REFEREED PAPER

THE TRANSFER OF NON-SUCROSE SPECIES INTO THE SUCROSE CRYSTAL: CAN IT BE USEFUL?

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Abstract

The crystallisation of sucrose has been, and still is, extensively investigated both in academia and in industry. The literature is reviewed to summarise the main points which have been well established, the many areas where work still needs to be done, and more particularly to highlight the effects of non-sucrose species both on classical crystallisation to produce food grade sugar, and on the possibilities of manufacturing co-products through co-crystallisation processes. The literature shows that the non-sucrose species which affect the crystallisation process can be categorised in two groups: those which enter the crystal but do not alter the crystal shape, and those which enter into the crystal and cause deformation. This second group can also severely slow down the sucrose crystallisation rate. Investigating the mechanisms through which sucrose crystallises is difficult; various models have been tested. Finally, recent work used mathematical models, based on industrial data, to improve the quality of the sugar produced. The financial impacts of the modifications were also investigated.

It was suggested that apart from improving sugar quality the knowledge obtained about the crystallisation of sucrose should be used, and extended, to investigate the possibilities of producing high value co-products through co-crystallisation with sucrose. Here the goal is not to prevent or reduce the incorporation of non-sucrose species (usually called impurities in classical literature) but, on the contrary, to increase and control the concentrations of selected species incorporated in the sucrose crystal. Secondly, the possibility of producing white sugar directly should also be re-visited. Obviously, these projects will require extensive technical and financial investigations.

Introduction

Smythe, in 1971, wrote a remarkable review titled “Sucrose Crystal Growth”. This 40-page document looks at the work done in the previous 10 years; it deals with the relevant properties of sucrose, of its solutions and with the growth rates and shapes of its crystals in pure, synthetic and industrial materials. The data obtained from the literature are discussed, compared and relevant comments made. Smythe states that “sucrose crystal growth has been studied more extensively than any other crystal growth from solution” and his review includes 131 references. The relevance of the crystallisation of sucrose is again highlighted by Van Hook (1981) and Shore *et al*. (1984). Work is continuing, both in the beet and cane industries, as evidenced by recent publications in sugar technology texts and congress proceedings.

It is instructive to ask why the crystallisation of sucrose is so interesting both from academic and industrial perspectives. From an academic point of view, sucrose has many advantages because of its high solubility in water giving a wide range of supersaturated solutions of good stability, of high viscosities and low diffusion coefficients, properties which are helpful in research (Smythe, 1971). From the industrial perspective, sucrose is a safe and inexpensive

food which crystallises easily without water of crystallisation (Van der Poel *et al.,* 1998) from pure and even less than pure solutions. Crystalline sucrose is easy to weigh, store, pack and transport; it can easily be redissolved if necessary. It keeps reasonably well. Crystallisation is by far the best purification process available to produce industrial quantities of very pure sugar; most of these facilities are not found with glucose, fructose and many other sugars. There is, however, a less obvious reason which is becoming more and more important: with the world sugar market being dominated by a few large producers it becomes vital for smaller producers to diversify. The ease with which sucrose crystallises should again be an advantage but now for the manufacture of co-products.

This paper reviews the literature to highlight what has been achieved more recently, particularly in terms of the impact of non-sucrose species on the crystallisation of sucrose. Smythe's findings and recommendations are used as guidelines.

Literature

The shape of sucrose crystals

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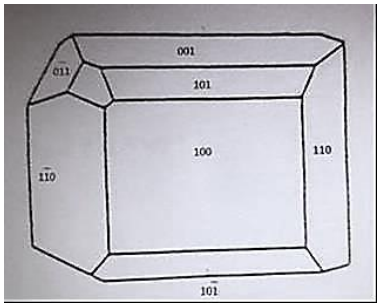

Figure 1: A normal sucrose crystal

A normal sucrose crystal can be represented (Van der Poel *et al.*, 1998), as shown in Figure 1, with some of the Miller indices included. Miller indices are used to identify the different faces of a crystal (Honig, 1959); crystal faces and their identification are important aspects as different faces may behave very differently during crystallisation. Many authors (Morel du Boil, 1985, 1991, 1995, Cremata *et al*., 1983, and Lionnet, 1998) have used two axes, a vertical one parallel to the 110 face and a horizontal one parallel to the 101 face usually called c and b respectively, to characterise the shape of sucrose crystals by calculating the ratio c/b.

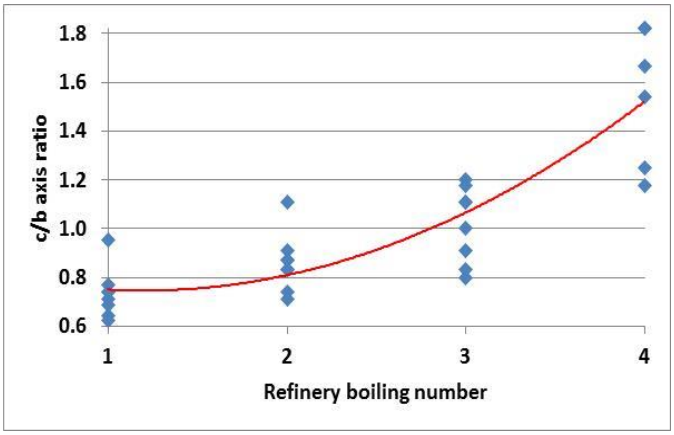

Figure 2: c/b ratios for crystals produced in different refineries (Morel du Boil, 1985)

Morel du Boil (1985) states that the natural shape of a pure sucrose crystal grown in water is about twice as long in the b-direction as in the c-direction. Crystals with c/b ratios (or elongation ratios, ER) of 0.5 to 0.6 are normal; ER values greater than 0.8 indicate crystal elongation. Data obtained by Morel du Boil from five different refineries are shown in Figure 2. Clearly the c/b ratio increases as purities decrease.

The c/b ratio will be used extensively here to characterise the shape of sucrose crystals.

Impacts of the presence of non-sucrose species

Investigations dealing with the effect of non-sucrose species are not new. Honig (1959) and Spencer and Meade (1948) give references dating from 1784 and much work was done in the 1920s and 1930s.

Generally, various studies show that different pairs of faces of the sucrose crystal have inherently different growth rates due to the nature of the bonding of the sucrose molecules at these faces. Specific non-sucrose species can alter the relative growth rates of pairs of faces leading to changes in the crystal shape. Inorganic salts and invert sugar do not have marked effects, but certain oligo- and polysaccharides produce significant changes (Smythe, 1971).

Smythe measured growth rates of sucrose crystals in solutions containing various concentrations of a wide range of non-sucrose species. Their effects on the solubility of sucrose and the effects of supersaturation, temperature, relative velocity of crystal and solution on crystal growth rates were studied.

The non-sucrose species fell into two broad groups:

1. Those that reduce growth rate by increasing viscosity and reducing the rate of mass transfer of sucrose. These species include invert sugar, electrolytes and a wide range of organic compounds; and

2. Those which hinder the incorporation of sucrose at the crystal surface by being adsorbed on specific faces. These species, which include oligosaccharides, also produce marked changes in the shape of the sucrose crystal by altering the relative growth rates of different pairs of faces.

Smythe also determined the relative growth rates of the eight principal pairs of faces of sucrose crystals grown in the presence of impurities (10-20 g/100 g water) and compared them with growth rates in pure solutions. His results are summarised in Table 1.

Smythe's work identifies specific non-sucrose species and the faces they affect. Inorganic salts and invert sugar did not have marked effects on these relative growth rates, but certain oligo- and polysaccharides produced significant changes.

Another important consideration in the study of the impact of non-sucrose species is to define carefully where these species are located in the sugar crystal. Shore *et al.* (1984) give information on the distribution of colour bodies in sugar crystals by using a progressive dissolution process, as shown in Figure 3. There is a higher concentration of colour in a film-like region around the crystal; this concentration reaches an approximately constant value when about 25 % of the crystal has been removed by a progressive dissolution. Mackintosh and White (1969), Guo and White (1984), and Lionnet and Moodley (1995) also mention this film effect.

Table 1: Species inhibiting growth on principal faces of the sucrose crystal (Moore, 1972). (The values given are relative to the rate for pure sucrose expressed as 100 %)

Non - suc species	Miller Indices of faces of a sucrose crystal							
	(100)($1\bar{0}0$)	(001)($00\bar{1}$)	($1\bar{1}0$)($\bar{1}\bar{1}0$)	(101)($\bar{1}0\bar{1}$)	($10\bar{1}$)($\bar{1}01$)	(110)($\bar{1}10$)	($0\bar{1}1$)($0\bar{1}\bar{1}$)	(011)($01\bar{1}$)
Raffinose	<5 %	5–20 %			<5 %	<5 %		
Stachyose	<5 %				20–50 %	<5 %		
Gentianose	<5 %	5–20 %				<5 %		
Neokestose	<5 %	20–50 %				<5 %	20–50 %	
Trisac. (?)	<5 %				<5 %	<5 %		
Kestose		<5 %	<5 %		<5 %		<5 %	
1-Kestose			5–20 %	20–50 %	20–50 %	5–20 %	5–20 %	20–50 %
Invert sugar			20–50 %			20–50 %		20–50 %

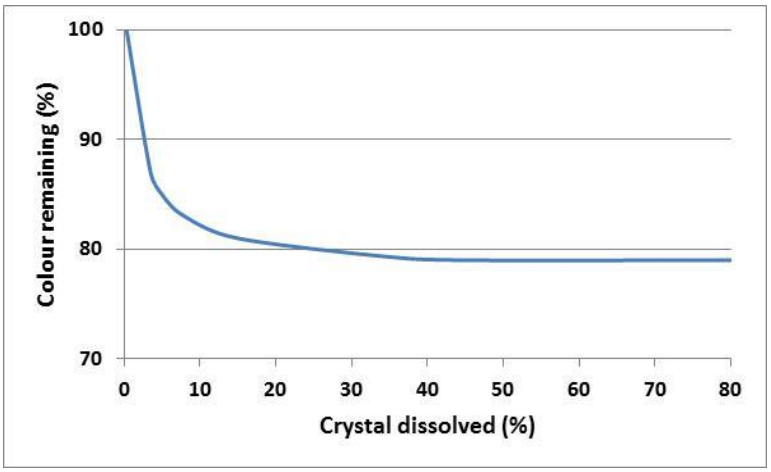

Figure 3: Distribution of colour in a crystal (Shore, 1984)

Michael and Thelemaque (1984) developed a laboratory affination technique which removes a reproducible film from refined sugar crystals produced in South Africa. It is essential to have a technique which allows non-sucrose concentrations in the film and in the crystal to be determined reproducibly.

Non-sucrose species which do not cause crystal elongation

Using a pilot pan, Lionnet (1998) studied the transfer of K^+, Ca^{2+}, Ni^+, Li^+, ICUMSA colour, dyes and starch into the crystal, under refinery crystallisation conditions. The minimum, maximum and mean values of 88 c/b axis ratios were 0.58, 0.84 and 0.74 respectively. The investigation was not designed to look at ER but it can be assumed that there is no evidence of severe crystal elongation. These results fall in the first boiling range of Figure 2 even though the ranges of concentrations of the species tested included high values.

Kamoda *et al.* (1968) investigated the effects of the concentrations of gums, starch, silica, phosphate and oligosaccharides in raw sugars from five countries on their c/b axis ratio. The author states that starch, silica and phosphate had no statistically significant effect on the c/b ratio.

Morel du Boil (2005) has investigated the effects of dextran in South Africa. There is no doubt that it is produced during post-harvest cane deterioration. It increases viscosity thus slowing down crystallisation and affecting sugar recovery negatively. There is also the possibility of slower crystallisation caused by habit modification, although most of this stems from the oligosaccharides also formed during cane deterioration. It is therefore difficult to separate the effects of the different oligo- and polysaccharides formed during post-harvest cane deterioration when industrial materials are used to study crystallisation.

Non-sucrose species which cause crystal elongation

Smythe (1971) notes that the ranges of supersaturation, stirring and temperature normally encountered in pure sucrose crystal growth have only minor effects on the relative growth rates of the various pairs of faces. These effects are generally insufficient to cause a marked change in the habit of the sucrose crystal.

Raffinose, probably because of its presence in beet, was involved in many ER experiments during the 1960s. Smythe showed that with raffinose the growth rate approached a second-order dependence with supersaturation. Secondly, the inhibition caused by this non-sucrose was very much greater when compared to other species at the same concentrations. It was concluded that raffinose retarded the rate of step movement on the (100) face by adsorption due to its ability to form strong fructose-fructose bonds on the surface, whereas other substances did not.

The general findings of these early studies are that different pairs of faces of the sucrose crystal have inherently different growth rates due to the nature of the bonding of the sucrose molecules at these faces; specific non-sucrose species can significantly alter the relative growth rates of these pairs of faces leading to changes in the crystal shape. Inorganic salts and invert sugar do not have marked effects on these relative growth rates, but certain oligo- and polysaccharides produce significant changes.

Kamoda *et al*. (1968) investigated the relationship between the crystal shape of raw sugars and the concentrations of gums, starch, silica, phosphate and oligosaccharides contained therein. Reworking his data shows that:

i) The gums and oligosaccharides concentrations are highly correlated; and

ii) The c/b elongation ratio correlates only with the oligosaccharide (OL) concentrations and with the origin of the sample.

Equation1 was obtained

c/b ratio = 0.827 + 0.000275xOL - 0.1003xC1……....(E1),

where C1 is a dummy variable representing two sets of statistically different sources of the sugar. The adjusted R^2 value is 0.92 for 23 sets of information and all the variables are statistically significant at 5 %. A plot of c/b calculated from Equation 1 against the measured values shows a tight fit and no evidence of bias. The c/b axis ratios average 1.01, with a maximum of 1.67 and a minimum of 0.87; the OL minimum, maximum and average concentrations (mg/kg Brix) are 210, 2 960 and 750 respectively.

Since the concentrations of gums and of oligosaccharides are correlated it is unclear if only one or both species are involved. None of the other non-sucrose species show statistically valid effects on the c/b axis ratio. Kamoda *et al*. therefore show that fractions rich in oligosaccharides (or in gums) are related to ER. In addition, the data show that the origin of the sugar can have a statistically significant effect on ER.

Cremata *et al*. (1983) studied the impacts of different polysaccharide fractions produced during post-harvest cane deterioration on crystal habit modifications. This was prompted by conflicting reports in the literature about the impact of dextran in deteriorated cane on the shape of crystals. The authors extracted various fractions from the juices and carried out laboratory crystallisations under reproducible conditions. Again, there are statistically significant correlations between the concentrations in the different fractions: the concentrations of dextran and those of low molecular weight species in their respective fractions are highly correlated. There is, however, a highly statistically significant relation between the low molecular weight fraction, prepared to contain the oligosaccharides, and the c/b ratio as shown in Figure 4. The correlation between the dextran fraction and ER is weaker. The authors conclude that it may be oligosaccharides in the low molecular weight fraction that affect the c/b ratio.

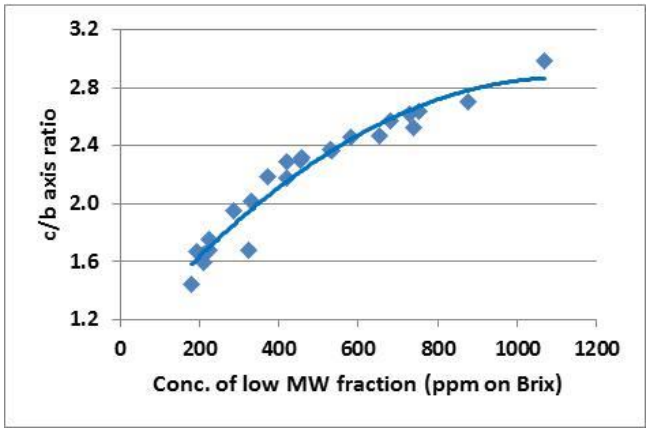

Figure 4: Impact of the concentration of low molecular weight species on ER

Morel du Boil *et al.* (1970) isolated a number of trisaccharides present in refinery low purity molasses. Raffinose and kestoses were identified. This pioneering work allowed further investigations on the impact of these species on the c/b ratio.

In 1985, Morel du Boil used molasses from a third recovery boiling as a source of concentrated elongating constituents. Under controlled laboratory conditions increasing quantities of this molasses were added to pure sucrose solutions so that the sucrose/water (S/W) ratio remained constant at 3.075 while the non-sucrose/water ratio (NS/W) increased from 0.05 to 0.60. The author plotted the c/b axis ratio against NS/W to confirm that higher concentrations result in increasing crystal elongations, as shown in Figure 5.

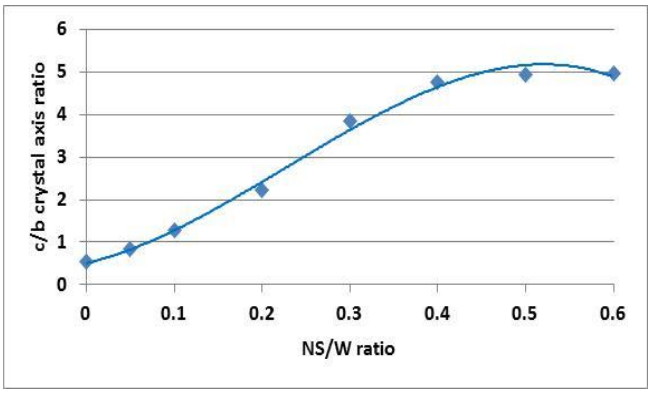

Figure 5: Influence of the concentration of non-sucrose species from refinery molasses on the c/b ratio

This work also confirms the effect of increasing non-sucrose concentrations on the crystallisation rate of sucrose, as shown in Figure 6.

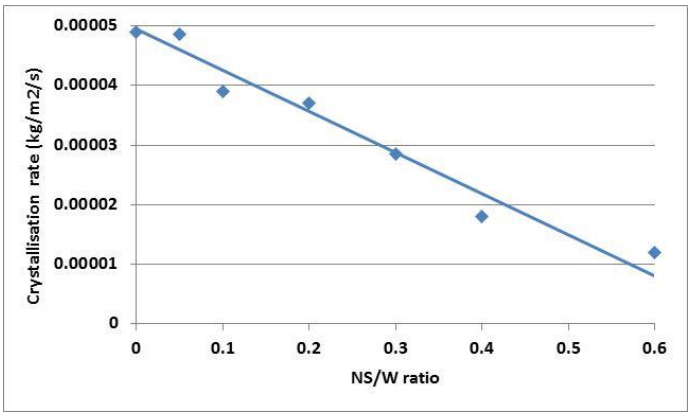

Figure 6: Influence of the concentration of non-sucrose species from refinery molasses on the crystallisation rate of sucrose

In 1991, Morel du Boil developed reproducible laboratory methods for measuring crystal growth rates and crystal shapes, under closely controlled conditions not dissimilar to those prevailing in a factory. Fractions containing the oligosaccharides were isolated and their effects on crystal shape assessed. The results are summarised in Table 2.

Table 2: The impact of fractions from a refinery molasses on ER

Fractions	c/b axis ratio
Sucrose	0.54
Refinery molasses	1.33
Polysaccharides	0.51
Mono-, di- and oligosaccharides	1.25
Mono- and disaccharides	0.59
Oligosaccharides	1.11

Finally, small amounts of reasonably pure individual oligosaccharides were obtained and it was possible to conclude that the extensive sucrose crystal c-axis elongation observed in refineries was attributed mainly to the presence of oligosaccharides containing a fructose moity. The polysaccharide components were found to exert little influence on ER at the concentrations encountered.

Morel du Boil therefore finally answered the question raised by Cremata *et al*. in 1983.

Mechanisms for the transfer of non-sucrose species into the crystal

Mechanisms for the transfer of non-sucrose species into the sucrose crystal is a complex subject. Many authors (e.g. Smythe 1971; van Hook 1981; Lionnet 1987, 1988, 1998; Mullin 1993) stress the importance of the sucrose crystallisation rate on the transfer of non-sucrose species into the sucrose crystal.

Smythe summarises the information available in 1971. He considers the following factors:

Sucrose supersaturation
Crystal growth from solution involves the mass transfer of molecules of the solute from the bulk of the solution to sites on the growing crystal surface where they are incorporated into the crystal lattice. Crystal growth rate might therefore be controlled by the mass transfer process, by the surface incorporation process or by a combination of both. Mass transfer (i.e. transport or diffusion) and surface incorporation (i.e. kinetic or interface step) are relevant. Concentrations of sucrose and of non-sucrose affect diffusivities and viscosities, both of which impact on transport and kinetics.

Effect of temperature
Over the usual temperature ranges studied experimentally, neither mass transfer nor surface incorporation can be neglected in its contribution to the overall crystal growth rate and therefore to the transfer of non-sucrose species into the sucrose crystal.

Relative velocity of crystal and solution
A better understanding of mass transfer is required since it is affected by velocity, viscosity, density, diffusion coefficient and crystal size.

Nature and concentration of non-sucrose species in solution
Many non-sucrose species decrease the crystal growth rate when allowance is made for their effects on the solubility of sucrose. Thus, at a constant supersaturation, increasing non-sucrose concentrations reduce the growth rate.

Nature of the crystal surface
The influence of the condition and nature of the sucrose crystal surface are also relevant.

The effect of non-sucrose species on the growth rate can be divided into two basic categories: those which predominantly affect growth rate by reducing the rate of mass transfer through increased viscosities and lowered diffusion coefficients, and those which reduce the rate of the surface incorporation step by being adsorbed on specific surfaces of the sucrose crystal. This latter category of non-sucrose species also produces marked changes in the shape of sucrose crystals by altering the relative growth rates of the different pairs of faces.

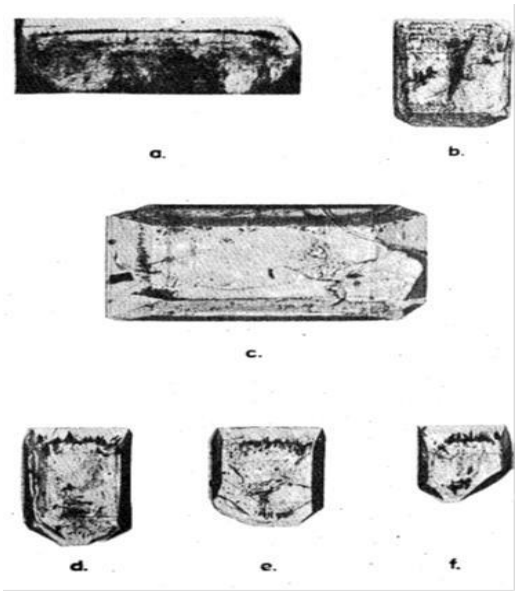

Figure 7: Enclave inclusions

Mackintosh and White (1968, 1969), and Guo and White (1983, 1984) investigated enclave inclusions in sugar crystals formed readily by partly dissolving a crystal and then regrowing it. These inclusions are formed by overgrowth of the surface irregularities (etch pits or channels) caused by the erosion or dissolution stage. The authors give clear photomicrographic evidence for this type of mechanism, as shown in Figure 7. They are also formed industrially as the result of alternate periods of undersaturation and supersaturation in a pan.

Photomicrographs of crystals obtained from the crystallisation of refinery liquors spiked with selected non-sucrose species and produced in a laboratory pan operating under conditions similar to those found in a carbonation/ion exchange refinery are shown (Lionnet, 1998) in Figure 8. Although the photomicrographs are less clear than those of Figure 7, there is no evidence of enclave inclusions.

Figure 8: No evidence of enclave inclusions

Under steady crystallisation conditions where growth rates are slower than those used by Mackintosh and White, and by Guo and White, enclave inclusions are not usually formed. This conclusion is supported by Van Hook (1981) and Wright (2002). However, in raw house operations where B- and C-magmas may be used to produce raw A sugar, the magmas are often conditioned in the A-pan. The conditioning process, which involves partial dissolution followed by regrowth, may well cause enclave inclusions.

Van Hook (1981) notes that non-sucrose species in sugar crystals may occur in three ways:

1. They may be contained in mother liquor which has not been completely removed. This is particularly evident in the marked improvement in colour of ordinary raw sugar upon affination;
2. Some (such as oligosaccharides) are bound to the crystal surface by adsorption forces and found throughout the crystal. These forces may be weak or strong chemi-sorptive ones; and
3. If the growth is rapid mother liquor or even suspended solids may be mechanically trapped within the growing crystals as enclaves.

Point 1 above stresses the importance of distinguishing between non-sucrose species held in the "film" around a normal sugar crystal and those held inside the "crystal" itself. When crystalline sugar is separated from massecuites by centrifuging the amount of mother-liquor left in the film depends on many conditions (speed of rotation, amount of wash liquid, crystal size distribution) during the centrifuging process. These conditions cannot be controlled with the precision required to always leave the same amount of mother-liquor on the crystal. Since the concentration of non-sucrose species in the film can be 100 times greater than in the crystal itself, it is essential to develop a technique which results in a reproducible film removal. Michael and Thelemaque (1984) investigated various laboratory affination techniques and developed a procedure which met the reproducibility criterion for refined sugars produced in South Africa (Lionnet, 1998).

Lionnet (1998) investigated mechanisms for the transfers of K^+, Li^+, Ca^{2+}, Ni^{2+}, ICUMSA colour, and starch, using a laboratory pan operated under crystallisation conditions found in a carbonation/ion-exchange refinery and the affination technique mentioned above. The author concludes as follows:

1. The transfers of colour, potassium (K^+), lithium (Li^+), calcium (Ca^{2+}) and starch did not take place through a mechanical inclusion of droplets of mother-liquor.

2. The concentrations of the selected non-sucrose species in the crystal were linear functions of their respective concentrations in the feed liquor. The transfer rates were very different for the different non-sucrose species; the trends were: Starch >> colour > Ca^{2+} > K^+ > Li^+

3. Evidence that the starch present inside the crystal had a molecular arrangement somewhat different to that of the starch present in the feed-liquor, was obtained.

4. The results obtained suggest that the non-sucrose species, except starch, are distributed throughout the crystal by an interfacial breakdown process involving the inclusion of mother liquor. This interfacial breakdown may not be the sole mechanism.

5. The author added that the interfacial breakdown model did not fit the results obtained with starch, an important non-sucrose species in cane sugar.

The observation in point 5 above is not unexpected in view of very different effects that various non-sucrose species can have when they are present during the crystallisation process. No evidence of crystal elongation was obtained in Lionnet's work; this indicates that the non-sucrose species tested fall in the group which does not severely affect the growth rates of different faces of the crystal. Starch is known to modify the properties of calcium carbonate crystals during refining and to affect filtration processes very negatively (Murray *et al*., 1976). It could therefore be transferred in the sucrose crystal through a different mechanism.

Doherty and Wright (2001), and Wright (2002) used a different approach to investigate mechanisms for the transfer of non-sucrose species into sugar. They developed and validated a pan stage model, based on industrial data from a number of factories, which incorporated expressions for the partitioning of species such as starch, dextran, ash and colour.

The colour and other non-sucrose species in sugar were assumed to be associated in three different physical locations in and around each crystal:

1. Species co-precipitated in the crystal lattice;

2. Species in the included droplets of molasses (enclave inclusions) held within the crystal; and

3. Species in the molasses film on the crystal surface.

The quantity of molasses film contained in sugar was estimated from a mass balance calculation using the purities of the sugar, crystal and molasses. In the model, data entry included values for the ratio measured species/total non-sucrose species in the evaporator feed syrup, for the species-partitioning coefficient, and for a super-concentration ratio, SCR, for the species. For colour, there is also a value to quantify the percentage increase in colour through each of the three industrial strikes.

This is a new approach based on industrial rather than laboratory scale data, with no sugar affinition and dealing with A, B and C sugars.

Doherty and Wright (2001), and Wright (2002) used a simple method for determining the partitioning coefficient (the ratio of non-sucrose species to sucrose in the crystal to the ratio of non-sucrose species to sucrose in the feed syrups) for each non-sucrose species which was computed directly from the results. The partition coefficients varied widely, depending on the specific non-sucrose species, as shown in Table 3.

Table 3: Partition coefficients from industrial data

Non-sucrose species	Partition coefficient
Potassium	<0.0
ICUMSA colour pH 4	0.011
ICUMSA colour pH 7	0.007
ICUMSA colour pH 9	0.005
Starch	0.090
Dextran*	0.150

*No specific properties given

This approach allowed the authors to estimate the impacts of various process changes on the pan floor on sugar quality. A base case was chosen to suit typical operating conditions under the Australian three-massecuite pan stage system. Trials were then carried out with a range of modifications made to this typical scheme. The results are shown in Figure 9, where the case numbers are 1 (base case) to 8.

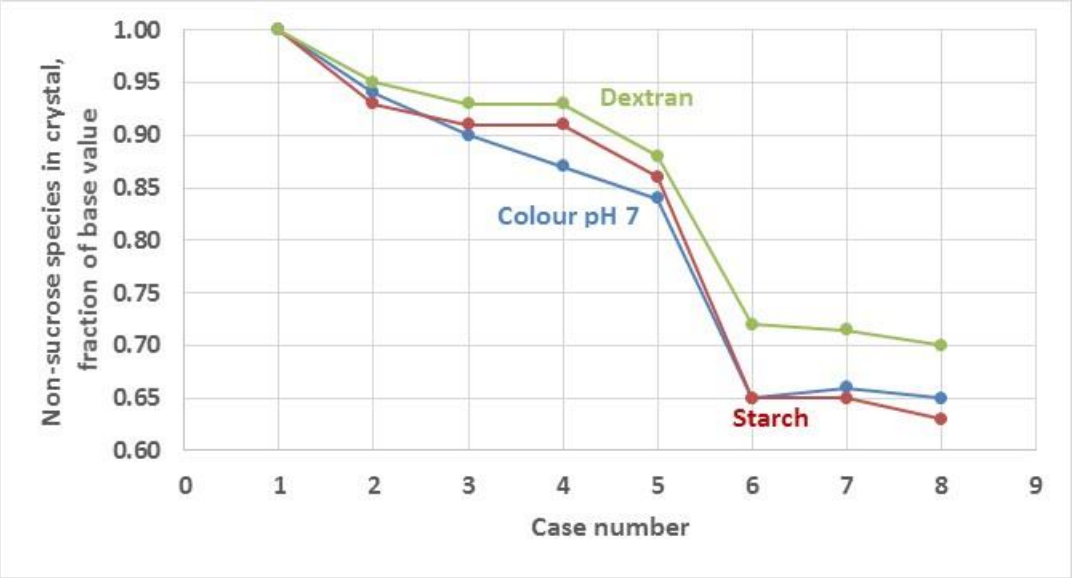

Figure 9: The effect of different crystallisation schemes on the quality of the sugar (No specific properties given for dextran)

ICUMSA colour, starch and dextran follow the same improvement trends compared to the base case. The results indicate that relatively small improvements in quality, of the order of 4 % to 8 % reduction of non-sucrose species in sugar, and 12 % to 15 % reduction in the crystal, are possible for low cost techniques. Larger improvements in quality, about 17 % to 22 % reduction of the non-sucrose species in the sugar, and 29 % to 35 % reduction in the crystal, need schemes which require more heating steam, more high-grade pan and centrifugal capacity, and extra vessel capacity for high-grade seed. The authors use local financial information to investigate the impacts of the different cases in terms of costs and revenues.

These results are remarkable; they show how industrial crystallisation data can be modelled to control both the film and crystal qualities and to estimate the financial aspects of the operations.

Discussion

Crystalline sugar is still one of the major products of the sugarcane industry. Understanding and controlling the crystallisation process of sucrose must therefore be one of the most important technological aspects of the industry. The work reviewed here involves two experimental approaches, both aimed at improving the quality of the sugar:

Laboratory or pilot plant investigations of the crystallisation of sucrose and of the impacts of undesirable non-sucrose species which affect the qualities of the film around the crystal and of the crystal itself, and

Industrial investigations involving mathematical models to provide solid industrial data about film and crystal qualities. Financial aspects are included.

There is no doubt that both approaches are essential. The first provides fundamental data required for the basic understanding of the sucrose crystallisation process under well controlled experimental conditions. The second applies these basic concepts for investigating industrial crystallisation processes to produce a sugar quality which maximises financial returns.

At present it appears that more work has been done using the first approach.

There are, however, other research directions which are becoming more and more relevant for the sustainability of the industry. The first is to use both approaches to investigate the possibility of using co-crystallisation processes to produce high value by-products from sucrose. Here the goal is not to prevent or reduce the incorporation of non-sucrose species (usually called impurities in classical literature) but, on the contrary, to increase and control the concentrations of selected species incorporated in the sucrose crystal.

The second direction is to re-start investigating the possibility of producing "refined" sugar directly from cane sugar factories. Improving the clarification process and investigating decolourisation processes, together with improved crystallisation techniques should be investigated at laboratory and at pilot plant scales.

Conclusions

The ability of sucrose to form a pure crystal under industrial conditions has been used for centuries to make sugar; 171 million tonnes were produced worldwide in 2016/2017 (Anon, 1). The sugarcane plant converts solar energy into carbohydrates efficiently. Its cultivation and utilisation are well understood and managed.

It was suggested that the sucrose crystal, obtained from an established agricultural industry, could be utilised industrially outside of the food sector. The possibility of producing white sugar directly should also be re-visited. Obviously, these projects will require extensive technical and financial investigations.

It can be concluded that the answer to the question in the title is a clear "Yes".

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