SUCROSE LOSS IN THE MANUFACTURE OF THE CANE SUGAR

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ABSTRACT

The loss of recoverable sucrose in sugarcane harvesting, raw sugar manufacture and sugar refining is a serious economic problem to the entire sugar industry. Chemical and microbial destruction of sucrose begin sometime even before harvesting, and continue through factory and refinery, and during storage of raw and refined sugars. In this paper, the various causes of sucrose loss, including inversion, thermal destruction, alkaline degradation, and microbial action are described, and factors responsible for pathways of sucrose destruction are discussed. Problems other than sucrose loss, such as colorant formation and microbial polysaccharide development, are investigated. The quantities of sucrose loss under various conditions in process, and methods for the estimation of sucrose loss are discussed. An overall picture of sucrose loss, the reasons and results from field to factory and refinery is presented.

INTRODUCTION

The loss of sucrose, at all stages from sugarcane in the field to refined sugar in the bag, is a serious economic problem to the sugar industry. The overall loss, from preharvest to final product, is estimated at between 5% and 35%, varying with geographical and technological criteria. At this time, when increasing costs and decreasing availability of land are worldwide problems, it is of great benefit to the industry to cut these losses to the lowest possible levels.

A considerable amount of lost sucrose is recoverable through readily available measures; of this amount, certain losses, which may initially seem easier to maintain than to recover, lead to increasing complications in subsequent processing. In addition to the loss of recoverable sucrose per se, and the potential income thereby lost, technical problems are created by the products of chemical, microbiological and thermal sucrose loss.
Microbiological deterioration, in field, factory and refinery, produces polysaccharides, which decrease extraction and crystallization yields, increase viscosity and lower throughput rates, and also produce color and acid forming compounds. Chemical and thermal sucrose breakdown also lower pH and produce colored compounds and color precursors. All of these non-sucrose compounds must be removed in processing, and all have a melassigenic effect, i.e., they carry sucrose with them to molasses, which increases the loss of recoverable sucrose. The costs of additional processing to remove the degradation products increase the economic burden of sucrose loss.

A critical analysis of the causes of sucrose loss is essential to identify the areas where losses may be cut back, and sucrose yield increased. In this paper, physical losses will not be discussed. These include direct losses due to poor cane-harvesting techniques, storage or transport of cane or sugar, spillage, sucrose lost to waste waters, waste muds and adsorbents. The causes, and the means of elimination of these losses are well known, though if these latter were better practiced, the extremely high rates of losses in some areas could be reduced to a more acceptable figure. The various types of chemical, thermal and microbiological loss, their effects and remedies will be discussed.

MICROBIOLOGICAL CAUSES OF SUCROSE LOSS

Dextran Formation

The major microbiological cause of sucrose loss is the formation of dextran by _Leuconostoc mesenteroides_, primarily, by _L. dextranicum_, to some extent, and by other slime-forming bacteria (Imrie and Tilbury12, Moroz12). Apart from the loss of sucrose to dextran formation, dextran causes an increase in solution viscosity which creates problems in evaporators and vacuum pans. Dextran also causes elongation of the sucrose crystal, along the C-axis (the so-called needle-grain) which makes purging of the centrifugals difficult and increases losses to molasses and wash water. Dextran also gives artificially high pol values, since it is dextrorotatory.

Dextran is a general name for polysaccharides that are polymers of glucose. The straight chains contain α-1, 6-linked glucose moieties, with α-1,3 and α-1,4 linkages at the branching points. At least 50% to 60% of the linkages must be α-1,6 to define a dextran. There is a wide range of molecular weights, from a few thousand up to several million.

The degree of branching depends on the strain of bacteria that produced the dextran (13), and many of the differences in properties of various dextrans are due to these structural differences. Not all strains of _L. mesenteroides_ will grow in sucrose solution, and of those that will, none will synthesize dextran over 60°C, or at high Brix.
Dextran is synthesized from sucrose by the enzyme dextranucrase shown in Fig. 1, where a linear chain is represented. Although the variously branched dextrans behave in similar ways and cause similar problems in sugars, the variation in molecular structure and molecular weight make quantitative analysis confusing and difficult. The question of analysis (Coll et al.6,6), has caused confusion in the literature with regard to levels of dextran that bring about problems in the refinery. Haze-forming tests are generally used, with some sort of alcohol precipitation. However, if interfering substances (e.g. starch, protein) are not eliminated (Meade and Chen16), the high haze levels observed will not accurately reflect the dextran levels present that cause needle-grain and other problems to develop.

![Growing linear dextran chain](image)

*Figure 1. Synthesis of dextran from sucrose*

It will be noted in Fig. 1 that for every molecule of sucrose consumed, only the glucose portion is used in dextran formation, while a fructose moiety remains. This fructose subsequently decomposes into organic acids and colorant compounds, causing a decrease in pH, which in turn increases the rate of inversion, leading to further sucrose loss, and further formation of acids and colorants from the newly formed invert sugar. In addition to the fructose breakdown products, byproducts of the enzymic dextran formation are acetic and lactic acids, mannitol, and probably ethanol (Hirschmuller10), all of which enhance the problems of pH drop, colorant formation and increased sucrose loss to molasses later in processing.
To calculate losses from dextran formation, an average 25% yield of dextran is assumed (Hirschmuller10). Levels of dextran found in raw sugars are shown in Table 1, with the respective sucrose losses incurred to produce these dextran levels, and the amounts of fructose and acids (about 30% yield) formed. Dextran levels of 500 ppm (0.05%) are on the high side of average and above this level needle-grain formation will be a problem. These are levels found by a detailed haze analysis, with interferences eliminated (Coll et al5,6)

**TABLE 1.** Dextran levels and sucrose loss in raw sugars

<table>
<thead>
<tr>
<th>Dextran, % (lb/ton sugar)</th>
<th>Sucrose lost</th>
<th>Fructose formed (lb/ton sugar)</th>
<th>Acids formed</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05</td>
<td>0.20 (4.4 lbs)</td>
<td>2.2 lbs</td>
<td>0.07 %</td>
</tr>
<tr>
<td>0.1</td>
<td>0.40 (8.81 lbs)</td>
<td>4.4 lbs</td>
<td>0.14 %</td>
</tr>
<tr>
<td>0.5</td>
<td>2.0 (44 lbs)</td>
<td>22 lbs</td>
<td>0.7 %</td>
</tr>
</tbody>
</table>

It must be emphasized that these amounts of sucrose represent only those lost directly to dextran formation. Three to five times these levels may be lost later in processing, because of the other organic materials formed conjointly with dextran.

*Additional microbiological causes of sucrose loss*

In addition to dextran-forming organisms, many other bacteria, fungi and molds exist in cane fields, factories and refineries (Meade and Chen15, Skoel et al26). Damaged, including freeze-damaged cane, burnt cane and chopper-harvested cane are particularly susceptible to growth of yeasts and bacteria. Especially noticeable, because of their end products found in sugars, are yeasts of the *Saccharomyces* species, which produce ethanol, and the butyric-acid producing *Clostridium thermosaccharolyticum*. In addition to consuming sucrose, these organisms have end products that create more processing and marketing problems.

The sucrose loss caused by microbial action can be minimized or eliminated by proper handling and sanitation. These points are amplified in a later section of this paper.

**THERMAL SUCROSE LOSS**

The breakdown of sucrose by heat, to form polymeric and/or colored compounds occurs during storage of sugars, juices and syrups; this is generally known as caramel formation. The reactions that take place are essentially the same in solid sugars and in process liquors, since most of the breakdown takes place in the
molasses or syrup coating of the crystal, where there is sufficient water for the chemical reaction to occur. The fact that sugar losses on storage increase with increasing temperature of storage is well known.

Fig. 2 shows the pol of stored raw sugars of various types with increasing temperature (Muro et al.19,20, Priester22). In extreme cases (Priester22), where sugar was piled at high temperature, as much as five degrees of pol loss have been observed in five days. This loss was not all due to thermal decomposition; chemical decomposition, of which thermal decomposition is a special case, is also responsible. The pol drop is accompanied by color formation; in fact it is preceded by color formation, because in either syrup or stored crystal sugar, increase in color is noted before sucrose loss is observable. It must be remembered that pol drop can be a deceptive measure of sucrose loss. If sucrose is first inverted, and the fructose and glucose so formed are further reacted at unequal rates, the pol can appear artificially high, if fructose disappears more rapidly than glucose, or artificially low, if glucose disappears more quickly than fructose. The former is the usual case in refineries; the latter in raw sugar factories (Clarke and Brannan4, Morel du Boil and Schaffler17).

**FIGURE 2.** Pol loss of sugars on storage at different temperatures. Numbers on curves indicate number of literature reference
It is well known that an increase in color indicates a loss of sucrose, but every few quantitative estimates have been made to relate color formed to sucrose loss, because there is such an extremely complex and diverse family of color-forming reactions, and such a wide range of intensity or degree of color in the reaction products. The majority of the sucrose decomposition reaction products are not, in fact, colored.

A very approximate estimate (Fleming et al.) that 20% of glucose ends up as colored compounds gives a factor of five, for molecules of sucrose lost per every six carbons of colorant compound formed. When the mellassigenic factor of three to five molecules of sucrose lost to molasses with each molecule of color is considered, then for an average colorant molecular weight of 600, where 40% of this molecular weight is carbon:

\[
\frac{5 \times 600 \times 4}{72 \text{ (mol. wt. of 6 carbons)}} + (3 \text{ to } 5) = 19 \text{ to } 22 \text{ molecules of sucrose}
\]

have been lost.

A quantitative value for color in refined sugar of 3 ppm (Smith27) gives an estimate of 300 ppm in raw sugar; this agrees quite well with a value of 1% colorant in mill syrup solids (Smith et al.28). A 50 Brix syrup would contain 0.5% colorant, and the raw sugar from more than, 0.05%, or 500 ppm. So, on a weight basis, one ton of raw sugar is estimated to contain 0.5 kg, colorant. At the above mentioned molecular weight of 600 g and the ratio of 19 to 22 molecules of sucrose lost for each molecule of sucrose formed, this gives as an extremely general estimate, 15.8 to 13.3 molecules or 5.4 to 6.3 kg sucrose per ton of raw sugar (0.5% to 0.6%) lost in the formation and subsequent removal of this colorant. This approximation ignores the facts that (1) some color comes from plant sources, and is not manufactured from sucrose; (2) there is a wide molecular weight for colorant, from less than 100 to several thousand; (3) a great deal of colorant is removed by absorbents and clarifying agents and does not go to molasses; (4) colorant is continually being formed throughout processing; (5) since high molecular weight color is selectively occluded in the crystal (Roberts and Godshall24), a higher proportion of low molecular weight color goes to molasses and (6) not all sugar color is formed through glucose.

This colorant includes not only that made from thermal sucrose loss, but also that from chemical decomposition, which is more properly discussed in the following section.

CHEMICAL SUCROSE LOSS

The chemical degradation of sucrose includes thermal degradation to caramel-
type products as discussed above. There are two general divisions of chemical degradation: those under acidic conditions and those under basic conditions. The optimum pH for sucrose stability is between 8 and 8.5.

**Acidic Conditions**

The initial reaction is inversion of sucrose to glucose and fructose. In cane juice, this can be catalyzed by invertase enzyme and in any environment by low pH. Invertase enzyme is inactivated by an increase in temperature to 80°C or more, and acid inversion is inhibited by raising the pH above 6. There is always some invert present, and these reducing sugars deteriorate further through many series of reactions to form colorant compounds, colorant precursors, and non-colored organics, with yet again the attendant problem of the melassigenic effect of non-sucrose compounds (Feather and Harris, Fleming et al., Parker).

The rate of inversion has been the subject of many studies (Clarke and Brannan, Goodacre and Coombs), using either measurement of invert formed (Barnett and O'Connor, and Parker) or of sucrose lost (Clarke and Brannan, Parker), or acid consumed. There has been some controversy about rates of inversion depending on the experimental method used to follow the reaction. The rate is generally considered to depend on temperature and the concentration of hydrogen ion, sucrose, and water.

The invert sugars are comparatively stable in acid solution, but there is continual color formation due, in part, to oxidation through several intermediates to 5-hydroxymethylfurfural (HMF) and to its colored decomposition products. Other pathways of color formation in acid solution include condensation of HMF with amino acids to form nitrogen-containing brown compounds, and the condensation of glucose with amine compounds, to form a product which, after undergoing an Amadori rearrangement, is polymerized to form the familiar brown Maillard reaction products, or melanoids (Ramchander and Feather). These color problems at low pH occur upon destruction of sucrose in cane juice, or anywhere else in processing where there is a localized temporary area of low pH.

**Basic Conditions**

Sucrose degradation under basic conditions is not as serious as that under acid conditions from the point of view of direct sucrose loss, but it is more serious from the point of view of color formation, with the increased processing and loss to molasses thereby entailed. Color formation under basic conditions is an extremely complex field.

Alkaline degradation of sucrose to reducing sugars is probably the first reaction step (Shaw et al., Whistler and BeMiller), although there is some contention that glucose and fructose are not found in base hydrolysis (Parker).
The major products of alkaline degradation are organic acids, especially lactic acid—which tends to lower pH—and polymeric colored products, either melanoidins, or compounds formed through a series of saccharinic acids, a series of reactions that is catalyzed by calcium ions (Carpenter and Roberts2, Hodgell, Parker21).

The presence of reducing sugars in an alkaline medium is the optimum for color formation, i.e., the worst situation for processing. This situation is obtained when cane juice is allowed to remain at acid pH for some time before the pH is raised. In this case, the lime is said to destroy the invert; it does, but the destruction reactions create color. In addition, invert in solution will react with amine compounds, from protein breakdown, to form melanoidins. Excess lime will also catalyze breakdown of sucrose to organic acids (Montgomery17).

**SUMMARY**

In summary, the stages of sugar production are considered, with regard to the possible problem areas for sucrose loss, and measures that may be taken to prevent those losses.

*Cane Harvesting*

The most serious losses here occur when cane is allowed to become stale before being taken to the mill. Invertase enzyme inverts sucrose, and the pH drop which begins on cutting—or when cane is damaged—also causes sucrose to invert. Organic acids produced from invert degradation further decreases the pH. *Leuconostoc mesenteroides* infection and production of dextran proceed most rapidly under acid conditions, using up sucrose quickly. Dextran production rate increases with increasing ambient temperature and wetness. The amount of dextran present in chopper-harvester cane has been shown to increase from effectively none to 25% on Brix, when the cane is held for 24 hours (Keniry et al14).

The remedies here are apparent: to minimize burn-to-acid and cut-to-crush times as much as possible. It is often asked if there is not a biocide that can be used to get rid of *L. mesenteroides*. The organism is so prevalent—in most soils, air and water around the world—that such a biocide would have to be used in impractical-ly wide application. Efficiency in harvesting prevents are growth of the organisms, and conserves the sugar lost to its growth.

Losses of sucrose in this area can range from 5% to 25% and even higher; where cane is extremely deteriorated, it may not be possible to make sugar at all, but only molasses.

*Raw Sugar Mill*

Deterioration of cane in the mill yard can lead to severe sucrose loss. (Coll
et al\(^\text{5}\), but here again the remedy is obvious: efficient harvesting procedures combined with minimum storage times for cane, under optimum conditions of sanitation.

Storage of cane juice is another potential cause of severe loss, particularly for any holding period before the pH is raised. Over-compensation for pH drop by overliming only increases the problems of chemical sucrose loss and color formation. Storage of juice or syrup at any stage at elevated temperatures affords potential sucrose loss. An ever-present problem is dextran formation, which can be prevented only by good housekeeping, minimum storage of low Brix solutions and use of bactericides.

In storage of raw sugar, and in transport, chemical or thermal sucrose loss is incurred when the sugar is stored at too high a temperature, i.e. if it is not cooled to 100°F before piling. The drier the stored sugar, the less deterioration will occur, but the low temperature is the most important factor\(^{29}\).

Losses here, other than physical losses such as sucrose to bagasse, generally run from 3% to 80%.

**Cane Sugar Refinery**

In most refineries, the pH of liquors and syrups is generally between 7 and 9, a stable range for sucrose. However, chemical sucrose loss occurs in stored sweetwaters, once again by the self-catalyzing destruction of invert to organic acids. Recent studies (Clarke and Brannan\(^3,4\), using high pressure liquid chromatographic techniques, indicate that there is some chemical sucrose loss in clarification, particularly during carbonation, where invert is formed and destroyed within the carbonation system. Other recent studies, using radioactive tracer techniques Goodacre\(^9\), show sucrose loss of 0.004% to over 0.04% in neutral or alkaline pH liquors. There is always chemical, including thermal loss when sucrose is held at high temperatures, even in high Brix solutions at neutral pH (Clarke and Brannan\(^3\)). The potential for dextran formation is still present, particularly, in low Brix solutions and low purity sweetwaters. Chemical, thermal and microbiological losses are generally kept below 2% in modern refineries.

**CONCLUSION**

In this paper the nature and reasons for sucrose loss, by thermal, microbiological and chemical means, have been followed from the cane field through the refinery. Particular emphasis has been placed on control of losses because of polysaccharide formation and incorrect pH.
REFERENCES


PERDIDAS DE SACAROSA EN LA FABRICACION DE AZUCAR DE CAÑA

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RESUMEN

La pérdida de sacarosa recuperable durante la cosecha de caña, la fabricación de crudo y la refinación constituye un serio problema económico en toda la industria azucarera. La destrucción química y microbiológica de la sacarosa empieza a veces antes de la cosecha, y continúa en la fábrica y la refinería, así como durante el almacenamiento del azúcar crudo y la refinada. En este trabajo se describen las varias causas de pérdidas de sacarosa, incluyendo inversión, destrucción térmica, degradación alcalina y acción microbiana y también se discuten los factores que conducen a la destrucción de sacarosa. Se investiga, además, problemas distintos a la destrucción de sacarosa como son la formación de colorantes y el desarrollo microbiano de polisacáridos. Se discuten las cantidades de sacarosa pérdidas bajo distintas condiciones del proceso así como métodos para estimar estas pérdidas. Hay una referencia especial a métodos de análisis por cromatografía gaseosa y líquida para azúcares, colorantes y polisacáridos. Se presenta un cuadro general de pérdidas de sacarosa, sus causas y resultados, desde el campo hasta el engenio y la refinería.