDA requirements

			Color (ICUMSA)
Melt liquor			1070
PuriAids	CP 25	(300 ppm)	
PuriAids	HP 35	(300 ppm)	
PuriAids	DC 22	(200 ppm)	
Phosphatation		(500 ppm)	140

Decolorization test II

			Color (ICUMSA)
Melt liquor			1092
PuriAids	CP 25	(500 ppm)	
PuriAids	HP 35	(300 ppm)	
PuriAids	DC 22	(200 ppm)	
Phosphatation		(500 ppm)	155

Decolorization test III

			Color (ICUMSA)
Melt liquor			1093
PuriAids	CP 25	(500 ppm)	
PuriAids	HP 35	(300 ppm)	
PuriAids	DC 22	(200 ppm)	
Phosphatation		(500 ppm)	135

From above decolorization tests, it is obvious that phosphation process, together with addition of various purification aids, can produce pan feed liquor color of less than 155 for boiling of refined sugar even when the input raw sugar liquor color were as high as 1100 ICU.

The refinery, which consists only phosphatation and press filtration and is designed for production of 35 ICU liquid sugar, normally has an input raw/melt liquor color of less then 1000 ICU. However, when the VHP raw sugar exceeded 1000 ICU, the dose of Puriaids CP 25 can be increased to improve decolorization as shown in the decolorization test IV data.

The phosphataion process was able to reduce color from as high as 1582 ICU to 226 ICU level for boiling of refined sugar. It appears that puriaids CP 25 is a very effective decolorizing agent.

Decolorization test IV

		Color (ICUMSA)
Melt liquor		1582
PuriAids	CP 25 (800 ppm)	
PuriAids	HP 35 (300 ppm)	356
Phosphatation	(500 ppm)	226

When the puriaids CP 25 was reduced from 800 ppm to 500 ppm, the rate of color removal was considerably decreased as shown in decolorization test V. Further reduction in the dosage to 300 ppm greatly effect the color removal efficiency as shown in declorization test VI.

Decolorization test V

		Color (ICUMSA)
Melt liquor		1317
PuriAids	CP 25 (500 ppm)	
PuriAids	HP 35 (400 ppm)	
Phosphatation	(500 ppm)	402

Decolorization test VI

		Color (ICUMSA)
Melt liquor		1317
PuriAids	CP 25 (300 ppm)	
PuriAids	HP 35 (300 ppm)	
Phosphatation	(500 ppm)	618

Although the color of 402 ICU in the decolorization test V and 618 ICU in test VI are not sufficiently good enough to boil refined sugar, other purifying aids can be added in the following filtration step to reduce the color to less then 275 ICU for boiling as shown in the next section.

(II b) the color of raw sugar is less than 600 ICU. In this case, ONLY press filtration with addition of various Puriaids, is need to reduce pan feed color to less then 275 ICU for boiling of refined sugar, as shown in the decolorization test VII below:

Decolorization test VII (By press filtration ONLY)

		Color (ICUMSA)
Melt liquor		600
(a) PuriAids	DN 22 (1%)	44
(b) PuriAids	DN 22 (0.6%)	66
(c) PuriAids	DC 22 (0.55%) + DR 22 (0.075%)	100
(d) PuriAids	DC 22 (0.55%) + DN 22 (0.1%)	80
(e) PuriAids	DC 22 (0.55%) + DN 22 (0.2%)	50

With 1% of puriaids as shown in (a), the liquor color was reduced from 600 to 44 ICU. The high dose of 1% was used because the refinery wanted to produce liquid sugar of less then 80 ICU. To reduce cost, when puriaids was reduced to 0.6% (b), the resulting liquor was still 66 ICU. Various tests was performed, from (c) to (e), to optimize the cost of production. For this particular customer there was no need to remove ash.

From the above tests it appears that for production of refined sugar, which only need a pan feed liquor color of less than 275 ICU, no phosphatation will be needed if the melt/raw liquor color is less than 600 ICU. Only press filtration with addition of some puriaids is sufficient to reduce color to less than 275 ICU for pan boiling.

(III) Attached a simplified refinery to a sugar mill

Based on the presentation/discussion of the above section (II), the raw sugar produced in the mill and to be fed to the attached simplified refinery must have a color of less then 1000 ICU.

A sugar mill with conventional lime clarification can be easily improved/modified to achieve the targeted color of 1000 ICU by installation of phosphatation process to clarify evaporated syrup as described in section 5.77 of the 12th edition of "Cane sugar handbook".

(III a) a standard process flow of a lime juice clarification sugar mill, with a raw /evaporated syrup clarifier added, is shown below:

Mixed cane juice (from mill) => Adjust PH to 6.2 to minimize inversion => Juice Heaters (heating to 103-105 ℃) => Flash Tank (to 100 ℃) => Liming tank (adding lime milk to hot cane juice) and mixing to reach pH 7.5 – 7.7 => Continuous Clarifier (e.g. Dorr Oliver Co.) => Clear juice with PH of around 7.1 (20^{o}C) => to 150 mesh strainer to remove suspended matter and/or microbes => to Multi-effect Evaporators (to 63-68 Bx) => Raw/evaporated Syrup clarifier => 24 mesh strainer to remove scale => to Boiling House (Use Step-up Three Boiling System).

A sugar mill with sulfitation can be converted to lime juice clarification practically with practically no change in equipment. Use of sulfur will be eliminated.

The most important factor to produce VHP raw sugar with high refining quality is to have stability and clarity in the juice continuous clarifier, including but not limited to:

(1) Lime recirculation loop to avoid blockage of milk of lime.
(2) Good automated PH control.
(3) Good automatic temperature control.
(4) Sufficient addition of P_2O_5

(III b) Improved phosphatation clarifier in the attached refinery is achieved by installing a simplified highly efficient aeration system to minimize phosphatation carry- over and after floc

The following data is collected from a liquid sugar production refinery on turbidity removed by phosphatation followed by that removed by press filtration. The data show that the turbidity of clarifier effluent are excellent, i.e. all below 6 NTU. No deep bed filters are needed as generally required in a conventional phosphatation sysyems.

The turbidity of press filtrate are all less than 2 NTU which is as good as LCMT (low color, mineral, turbidity) value added special syrup for both pharmaceutical and cordial industries.

Refinery data
Turbidity removal by phosphatation and by press filtration

Turbidity (NTU)

Time of Sampling	Clarifier feed liquor	Clarifier effluent liquor	Press filtrate
14:00	151	4.31	1.34
18:15	33.9	2.33	1.57
22:15	47.8	5.78	1.37
2:00	130	3.08	0.87
6:00	28.3	2.7	0.88

The following table shows the refinery color profile with VHP raw sugar input over a month period. As expected, the color removal across the clarifier is about 25 %. A typical color removal averaged 30 to 35 % if the input melt color is around 1000 to 1200 ICU. With the addition of color precipitant into the clarifier the color removal should be about 50 to 60%.

Refinery Color Profile							
Date	Raw	Raw Melter	Clarifier	Column Feed	Anion	Cation	BV
1/4/2009	589	445	291	287	25	37	12
1/5/2009	547	368	254	263	15	24	15
1/7/2009	528	327	267	277	12	24	10
1/9/2009	575	365	304	290	14		12
1/12/2009	555	419	319	311	20	33	10
1/14/2009	564	376	309	298			11
1/16/2009	572	395	322	170*	9	25	10
1/23/2009	561	445	287	333	14	17	16
1/27/2009	564	442	302	291	27	36	12
1/29/2009	556	482	359	255	13	19	15
Average	**561.1**	**406.4**	**301.4**	**289.4**	**17.50**	**26.9**	**12.3**
	* Part of feed was pan materail						

(IV) Pan capacity in attached simplified refineries

When a simplified refinery is attached to a sugar mill, it is obvious that additional pan capacity will be needed to boil refined sugar. The problem can be alleviated by the following undertakings:

(1) Install stirrer in A & B pans.
Stirrers will reduce the boiling time by 30%.
(2) Increase the brix of evaporated syrup to 65 Brix minimum to free up vacuum pan for refined sugar boiling.
(3) Conversion of sulfitation plants to lime clarification will also increase pan capacity by reducing the pan scale.

(V) Energy saving of attached Simplified refineries.

The energy saving can be assessed by the following calculation:

Typically for bagasse, the percentage of bagasse to cane range between 25-35% depending on the fiber content of the cane. 30% will be a good average number which means 30 tons of bagasse/100 tons of cane. Steam generated per ton of bagasse again depends on the efficiency and pressure of the boiler and moisture content of bagasse . Typically 2.2 lb steam/lb of bagasse burned.
Therefore, 100 tons of bagasse will produce 220 tons of steam (High pressure out of boiler). Therefore, 100 tons of cane will produce 66 tons of steam (220/100x30=66). Assuming the sugar yield is 11% of cane, each ton of raw sugar would have 6 tons of steam available (66/11=6). The energy usage and availability is shown below:

Energy usage and availability

Energy consumption for a VHP refinery --------------- 0.8 ton of steam /raw sugar
Energy consumption for a Cane mill -------------------- 3.2 tons of steam /raw sugar
Energy needed for a cane mill with attached refinery -- 4.0 tons of steam /raw sugar
Energy available in a mill with attached refinery------- 6.00 tons of steam /raw sugar
Excess energy in cane mill if process is optimized------- 2 tons of steam /raw sugar

It appears that there is an excess of 2 tons of steam /raw sugar in cane mill even with a simplified refinery attached to it if operation is optimized. Bagasse is the only fuel needed for the mill. No other source of energy, such as coal, gas, or oil should be needed

The cost saving of refined sugar produced in an attached refinery is equivalent to 0.8 tons of steam per ton of sugar refined compared to that produced from an autonomous VHP sugar refinery.

(VI) Capital cost of an attached simplified refinery is much less than that of an autonomous simplified refinery.

(VII) Summary

(1) A simplified refinery consists of phosfloatation and press filtration only
(2) The color of VHP raw sugar entering the refinery should not exceed 1000 ICU.
(3) If color is less than 600 ICU, It is optional to use phosphatation process. Only press filtration with decolorizing processing aids is needed.
(4) If color exceeds 600 ICU, selective decolorization aids will be needed at the phosfloatation clarifier depending the VHP raw sugar color level.
(5) Baggasse is the only fuel needed for a mill with an attached refinery to produce refined sugar.
(6) There is a saving of 0.8 ton seam per ton sugar processed in an attached mill as compared an autonomous refinery.
(7) No sulfitation, ion exchange decolorization process, carbonation, and Granular carbon system are needed in a simplified refinery resulting in considerable savings in both capital and operating cost.
(8) An attached simplified refinery is ideal for countries where the crop (cane grinding) season is over eight month a year.

(9) Capital cost of an attached simplified refinery is much less than that of an autonomous simplified refinery.

(VIII) Attachment below presents the function of a refinery and criteria for selection of processes for a simplified refinery.

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Attachment

(I) Function of "refining"

Sugar refining involves purification of sugar to meet food safety requirements and customers' demand. There are five groups of non-sugar: color, ash, macromolecules (turbidity), microbes, and heavy metal. Food safety requirements would mandate that microbes and heavy metal in the final sugar products must meet food grade quality. Turbidity, mostly consists of macromolecules such as polysaccharides, waxes, gum, need to be removed for customers' quality control. Microbes and turbidity can be remove by carbonation, phosphatation during the processes of decolorization and finally polished by tight filtration via filter presses with diatomaceous earth (DE). Color and ash removal are optional, depending on customers requirements. For example brown sugar is a refined product but the color and ash are many times that of refined white sugar.

(II) Selection of Decolorization Processes

To achieve the desired degree of decolorization, The decolorization process chosen should be designed to give a fine (pan feed) liquor color of 250 maximum and an average of 200 color (ICUMSA method at 420 nm) from an input color of 1000 ICU. In North America, a decolorization scheme generally includes a primary decolorization process such as carbonation or phosphatation, followed by a secondary decolorization process such as bone char, granular activated carbon, or ion exchange process. However, more often than not, due to inefficiency in its operation many refiners would use more than one secondary decolorization processes, such as ion exchange process followed by granular activated carbon.

(A) Primary decolorization process: Carbonation vs. Phosphatation

Carbonation *is technically the best choice for decolorization*

a) Percent color removal

Carbonation removes about 55-60% of color. Phosphatation removes only about 25-30% of color at a dosage of 250 ppm P_2O_5. This is because that similar type of colorants was removed in the raw sugar mill clarification process, which is basically a phosphatation process at a minimum dosage of 300 ppm P_2O_5.

It is know that use of Talofloc (Quaternary Ammonium salt, a color precipitant) in conjunction with phosphatation would improve the decolorization level to that of carbonation. However, the use of Talofloc will reduce the degree of decolorization by the ion exchange resin and, therefore, less cost effective. The reason is that both Talofloc (Quaternary ammonium salts) and ion exchange resin remove similar type of anionic colorants. If combination of phosphatation with color precipitant is selected, it is suggested Ion exchange resin in OH^- and H^+ form respectively be considered for both color and ash removal. Carbonation is more compatible with ion exchange system regarding decolorization efficiency.

b) Destruction of Invert

Carbonation, because of high pH in the first A saturator, eliminates most invert from sugar liquor. Phosphatation process not only does not destroy invert, it actually creates more invert, because of low pH.

Invert, at high temperature, is converted to organic acids which lower the pH and destroy sucrose, creating more invert. It is a vicious cycle.

In beet sugar production, practically all invert is destroyed in its carbonation process. The carbonated beet liquor going to pan boiling has a pH of above 8.5. Under this condition, no invert is formed by inversion of sucrose in the subsequent processes. This is the reason that invert content in beet molasses is less than one (1) %, as compared to 10% to 25% of invert in cane molasses depending on the type of decolorization process used in refineries.

c) Removal of ash

Carbonation removes up to 20% ash mostly sulfate, which is a culprit of scaling in both evaporators and vacuum pans. Phosphatation does not remove ash, and, therefore, has more scaling problem, unless ion exchange resin in OH^- and H^+ form as discussed in the previous section.

d) Turbidity removal

The clarity of carbonated liquor is superior to that of phosphatation liquor due to the fact that carbonated liquor is pressed filtered using carbonated cake (created in situ) as filtering media. In addition, phosphatation is known to have “secondary floc” which would give precipitate after sand filters, unless press filters are used. Also required back washing for sand filters result in lower process efficiency.

e) Quality of sugar product

Sugar produced by carbonation with press filtration is much more "sparkling" and has much less sediment in the final products. Sugar produced by phosphatation is of lesser quality due to a) secondary floc and b) some particulates are not removed by sand filter used in phosphatation process. Sand filter is known to remove only particles over 5 micron size.

f) Buffer capacity/sucrose loss

Carbonated liquor maintains a much higher buffer capacity (pH of 7.8-8.2) as compared to that of phosphate liquor at pH of 6.8 to 7.1. Higher buffer capacity also mean that liquor will remain at higher pH as sugar boiling proceeded to 2^{nd} or 3^{rd} strike boiling, resulting in a much lower chemical sucrose loss.

g) Stability of process

Carbonation is known to have excellent process stability. In addition, process upset due to poor raw sugar quality, particularly high starch content, can be resolved by adjusting operating conditions, such as brix, temperature, filter aid level and press cycle, without reducing plant through-put.

The process stability of phosphatation is known to be "temperamental", particularly when scum desweetening process is used. It is preferred to use dewatering press to desweetening the scum. The result are both high physical and chemical sucrose loss, and high turbidity. In addition, when there is a process upset, the operating variable available to resolve the problems is limited.

h) Capital cost

It goes without saying that carbonation will have higher capital cost.

i) Disposal and Environmental issues

I do not think that both carbonated cake and phosphate scum will have environmental problems. It is a matter of communication with government agencies. Both processes are widely used in US and Canada where governmental regulations regarding waste disposal are un-compromising.

Carbonation will have 4 to 5 times more in volume of solid cake to be disposed of than with phosphatation.

j) Additional benefit of the carbonation

The following additional benefits are expected from carbonation processes:

1) Products contamination by pan scale due to sulfates will be practically eliminated.

2) Acid washing of vacuum pan scale will be avoided. This will give vacuum pans longer service life and higher productive cycle.

3) The operation of a carbonation process generally is more consistent than other decolorization process, resulting in a steadier and/or higher melt rate (refinery capacity).

Phosphatation

phosphatation process is known for both high sucrose loss and energy consumption due to low pH and process instability. However the initial capital cost is lower than that of Carbonation.

As previously discussed, The process stability of phosphatation is known to be "temperamental", particularly when scum desweetening process is used. The result is both high physical and chemical sucrose loss, and high turbidity. In addition, when there is a process upset, the operating variable available to resolve the problems is limited. It is preferred to use dewatering press to desweetening the scum.

(B) Secondary Decolorization Process :Granular Carbon versus Ion Exchange

Granular Activated Carbon

For a 1000 ton per day capacity refinery, in a granular carbon configuration, 8 columns 10'd x 42'h with column carrying 2,400 cubic feet of granular carbon and a carbon regeneration kiln with many peripheral equipment are required. In an ion exchange decolorization scheme, only 3 columns 8'd x 24' h are required. The more equipment necessary to run the operation, the more manning and maintenance are expected, resulting in higher refining operating costs.

Granular Activated Carbon (G.A.C.) is technically preferred as the adsorbent for removing color after carbonation. G.A.C. will also remove the odor in liquor, if any. An after burner for the stack gasses is required to eliminate odor emission problems from the furnace's regeneration of G.A.C. A GAC system is known to be capital intensive as compared to an ion exchange system.

One disadvantage of the granular carbon system is the high sucrose loss associated with the process; sucrose loss probably averages about 0.04% on an operating day and as much as 0.4% during weekend shutdown periods. To minimize the sucrose loss due to inversion, magnesite is added to the system during the revivification of G.A.C. to maintain the PH of treated sugar liquor.

Ion Exchange resin process

Two problems with resin regeneration are the disposal of the high colored chemical effluent from the regeneration process and the disposal of the spent beads after their useful life. Recent innovations, nano membrane filtration for treating the high colored effluent, has reduced the quantity sodium chloride that must be disposed of outside the refinery. However, it is increasingly difficult to dispose of the remaining dark color nano membrane waste.

Some refiners have had product contamination that is organoleptic sensed (odor) when resins are used. The pre-washing process of make-up resins must be monitored and steps taken to insure that some of these resin beads are not exposed to elevated liquor temperatures.

The operating and capital costs of the ion exchange process are about half and one third respectively of that of the granular carbon system.

(III) Press filtration

One of the greatest nuisances in the refining process can be "debris" fouling the adsorbent for ash and color removal after carbonation or phosphatation. For clarity of this writing, debris or secondary floc is particles that form with time from an interaction of chemicals such as calcium and phosphates or other similar non-soluble particles that are known to pass through the above mentioned processes. Quantitatively this debris is small; however, over time it will be deposited on equipment and/or block the surface area of the adsorbent.

Polishing filters are an important process innovation for getting rid of this nuisance. Debris can stop the flow over fixed bed resins or granular adsorbents. This debris will block the surface sites that remove ash and color on resins or block the surface sites for color removal on G.A.C. This blockage adversely impacts on sucrose losses, increases energy requirements and requires more new makeup of resins or G.A.C. to maintain the final product quality. I strongly recommend the inclusion of polishing filters before G.A.C. or resins.