THE EFFECT OF SOME IMPURITIES ON THE TARGET PURITY FORMULA

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Abstract

In the South African cane sugar industry the Target Purity Difference (TPD) figure is used as a measure of factory performance in terms of molasses exhaustion, and is calculated on a weekly basis from analyses of composite final molasses samples. Some factories always have lower TPDs than others, while there is also a prominent seasonal effect. The factors affecting TPD are highly complex and trends or unexpected values cannot always simply be attributed to specific factors.

High TPD levels at some factories in recent years spurred an investigation into the possibility of including polysaccharides or specific ash components into the Target Purity (PD) formula in an attempt to limit the factors affecting the TPD to those that are under factory control.

Molasses sub-samples were spiked with starch, dextran and sarkaran to quantify the effects of polysaccharides on exhaustion. Molasses samples from three factories were collected in the 2004/5 season and analysed for polysaccharides and individual ash components. TPs were calculated and the samples were subjected to boil-down tests to determine the Equilibrium Purities.

The investigation found that none of the components under consideration had an effect on the molasses purity obtainable under equilibrium laboratory conditions. Inclusion of any of these components in the TP formula is therefore not justified.

Keywords: purity, exhaustion, polysaccharides, ash, molasses, reducing sugars, factory process

Introduction

The final molasses Target Purity Difference (TPD) is the difference between a calculated Target Purity (TP) (a function of reducing sugars and ash content of the sample) and the true purity obtained by the factory (sucrose/dry solids). The TPD figure in the South African cane sugar industry is calculated on a weekly basis from analyses of weekly composite molasses samples, and is used as a measure of factory performance in terms of exhaustion. Some factories always have lower TPDs than others, while there is also a prominent seasonal effect. This is illustrated in Figure 1, which shows TPD values for three factories operating in different growing areas in the 2004/5 season.

The factors affecting TPD are highly complex and trends or unexpected values cannot always simply be attributed to specific factors. In recent years some factories have again been experiencing unexpectedly high TPD values. It was suggested that the TP formula might not be adequate, in that factors outside of factory control (such as the presence of certain polysaccharides) are affecting the TP values. This suggestion spurred the extension of previous work (Sahadeo, 1998 and 1999) into the possible effects of polysaccharides and specific ash components on the TP with a case for including more factors in the TP formula.

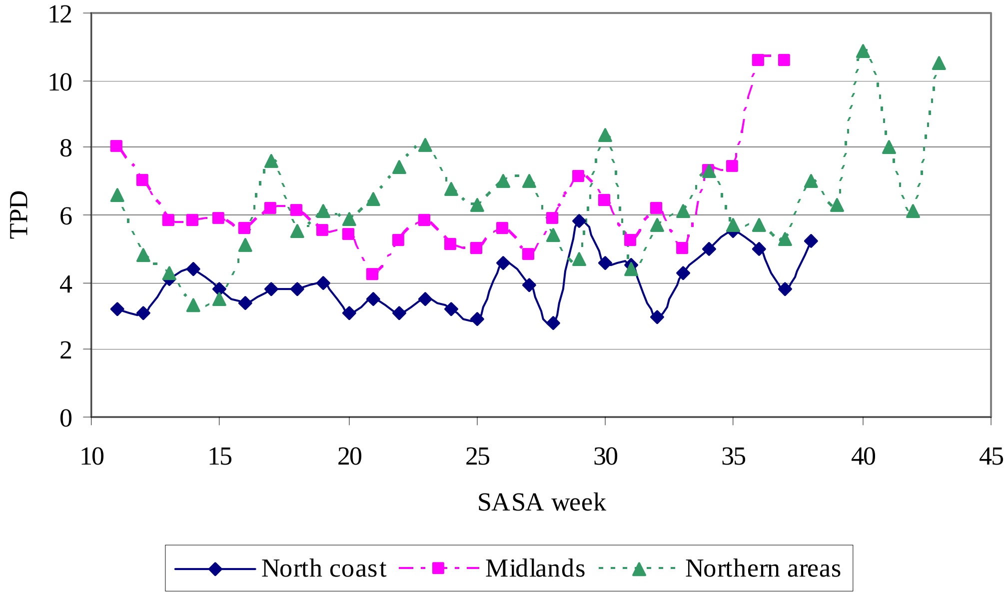

Figure 1. Target Purity Difference (TPD) values for three factories in different growing areas (2004/5 season).

Final molasses purity

Due to the complex nature of molasses and the many factors that affect crystallisation it would be very difficult to obtain a completely exhausted final molasses. It is important to remember that total exhaustion can also not be achieved with the equipment that is currently being used in a typical factory environment, since some of the sucrose from the crystals in the massecuite will inevitably redissolve due to the use of steam and water during centrifugation of the massecuite into sugar and molasses. However, with tight control and the correct and careful use of equipment and instruments, sucrose losses in final molasses can be reduced to a minimum. In this regard the experience of the operators and particular attention to detail is vitally important, as are specific conditions such as the massecuite temperature, amount of washing in the centrifugals and the state of the centrifugal screens. The best performing factories can achieve a seasonal average TPD of around 2 to 3 units, but lower values are not uncommon.

It is generally agreed that it is difficult to determine whether a molasses is completely exhausted or not. The term *exhaustibility* is used to indicate that more sucrose can potentially be recovered from a molasses. Certainly the mere use of purity is not a very good indicator, since exhaustion depends strongly on the presence of other impurities. For example, it is well known that the presence of reducing sugars lowers the solubility of sucrose, whereas the presence of ash components, particularly the alkali metal salts, increases the solubility of sucrose. The sucrose solubility largely determines the final purity of molasses that can be achieved (DeCloux, 2000).

It was also suggested that sucrose in every molasses can crystallise further upon evaporation but that this process is slow, and that such crystals would be small and only visible under a microscope (Kelly, 1956). The process of exhaustion therefore aims at a maximum recovery of sucrose in a minimum of time, leaving the uneconomically recoverable sucrose behind in the molasses.

The viscosity of the sample is dependent on the temperature, degree of supersaturation and the nature and concentration of non-sucrose constituents, amongst other things. The main effect of viscosity is to impede the migration of dissolved sucrose to the growing crystal surface and effectively reduce the crystallisation rate. While the same final purity would be reached, crystallisation in highly viscous massecuite samples would take longer to reach a similar level of final molasses purity (DeCloux, 2000), compared to low viscosity massecuites.

Viscosity may also be seen as the limiting physical property in terms of the handling of the massecuite, and high viscosities require increased crystalliser capacity for longer retention times. At lower temperatures and higher Brixes the viscosity will be too high to handle, and the rate of crystallisation will become so low that any further crystallisation would be uneconomical (Morera and Mishchuk, 1978). Hence, viscous massecuites must be maintained at a higher temperature for handling purposes, thus increasing sucrose solubility.

Molasses composition varies between regions and between seasons. The particular effect of growing conditions on the molasses exhaustibility has long been recognised, but identification of the complete range of factors that play significant roles has been extremely difficult. Although important, chemical or mechanical factors under factory control are limited and less effective than other factors (such as the molasses composition) in determining exhaustibility (Kelly, 1956).

The use of Target Purity formulae

The Douwes-Dekker (1949) formula estimates an ideal TP for exhausted molasses and has found wide application since the 1950s. This formula determines a theoretical purity which should be obtained based on the reducing sugar and ash contents of the molasses on the assumption that the presence of ash will increase, and the presence of reducing sugars will decrease the solubility of the sucrose in the molasses. Conditions are chosen such that the kinetic effects of viscosity are eliminated in accordance with the TP definition. The TP is compared to the true purity and the difference indicates the purity drop which must be realised in order to properly exhaust that particular molasses, representing the level of exhaustion performance. These properties of molasses (purity, reducing sugars and ash) have always been relatively easy to determine, which encouraged their use in attempting to quantify exhaustibility (Hugot, 1960).

Today different countries use different formulae to express exhaustibility, some of which were discussed in reviews by Moritsugu (1974), Watson (1981) and DeCloux (2000). Although mostly based on the same principles as the Douwes-Dekker (1949) formula, these can clearly not simply be applied across the board, since exhaustion is affected by the specific growing conditions of each region. However, investigators in the United States recently considered the use of the South African TP formula as an adequate benchmark for exhaustion in their own regions (Saska *et al*, 1999; Rein *et al*, 2002).

The Douwes-Dekker (1949) formula was used widely in South Africa until 1972, when a new formula was suggested by Bruijn *et al* (1972). This formula was revised in the same year by Fitzgerald and MacGillivray (1972) to use a logarithmic instead of a linear equation (called the SMRI target purity formula), and again in 1973 by Fitzgerald and Wallace-Tarry, who proposed the use of refractometer Brix and conductivity ash instead of dry solids and sulphated ash in the formula. The use of refractometer Brix was never implemented and the use of conductivity ash only became routine after 2000 (van Staden *et al*, 1999). The final formula was published in 1976 by Matthesius and Mellet, who used a calculated true purity based on the refractometer gravity purity (this calculated true purity formula never found wide application in the South African sugar factories). Revisions were published in 1981 by Rein and Smith, incorporating the use of chromatography instead of colourimetry when determining the reducing sugars content, the applicability of which was confirmed by Ravnö and Lionnet (1982). Smith (1995) published a further revision incorporating an exponential instead of logarithmic equation, which was deemed to be more appropriate for low reducing sugar levels.

Equilibrium purity (EP)

A boil-down test was developed by Bruijn (1977) to determine the maximum exhaustion of a molasses that can be achieved under ideal (laboratory) conditions. This test was further discussed by Bruijn *et al* (1980) and by Rein and Smith (1981). A molasses sample is evaporated to a constant viscosity or a constant dry solids content, and castor sugar is added to saturate and seed the molasses. While the use of a constant consistency (through viscosity) rather than a constant dry solids content may somewhat account for the effect of viscosity on the crystallisation rate (Saska *et al*, 1999) the use of a high level of dry solids (87%) should completely eliminate the effect of viscosity on the maximum exhaustion that can be obtained (Bruijn *et al*, 1980; Rein and Smith, 1981). It has been found (unpublished, June 2004) that the final purity is dependent on this dry solids content. The sample is allowed to crystallise for 48 hours at 40ºC, after which the crystals are separated using a Nutsch filter and the purity of the Nutsch molasses determined.

This purity is referred to as *equilibrium purity* (EP) and should in theory give the same value as the TP formula. The difference between the true purity of a sample and its EP determined by the boil-down test is termed the Equilibrium Purity Difference with the acronym *EPD*.

Sahadeo (1998) evaluated the effect of using crystallisation times of two, three, four and five days on the exhaustion of a molasses sample, and concluded that equilibrium purity is reached within three days. It was therefore decided that the use of 72 hours crystallisation time would completely eliminate the effect of viscosity, which is merely to slow down the rate of crystallisation while still reaching the same equilibrium purity.

Other organic non-sugars

After a formula was proposed in Australia (Miller and Wright, 1977) which incorporated the dextran content of the molasses, investigation into the effect of gums (total polysaccharides) on South African molasses exhaustion was done (Bruijn *et al*, 1980). It was found that high levels of gums had a significant effect on the viscosity of molasses, which suggested that the exhaustibility of the molasses would also be affected. However, gums concentrations of the order of 1-4% in molasses had no significant effect on the exhaustibility of the sample.

Sahadeo (1998) found a clear correlation between the gums (polysaccharide) content of molasses samples and the difference between the target purity and the equilibrium purity that was obtained through boil-down experiments in the range of 10 000-50 000 mg/kg gums on dry solids, indicating that gums affect exhaustion through sucrose solubility.

In a subsequent investigation (Sahadeo, 1999) the effects of spiking a molasses with fructose, glucose, dextran and starch were evaluated. Results were very close to the experimental error of the boil-down test, indicated as ± 0.5 units and the conclusions are therefore limited.

Ash

Day-Lewis (1993), in a survey of literature on the ash components in molasses and their effect on exhaustibility, found general agreement that alkali metal salts are highly melassigenic, although the order of melassigenesis was not established. Potassium was, however, by far the most melassigenic and was further highly significant because of its high concentration in molasses (3-6% m/m), with sodium only constituting 200-1 000 ppm. Of the anions, chloride was found to be significantly melassigenic at concentrations of 2-4% (m/m). Gupta *et al* (1973) showed that the purity of Indian molasses is more dependent on the chloride content than the reducing sugars to ash ratio. While phosphate has a favourable effect in that it reduces sucrose solubility, most of the phosphate is removed by clarification.

In contrast, Sahadeo (1998, 1999) found potassium to be the least melassigenic in the series on the assumption that the counter anion comparatively has no effect on molasses exhaustion.

Broadfoot and Steindl (1980) indicated that several inorganic salts, particularly those which form stable hydrates, actually decrease sucrose solubility so that it is necessary to also consider the nature of the ash components.

Experimental

Boil-down procedure (determination of EP)

The procedure used for the boil-down tests to determine the equilibrium purity was described by Bruijn (1977) and modified by Sahadeo (1998, 1999) as follows. Instead of boiling the sample to a constant viscosity, the sample is boiled to a constant dry solids of 87 ± 1%; the mass of water to be removed from each sample to achieve this concentration is calculated, and a condenser and balance is used to collect and weigh the amount of water that is boiled off; the massecuite is crystallised for 72 hours instead of 48 hours.

The effect of added polysaccharides on C-molasses exhaustion potential

In order to evaluate the effect of polysaccharides on final molasses exhaustibility, a final molasses sample was sub-sampled and spiked with specific polysaccharides. Dextran (250-1 500 mg/litre), pullulan (sarkaran) (250-6 500 mg/litre) and starch (100-4 500 mg/litre), and an appropriate amount of sucrose to maintain the purity at the same level, were added in different combinations according to a *hybrid response surface design* to reduce the number of experiments to a minimum, since the boil-down test is extremely time-consuming.

The experiments were randomized to avoid experimental bias. Centre points (indicated by 0) were included in triplicate to estimate the repeatability of the method. Boil-down tests were done to determine the maximum exhaustion that could be achieved under ideal (laboratory) conditions.

Correlation of seasonal target and equilibrium purities with polysaccharide levels

C-molasses samples from three South African factories were collected during the 2004/5 milling season. The factories were selected based on their propensity for high levels of dextran, sarkaran and starch: two factories were particularly prone to high levels of polysaccharides (Midlands and north coast), while the third generally had low levels of polysaccharides (northern areas). The polysaccharide levels of the samples were quantified in terms of starch, high and low molecular weight dextrans, high and low molecular weight sarkaran, total gums and viscosity. The purities and target purities of the samples were determined. Each sample was subjected to the boil-down test to determine the EP that could be achieved in the laboratory.

Correlation of seasonal target and equilibrium purities with ash components

The C-molasses samples collected from the three South African factories during the 2004/5 milling season were analysed for a range of ash constituents, as indicated below. The differences between the calculated TP and experimentally determined EP values of the samples were compared to the measured selected ash levels to determine whether the ash constituents had any observable effect on the final exhaustion that could be achieved in the laboratory.

Cations: sodium (Na^+), ammonium (NH_4^+), potassium (K^+), magnesium (Mg^{2+}), calcium (Ca^{2+})

Anions: chloride (Cl^-), phosphate (PO_4^{3-}), sulphate (SO_4^{2-})

Sucrose, fructose and glucose

High performance anion exchange chromatography with pulsed amperometric detection (HPAEC-PAD) was used to analyse for sucrose, fructose and glucose according to the SASTA Method 6.6 (Anon, 2005).

Dry solids

The dry solids were determined according to the Karl Fischer method (Anon, 1997a) for low viscosity samples and the Vacuum Oven method (Anon, 1997b) for high viscosity samples.

Dextran and sarkaran

High performance anion exchange chromatography with pulsed amperometric detection (HPAEC-PAD) was used to determine the dextran and sarkaran content according to the method described by Morel du Boil (2000).

Starch

The SMRI starch method (Anon, 1997c) was used to determine the starch content.

Gums

The gums content was determined according to the SMRI method (Anon, 2004).

Conductivity ash

The conductivity ash was determined according to the SASTA method (Anon, 2005).

Anions and cations

The anion and cation contents were determined using ion exchange chromatography according to the methods described by Walford (2000).

Viscosity

A Brookfield RVDV III rotational viscometer and a No. 2 spindle were used to determine the viscosities. Molasses samples were used at the natural Brix and 30°C and the torque measured at four different speeds. The apparent viscosity was calculated at a theoretical 74% dry solids.

Analysis of data

All data analysis was done on MS Office Excel and Statistica software packages.

Calculations

Target Purity (TP)

The Target Purity is calculated using the formula derived by Smith (1995) indicated below.

$$\text{Target Purity (\%)} = 43.1 - 17.5 \times \left\{1 - e^{-0.74 \times [(f+g)/a]}\right\}$$

where f ≡ fructose (%)
g ≡ glucose (%)
a ≡ conductivity ash (%)

True Purity

$$\text{True Purity (\%)} = \frac{\text{Sucrose}}{\text{Dry solids}} \times 100$$

Results and Discussion

Appendix A contains the raw data available from this study (Tables A1 to A3).

Theoretically, the EP and TP for a sample should be the same, since the equilibrium purities were used in the first place to construct the TP formula, albeit at a relatively weak correlation level (r = 0.835; Smith, 1995). Should the EP and TP differ by more than just experimental scatter, a strong correlation between the difference and the concentration of any non-sucrose component would justify the inclusion of that component into the TP formula, to bring the EP and TP values closer together.

The effect of added polysaccharides on C-molasses exhaustion potential

Molasses samples were spiked with different amounts of polysaccharides and the resulting EP values were compared to the TP values calculated for the samples. Results are indicated in the last column of Table 1 and in Figure 2.

Table 1. Hybrid response surface design.

Experimental run order	Dextran (mg/l)*	Pullulan (mg/l)*	Starch (mg/l)*	EP-TP
8	250 (-1)	250 (-1)	100 (-1)	5.1
2	250 (-1)	250 (-1)	4 500 (1)	4.3
6	250 (-1)	6 500 (1)	100 (-1)	2.9
3	250 (-1)	6 500 (1)	4 500 (1)	2.8
1	875 (0)	3 375 (0)	2 300 (0)	2.7
4	875 (0)	3 375 (0)	2 300 (0)	2.8
10	875 (0)	3 375 (0)	2 300 (0)	4.4
7	1 500 (1)	250 (-1)	100 (-1)	3.2
9	1 500 (1)	250 (-1)	4 500 (1)	3.3
5	1 500 (1)	6 500 (1)	100 (-1)	2.8
11	1 500 (1)	6 500 (1)	4 500 (1)	5.7

** coded values are indicated in brackets*

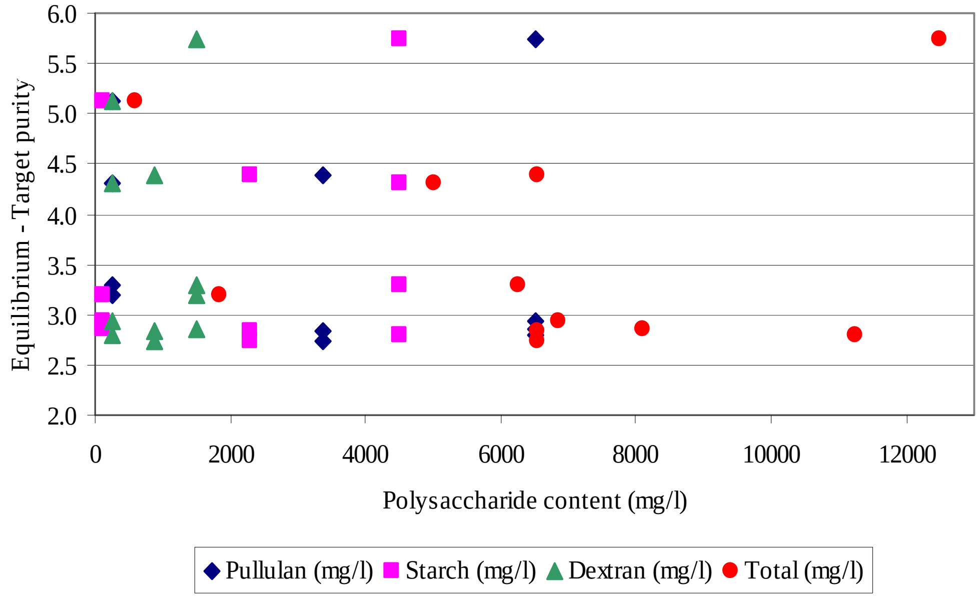

Figure 2. The effect of polysaccharides on exhaustion.

Analysis of variance (ANOVA) indicated significant differences in the variances of the three sets of data, namely the starch, dextran and pullulan contents, compared to the difference between the equilibrium and the target purities (F-values ranging from 15 to 27; F^{crit} = 4.4). ANOVA also indicated significant differences in the variances of the total polysaccharide content and the difference between the equilibrium and the target purities (F-value of 39; F^{crit} = 4.4). Note that the relative standard deviation (RSD) of the triplicate centre points in the design is 28% (standard deviation = 0.9 units). No correlations are therefore evident.

Correlation of seasonal target and equilibrium purities with polysaccharide levels

Molasses samples from three factories were analysed for starch, high molecular weight (HMW) dextran, total dextran, high molecular weight (HMW) sarkaran, total sarkaran, gums (total polysaccharides) and viscosity. The results are summarised in Table 2, with correlation coefficients for comparison of the levels against the difference between EP and TP indicated in Table 3. (Refer to Tables A1 to A3 in Appendix A for the actual results.)

No strong correlations ($r > 0.7$) were observed between the polysaccharide levels (either separately or in combination) and the equilibrium purities, indicating that the presence of the polysaccharides did not have an effect on the final molasses purity that could be achieved in the laboratory.

It appears that the polysaccharides' effect on TPD is therefore via kinetics, in that the rate of crystallisation is affected (through viscosity) but final equilibrium purity (i.e. sucrose solubility) is not, for the ranges of polysaccharide concentrations considered.

Table 2. C-molasses polysaccharide levels.

Factory	No. samples	Parameter	Units	Range
A	13	Starch	mg/kg	1 500 – 4 000
		HMW dextran	mg/kg	0 – 800
		Total dextran	mg/kg	700 – 2 000
		HMW sarkaran	mg/kg	400 – 900
		Total sarkaran	mg/kg	1 000 – 1 500
		Gums	mg/kg	19 000 – 31 000
		Viscosity	cP	10 – 50
B	14	Starch	mg/kg	2 000 – 4 000
		HMW dextran	mg/kg	0 – 500
		Total dextran	mg/kg	500 – 2 500
		HMW sarkaran	mg/kg	1 000 – 5 000
		Total sarkaran	mg/kg	2 000 – 9 000
		Gums	mg/kg	19 000 – 31 000
		Viscosity	cP	5 – 25
C	12	Starch	mg/kg	500 – 2 000
		HMW dextran	mg/kg	0 – 100
		Total dextran	mg/kg	0 – 400
		HMW sarkaran	mg/kg	50 – 270
		Total sarkaran	mg/kg	200 – 1 000
		Gums	mg/kg	10 000 – 14 000
		Viscosity	cP	10 – 30

Table 3. Correlation coefficients (r) of C-molasses polysaccharide levels vs EP-TP.

Parameter	Correlation coefficient (r)			
	Factory A	Factory B	Factory C	Combined
Starch	0.15	0.21	0.24	0.07
HMW dextran	0.13	0.19	0.19	0.10
Total dextran	0.15	0.42	0.26	0.05
HMW sarkaran	0.12	0.35	0.08	0.36
Total sarkaran	0.01	0.35	0.44	0.38
Gums	0.10	0.50	0.04	0.07
Viscosity	0.13	0.44	0.23	0.14

Correlation of seasonal target and equilibrium purities with ash components

Molasses samples from three factories were analysed for a range of cationic and anionic ash components. The results are summarised in Table 4, with correlation coefficients for comparison of the levels against the difference between EP and TP indicated in Table 5. (Refer to Tables A1 to A3 in Appendix A for the actual results.)

A total of 39 samples were analysed. No strong correlations ($r > 0.7$) were found between the levels of the ash constituents and the difference between the EP and TP values. A summation of the individual ash components could not be correlated to the conductivity ash of the samples. This could be expected, since the conductivity ash measurement includes other ionisable components such as organic acids.

Table 4. C-molasses ash levels.

Factory	No. samples	Parameter	Range (%)
A	13	Ammonium	0.00 – 0.04
		Sodium	0.1 – 0.2
		Phosphate	0.1 – 0.3
		Magnesium	0.6 – 0.8
		Calcium	0.8 – 1.4
		Sulphate	1.2 – 2.1
		Chloride	2.1 – 3.8
		Potassium	3.6 – 4.8
		TOTAL	9.6 – 11.7
B	14	Ammonium	0.00 – 0.04
		Sodium	0.1 – 0.2
		Phosphate	0.0 – 0.2
		Magnesium	0.5 – 0.8
		Calcium	0.9 – 1.5
		Sulphate	0.9 – 1.8
		Chloride	1.4 – 4.2
		Potassium	2.8 – 4.3
		TOTAL	7.6 – 11.4
C	12	Ammonium	0.00 – 0.04
		Sodium	0.0 – 0.2
		Phosphate	0.0 – 0.1
		Magnesium	0.6 – 0.8
		Calcium	0.8 – 1.4
		Sulphate	1.1 – 2.2
		Chloride	1.6 – 3.5
		Potassium	3.2 – 4.7
		TOTAL	8.6 – 10.7

Table 5. Correlation coefficients (r) of C-molasses ash levels vs EP-TP.

Parameter	Correlation coefficient (r)			
	Factory A	Factory B	Factory C	Combined
Ammonium	0.27	0.51	0.40	0.24
Sodium	0.27	0.12	0.09	0.30
Phosphate	0.11	0.03	0.01	0.23
Magnesium	0.36	0.18	0.20	0.05
Calcium	0.01	0.29	0.09	0.22
Sulphate	0.00	0.20	0.62	0.14
Chloride	0.37	0.20	0.04	0.15
Potassium	0.57	0.05	0.22	0.34
TOTAL	0.53	0.17	0.21	0.19

Conclusions

Contrary to expectations, EP and TP values were found to be different, with EP being generally higher than TP. In addition, no correlations could be found between the selected non-sucrose contents of the samples and the differences in EP and TP values. This lack of correlation between the measured polysaccharide or ash content of the final molasses and the extent to which exhaustion could be achieved is either because:

- there are no correlations, or
- the correlations are obscured by the experimental error associated with the boil-down test, the uncertainty associated with the TP formula or the effects of other non-measured factors.

The correlation coefficient (r) associated with the target purity formula is 0.835 (Smith, 1995) indicating that an uncertainty of ± 1.9 units can at best be expected. Sahadeo (1999) suggests that the experimental error associated with the boil-down test is ± 0.5 units. For any correlations to be observable, the effects must therefore exceed these uncertainties.

From results published by Sahadeo in 1998, the absolute difference between the target purity and equilibrium purity values for 16 actual molasses samples from different factories was ± 0.6 units. From results published by Sahadeo in 1999, this difference for 19 samples was ± 3.0 units. The same difference for the 39 samples in the current investigation is ± 2.1 units.

It is the final conclusion of this work that the inclusion of either individual polysaccharide levels or individual ash components in the TP formula cannot be justified.

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APPENDIX A – SEASONAL DATA

Table A1. Factory A seasonal data.

SASA week	Na^+ (%)	NH_4^+ (%)	K^+ (%)	Mg^{2+} (%)	Ca^{2+} (%)	Cl^- (%)	PO_4^{3-} (%)	SO_4^{2-} (%)	Viscosity (cP)	Gums (mg/kg)	Starch (mg/kg)	Total dextran (mg/kg)	HMW dextran (mg/kg)	Total sarkaran (mg/kg)	HMW sarkaran (mg/kg)	Target purity (%)	True purity (%)	Equilibrium purity (%)
11	0.17	0.02	4.16	0.66	1.25	3.00	0.16	1.38	–	22 500	1742	954	153	1082	395	33.9	36.7	33.3
13	0.07	0.00	3.97	0.67	0.97	2.84	0.20	1.49	28	25 400	2093	974	123	1032	487	33.4	37.4	36.7
14	0.16	0.00	4.28	0.60	0.94	3.09	0.15	1.64	24	21 600	2167	868	138	1129	646	33.5	36.6	35.1
15	0.09	0.03	4.21	0.60	0.94	3.06	0.17	1.53	26	21 100	2236	860	75	1110	529	33.5	37.1	34.1
16	0.08	0.04	4.37	0.68	1.04	3.10	0.22	1.59	22	20 200	1889	824	61	961	449	33.5	37.0	35.4
19	0.13	0.03	4.60	0.73	1.02	2.71	0.09	1.25	18	21 300	1902	911	92	1249	616	33.6	37.5	34.1
21	0.12	0.04	4.65	0.77	0.97	3.39	0.14	1.57	–	21 600	2210	830	69	1036	505	33.8	36.5	31.5
23	0.09	0.00	4.45	0.71	0.83	3.23	0.32	1.40	26	24 200	2034	968	178	1185	652	34.1	37.5	33.9
25	0.08	0.03	4.31	0.65	1.07	2.41	0.06	1.40	32	27 600	3281	1069	203	1257	841	36.9	39.5	37.8
28	0.11	0.03	4.21	0.60	0.90	2.18	0.13	1.32	43	30 300	3647	1197	302	1664	588	37.7	39.8	36.9
29	0.15	0.03	4.72	0.57	1.06	2.25	0.08	1.41	52	29 000	3864	1189	300	1142	508	37.1	42.4	38.9
32	0.13	0.03	4.30	0.60	0.89	2.20	0.08	1.32	19	24 400	3553	1011	176	1255	521	37.7	40.1	39.5
36	0.10	0.03	3.77	0.74	1.36	2.30	0.12	1.20	15	26 100	2427	1858	779	1322	621	36.0	41.1	39.2

Table A2. Factory B seasonal data.

SASA week	Na^+ (%)	NH_4^+ (%)	K^+ (%)	Mg^{2+} (%)	Ca^{2+} (%)	Cl^- (%)	PO_4^{3-} (%)	SO_4^{2-} (%)	Viscosity (cP)	Gums (mg/kg)	Starch (mg/kg)	Total dextran (mg/kg)	HMW dextran (mg/kg)	Total sarkaran (mg/kg)	HMW sarkaran (mg/kg)	Target purity (%)	True purity (%)	Equilibrium purity (%)
11	0.11	0.00	2.98	0.62	1.40	1.98	0.07	1.04	5	20 500	2032	1366	220	2426	1133	31.6	39.0	34.9
12	0.09	0.01	2.89	0.50	1.12	1.90	0.08	1.17	5	19 700	2108	1344	258	2302	1125	32.5	39.9	34.9
13	0.06	0.01	3.01	0.46	0.93	2.06	0.07	1.25	8	22 600	2154	1352	211	2499	1368	32.7	38.5	34.3
14	0.10	0.00	3.20	0.50	0.90	2.06	0.07	1.27	7	20 000	2403	1071	119	2523	1535	33.1	39.1	36.1
15	0.07	0.01	3.54	0.56	0.98	2.17	0.08	1.28	6	20 000	2500	1003	95	2975	1762	33.1	38.6	34.3
16	0.19	0.03	3.25	0.55	0.99	2.05	0.12	1.33	7	21 900	2722	1048	94	3518	2083	33.1	38.9	35.1
21	0.13	0.03	3.86	0.61	1.05	2.42	0.14	1.43	–	23 100	3241	807	64	4047	2369	34.0	37.5	32.5
23	0.10	0.03	3.51	0.52	1.06	2.28	0.12	1.41	14	24 000	2942	942	208	4640	2734	33.3	39.0	34.6
25	0.08	0.02	4.34	0.65	1.25	4.23	0.18	1.72	17	25 200	4095	929	172	5723	4358	34.6	39.8	34.6
27	0.12	0.02	3.99	0.65	1.39	3.82	0.09	1.29	15	25 900	4271	1298	296	7518	3436	34.8	39.7	36.5
28	0.15	0.02	3.51	0.50	0.94	1.54	0.07	1.13	16	26 500	4190	1311	277	6733	3816	34.7	40.5	36.0
29	0.13	0.04	3.43	0.50	0.97	1.40	0.04	1.06	16	30 700	3973	1226	289	8151	4984	35.5	42.2	37.1
34	0.15	0.04	3.52	0.63	1.32	1.80	0.06	1.00	25	26 500	3661	1422	422	7523	3960	34.3	41.4	36.6
36	0.09	0.03	3.10	0.62	1.51	1.62	0.05	0.86	17	29 300	3119	2627	–	6995	2692	34.2	45.2	39.3

Table A3. Factory C seasonal data.

SASA week	Na^+ (%)	NH_4^+ (%)	K^+ (%)	Mg^{2+} (%)	Ca^{2+} (%)	Cl^- (%)	PO_4^{3-} (%)	SO_4^{2-} (%)	Viscosity (cP)	Gums (mg/kg)	Starch (mg/kg)	Total dextran (mg/kg)	HMW dextran (mg/kg)	Total sarkaran (mg/kg)	HMW sarkaran (mg/kg)	Target purity (%)	True purity (%)	Equilibrium purity (%)
11	0.23	0.02	4.00	0.66	1.28	2.72	0.01	1.75	13	10 400	542	299	44	419	88	32.6	39.1	34.9
12	0.10	0.02	3.95	0.55	1.10	2.56	0.06	1.76	9	11 900	708	319	42	422	100	33.3	37.6	32.4
13	0.12	0.00	4.04	0.61	0.88	2.43	0.05	1.93	22	14 000	778	309	57	239	62	32.3	36.4	34.3
14	0.10	0.00	4.06	0.57	0.93	2.70	0.07	2.11	–	12 300	1024	263	50	251	86	33.0	36.7	34.5
15	0.14	0.00	4.05	0.68	0.95	2.56	0.05	2.21	10	13 500	1153	246	31	351	128	33.0	36.5	34.4
21	0.13	0.02	3.89	0.71	0.97	2.88	0.05	1.86	18	14 100	1871	267	0	506	131	33.1	38.8	33.2
23	0.13	0.02	3.72	0.80	1.07	2.99	0.06	1.67	31	13 200	1519	235	85	518	115	33.4	41.4	35.2
25	0.17	0.03	4.70	0.83	1.24	3.50	0.05	2.07	22	11 900	1641	188	71	680	270	35.4	41.9	40.1
27	0.12	0.03	4.24	0.77	1.11	2.55	0.05	1.12	33	11 800	1410	113	31	960	249	35.2	42.4	35.8
31	0.22	0.03	4.29	0.73	1.05	1.78	0.05	1.67	38	10 200	1193	187	0	707	235	34.4	38.6	35.0
34	0.18	0.04	3.51	0.56	0.76	1.84	0.02	1.66	19	13 100	868	263	63	886	239	32.6	40.2	36.2
37	0.12	0.03	3.35	0.68	1.20	1.85	0.04	1.32	27	12 500	1166	313	65	529	146	32.8	38.1	35.2