

# DEALING WITH DEXTRAN IN THE SOUTH AFRICAN SUGAR INDUSTRY

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## Abstract

A short review is presented on the formation and occurrence of dextran in the cane sugar industry. Although it can be formed within the factory, it is widely accepted that the bulk of the dextran present in processing streams arises from the post harvest degradation of sugarcane prior to crushing. For many years it appeared that the South African sugar industry did not have a dextran problem. Some possible reasons for this are put forward. However, evidence is presented that dextran is present in many South African factories at levels which can, and do, have an effect on both factory performance and sugar quality. Several case studies are discussed in which there is evidence of a very significant effect at certain times of the season. A possible explanation is put forward as to why this effect is more marked at certain factories. Some recommendations are made for minimising the incidence and the effects of dextran in South African factories.

*Keywords:* dextran, sugar quality, cane deterioration, filterability, clarification, recovery

## Introduction

Dextran is a deterioration product formed by bacterial action on sugars. It has not generally been regarded as a major problem in the South African industry, mainly because cane is harvested manually in whole stick form and the intact stalks are not prone to severe bacterial infection.

A number of global trends are emerging which make it important for the South African industry to pay more attention to the control of dextran. These include:

- Increasing competition and quality awareness in the market, with overseas customers calling for lower levels of dextran in raw sugar.
- Increasing mechanical harvesting, which exacerbates dextran formation by chopping the cane stalks and thereby facilitating bacterial infection.
- Increasing chances of rogue consignments of badly deteriorated cane due to:
  - Increasing pressures to restrict cane burning to times when wind conditions minimise nuisance from the smoke. This introduces a tendency to burn larger areas during the limited periods of acceptable wind conditions. These large burnt areas increase the average delay between burning and cutting. Such delay is a major cause of cane deterioration.
  - Difficulties of coordinating the harvesting and transport of small consignments of cane from small-scale growers. These small consignments are often combined for transport and there may be long delays while sufficient cane accumulates for a full load.

- The existence of back-end refineries that recycle dextran back to the raw house (in refinery returns) instead of passing it out with refinery molasses. If a backend refiner also imports additional supplies of raw sugar from other mills, this can exacerbate the potential for dextran recycling. This specific problem is usually confined to the backend refiner and is not passed on to the wider raw sugar market, except when the mill produces some raw sugar in addition to refined sugar.

Good scientific work has been done both internationally and in South Africa to enable an understanding of dextran formation and its effects. It is now appropriate in South Africa to translate this information into effective procedures and policies for reducing the adverse effects of dextran (and associated deterioration products). This paper summarises some salient technical information as an additional motivation for the industry to adopt the guidelines and industrial incentives that are under consideration.

### **The origins and characteristics of dextran**

Dextran is the subject of a number of excellent reviews (Tilbury, 1971; Atkins and McCowage, 1984; Kitchen, 1988) and a recent paper of particular relevance to South Africa (Morel du Boil and Wiense, 2002). Some of the more important points relating to the control of dextran include:

- Although there is a tendency to regard dextran as the troublesome component in deteriorated cane, it is important to realise that a number of deterioration products cause problems. Some of these cause high viscosity, while others affect crystal growth without necessarily affecting viscosity; some interfere with clarification and others are strongly melassegenic; finally some are acidic and lead to increased inversion of sucrose. All these effects are generally observed when deteriorated cane is processed. For purposes of simplicity in this paper, this whole family of deterioration products will sometimes be referred to simply as 'dextran'.
- True dextran consists of glucose molecules linked predominantly by 1,6 bonds to form long chains. Some branching of these chains does occur. The molecular size is not fixed – there is a family of variously sized molecules, with the large molecules being more troublesome than the smaller ones.
- The influence of molecular size makes it important to interpret correctly the results of different analytical methods – some methods detect only high molecular weight (HMW) dextran while others detect total dextran (both high and low molecular weight fractions).
- Dextran is formed mainly during deterioration of cane. It can also be formed in factories, if there is inadequate attention to hygiene, but the amount produced is generally small, especially in diffuser factories, where high temperatures pasteurise the incoming cane and prevent growth of dextran-forming bacteria in the extraction plant.
- The energy in the glucose-fructose bond of sucrose is important for dextran formation. The bacteria can use only sucrose, not free glucose, for dextran formation (Stanier *et al*, 1987). In other words, any dextran found in cane or juice is not produced from invert sugars.
- Burnt cane is more prone to dextran formation than is unburnt cane.
- Billeted cane is much more vulnerable to dextran formation than is wholestick cane, and short billets deteriorate more rapidly than long billets.
- Dextran and many of its associated compounds show relatively high (17-25%) transfer from mother liquor to crystal (Morel du Boil, 2005). This results in high carry-through from raw house to refinery.

- Normal dextran levels in South African mixed juice are of the order of 200 mg/kg Brix but can exceed 10 000 mg/kg Brix in deteriorated cane (Morel du Boil, 2005). Levels above 1000 mg/kg in mixed juice are definitely problematic. It has been shown that to meet a specification of 150 mg/kg in raw sugar, the level in mixed juice must be below 750 mg/kg (Morel du Boil and Wienese, 2002). Simple arithmetic shows that a mill will face problems if 94% of its cane supply is normal (200 mg/kg) and only 6% is seriously deteriorated (10 000 mg/kg). Towards the end of season the ‘normal’ level rises. If it rises to 500 mg/kg Brix, then only 2.6% of the cane need be seriously deteriorated to push the average level in mixed juice above the 750 mg/kg threshold. The fact that a small percentage of cane can have such a high impact requires special focus when developing dextran control strategies.
- Deterioration rates are accelerated strongly by higher temperatures and by wet conditions (Tilbury, 1971). It is therefore usual for dextran levels to be lowest in mid-winter and to increase sharply towards the end of season.

Although dextran is problematic in sugar processing and marketing, it is not considered toxic to humans – as evidenced by its use as a partial substitute for blood plasma (Krueger and Johansson, 1959).

### **The influence of dextrans on factory and refinery performance**

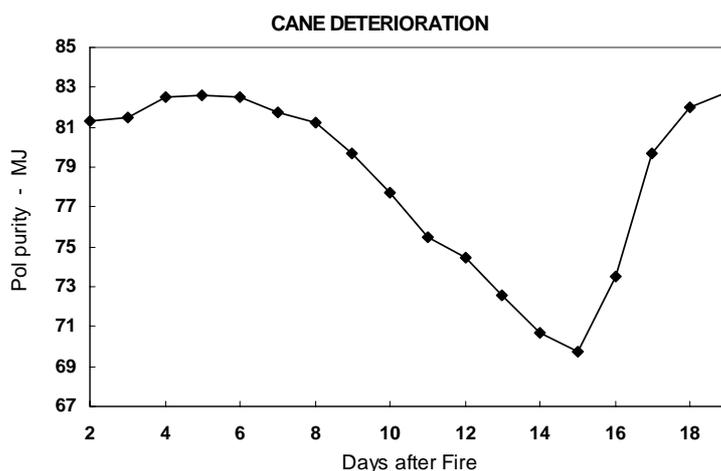
#### *Sugar recovery*

The presence of dextran indicates that sucrose has been lost and impurities have been formed. The ratio of sucrose lost to dextran formed is not fixed but a dextran level of 1000 mg/kg Brix indicates that at least 0.4% of the original sucrose has been lost (Cerutti de Guglielmo *et al*, 2000). The lost sugar causes a reduction in juice purity and thereby diminishes the recovery of remaining sugar. This will be quantified later.

Some products of deterioration (including dextran) are known to block growth on specific crystal faces (Kitchen, 1988; Morel du Boil, 1991, 1998; Vaccari *et al*, 1999). This causes the crystals to grow slower and to be mis-shapen (elongated). The elongated crystals are fragile and tend to break during centrifugation, resulting in crystal loss through centrifuge screens. The elongated crystals also hinder the purging of massecuites, resulting in a need for additional wash water and consequential loss of sucrose to molasses.

Further loss will occur due to the high viscosity and blocked crystal faces, which together cause incomplete crystallisation in the time available. Under extreme conditions, the high viscosity may prevent further processing, and the target purity differences (TPD) has been known to rise above ten units. Such conditions occurred at Noodsberg when prolonged spring rains caused delays in the crushing of cut cane. Koster *et al*. (1992) described the consequences as “extreme elongation of crystals”, “viscosity of massecuites increased to virtually unmanageable levels”, “C-masseccuite wrapped itself around stirrer elements like toffee” and “A-pans boiled so slowly that it was suspected that fouling of the tubes was occurring.”

A further example of the effect of extreme deterioration was evident when an extensive area of cane was accidentally burnt in the Darnall/Gledhow/Maidstone area in 1992. All three factories stopped their normal cane supplies and attempted to process this ‘fire cane’ as quickly as possible. After five days the purity dropped rapidly as shown in Figure 1 for the Darnall mill (Smith, 1993). These figures are representative of what happened at all three mills. Eventually the factories ‘gummed up’ so badly that they were unable to process any more of the fire-damaged cane.



**Figure 1. Pol purity of mixed juice from fire cane at Darnall (Smith, 1993).**

#### *Clarification, filtration and throughput*

It is frequently observed (Stewart and Rehbein, 1964; Tilbury, 1971) that poor clarification in the rawhouse is associated with dextran in juices. Davis (1959) postulated that the dextran acts as a protective colloid and inhibits coagulation, thus allowing fine suspended matter to carry over into the clarified juice. This carry-over increases the colour and ash of sugar made from the juice (Sahadeo *et al*, 2002). More importantly, the suspended matter may carry through to the refinery and cause poor filtration of melts, leading to reduced throughput. The reduction can be substantial, causing affected refiners to seek alternative supplies of raw sugar.

### **The influence of dextran on sugar quality**

Apart from its impact on factory performance, dextran is also an important parameter in the assessment of raw sugar quality, as evidenced by the fact that it is included as a penalty item in a number of overseas purchase contracts (McCowage, 1997). The main influences of dextran on raw sugar quality are briefly summarised below.

#### *Polarisation*

Dextrans are highly dextro-rotatory with specific rotation values at least three times that of sucrose. Hence they have the potential to falsely enhance polarisation. Theoretically the increase should be proportional to the amount of dextran present, with the enhancement being about 0.3°Z per 1000 mg/kg of dextran. However, in practice it was found that lead acetate clarification removes about two-thirds of the dextran in the sample (Morel du Boil, 2005). In a number of instances, high levels of dextran in raw sugar have been implicated by the fact that large pol differences between NIR polarimetry (no clarification) and lead clarified solutions tended to correspond with high values of dextran (Paton *et al*, 1993; Wilson, 1996).

#### *Filterability*

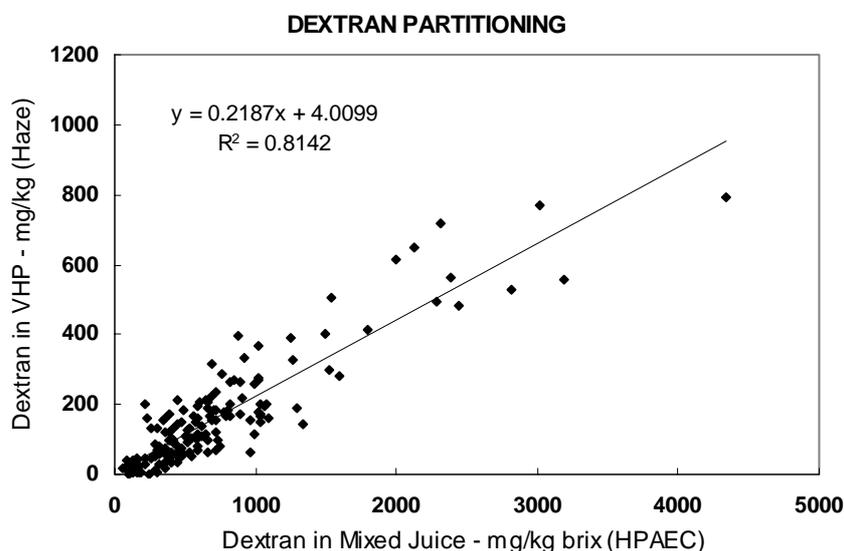
It is often assumed that there is a link between the dextran content and filterability of a raw sugar. Some researchers in Brazil recently found an inverse linear correlation (Amorim *et al*, 2000). Data from Sezela mill for the 2004/2005 season showed a weak correlation ( $R^2=0.648$ ), which appears to provide some support for this contention.

The adverse effect of dextran on juice clarification (mentioned earlier) explains how dextran could affect filterability of raw sugar. However a high dextran level in raw sugar does not always lead to poor filterability. Recent data for the Pongola mill in 2004/05 showed no correlation over a wide range of dextran values. However, this contradictory observation may be due, in part, to the fact that the Pongola mill produces mainly refined sugar by carbonatation. Hence all the refinery returns to the raw house have been processed through a carbonatation and filtration step in the refinery, thus clearing this stream of any carry-over resulting from poor clarification in the raw house. Hence, if there is some other process in place that can eliminate or reduce the quantity of suspended matter carried over (as a result of the dextran), then it is quite feasible that high levels of dextran will have little or no effect on filterability. A further indication that dextran is not the direct cause of poor filterability is provided by the demonstration (Lionnet, 2002) that a high dextran raw sugar showed no improvement in filterability after enzymic removal of the dextran.

From the above discussion it seems evident that the apparent influence of dextran on filterability is probably indirect, as a result of its effect on clarification and carry-over.

#### *Raw sugar*

Unlike many of the other impurities present in the raw house, dextran is readily occluded in the sugar crystal. A study in Louisiana showed that, at low dextran concentrations, about 10% ends up in the sugar, whilst for dextran levels above 5000 mg/kg brix in syrup, this percentage increased rapidly to over 30% (Day, 1984). More recently Morel du Boil (2005) has reported on the partitioning of dextran between mixed juice and VHP sugar for a number of South African mills. A total of 644 data pairs were gathered over the period 2000 to 2003, with dextran levels in juice ranging from 100 to 5000 mg/kg brix. A fairly good linear correlation was found with a slope of 0.208 ( $R^2=0.714$ ). This indicates that over the range of values covered in the study, around 20% of the dextran in juice was occluded in the VHP sugar. The scatter diagram for the 2002/03 season is shown in Figure 2.



**Figure 2. Effect of MJ dextran on VHP dextran for the 2002/2003 season.**

It is evident that a significant amount of the dextran from the raw house will be passed on to the refiner, where it can potentially cause a number of processing problems. In addition a certain amount of this input dextran will finally end up in the refined sugar product. Refiners are now far more discerning and will seldom tolerate the frequent receipt of cargoes having a high dextran content.

### *Refined sugar problems*

Aside from the processing difficulties caused to the refiner, there are several accounts in the literature of problems encountered with refined sugar which are ascribed, at least in part, to the presence of dextran.

*Alcohol floc and acid beverage floc.* Although the haze which becomes visible after storage of acidified syrups – known as *acid beverage floc* (ABF) – is probably the most troublesome, there are other types of floc. These include the floc observed in sweetened alcoholic beverages caused by the precipitation of dextrans, starches and other polysaccharides in the presence of alcohol. High levels of dextran in the raw sugar input often lead to unacceptable levels in the refined product. Some refiners routinely test for alcohol floc in their final sugar. The test is considered positive if haze forms when the sugar is dissolved in 50% ethanol.

It is widely reported that ABF is formed by the interaction between a positively charged protein and a negatively charged polysaccharide (Morel du Boil, 1996). Floc formation occurs as a result of colloid de-stabilisation and the relative concentrations of polysaccharide and protein are claimed to be critical. The scavenging of any other impurities that might be present in solution (e.g. silica, starches, dextran, gums and other polysaccharides) markedly affects the visual appearance of any ABF formed. Hence dextran, which is a neutral (uncharged) polysaccharide, is not directly implicated in the formation of ABF, although it may later become trapped in the floc lattice.

*Sugar drying.* High levels of dextran are reported to make it more difficult to dry and condition refined sugar. Dextran is also known to cause sticky (gummy) soft sugars, which are difficult to package (Chou and Wnukowski, 1980; Hanson, 1980; Fowler, 1981).

*Distortion of hard candy.* A number of references in the literature refer to the problem of distortion of ‘hard candy’ in which dextran has been conclusively implicated. It appears that dextran levels of 100-150 mg/kg (haze) in refined sugar are sufficient to cause distortion (Vane, 1981; Dickey, 1984; Haynes *et al*, 2004).

### **Monitoring of dextran**

The fact that dextran consists of a family of molecules of different molecular masses and different branching structures makes it difficult to develop a specific analytical technique. Considerable effort and debate has centred on the problem but a variety of methods still remain in use, each giving different results according to the specific component(s) being detected.

Detailed discussion of the issue is beyond the scope of this paper but a summary of the major methods and their features is presented in Table 1.

The fact that analytical methods have, until recently, been tedious and not well suited for application to incoming cane, has limited the monitoring of cane supplies. The immunological method (Rauh *et al*, 2003) has now been developed sufficiently to warrant trials for this purpose. Local tests on VHP sugar have proved promising (Morel du Boil and Schoonees, 2005), but need to be extended to DAC samples. The method is quick and simple, but it is expensive and needs to be performed by a competent analyst. It would not be rational to apply it to all DAC samples, but it might provide an objective criterion for cane rejection if it could be applied to small samples of cane before offloading.

**Table 1. Features of different methods for dextran analysis.**

<b>Methods</b> (including Key References)	<b>Principles</b>	<b>Comments</b>
<b>Haze/ICUMSA.</b> (Nicholson and Horseley, 1959; Anon, 1994)	After sample dissolution, starch is removed by enzyme, proteins are precipitated with TCA and filtered off. Filtrate is mixed with an equal volume of 100% ethanol to form a dextran haze. Turbidity of the haze is measured by spectrophotometer at 720 nm to reflect the dextran concentration. Standardised against Dextran T110 or T500.	Good indicator of trouble because only high MW dextran forms haze in the <u>50% ethanol</u> . Relatively easy and precise. Widely used. An official ICUMSA method. Prone to interference from other impurities in low purity products, therefore used mainly for raw and refined sugars. Requires additional sample pre-treatment and care if applied to other products.
<b>Roberts/AOAC</b> (Roberts, 1983; Anon, 1990)	All dextran polymer is precipitated with <u>80% ethanol</u> . Precipitate (ppt) is re-dissolved in water. Alkaline copper reagent is added to selectively ppt a dextran-Cu complex which is re-dissolved in sulphuric acid. Dextran is measured by phenol-sulphuric acid method, which first hydrolyses dextran to glucose and then forms colour with glucose. (Therefore contamination of final ppt by sugar must be avoided.)	Originally thought to have advantages of specificity and embracing entire MW range. In practice, detection of high MW dextran is more useful than total dextran. Used in USA and was used at SAST for some years. Does not correlate well with Haze method. Can be applied to juices and molasses.
<b>'MAU'</b> New York No. 14 contract	Similar to the Haze method but includes an ash removal stage (ion exchange) and expresses results as milli absorbance units (MAU) – i.e. as a standardised spectrophotometer reading without calibration against dextran.	Various linear correlations between MAU and Haze dextran have been defined (e.g. ppm dextran = (MAU+118)/0.659, based on dextran T-40 standard (Rauh <i>et al</i> , 2003) but do not agree well, probably because the relation between absorbance and dextran is not linear, or different MW standards have been used.
<b>Enzyme-HPEAC</b> (Zimmer <i>et al</i> , 1999; Morel du Boil, 2000).	Polysaccharides are precipitated with either 80% or 50% ethanol (distinguishes total or high MW dextran respectively), redissolved and then exposed to dextranase. The dextran degradation product (iso-maltose) is measured chromatographically to reflect original dextran content.	Highly specific, therefore applicable to impure streams. Tedious and high capital cost – not suitable for routine or quick results. High MW results agree reasonably well with Haze and Immuno methods, not Roberts. Minor change enables specific measurement of other polysaccharides – e.g. sarkaran.
<b>Immunological</b> (Rauh <i>et al</i> , 1999 and 2003)	Measures turbidity resulting from the reaction of monoclonal antibody with dextran. Standardised against dextran T-2000.	Quick (3-5 min), portable, specific and applicable to all factory products, requires only filtration for pre-treatment and only 10 µl of filtered sample. Dextran smaller than 40000 Daltons are not detected.

On-line measurement of ethanol in shredded cane provides a means of monitoring continuously for deteriorated cane (Lionnet and Gooch, 2002). This could be used to highlight specific cane supplies that justify dextran analyses before offloading. Caution is required because Morel du Boil (2005) showed that the ethanol content of DAC extracts does not correlate with dextran content. This is understandable in terms of the curve shown later in

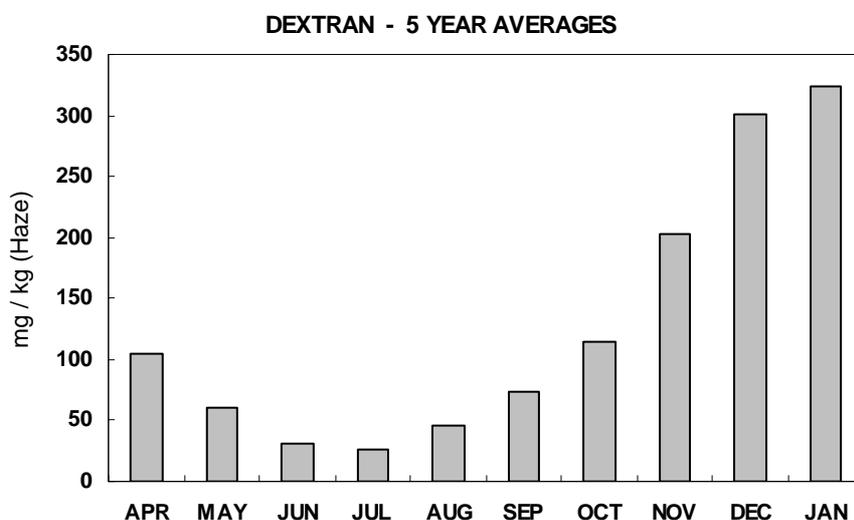
Figure 7, which demonstrates that the early stages of deterioration give rise mainly to products other than dextran. Thereafter about 25% of the sugar lost is converted to dextran. Depending on the stage of deterioration, there will therefore be different relationships between dextran and ethanol. Morel du Boil's scatter graph shows that when dextran levels are high, there is inevitably a raised level of ethanol, but the highest ethanol levels do not coincide with very high dextran levels. The scatter pattern fits the supposition that ethanol is formed rapidly in the first phase, but that dextran may become the dominant product in a later phase.

### Dextran levels and costs in South Africa

#### *Some illustrative trends in dextran levels*

There are a number of interesting trends, which become clear from a study of the occurrence of dextran in the South African sugar industry. Three of these will be dealt with here, namely the annual seasonal variations (based on monthly averages), longer-term trends (based on annual averages) and geographic/regional effects (arising from the wide geographic dispersion of the industry).

*Seasonal trends.* Dextran levels in harvested cane follow a predictable pattern across each crushing season. They can be fairly high at the start of the season and then usually drop to very low levels during the winter months before climbing again, sometimes very sharply, with the onset of the spring rains and increased daytime temperatures. This is readily apparent from the data in Figure 3, which shows the average monthly dextran levels in VHP sugar delivered to the terminals in Durban and Maputo over the past five seasons.



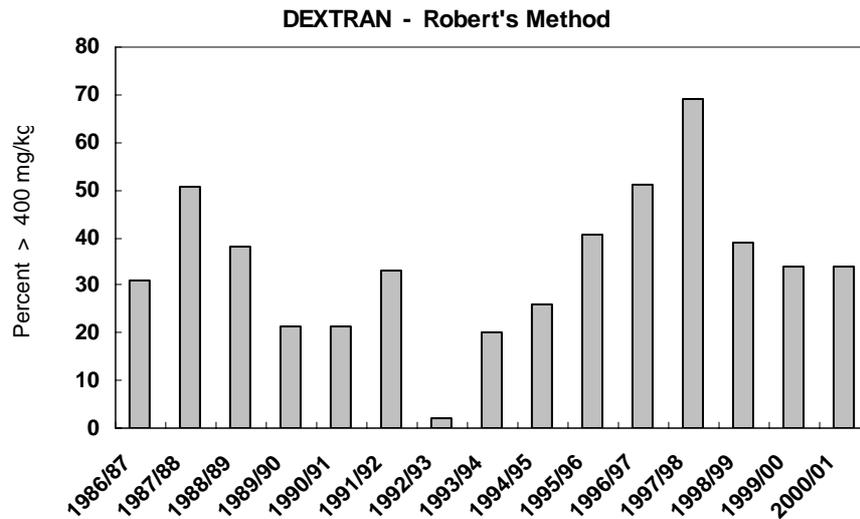
**Figure 3. Variation of dextran levels in VHP sugars over the season.**

All mills encounter a similar shaped curve, although the absolute levels can vary considerably from mill to mill. Dextran is not a natural constituent of sugarcane, but is produced bacteriologically during post-harvest degradation of cane. Hence it is to be expected that the most important variables governing the production of dextran are temperature, moisture and residence time (as a result of cane/rain delays). A number of studies have shown the close correlation between rainfall and increased levels of dextran. In all probability, this is mainly an indirect result of rain-induced delays between burning/cutting and crushing – the so-called burn/harvest to crush delay (or BHTCD). There is evidence, however, that burnt, wet cane deteriorates more rapidly than burnt, dry cane (Atkins and McCowage, 1984; Anon, 1993).

This observation fits the hypothesis that burnt cane is often partially covered externally with juice, which then supports extensive bacterial growth if it does not dry out immediately after burning.

*Long term trends.* For many years the South African industry appeared to have very few problems which could be ascribed to the presence of dextran (Alexander and Ravnö, 1984). In part, this could be due to the fact that the industry used both the official AOAC (Robert's) method and the haze method to measure dextran in VHP up until 1990. From 1991 onwards, the haze method – not yet officially adopted by ICUMSA – was dropped, as the figures being obtained were very low and perhaps somewhat misleading. Instead the Roberts method was officially adopted by SASTA.

The results for the period 1986 to 2000 by the Roberts method are shown in Figure 4.

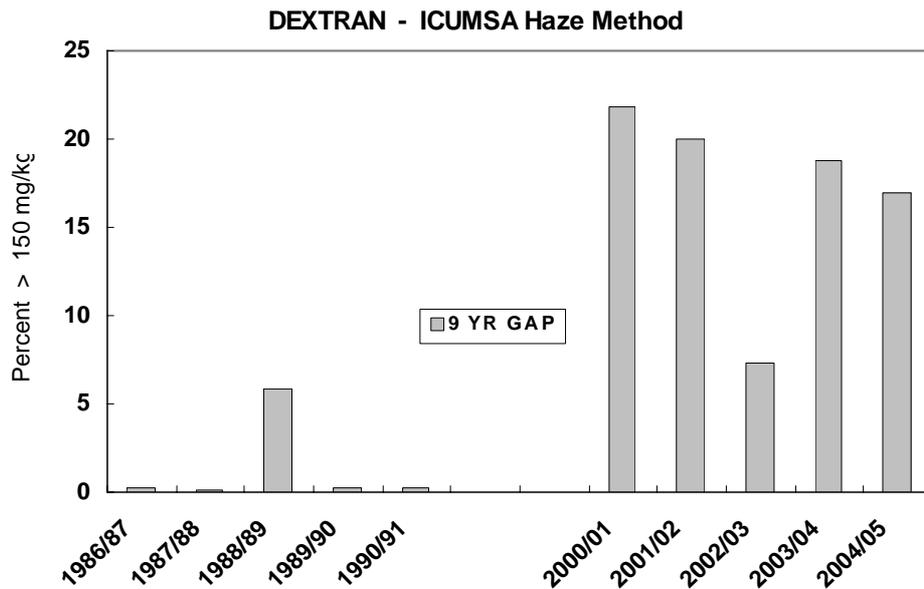


**Figure 4. Robert's dextran in VHP deliveries; a 15-year survey.**

The graph depicts the percentage of annual deliveries that exceeded 400 mg/kg. Apart from the steep increase immediately following the devastating drought years (from 1992 to 1994), the figures do not indicate that there has been any major shift in the pattern of dextran occurrence. This was probably a large factor in lulling the industry into a 'false sense of security' that dextran was still not a problem in the year 2000!

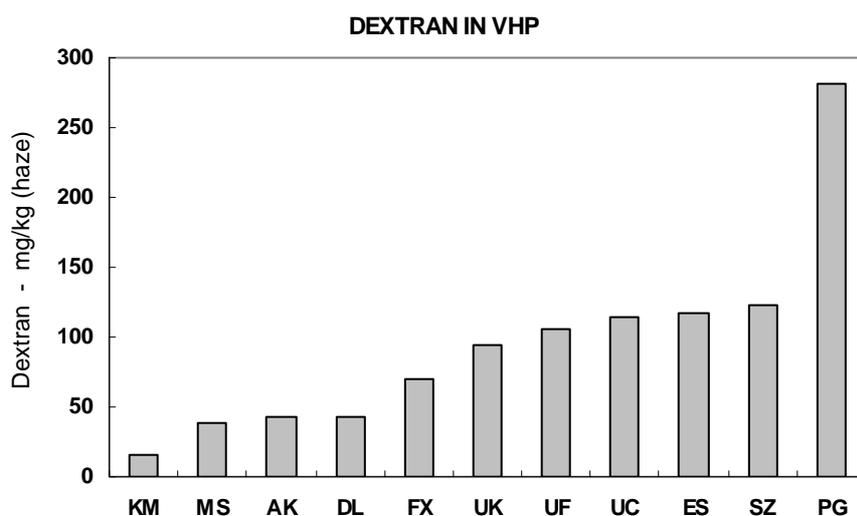
There was a growing realisation that the high molecular weight (HMW) fraction of the total dextran is largely responsible for the severe processing problems and high viscosities encountered (Greenfield and Geronimos, 1982). Hence in 2000, the industry switched back to the ICUMSA haze method (which specifically detects HMW dextrans). It was alarming to note the change in dextran figures, compared to the levels obtained nine years earlier with this method. These are depicted in Figure 5.

The bar chart shows the percentage of deliveries, which exceeded 150 mg/kg sugar over the two 5-year periods, almost a decade apart. This situation was driven home when several quality complaints, attributable to high dextran, were received from overseas customers during the 2000/2001 season. Since that time the situation has stabilised and there has been some improvement in the absolute levels of dextran, which is not fully reflected in the data in Figure 5.



**Figure 5. Comparison of haze dextran in VHP for two 5-year periods.**

*Regional/geographic effects.* There are many factors, which can give rise to regional differences between the levels of dextran encountered at each mill. The magnitude of these differences is shown in Figure 6, which illustrates (in ascending order) the mean annual dextran content of VHP sugar (by mill) delivered to Durban and Maputo over the past five seasons. The figures for Gledhow (GH) and Noodsberg (NB) have been excluded on the grounds that they have back-end refineries and only deliver very small tonnages of VHP on an intermittent basis. However in a separate study, dextran levels in raw sugar were measured across an entire season at Noodsberg during 2003 (Morel du Boil, 2005). These data yielded a season average of 112 mg/kg (haze) which is in line with figures obtained at the neighbouring Union Co-op (UC) mill.



**Figure 6. Regional variations in average annual dextran in VHP sugar.**

There are two particular features in the above results which require explanation:

- It will be noted that the three inland mills, namely UC, ES (and NB), all display similar average levels of dextran at the higher end of the scale. Most cane in these areas is on a two-year crop cycle and is burnt prior to harvesting. At these higher altitudes – generally above 700 m – there is wide diurnal temperature variation. Mean daytime temperatures during the winter months are low enough that the normal 72-hour (average) delay between burning and crushing probably does not lead to significant dextran formation. However with the onset of warmer daytime temperatures and spring rains (accompanied by frequent heavy dew and mist which is characteristic of the area), conditions become conducive to microbial degradation and there is often a steep rise in dextran levels, particularly at these mills. The problem in the Midlands is compounded by the periodic presence of an additional polysaccharide – known as sarkaran – which has been found in mixed juice at levels of up to 2000 mg/kg brix (Morel du Boil, 2001). It is highly likely that sarkaran, which also causes viscosity problems in the factory, will register as dextran in the haze analysis procedure.
- Although Pongola mill produces mainly refined sugar, their VHP consistently contains much higher levels of dextran than any other mill in the industry (see Figure 6). Over the years a number of special studies have been undertaken at Pongola, which have confirmed that the probable source of the dextran is in the cane entering the mill (Morel du Boil and Barker, 2000; Morel du Boil, 2005). However, it has not been possible to quantify any abnormal cane delays which could explain the significant differences between Pongola and the other mills in the industry.

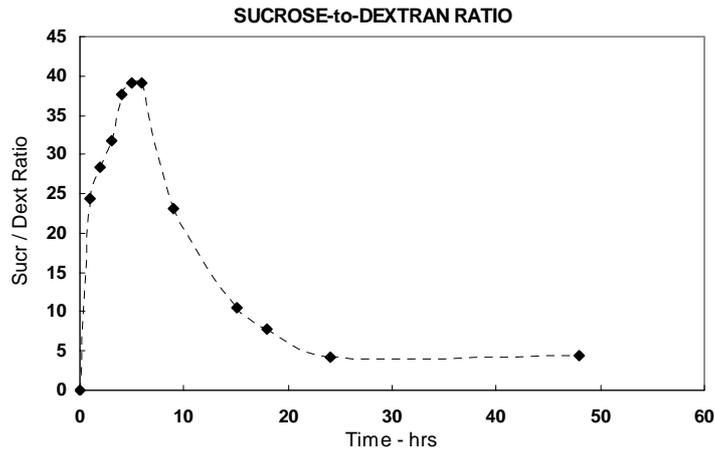
It has already been noted that, despite high levels of dextran at Pongola, their VHP does not exhibit the low filterability, which is usually associated with such levels. This unexpectedly high filterability, together with inexplicably high levels of dextran in mid-season, may be related to the fact that, although Pongola has a back-end refinery, it also produces some VHP sugar. The refinery returns have the effect of retaining dextran in the system longer than would be expected if there was no refinery. Furthermore these returns will have been filtered in the refinery, thus removing the filter impeding solids often associated with dextran. Obviously, this phenomenon provides some very fertile ground for further research.

#### *Quantification of losses*

As has already been discussed, dextran is responsible for a variety of inter-related problems in a sugar mill. An attempt has been made to quantify the more important of these in the following sections.

*Sucrose destruction.* Sucrose is destroyed directly when dextran is made. It has been found that, after 48 hours of incubation, approximately four parts of sucrose are consumed for every one part of dextran produced (Cerutti de Guglielmone *et al*, 2000), as illustrated in Figure 7.

It is also evident that the amount of sucrose utilised for every part of dextran formed can be much higher during the initial stages, reaching a value of almost 40:1. Hence the use of a 4:1 ratio to quantify the potential sucrose losses is likely to err on the conservative side.



**Figure 7. Ratio of sucrose destroyed to dextran produced at 30°C.**

Using the equations (1) and (2), it is possible to construct a series of values relating sucrose (and hence purity) losses in juice to the estimated dextran content in VHP:

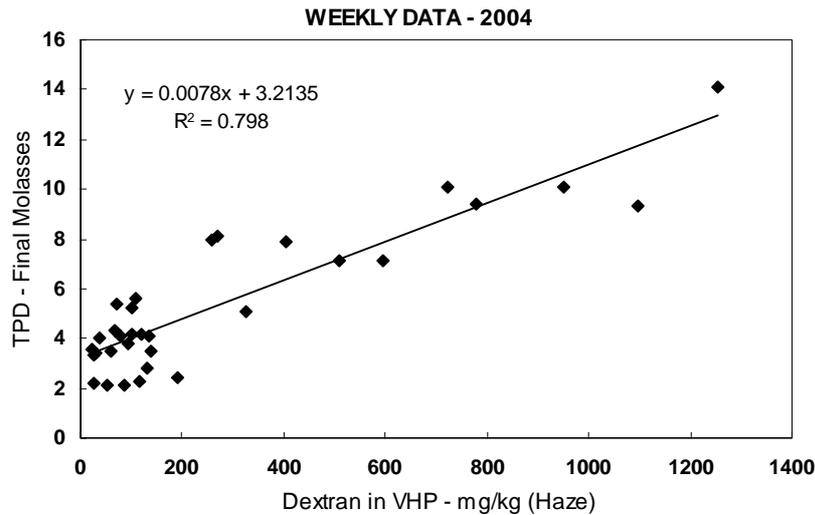
$$\begin{aligned} \text{Sucrose lost in MJ (mg/kg Brix)} &= 4 \times \text{Dextran in MJ (mg/kg Brix)} \dots\dots\dots (1) \\ \text{Dextran in VHP sugar (mg/kg)} &= 0.20 \times \text{Dextran in MJ (mg/kg Brix)} \dots\dots\dots (2) \end{aligned}$$

*Sugar recovery.* The conversion of sucrose to dextran and other metabolites leads to a reduction of juice purity and therefore sugar recovery in the boiling house. Over and above the recovery lost due to lower purity, there are additional losses as a result of increased viscosity, lower crystallisation rates and poorer purging in the centrifugals. It has been shown that there was an indirect relationship between molasses exhaustion, as expressed by the target purity difference (TPD) formula, and the dextran content of mixed juice across a number of factories during the 2000/2001 season (Morel du Boil, 2005). A similar relationship was found in the present study between TPD and the dextran content of the resultant VHP sugar. The correlation improved when weekly data from a single mill were used, presumably because this removed a number of extraneous factors relating to differences in installed equipment capacity and operator efficiency at different mills. The relationship for Pongola mill – which showed the widest spread of dextran values across the season – is shown in Figure 8.

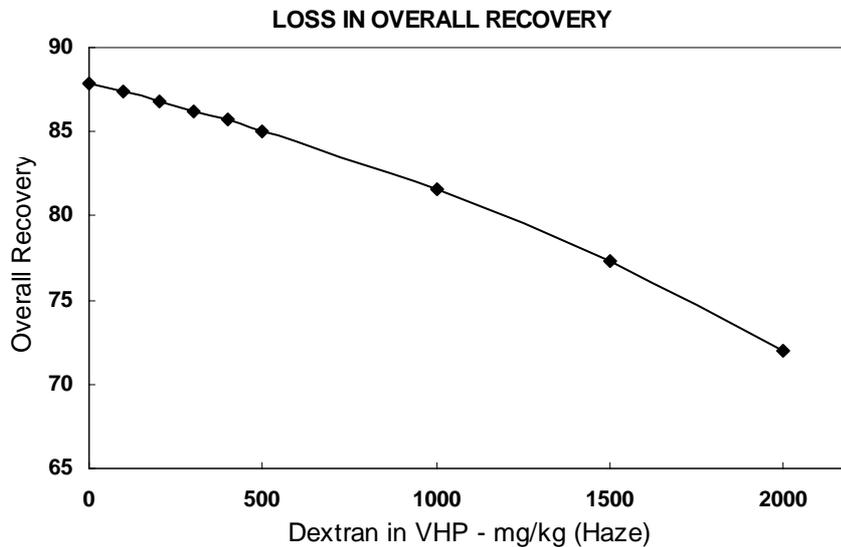
From this correlation it was possible to derive equation (3) below, which shows the estimated increase in molasses purity for various levels of dextran in VHP sugar.

$$\text{Estimated increase in molasses purity} = 0.0078 \times \text{Dextran in VHP (mg/kg)} \dots\dots\dots (3)$$

These expressions were used to derive an estimated juice and molasses purity for a range of dextran values. These were then ‘plugged into’ the standard S-J-M recovery formula, using 99.85 as the purity of VHP sugar and an extraction level of 98% to estimate an overall recovery figure (OR) for the same range of dextran values. The industrial average purities from the 2004 season for mixed juice (85.81) and final molasses (39.61), together with a figure of 70 mg/kg for dextran in VHP sugar were used as the base reference point against which the changes in S-J-M recoveries were measured. The results are depicted in Figure 9.



**Figure 8. Relationship between TPD and dextran at Pongola during 2004.**



**Figure 9. Estimated loss in sugar recovery due to dextran.**

In order to quantify these losses in terms of actual production, the data have been applied to a standard sugar mill crushing 1.5 million tons of cane in a 36-week season. The loss of recoverable sugar has been expressed both in terms of tons per annum and kg per ton of cane crushed. The figures are shown in Table 2.

Other authors have reported similar losses due to dextran:

- Rauh *et al* (1999) stated that, “Sugar losses, weighted for dextran distribution, show that, in Louisiana, an average of 1.5 kg of recoverable sugar per ton of cane (3 pounds/short ton) is lost to molasses due to dextran.” Under South African conditions this would be consistent with an estimated dextran level in sugar of between 200 and 300 mg/kg (Haze), which is fairly high. However, it is understood that dextran poses a serious problem during the relatively short and (often) wet harvest period in Louisiana.

- Koster *et al* (1992) report an estimated recoverable sugar loss of 1626 tons over a 9-week period at Umzimkulu, Sezela, Illovo and Noodsberg in 1992. It seems apparent from the text that the Noodsberg mill was the worst affected by the spring rains and accompanying dextran-related problems. It is estimated that these four mills would have crushed less than a million tons of cane during the period in question. This translates to an average loss of about 1.6 kg per ton cane. However it is probable that the actual figure at Noodsberg was considerably higher than this, as their TPD was above 10, eventually reaching a figure of 18 for the last two weeks of the season. The Noodsberg situation is compounded by the fact that:
  - they refine all their sugar plus they import additional raws from the neighbouring Union Co-op factory which also had high dextran levels at that time of year. Hence they are particularly prone to the problem of dextran recycling around the raw house, as discussed earlier for Pongola.
  - both Noodsberg and Union Co-op are known to encounter periodic outbreaks of sarkaran in their cane. It is not known whether this was a feature of the 1992 season.
  - large quantities of cane are stockpiled each week in their cane-yard, which results in substantially higher cane delays than is the case at the other mills.

**Table 2. Estimated losses of recoverable sugar due to dextran.**

Dextran in VHP	Overall recovery	Sugar losses	
		Tons p.a.	kg/tc
0	87.88	0	0.0
100	87.36	1051	0.7
200	86.82	2141	1.4
300	86.26	3277	2.2
400	85.68	4461	3.0
500	85.07	5694	3.8
1000	81.62	12697	8.5
1500	77.35	21349	14.2
2000	72.05	32106	21.4

*Factory throughput.* It will be apparent that factory capacity will be seriously compromised whenever the dextran levels rise to the point that they cause significant viscosity increases, slow boiling rates and serious crystal deformation. This often leads to an increase in season length and a higher carry-over cane tonnage, which are costly to both miller and grower. These are the inevitable financial consequences, which will vary from mill to mill, depending on individual circumstances.

### **Incentives for reducing dextran in raw sugar**

Although dextran has long been known to cause problems during sugar processing, there are few industries around the world that have adopted strong and clear-cut guidelines for dealing with the problem. By far the most significant cause of high dextran levels in raw sugar is post harvest deterioration of sugarcane, especially where this is mechanically harvested in billeted form. The Australian industry, which switched from manual to mechanical harvesting during the 1960s and 1970s, was quick to recognise the problems brought about by the major increase in dextran levels that accompanied this change. New guidelines and incentives were developed to encourage and ensure that cane was delivered for crushing within a matter of hours after burning/harvesting.

Increasingly refiners are now seeking raw sugars which have low levels of dextran and many international purchase contracts now specify maximum dextran levels.

*International penalty-bonus systems*

One of the first buyers' contracts to include a specification for dextran was the New York No. 14 Contract, which governs much of the sugar purchased by USA refiners. This specifies a maximum dextran content of 250 m.a.u. and the contract contains a series of monetary penalties – related to the basis price for sugar (Arias, 1993; McCowage, 1997). Details of these penalty values are given in Table 3.

**Table 3. Dextran penalties attached to the New York No.14 Contract (1984).**

Parameter	Specification	Penalty
Dextran	Less than 250 m.a.u.	Deduct 0.007% for each 1 m.a.u. above 250 up to 350
		Deduct an additional 0.009% for each 1 m.a.u. above 350 up to 450
		Deduct an additional 0.011% for each 1 m.a.u. above 450 up to 550
		Deduct an additional 0.013% for each 1 m.a.u. above 550

The Domino Contract in the USA contains almost identical wording in respect of dextran. The ACP London Sugar Group has a similar type of penalty scheme, which governs supplies into the EC from the ACP Sugar Group. Details are listed in Table 4.

**Table 4. Dextran penalties attached to the ACP London Sugar Group Contract (2000).**

Parameter	Specification	Penalty
Dextran	Less than 350 units	Deduct 0.010 euros per ton for every 5 units above 350 up to 450
		Deduct an additional 0.013 euros for each 5 units above 450 up to 550
		Deduct an additional 0.016 euros for each 5 units above 550

Increasingly buyers on world markets are indicating that they require low dextran raw sugars (<100-150 mg/kg haze), even where the purchase contract does not contain a dextran specification.

*Dealing with the dextran issue in South Africa*

Fifty years ago, starch was a serious problem in the South African sugar industry. However with advent of bacterial amylases capable of hydrolysing starch, coupled with the widespread introduction of the diffusion process for extracting juice from cane, the 'starch problem' is now well controlled.

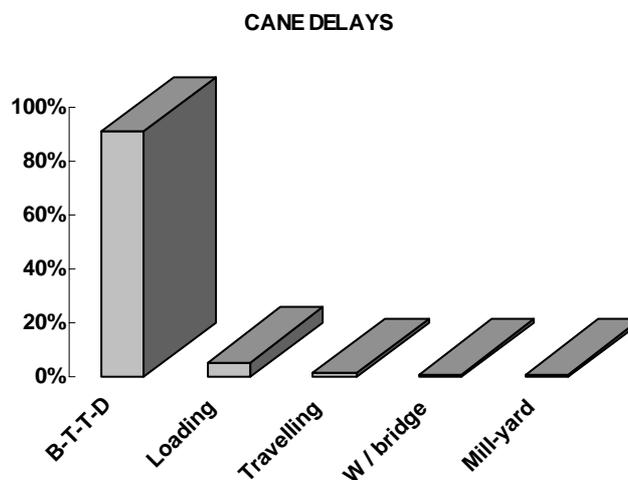
There is a growing realisation that dextran has become a more serious sugar quality issue in South Africa. This is partly due to the fact that markets are becoming more discerning and, of greater concern, that the levels of dextran in South Africa have increased over the past decade. Hence it is timely that the industry is reviewing its current raw sugar quality incentive scheme in order to render it more effective in ensuring that the quality of South African raws is aligned to changing market demands. Amongst other matters it is considering the introduction of a dextran limit in the raw sugar quality specification. Dextran would then join polarisation, colour, starch, filterability and grain size as the priority quality parameters, which would be subject to quality incentives (premiums and discounts).

## Practical guidelines for reducing dextran

From the foregoing discussion it should be abundantly clear that every effort should be made to *minimise dextran formation* and to *prevent it from entering the boiling house*. Given the increasing realisation of the impact which dextran has on both factory performance and sugar quality, greater focus needs to be placed on various ways of addressing the problem.

### *Minimum burn-to-crush delay*

A recent study commissioned by the South African Cane Growers Association provides quantification of the current burn/harvest to crush delays across the industry. Although there were some differences between individual mills, the average BHTCD was found to lie between 60 and 72 hours at most centres. It was significant to note that over 90% of the total delay occurs between burning/cutting and loading onto the cane transport/delivery system – the so-called burn-to-truck-delay or BTTD. A pictorial breakdown of the overall delay is shown in Figure 10.



**Figure 10. Breakdown of the major components of cane delays**  
(Courtesy of SA Cane Growers' Association).

In this study a number of strategic recommendations were made with the aim of reducing the BTTD by at least 24 hours initially and by up to 48 hours in the longer term. Amongst these the most important were the following:

- **Don't burn cane**, but if this cannot be avoided, then do it **daily** and in the **early mornings**, if at all possible.
- Clear **all cut cane** out of the fields and on to the zone/mill on the **same day that it is burnt/cut**.
- Introduce and encourage (incentivise, if necessary) **group harvesting** wherever possible.
- Facilitate **priority processing** of accidental fire cane (and frosted cane)

Although many of the above actions have financial implications, particularly for growers, the benefits to the industry of controlling dextran will far outweigh any increased costs.

### *Detection (and rejection) of seriously deteriorated cane*

The importance of early detection of seriously deteriorated cane cannot be over-emphasised. It has already been demonstrated that it only requires a very small percentage of badly deteriorated cane to seriously compromise factory operations and sugar quality to the detriment of all stakeholders. Although there is, as yet, no practicable means for testing each

and every cane consignment for dextran, a fair amount of scientific work has been undertaken both here and abroad to find some form of 'early-warning-system' for cane deterioration (Lionnet and Gooch, 2002). In addition a new dextran immuno-assay kit is now commercially available, which can produce a result within a few minutes. The system has been assessed recently and was found to be suitable for estimating dextran in VHP sugar (Morel du Boil and Schoonees, 2005). In principle, the procedure should be applicable to all factory products, including DAC extracts, as it requires no sample preparation other than dilution. Hence it is recommended that trials should be undertaken using:

- On-line ethanol measurements as a quick response system to identify badly deteriorated cane, as evidenced by high levels of ethanol.
- Introduction of portable, quick dextran measurement (using the immunological method) for confirmation and rejection (if necessary) *prior to crushing* of any cane with unacceptable levels of dextran. It will be necessary to devise a method for obtaining a representative sample from a cane consignment.

#### *Use of dextranase enzymes*

The first priority should be to adopt practices that prevent or minimise the incidence of high dextran levels entering the boiling house. However there will be occasions when it is inevitable that dextran will become troublesome. It has been shown that enzymic removal of dextran in the process house is possible, but expensive. The following observations can be made:

- In Australia, use of the enzymic process results in the production of raw sugar of reasonably good quality without the discarding of large quantities of intermediate purity molasses or the rejection of cane for its dextran content alone (Inkerman, 1980). The overall use of the process is rather restricted under Australian conditions. In 1980 less than 2% of Australian raw sugar was produced with the aid of dextranase. However if enzymic treatment had not been carried out, a considerably larger percentage of sugar would have been affected due to the persistence of dextran in the factory well after the initial influx of deteriorated cane. Mill breakdowns, industrial stoppages and unavoidable delays in cane supply are envisaged as conditions under which the process may (should) be used.
- More recently a laboratory evaluation of dextranases has been undertaken in the local industry (Morel du Boil and Wienese, 2002). Thermal stability is a problem but newer enzymes are reasonably stable in the presence of high concentrations of sugar. It was found that under enzymic hydrolysis, dextran breaks down into lower molecular weight fractions, which are not troublesome in the boiling house and hence it offers the possibility of a practical control of dextran. This study confirms the earlier pioneering work done by Inkerman (1980). Unfortunately the high temperature profiles in most factories dictate that the enzyme cannot be added prior to clarification, so any adverse effects of dextran on clarification will not be removed.
- It is strongly recommended that further work be commissioned in the local industry in order to establish the practicality of applying dextranases on a production scale. In particular it will be necessary to confirm the optimum point and rate of application for both diffuser (high temperature) and milling factories.

#### *Miller/Grower cooperation*

Because dextran is primarily formed in cane before it enters the factory, it is imperative that millers and growers act in unison at both central and at local level to combat this problem. There needs to be consensus regarding the strategies which are adopted. It will be necessary

for both parties to understand and to cooperate with the occasional need for a complete cessation of burning and/or harvesting while the factory is cleared of deteriorated cane and juice.

#### *Factory hygiene*

It is well known that dextran can also be formed within the factory. There are a number of standard procedures for ensuring good factory hygiene and it is imperative that these are applied diligently.

#### *Raw sugar segregation*

Until the problem of dextran has been brought under acceptable control, it will be necessary for the receiving sugar terminals to have the capacity and infrastructure to segregate poor quality (high dextran) sugars, for separate disposal.

### **Conclusions**

Over the past thirty years a large amount of scientific work has been undertaken in sugar industries around the world to quantify dextran and the problems it causes and to seek ways of combating both its occurrence and its effects. In the present paper an attempt has been made to highlight a number of salient points, namely:

- Dextran has increased in significance as a parameter of cane and sugar quality in South Africa over the past decade.
- Dextran causes problems both for the raw sugar producer and for the refiner, both local and overseas. Hence there is a need to be more responsive to customer requests for tighter specifications and controls on dextran.
- Certain factories in South Africa, notably Pongola and Noodsberg (both of which are back-end refiners), experience severe dextran problems. It is likely that dextran recycling to the raw house compounds the problem.
- Some of the problems attributed to dextran may not be caused directly by dextran, but the problems are generally associated with cane deterioration, and dextran is an indicator of such deterioration. Effective measures for reducing dextran levels are well known (thanks to some good scientific work) but are not always well applied. Incentives for better control of dextran need to be considered, and such incentives need cooperation between growers and millers for policy formulation and practical application.
- If there is anything to be learned from the experiences of others, it is that dextran should be kept out of the boiling house if at all possible. This will require a concerted and coordinated effort from growers, harvesters, hauliers and millers, but is essential, if the local industry is to arrest and control the rise of dextran.

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