ULTRAFILTRATION/SOFTENING OF CLARIFIED JUICE – THE DOOR TO DIRECT REFINING AND MOLASSES DESUGARISATION IN THE CANE SUGAR INDUSTRY

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Abstract

Hawaiian Commercial & Sugar Company (HC&S) has been working on 'molasses desugarisation' in order to increase sugar recovery in the factory. A new process was developed jointly by Applexion and HC&S called the NAP (New Applexion Process) in which ultrafiltration and softening of clarified juice are incorporated between the clarifier and the evaporator stations. The new system was installed and has been in operation for a full season at the Puunene mill in Hawaii. The new system is described, and the operation and results are presented. A brief review of the potential applications to refining, molasses desugarisation, invert sugar purification and alcohol production is presented.

Keywords: Ultrafiltration, softening, clarified juice, desugarisation

Introduction

HC&S has been working on 'desugarisation of cane molasses' over a three year period. Various equipment and systems were tested to clean the cane molasses for it to be able to pass through a chromatographic separation system. They all failed to meet the required turbidity and cleanliness to pass through the special resins. In May 1993 a pilot ultrafiltration unit was received from Applexion. Initial testing was centered on clarifying C-molasses. The results obtained over a month of testing were excellent, with over 98% reduction in turbidity. In July 1993 the idea of using ultrafiltration on clarified juice, followed by softening, was initiated. Extensive tests were performed for the rest of the 1993 season. In October 1993, HC&S completed a feasibility study to desugarise molasses at its two sugar mills. In view of the large capital investment required for this project (about $18M), HC&S decided to do the project in two phases. The first phase was to condition the B-molasses using ultrafiltration and softening of clarified juice. The second phase was the chromatographic separation of the B-molasses to recover sucrose and invert sugar. In December 1993 the Alexander and Baldwin board of directors approved phase 1 of the Molasses Desugarisation Project. A contract was signed with Applexion in January 1994 to design, engineer and procure the equipment for phase 1. The system was completed and came on line in mid-September 1994. The system ran for the entire 1995 crop season.

The New Applexion Process (NAP)

The NAP system was developed jointly by Applexion and HC&S. In the new system two unit operations, namely ultrafiltration and juice softening, were added between the clarifier and the evaporator stations. Figure 1 shows the new process flow diagram. In this phase soft B-molasses, obtained from the soft juice produced by the ultrafiltration/softening process, is used to regenerate the resins. When the second phase is completed, the raffinate from the chromatographic separation will be used to regenerate the resins.

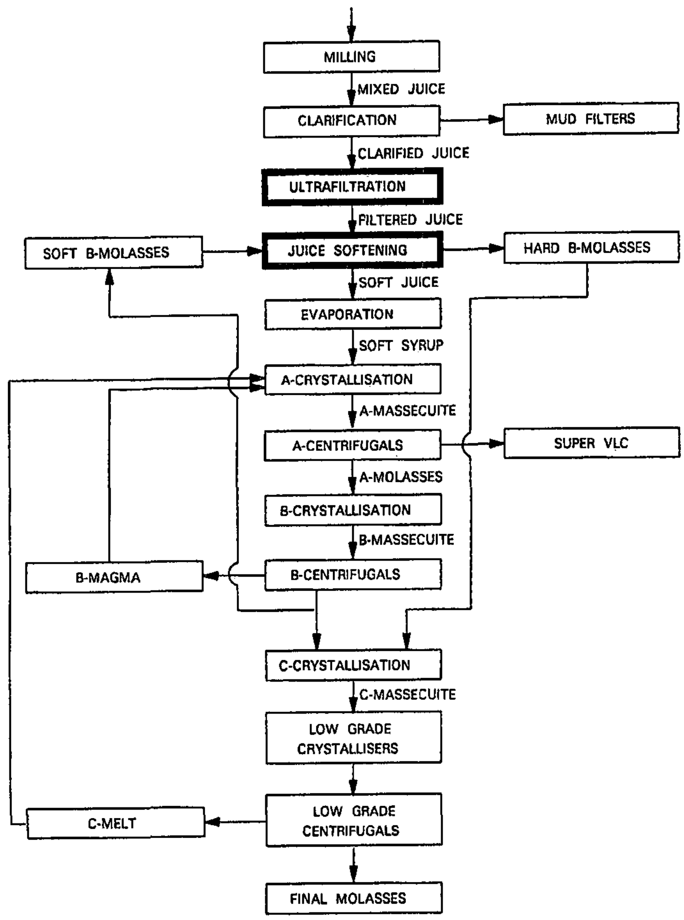

FIGURE 1: New process flow diagram

The first unit operation – juice ultrafiltration – is used to filter suspended solids, remove colloidal materials, wax, gums and high molecular weight polysaccharides such as dextran and starch.

The second unit operation – juice softening – is used to remove calcium and magnesium salts from the hard ultrafiltered juice. The main benefits derived from these two additional unit operations are:

- production of a higher quality sugar
- increased sugar recovery
- reduced chemical usage in evaporator cleaning
- reduced steam consumption.

The ultrafiltration system

The ultrafiltration (UF) installation consists of two parallel filtration lines using the three stage feed and bleed continuous system as shown in Figure 2. The UF system installed has the following specifications:

- 3 skids in series per line
- 10 modules/skid
- 99 Kerasep membranes/module
- Membrane length – 1 200 mm and 856 mm
- Membrane diameter – 25 mm and 20 mm
- 19 channels/membrane @ 2,5 mm diameter coated with zirconium oxide
- Membrane porosity – 0,02 micron
- Total filtering area – 940 square meters.

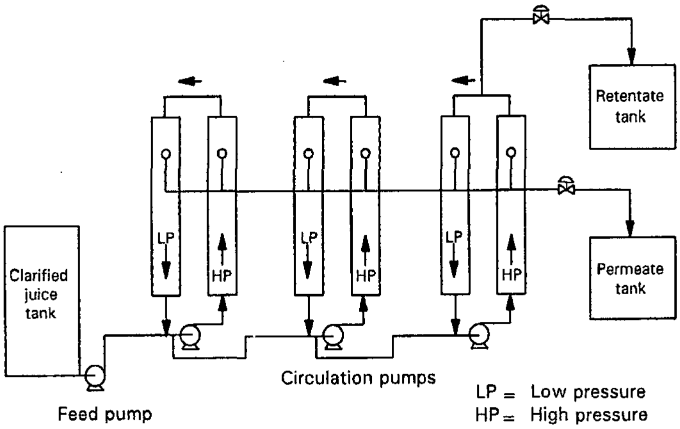

FIGURE 2: Ultrafiltration system. Three stage feed and bleed continuous system

Clarified juice, after screening through two Filtomat continuous filters, is sent to two buffer tanks. From these tanks the juice is sent to the UF supply tank. A variable frequency drive pump is used to maintain a constant pressure into the first skid. Juice is passed through a 60 mesh safety filter, heated to 95°C and then enters the two UF lines. Clarified juice is passed from one skid to the next with the circulation pumps providing the desired velocity in the channels. Permeate juice (clear ultrafiltered juice) is removed from the modules and collected into a common pipe header. The permeate flow is held constant with a control on the permeate circuit. The juice leaving the last skid, called 'retentate', is also controlled by a flow control loop. This flow, which is 10% of the total juice input into the UF system, contains most of the impurities and is recycled back to a separate retentate clarifier.

As the membranes are progressively plugged on the retentate side, the differential pressure increases progressively. When the transmembrane pressure reaches its maximum allowable limit, or when the permeate low pressure value is reached, the production line is automatically stopped and a cleaning cycle is initiated. A production run will last between 24 to 48 hours, depending on juice quality and other factors.

Cleaning in Process (CIP) System

The CIP system consists of a CIP tank, a CIP pump, hot water supply tank, safety filter, mixing pot and the chemical station. A cleaning cycle takes about two hours to be completed. The cleaning sequences are as follows:

- Draining of permeate and retentate from skids.
- Pre-cleaning with hot water to remove surface deposits on membranes.
- Basic cleaning using sodium hypochlorite (bleach) at 300 ppm.
- Rinsing with hot water.
- Acid cleaning using phosphoric acid at 0,5% concentration.
- Final rinsing with hot water and water test.

During the final rinse cycle, a water flux calculation is computed. If the water flux value is within the desired flow, the unit will automatically go back to production. If the water flux test fails, the computer will trigger an alarm. The operator will then have to make a decision whether to go back to production or to initiate another cleaning.

Juice softening system

The juice softening system consists of two softener columns, each containing 45 cubic meters of strong cationic resin and 15 m^3 of inert materials. The ion exchange column is 4 m in diameter and 7,6 m high. Figure 3 shows the production cycle in which hard ultrafiltered juice is pumped in an

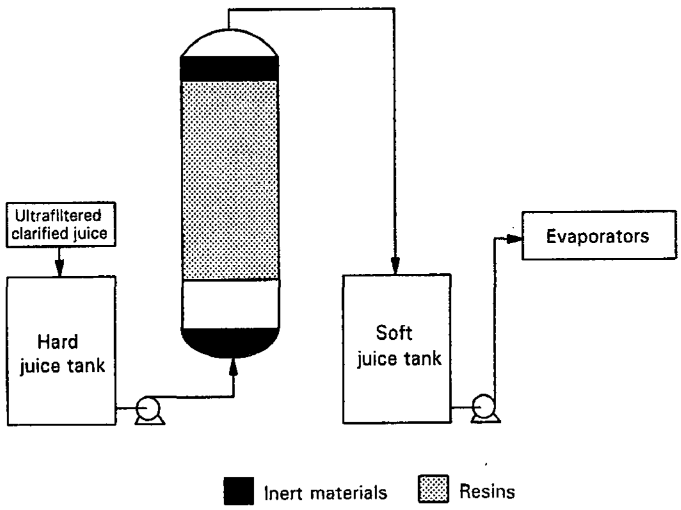

FIGURE 3: Juice softening system. Production cycle

upflow direction through the resin bed. Calcium and magnesium ions are exchanged with sodium and potassium ions in the resins. The soft juice is discharged from the top of the column into a soft juice tank and then pumped back to the evaporator supply tank. Depending on the amount of calcium and magnesium in the clarified juice, a softening cycle can last for 8-10 hours. The softeners are designed to remove 80% of the hardness in the juice.

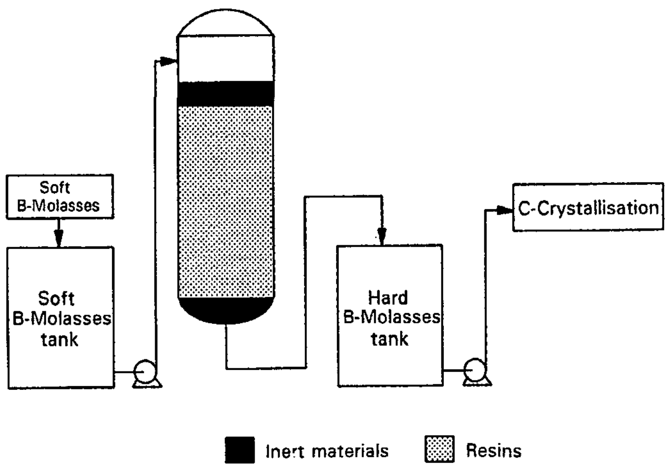

FIGURE 4: Juice softening system. Regeneration cycle

The regeneration cycle is shown in Figure 4. Soft B-molasses at 65-70° brix is pumped in a downflow direction through the resin bed. The soft B-molasses contains a high ratio of potassium and sodium in relation to calcium and magnesium. During the regeneration cycle, sodium and potassium ions are exchanged with the calcium and magnesium ions previously trapped by the resins. The hard B-molasses leaving the softener is sent back to the boiling house to be processed into C-massecuite. Sweet water is generated during the regeneration cycle and is used to dilute the soft B-molasses.

A brine system is also available to supplement sodium ions for regeneration if necessary. An air blower is used for air scouring to remove fines and broken resins from the system.

Control system

The control system used for the UF and softening is done through a Provox Distributed Control System (DCS) and a personal computer (PC) with Wonderware software program. The system combines the existing DCS to a new Programmable Logic Controller (PLC). The graphic displays for the plant are split between the two operator interface devices, namely the operator console and the personal computer. The PC is mainly dedicated to discrete functions while the DCS console is used mainly for analog functions. The DCS operates all the control loops and the sequential functions of the UF and softener. Signals are, in turn, passed to the PLC which operates the on/off valves, motor starter, and the interlocks. The DCS relies on the PLC for information about interlock, emergency stops, and discrete signals required in the sequential operation of the plant. The PLC relies on the DCS for commands to operate the valves and pumps.

The UF and softener are totally automated and are operated from the boiling house control room. From the DCS console, the plant is started and stopped, operating parameters are entered and changed, and regulatory functions and alarms are set. The PC plays a very important role for discrete element manipulation and dynamic displays of the plant status. First out alarm displays and field device status are displayed from the PC.

Once the plant is started, it runs unattended until the end of the grinding week. The only time operator intervention is required is when there is a problem or an abnormal situation arises. Normally the plant runs through its production cycle, cleans itself in the case of the UF, regenerates itself in the case of the softener, and puts itself back into production when it is finished or needed.

Operational problems

Safety filters

Plugging of safety filters with fine bagacillo was a major problem on start up of the new system. Safety filters had to be cleaned almost every hour. This was corrected by installing two continuous Filtomat self flushing filters of 100 microns.

Membrane breakage

During the early part of the 1995 crop season there was some membrane breakage on the first skid of both lines. The problem was due to the sudden change in pressure during the transition between cleaning and production. This has been corrected.

Membrane fouling and low flux

A gradual reduction of flux over the crop period was experienced. This was due to unsatisfactory cleaning of the membranes, especially in the last skid. Extensive studies and testing were conducted by Applexion, Tech Sep and HC&S to optimise the cleaning of the membranes. The cleaning procedures were re-examined and modified to allow for better cleaning of the individual skids.

Low production run cycle

The design calls for a production run of 48 hours before cleaning based on the pilot testing at HC&S. The actual production run, however, varies depending on the quality of the juice processed, the hardness and iron content of the juice, and other factors not easily identified at this stage. During the 1995 season, production runs varied from as low as 12 hours to as high as four days before cleaning was required. On average most of the production runs were between 24 and 36 hours.

Hot water usage

Clean condensate from the first cell evaporator is used for cleaning of the membranes. During long production runs, for example 3-4 days, the hot water will have cooled down to below 65°C. As cleaning with warm water is not very effective, a new heat exchanger was added in the CIP system to correct the temperature problem. At the end of the grinding week, hot water is required for both UF and softeners, although there is a shortage of hot water during the shutdown period. To accommodate this, the softener unit is stopped one shift ahead of the UF.

Soft molasses tank capacity

A normal regeneration cycle uses about 110 000 litres of 65-70° brix soft B-molasses. The original storage tank was only 75 000 litres in capacity, with the intent that the remaining 35 000 litres would be obtained from the continuous B-centrifugal station during the regeneration cycle. It was found that, due to timing in processing B-massecuite, the regeneration cycle was increased because of lack of molasses. The capacity was increased to solve this problem.

Results

During the 1995 crop season only 65% of the total clarified juice went through the UF/softening system. The following results were obtained:

- Sugar pol 99,45
- Sugar colour 600 ICUMSA
- Clarified juice purity increase 0,65%
- Clarified juice turbidity removal >99%
- Juice hardness removal 85%
- Increased Boiling House Recovery by 0,8%
- Reduced caustic soda usage for evaporator cleaning by 50%
- Reduced sulfamic acid usage for evaporator cleaning by 90%
- Reduced steam consumption in evaporator from 780 to 710 lbs (355 to 323 kg) steam/ton MJ.
- Reduced pan boiling by 15 minutes for A strike, and by 30 minutes for B strike.

Phase 2 – molasses desugarisation

With very clean soft B-molasses obtained using the NAP system, it is now possible to desugarise cane molasses eco-

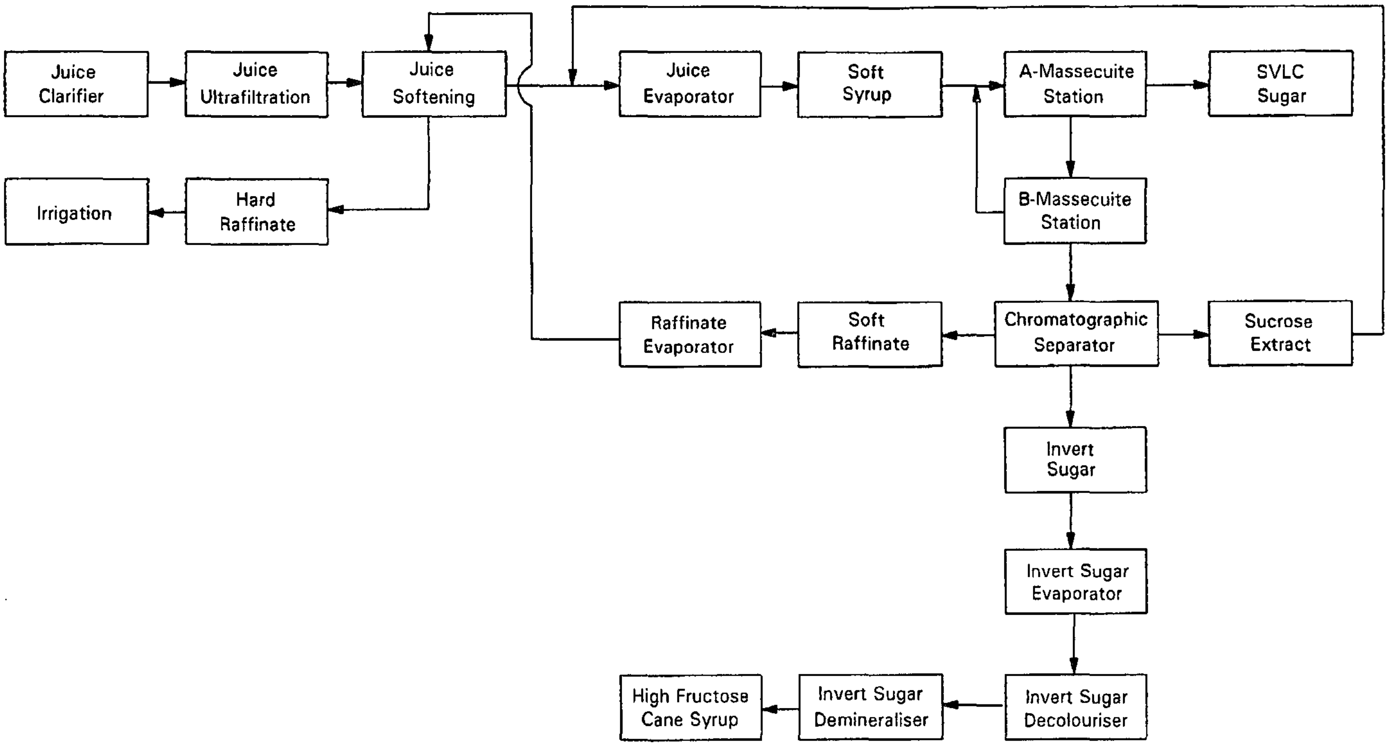

FIGURE 5: Proposed chomatographic separation system – Puunene. Phase 2

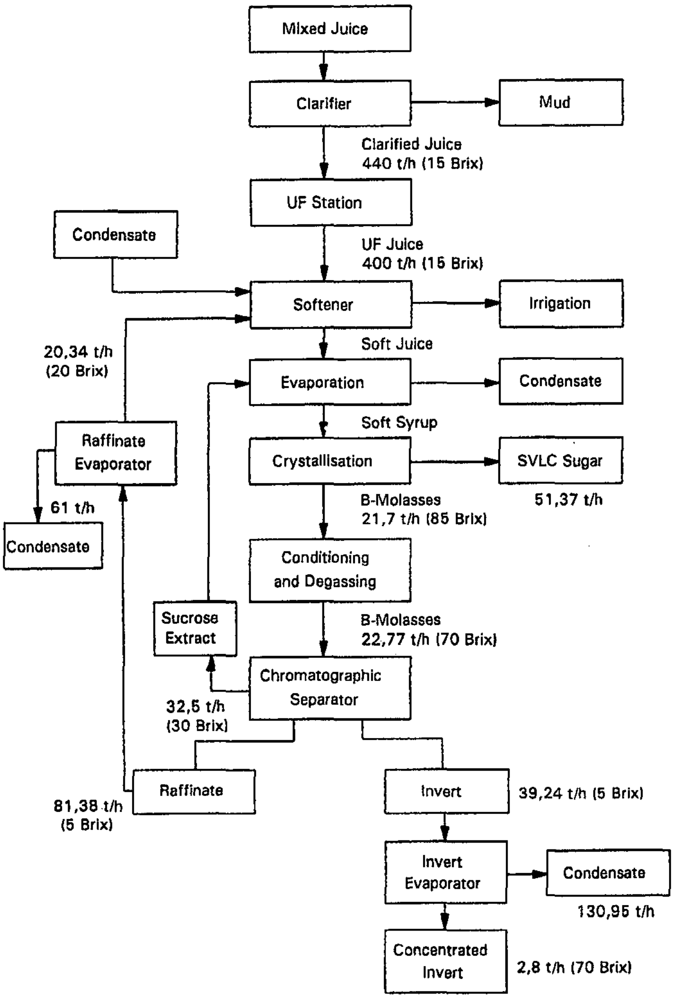

FIGURE 6: Anticipated material quantities during grinding season. Phase 2

nomically. In Phase 2 of the Molasses Desugarisation Project, B-molasses will be sent to two chromatographic separation systems where three fraction separations will be done. The new process flow diagram is shown in Figure 5. The sucrose fraction at 90+ purity and 30° brix will be sent to a new falling film evaporator train and recycled back to the crystallisation station. The raffinate fraction at 5° brix which contains most of the potassium and sodium salts will be concentrated to 20° brix and then used as regenerant for the softeners. The spent or hard raffinate will then be sent to the irrigation system. The invert fraction, which is high in colour, will be concentrated to 70° brix and then passed through a series of ion exchange columns for decolourisation and demineralisation. The resulting invert syrup at about 50-100 ICUMSA colour units will be sold as High Fructose Cane Syrup. A mass balance during the crop season is shown in Figure 6. During the off-season, which is about 3-4 months, final molasses from other sugar mills will be processed through the UF/Softening and chromatographic separation system to recover additional sugar and invert.

Refining

With the production of super very low colour sugar (SVLC) at 500 ICUMSA colour units, it will be very easy to refine sugar at a nominal cost. The process flow for a backend refinery will be simple, as shown in Figure 7. SVLC will be melted, screened, decolourised through ion exchange, concentrated and recrystallised in three stages. Refined sugar at less than 30 ICUMSA colour units will be obtained from the R1 and R2 crystallisation. R3-sugar at 100 ICUMSA colour units will be remelted and sent back to the decolourisation station. R3-sugar can be sold as Plantation White sugar. A color profile fcr a back-end refinery using SVLC sugar is shown in Figure 8.

Alcohol production (cane spirit)

Cane Spirit Rothschild (CSR) has a patent using ultrafiltered cane juice to produce a refined rum product. A pilot test using ultrafiltered clarified juice has produced excellent cane spirit. A feasibility study is now being completed to build a new alcohol plant for the production of four million litres/year of cane spirit.

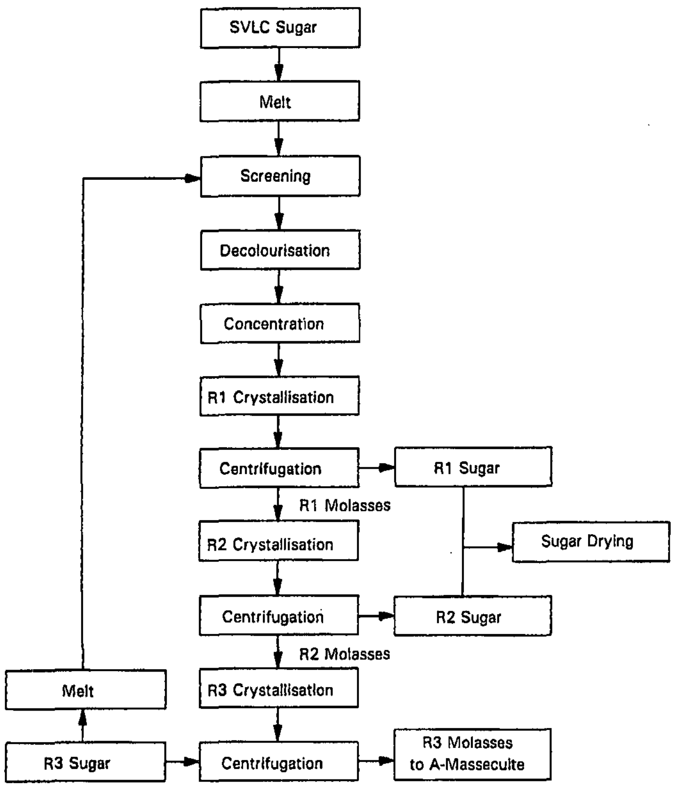

FIGURE 7: Refinery process flow diagram

Table 1
Refinery colour profile with SVLC sugar

Component	Colour (ICUMSA)
Syrup	8 000
A-sugar	458
Refined sugar	23
Final molasses	79 600
A-Massecuite	9 580
A-Molasses	23 380
B-Massecuite	26 890
B-Sugar	5 270
B-Molasses	47 790
C-Massecuite	54 960
C-Sugar	21 810
A-Sugar + R3-Sugar	421
Decolourised Liquor	88
R1-Massecuite	102
R1-Sugar	15
R1-Molasses	238
R2-Massecuite	274
R2-Sugar	41
R2-Molasses	593
R3-Massecuite	682
R3-Sugar	102
R3-Molasses	1 457

Raffinate fermentation

Michigan Biotechnology Institute (MBI) has been testing the raffinate fraction from the chromatographic separation. The raffinate is fermented using a special bacterial strain producing an additive for both vegetative and reproductive plant growth stimulus. MBI filed a patent in 1995.

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