ENHANCEMENT OF SUGAR PRODUCTION PART 1: PRODUCTION OF WHITE SUGAR IN THE RAW HOUSE

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Abstract

The application of technologies such as cross-flow filtration and polymeric resins to remove high molecular weight compounds and colour as well as colour forming substances from clear juice enables the production of white sugar in the raw house and a lower colour, sludge-free molasses. The technical and economic viabilities of the enhancement of sugar production in the raw house are based on extensive experimental evaluations carried out on a pilot scale, at the Komati Mill, since 1996.

Keywords: ultra-filtration, clear juice, white sugar, cost, raw house, NAP

Introduction

Sugar (sucrose) and its constituent monomers, glucose and fructose, are, apart from being sweeteners, also very important starting materials for many by-products. The price of sugar as conventionally manufactured, in general, precludes its use as a starting material for by-products. Many by-products such as those based on fermentation technologies (e.g. alcohol) do not need highly purified sugar but can use sugar juice as the starting material. In South Africa black strap molasses is the source of sugars for the alcohol and yeast industries.

During 1995 Transvaal Suiker Beperk (TSB) became involved in a project of the Industrial Development Corporation (IDC), which required a highly purified, low cost, invert sugar syrup for conversion to a mixture of glycols. The quantity of invert sugar required was about 180 000 tpa. The need could be satisfied by augmenting the available molasses sugars with sugar juice. This approach indicated the need to investigate the technical feasibility and cost of producing highly purified invert syrup from cane juice and the recovery of all the sugars (as invert) from molasses. The aim of this paper is to give an overview of the work done on the purification of sugar juice and the effects that the cleaning processes can have on the quality of sugar. Desugarisation of molasses will be discussed in another paper.

Impurities in sugar juice consist of soluble ash compounds, high molecular weight (HMW) gums and polysaccharides, some cane waxes, proteins, amino acids, plant colourants and suspended solid particles originating from the milling and extracting operations.

Clarification of mixed juice by the addition of milk of lime and flocculants results in the settling and removal of most of the suspended solids and some HMW substances, colourants and proteins. The resulting clear juice destined for the boiling house still contains appreciable quantities of impurities originally present (Walford, 1996; Roberts *et al.,* 1994; Godshal and Grimm, 1994). It was known (Hervé *et al.,* 1995; Kwok, 1995) that removal of insoluble and HMW substances can be achieved by employing crossflow filtration technology using micro- or ultra-filtration membranes. Ionic and coloured substances can be removed by means of ion exchange and colour adsorbing resins.

The first industrial scale ultra-filtration operation coupled with juice softening was reported by Applexion and HC&S, Puunene, Hawaii (Kwok, 1996). The process became known as the New Applexion Process (NAP). To utilise the knowledge a joint venture agreement between TSB, IDC and Applexion was made. This resulted in the provision and installation of an Applexion pilot plant at the Komati Mill in October 1996 and the execution of an extensive evaluation programme during the remainder of the 1996 cane season and almost the whole of the 1997 season. Unfortunately an extensive evaluation was necessary to minimise the risk in processing very poor quality juice. Juice from the drought stricken cane was of a poor quality and the evaluation trials had to be repeated later in the season when juice of a higher brix and purity was produced.

Overview of the test programme

The test programme was aimed at determining the feasibility of cleaning, de-ashing and decolourisation of both mixed and clear juices for manufacture of glycols. At the same time the application of the NAP process, used in Hawaii, to produce a very low colour sugar (VLCS) and the direct production of white sugar in the raw house was investigated.

The Applexion pilot plant consisted of an ultra-filtration unit having a filter area of 3,4 m^2 and the necessary heat exchanger, control and measuring systems. A softening column, an evaporator, a pilot sugar pan to conduct boiling tests and a sugar centrifugal formed part of the pilot plant. Six resin columns to conduct decolourising trials were locally provided. Sugar juices were taken directly from the Komati Mill and returned to the mill after treatment.

The technical and cost drivers of an ultra-filtration process are flow rate of juice and maintenance of flow rate. Experience in Hawaii indicated a practical compromise between flowrate and membrane surface area (and cost) to be about 280 litres/m^2/h for 22 hours out of 24 hours. The other two hours are allowed for cleaning duties. During the first part of the programme three membranes having different molecular weight cut-offs were evaluated.

A 0,1µm membrane (KERASEP, 19 channel Type K99B-W) conformed to the above requirements. The operating conditions were optimised to ensure maintenance of flow rate at a concentration factor of about 10 for an extended period of time. This was done by allowing the trans-membrane pressure to gradually increase to about 6 bar. This pressure signified the need for cleaning. Once the operating conditions were established the pilot plant was operated continuously to confirm conformance to requirements as influenced by juice quality and to determine the cost of cleaning cycles. Consistency of performance was measured by extensive analysis of juice inflows, outflows and sugar boilings.

Pilot sugar boiling

Comparison of standard Komati VHP sugar with experimental sugars was enabled by standardising the boiling conditions of the pilot pan to give the same colour sugar as that given by the Komati Mill when boiling mill run evaporator syrup.

Softening

Softening of the experimental juices was done by means of an acrylic macro-porous strong cation exchange resin in the monovalent sodium or potassium form. To limit the melassigenic effect of the monovalent cations, softening was limited to exchange only about 80% of the divalent cations. When working on a large scale, soft B-molasses is used for regeneration of the resin. During this pilot work ordinary salt solution was used.

Decolourisation

Numerous resins from various manufacturers (Purolite, Rohm and Haas, Lewatit) were evaluated for decolourisation capability. The averaged results were used to generate the preliminary design and to determine the cost implications. Results generated under standardised operational conditions and representing juices originating from bad and good quality cane were averaged.

Results and discussion

Effect of ultra-filtration and softening of juice

Due to severe fouling of the ultra-filtration membranes the purification of mixed juice was abandoned early in the test program and the effort was concentrated on the standard clarified juice from the Komati clarifiers.

The changes in average properties of clear juice by ultra-filtration are shown in Table 1.

Comparing the average juice properties it is evident that

- a slight (0,9%) increase in purity occurred
- juice colour remained much the same
- turbidity decreased by nearly 80% due to removal of high molecular weight substances
- ash content (as $CaCO_3$) did not change significantly.

The improvement in purity of sucrose can be expected to result in improved sugar recovery. The expected gain in sugar was not taken into account in the economics of the process. No significant sucrose losses are expected because the retentate from the ultra-filter is returned to the clear juice via a small additional clarifier.

The effect of ultra-filtration and softening on the sugar quality is shown in Table 2.

The comparison reveals:

- a 70% improvement in sugar colour due to removal of HMW colour precursors
- turbidity (in a sugar solution) is 55% lower
- softening reduced the ash (conductometric) by 58%
- sugar pol improved by almost one unit.

Table 1. Effect of ultra-filtration on juice quality.

	Brix	Purity %	Colour ICUMSA	Turbidity ICUMSA	Hardness mg $CaCO_3/\ell$
Clarified juice (CJ)	13,6	85,0	17 700	8300	1200
U/F permeate (UF)	13,6	85,9	17 400	1870	1160
Difference (UF-CJ)	0%	0,9%	-2%	-78%	-4%

Table 2. Effect of NAP on sugar quality.

	Colour ICUMSA	Turbidity ICUMSA	Ash % DM	pH	Pol %
A-Sugar (As)	1300	850	0,24	6,63	98,7
VLCS sugar (NAP)	400	380	0,10	6,90	99,5
Difference (NAP-As)	-70%	-55%	-58%		

Decolourisation for production of white sugar

For the direct production of white sugar (<100 ICUMSA) in the raw house it was necessary to reduce the colour of the NAP treated clear juice significantly.

A wide variety of decolourising resins as well as several activated carbons were evaluated. These trials revealed that a sugar having a colour of less than 100 ICUMSA units can only be boiled from a 60Bx syrup having a colour of less than 4500 ICUMSA units. Some decolourisation sequences tested resulted in sugars having colours as low as 15 and 25 ICUMSA units. Due to time constraints not enough experimental work on optimising these systems could be done. It was thus conservatively decided to base the design of a decolourisation system on a widely used and well-proven refinery-type anion acrylic resin (Rohm and Haas IRA 958Cl).

The averaged results are summarised in Tables 3 and 4.

Process design

The simplified process block diagram (Figure 1) shows the essentials on which the capital investment and operational cost estimates for an upgraded Komati Mill were based.

Provision is made for a small secondary clarifier to recover sugar from the retentate of the ultra-filtration plant. Another feature included was a nano-filtration system for recovery of brine from the regenerant of the decolourisation columns.

Investment and operational cost implications

Capital requirements

Applexion carried out the design extensions and did the cost estimates as if the plant was to be totally manufactured in France. At the time TSB was extending its mills and it was quite easy to establish that the cost of manufacture of large vessels and other equipment in South Africa was much lower than the manufacturing cost in France. It was judged conservative to accept the French cost estimates for South Africa. TSB designed and estimated the cost of installation, cleaning process (CIP) equipment, civils, electrical supply and piping.

Capital investment requirements

Equipment required

- Ultra-filtration: 12 skids of 240 m^2= 2880 m^2 installed in two parallel trains
- Softening plant: Four ion-exchange columns each with 36 m^3 of softening resin
- Decolourisation plant: 12 ion-exchange columns each with 20 m^3 of decolourising resin.

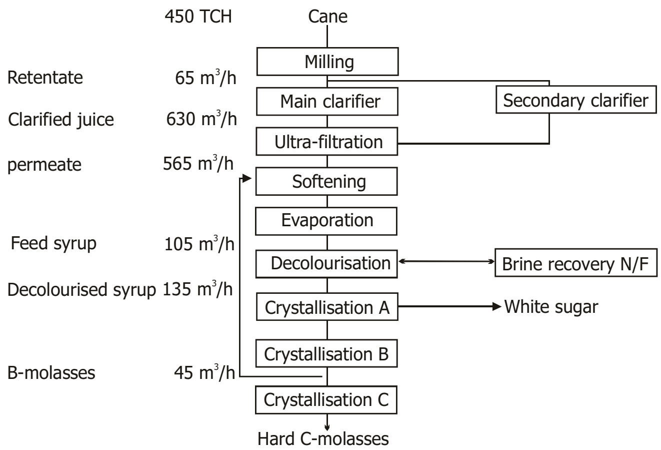

Figure 1. TSB Komati White Sugar Plant. Simplified process block diagram based on the New Applexion Process and including syrup decolourisation.

Table 3. Effect of resin decolourisation.

	Brix	Purity %	Colour ICUMSA	Turbidity ICUMSA	Hardness mg $CaCO_3/\ell$
Clarified juice	13,6	85,0	17 700	8300	1200
U/F permeate	13,6	85,9	17 400	1870	1160
Decolourised syrup	58,5	85,9	4500	500	250

Table 4. Effect of juice decolourisation on sugar colours.

	Colour ICUMSA	Turbidity ICUMSA	Ash % DM	pH	Pol %
A-Sugar	1300	850	0,24	6,6	98,7
White sugar	96	200	0,03	6,5	99,5
Difference (White – A sugar)	-93%	-77%	-82%		

Investment required for NAP only:

Ultra-filtration	R24 250 000
Retentate clarifier	R 784 000
Softening plant	R 6 000 000
Civils, electricals, piping	R 4 930 206
Total for NAP only (VLCS)	R35 964 206
Investment required for Decolourisation plant:	
Resin plant	R22 360 000
Total for NAP and decolourisation	R58 324 206

Operational cost implications

As shown in Appendix 1 the main operational costs incurred are for water, energy, chemicals and membrane and resin replacement. It was assumed that no cross subsidisation from the mill would occur. A summary of the expected operational costs is given below.

Operational cost of NAP

Unit operation	**Cost**
Ultra-filtration	R 2,206/t cane
Softening	R 0,386/t cane
Total for NAP	R2,592/t cane

Assuming 9 t cane/t sugar then:

Cost/ton 400 colour sugar	R23,33
Decolourisation	R25,19/ton sugar
Total cost mill white (60-100 ICUMSA)	R48,52/ton sugar

All the unit operations are highly automated and no additional operating labour was foreseen. The equipment is similar to that which is used in a sugar factory and no special maintenance skills were judged necessary. Maintenance cost was estimated as 3% of capital investment, which would add another R4,00/ton sugar.

Discussion

Overall the pilot experimental work at the Komati Mill confirmed the Hawaiian HC&S Puunene plant results. Removal of high molecular weight colour forming substances by ultra-filtration and softening as embodied in the New Applexion Process resulted in the reduction of the colour of normal Komati Mill sugar from 1300 to 400.

In a few experiments remelting and single strike crystallisation of 400 colour sugar yielded refined grade sugar of less than 30 colour. This showed that the NAP also removes those colour substances that are readily transferred to crystals and normally removed by the decolourisation operations in a refinery.

The additional operational cost to produce the 400 colour sugar amounted to R23/ton. A number of factors, when quantified, are expected to lower the final cost. Important in this regard are the higher expected recovery of sugar due to the improvement of the juice purity and a cost saving on chemicals for evaporator cleaning. Softened juice is expected to result in less evaporator fouling.

Removal of high molecular weight substances and turbidity from clear juice will also result in a much cleaner and sludge-free molasses. This will result in very low pretreatment cost for molasses where desugarisation is considered. Clean molasses will also be attractive to the fermentation industry because it will save the costs for installation, maintaining and operating centrifuges to remove sludge from molasses.

It was also found that once operating conditions for the selected membrane had been established, filtration of clarified juice could often proceed for much more than 22 hours before pressure increased to a level where cleaning was required. Cleaning never posed any real problems.

For an additional R25/ton of sugar, the NAP produced syrup can be decolourised to give a 60-100 colour, sparkling, crystal white sugar from the raw house.

In a single experiment Dr Raoul Lionnet of the Sugar Milling Research Institute evaluated the effect of sulphitation on a NAP syrup. The colour of the sugar boiled from the sulphited syrup was about 270 ICUMSA compared to the 410 ICUMSA of the untreated control. Sulphitation is considered to be a very low cost method of reducing colour.

It would have been useful to know what the effect of sulphitation prior to resin decolourisation would have been on the cost of resin decolourisation. However this was not further investigated.

The overall cost of producing a white sugar in the raw house was about 15% less than the cost of producing refined sugar in a conventional carbonation, sulphitation refinery. The capital investment required (R58 m) would be significantly lower than the R98m required for a conventional refinery [1].

It should be realised that the white sugar from the raw house was not a refined quality sugar. It is as far as could be established very similar to the Brazilian crystal white which at the time traded for a US$5 per ton discount on the refined premium.

With the limited experience gained with some other resin systems and carbons it is believed that a decolourisation system can be developed to make production of a refined grade sugar from a raw house a reality.

Conclusions

It was concluded that the technology exists to produce a low colour sugar or even an almost refined grade sugar in the raw house. It was also concluded that the additional production and investment costs could only be justified by further downstream value enhancement of sugar and molasses. For a refinery most of the decolourisation burden can be shifted to the raw house by means of a NAP type process. Molasses intended for desugarisation requires extensive and costly pretreatment and clarification. Removal of turbidity and soluble HMW substances early in the sugar manufacturing process

1. Bekker, PI (1998) Refinery Study. TSB Internal Report

will result in a substantially clean molasses that will need no or very little preparation for desugarisation.

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APPENDIX 1

Cost breakdown of unit operations

Ultrafiltration

		Per ton cane	Unit/cost in Rand	Operation cost
Cleaning water	m3	0.044	0.550	0.024
Cleaning NaOH	kg 100%	0.111	2.940	0.327
Cleaning HN03	kg 100%	0.056	3.920	0.218
Cleaning NaOCI	kg 100%	0.006	2.940	0.016
Electricity absorbed power	kWh	4.111	0.070	0.288
Membranes replacement cost	m2/1000	0.267	5.000	1.333
Total operation cost		Rand/ton cane		2.206

Softening

		Per ton cane	Unit/cost in Rand	Operation cost
B-molasses at 75 Brix 95°C	m3	0.100	-	-
Recycled soft juice at 15 Brix	m3	0.078	-	-
Softening resins	litres	0.037	10.000	0.370
Electricity absorbed power	kWh	0.222	0.070	0.016
Total operation cost		Rand/ton cane		0.386

Decolourisation

		Per ton DM	Unit/cost in Rand	Operation cost
Water	M3	2.254	0.550	1.240
NaCl 100% make-up	Kg	20.193	0.200	4.039
Decolourising resins (500 cycles)	Litres	0.939	18.000	16.908
Electricity absorbed power	KWh	3.099	0.070	0.217
Nano-filtration membranes	M2	0.002	600.000	1.409
Total operation cost		Rand/ton DM		23.810