OBSERVATIONS ON THE APPLICATION OF CHEMICAL TECHNOLOGY IN THE SOUTH AFRICAN SUGAR INDUSTRY

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Abstract

Two aspects are considered, namely juice clarification and raw sugar refinability. Sugar technology developments are traced as reflected by the Proceedings of the South African Sugar Technologists' Association over the past 50 years. Consideration of both the successes and the failures allows some extrapolation to the future possibilities.

Introduction

At the 10th South African Sugar Technologists' Association's Congress in 1937, Lanyon Paul commented "it is not generally realised that sugar production is a chemical industry, yet the fact is obvious, and are not carbonatation or defecation generally, filtration and crystallization, physico-chemical reactions?". Paul was describing the place of the chemist in the South African sugar industry and complaining bitterly that the value of the professional chemist had not yet been appreciated. The lack of chemical technology had generated "the vicious circle of insufficiency leading to inefficiency".

During the 50 years' existence of the South African Sugar Technologists' Association, the situation has changed dramatically. The quality of South African sugar, and the performance of its sugar industry as a whole has changed from a position near the bottom of the league to a place among the world leaders. It is, therefore, interesting to trace the course of events which have led to this dramatic change, and the Proceedings of SASTA Congresses provide a convenient source of opinions, experimental data and judgments, presented in chronological order. Elucidation of the problems facing the sugar industry has been met with a variety of attempts to find a solution which is both practical and economic. Much can be learned from a re-examination of those attempts in tracing the reasons for success or failure. Such a re-examination offers the possibility of extrapolation, to gain some insight into the future trends in sugar technology.

In the application of chemical technology to South African sugar manufacture, two aspects predominate: juice clarification and the refinability of raw sugar. These two aspects have therefore been chosen for review in this presentation, which refers only to papers published in the Proceedings of SASTA, as listed in the References and shown diagrammatically in Figure 1.

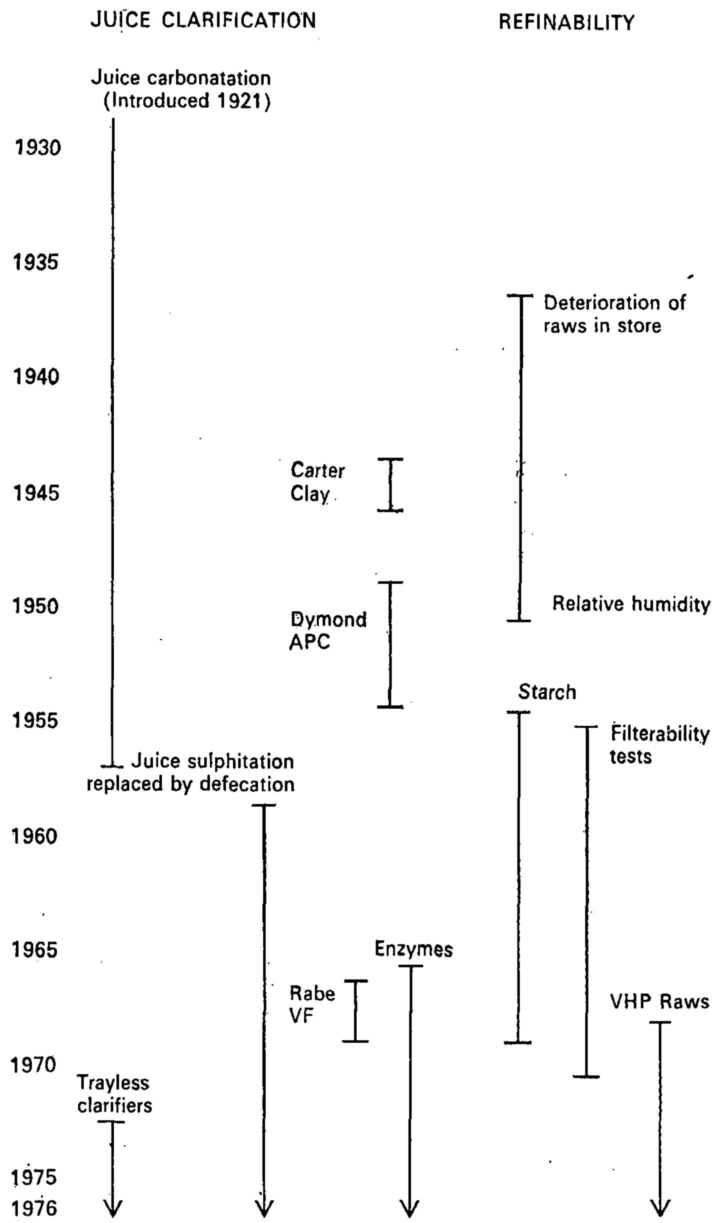

FIGURE 1 Topics discussed in SASTA Cogresses.

Juice clarification

The elimination of juice sulphitation

Fifty years ago the South African sugar industry was using juice sulphitation or juice carbonatation as modified by the experience of the Java sugar industry. In 1946 the Silver Jubilee of the juice carbonatation process in South Africa, Rault[1] reviewed the South African experience and concluded by endorsing the long-held view of Honig that the process was "one of the cheapest, cleanest and most reliable".

Juice clarification was reviewed again in 1950 by Douwes-Dekker[2], who drew attention to the possible need for two stages of clarification and commented on the middle juice and syrup carbonatation processes which had been practised in Java before the war. However, by this time, it was clearly recognised that the advantages of juice carbonatation were more than offset by its high operating cost. Twenty-five years later, today, the feasibility of syrup clarification has been re-established, but the technology is completely different.

In 1956 Boyes[3] described the replacement of juice sulphitation by defecation at Tongaat. Following the experience of the Australian and British West Indian sugar industries, the Double Liming Double Heating technique of defecation was introduced to treat refractory juices and a favourable conclusion was drawn. In the same year Van der Pol[4] described the change from juice sulphitation to a simple defecation process at a further four mills (Amatikulu, Darnall, Felixton and Umfolozi). Abandoning the use of sulphur in the production of raw sugars led to the following advantages:

(1) Saving in chemicals
(2) Saving in labour
(3) Saving on maintenance of equipment
(4) Increase in capacity of evaporators
(5) Simplification of the process lending itself to automatic control.

It may be concluded that the 30th Congress of SASTA sounded the death knell of juice sulphitation in South Africa, at least so far as the production of conventional raw sugar was concerned.

However, it is interesting to note that none of the publications distinguish between the clarification and colour stabilization effects of SO_2. Today, the organic chemistry of the addition complexes of SO_2 with colour precursors is well understood, and the technical effect of traces of SO_2 in juice is easily quantifiable.

Syrup colours in a juice sulphitation factory are only just over half those in a simple defecation factory, not because the SO_2 has removed colour, but because the SO_2 has prevented colour from forming during the heating, clarification and evaporation stages. It is for this reason that, around the world, SO_2 continues to be an essential processing aid in the manufacture of direct consumption white sugar.

New processes

The changeover to simple juice defecation described above followed, more or less, the experience of other sugar-producing areas and it was during this period that several attempts at innovation were made. In 1943 Viger[5] reported the consensus of opinion that simple defecation of Natal juice, without the aid of sulphur, had never been successful. He was concerned to discover why the floc produced in the simple defecation process in Natal juice settled slowly and gave a large mud volume and turbid juices, while the process was obviously successful elsewhere. He reported the discovery of R. A. Carter[6] that a yellow-coloured clay found locally near the Umfolozi Mill could be used as a clarifying agent. The clay process was embodied into the Carter clarifier and the first results obtained by the process were reported by the inventor in 1945. Unfortunately, no further reports appeared and the reasons for the failure of the process could only be surmised. Interestingly enough, the physico-chemical activity of certain clays, especially those of the Montmorillonite type, has been subsequently identified as concerning an ion exchange of calcium with sodium ions at the clay particle surface. There is no doubt that cane juice impurities can, under some circumstances, adsorb very strongly to such clay particles so that the use of this type of clay as a clarifying agent is technically feasible. Generally the clay is too expensive.

In 1948 Dymond[7] reported his studies on various combinations of pre-clarification techniques and discovered what came to be known as the acid pre-clarification process. This required the addition of sulphur dioxide to cold mixed juice down to pH 3,2, at which a floc appeared in the juice. It is of particular interest that Dymond reported "the iso-electric point for the apparent maximum elimination of the reversible colloids was therefore determined and found to be approximately pH 3,2". Some 10 years elapsed before the same value for the iso-electric point in West Indian cane juices was measured electrophoretically using a Mattson cell.

Further papers on the acid pre-clarification process were presented by Dymond in 1952 and 1953[8, 9] and these compared the performance of several types of juice clarification systems. By this time, as described above, the tide of opinion was turning against the use of sulphur in juice clarification. In addition, the settling of the acid pre-clarification floc was too slow to remove the hazard of inversion and, in any case, a second conventional clarification was necessary after conventional liming and heating. The acid pre-clarification process was never adopted commercially but must remain one of the most fascinating attempts to exploit a basic physico-chemical property of cane juice.

The Rabé[10, 11] vacuum clarification process emerged in 1967 as a direct consequence of the recognition of starch as a highly undesirable impurity in South African sugar. The Rabé process was an attempt to separate whole starch granules from mixed juice by carrying out a flocculation and flotation separation at a temperature lower than that at which the starch granules gelatinised. Several South African mills introduced the process, and many papers were presented at SASTA Congresses over the period 1967-1969. Several factors contributed to the discontinuation of the process which was expensive in chemicals and required secondary clarification by conventional juice defecation. One of the most interesting findings reported by Prince[12] in 1968, was that the starch content of juice from the vacuum clarifier at Darnall was as high as 400 ppm on brix, even though the clarification appeared to be operating efficiently as far as juice clarity was concerned.

By this time attention was being turned to enzymatic starch removal and amylases were becoming available at economically attractive prices. The Proceedings of SASTA Congresses showed an almost immediate swing of attention away from vacuum clarification towards the use of enzymes, firstly in mixed juice, making use of the naturally occurring enzymes in the juice but later using bacterial amylases in the mixed juice and in the evaporator syrup. The comparison of vacuum clarification with enzymatic starch removal was the subject of papers by Matic[13] and by Robinson and Jennings[14] in 1969, and these apparently marked the end of the vacuum clarification process.

Future Developments

In 1940 Viger[15] compared the performance of multi-tray continuous settlers with that of intermittent clarification tanks. Since then, apart from brief references in the context of review articles, very little has been reported in the Proceedings until 1973 when Allan[16] reported a study of developments in South African sugar industry plant installations. He reported that retention times in juice clarifiers had been reduced by as much as 50% over the four-year period since 1969, and went on to mention the introduction of the first trayless clarifier at Empangeni. Today more trayless clarifiers of the Australian SRI design are appearing in South African mills and undoubtedly these will be the subject of detailed investigation and performance analysis in future years.

Low retention-time juice clarifiers are totally dependent upon the satisfactory operation of two quite separate flocculation steps. Primary flocculation is brought about by the conventional juice defecation process, involving the precipitation of basic calcium phosphate, while secondary flocculation is caused by the addition of a relatively large dose of polyacrylamide. There is no doubt that under steady state conditions the juice-retention time in the clarifier can be reduced to as little as 10 minutes. Unfortunately, the raw sugar factory does not operate continuously in the steady state, and changes in the flow rate or quality of incoming mixed juice can be reflected by instability in the operation of the clarifier with concommitant carryover of floc.

Yet the concept of primary and secondary flocculation is entirely sound and will undoubtedly be utilised to an ever-increasing extent. It would appear that, at the level of our present understanding of flocculation technology, a juice-retention time of about one hour is a very realistic target and, in many cases, may be achieved by suitable modification of existing clarification equipment. The technology has become possible only through the successful development of polyacrylamide flocculants,[40] particularly during the last 10 years.

The separate treatment of clarifier muds has been referred to by Conijn in 1962,[17] and deserves further comment in the light of recent advances in flocculation technology. Currently, juice clarification and muds thickening are carried out in a single piece of equipment, but the possibility exists that these two operations might be separated.

Basically, solid/liquid phase separation processes are aimed at recovering only one of the two phases. There are four techniques available — sedimentation, flotation, filtration and centrifugation — and it is usually found that each requires a different set of conditions to achieve optimum performance. Thus, in cane juice muds, the conditions of flocculation which give optimum thickening in the bottom of the clarifier are not necessarily those which give optimum filtration behaviour on the rotary vacuum filters.

In the refinery, the introduction of a flotation process for the desweetening of liquor-clarifier scum has eliminated the need for filters in the scum treatment station, and it is possible that similar technology may find a place in the raw sugar factory.

Refinability of raw sugar

Turning now to the second aspect of this presentation, raw sugar quality and its effect on refinability, a first glimpse of the South African problem was given by Du Toit[18] and Hayes[19] in 1937, in their papers on the deterioration and refining quality of raw sugar in storage. The matter was raised again in 1950 by Douwes-Dekker[20] in his discussion on the importance of "relative humidity".

The subject came sharply into focus when overseas customer complaints about the filterability of South African raws reached the level of commercial significance. In 1954 Alexander[21] presented what has become recognised as a classical paper on starch in sugar manufacture, and began the witch-hunt for the cause of the problem. In 1957 Alexander[22] quantified the relationship between raw sugar filterability and several suspect impurities, concluding that wax and silica were more harmful than starch, at least when judged by the filterability test he had used. However, he commented that starch might have a far more drastic effect when the filtering medium has to be precipitated in its presence.

A year later, in 1958, Boyes[23] presented his paper on the partial removal of starch by enzymatic hydrolysis. It is interesting to note that more than 10 years elapsed before this process technology was adopted as standard industrial practice, ousting the new vacuum clarification process as described above.

Interest in filtration-impeding impurities became firmly focused on polysaccharides, which were conveniently divided into two classes, starch and gums[24-27]. Increasing attention was also given to the filterability measurement which had by 1965 become one of the most important routine analyses carried out in S.A. sugar factory laboratories.[28, 29]

Nevertheless, it was in 1965 that Douwes-Dekker, in discussion,[30] commented "probably the most vexing problem of our industry is the quality of our raw export sugars". In fact, the 1965 Proceedings carry three full pages of discussion on the filterability problem and a great deal of important information was exchanged on that occasion. There is something to be learned by re-reading that section even today, 11 years later.

It was no coincidence that from 1966 onwards, improvements in the quality of South African raws began to show up. Jennings[31, 32] reported the Huletts Refinery experience which showed that by 1966/67 two-thirds of their incoming raws had a filterability over 40%, compared with one-fifth in 1963/64.

By 1968 the use of enzymes to hydrolyse starch in cane juice had become well established, as reported by Bruijn and Jennings,[33] and the application of enzymes to evaporator syrup had also yielded promising results.

Various papers have appeared subsequently concerning other factors affecting enzymatic starch hydrolysis[34] and covering the decomposition products of this hydrolysis,[35] indicating that, today, the process of starch removal from juice and syrup is completely under the control of the technologist. The technology has, of course, been adopted almost completely throughout the whole of the South African sugar industry.

VHP raws appeared on the scene in mid-1969[36] and the problems of poor filterability ceased to be discussed in the Proceedings of SASTA after 1972.

One of the most fascinating physico-chemical aspects of this story concerns the measurement of filterability, and the realisation, right from the outset, that different sugar refiners, operating different processes, might take different views about the quality of South African raws. Thus Dawes published a laboratory carbonatation filterability test in 1967[37], while in 1971 Wilkes[38] described the relation between laboratory tests and plant observation in the Huletts refinery carbonatation station. Murray[39] summarised the situation in 1972, separating the effect of suspended solids on the CSR filterability test from the effect of starch on the carbonatation filterability test. Clearly, the phosphatation refiner needs a different raw sugar quality assessment to that required by the carbonatation refiner.

There can be no doubt that similar considerations apply to many other aspects of the sugar manufacturing process, and raw sugar quality assessment should, from a technical viewpoint, reflect many additional factors which affect the refining process. For example, the surface active properties of raw sugars at both the gas/liquid and the solid/liquid interfaces can have a profound bearing on process operations. The aeration of melt liquors, in preparation for flotation clarification in the refinery, is sensitive to changes in air/liquor interfacial tension, which therefore affects directly the amount of floc carryover and the observed liquor filterability. The same physico-chemical property also affects the adventitious aeration and hence viscosity of massecuites in both the raw house and the refinery.

Interfacial tension at the crystal/syrup interface must have some bearing on nucleation and crystal growth of sucrose in the vacuum pan, and much investigational work remains to be carried out on the effect of trace impurities, originating for example in stale cane.

In decolorization processes the composition of the inorganic ash content of the raw sugar undoubtedly affects the performance of bone char and ion-exchange resins, but is probably less important to the function of activated carbon adsorbents. Of course the composition of the colourant itself has a profound effect on the performance of the decolorization station and is well illustrated by the growing use of colour-precipitation processes.

During the last 50 years the raw and refining parts of the cane sugar industry have moved much closer together and the final section of this presentation will consider briefly the trends towards total fusion.

The relationship between raw and refining operations

The two aspects reviewed above, juice clarification and raw sugar refinability, can be drawn together by considering the separation between raw and refining operations. Political, economic, commercial and technical factors have all contributed to a dramatic change in the world's cane sugar industry over the last 20 years. Increasingly, refined sugar is being produced in white ends attached to the sugar mill and the "economies of scale" which provided the commercial basis for the operation of independent sugar refiners have shifted in favour only of the very largest independent refining units.

There can be no doubt that the introduction of VHP raws into the South African sugar industry some five years ago represents another step in the direction of a combined raw and refining process. For how much longer will both the raw sugar exporter and the refining importer incur the cost of mingling molasses with VHP sugar, only to strip it off again by affination as soon as the sugar enters the refinery?

The growth of the sugar beet industry, particularly in Europe under the impetus provided by the EEC, provides an adequate precedent for a sugar industry in which a raw sugar is never isolated. Instead B and C sugars are all remelted and fed back into the thick syrup stream, and the only product is a refined "A" sugar.

In the cane sugar industry the separation between raw and refined operations can ideally be related to the chemical technology of processing. In raw house operations the processes are aimed primarily at the extraction of sucrose, while in the refinery the processes are aimed at the selective extraction of impurities. The point at issue here is the question of where the changeover point should lie and it appears that the South African experience with VHP raws would indicate a changeover point around 99,5° pol. The impact on the refinery is dramatic and illustrated, in the broadest possible terms, by the observation that a rise in pol of raw sugar from 99,5° to 99,6° reduces the impurity load on the refinery by 20%. With a VHP raw around 99,5° pol as little as possible impurity is passed from the raw house into the white end refinery. The syrup run-offs from the final white sugar boiling are returned to the raw site which therefore also fills the role of a recovery house.

The development of new chemical technology in recent years has further hastened the growth of white end refining. Conventional refinery bone char coal or granular carbon plants have seldom found a place in white end refinery installations because of their very high capital cost. Remelt carbonatation, on the other hand, has found wide acceptance as a robust process, its relatively high capital plant cost being offset, perhaps until the recent escalation in lime price, by low operating costs. Now, with the advent of VHP raws, operating costs are determined more by filtration than by purification requirements, and much of the advantage of the process has disappeared. With the recent advances in phosphatation-flotation technology, very low capital cost process installations have become available, which allow clarification and decolorization to be carried out simultaneously in simple equipment. Polish decolorization is frequently unnecessary, but nevertheless can be achieved either by very small quantities of vegetable carbon (without additional equipment) or by the ever-increasing range of ion exchange resins appearing on the market.

The economic change which has occurred is the change from relatively high to relatively low fixed costs, with very little increase in the variable cost element. The result is a considerable reduction in the amount of capital tied up in process plant, coupled with an increase in processing flexibility which allows the actual cost of refining to be adjusted continuously to suit both the quality of incoming raw and the quality of product required. This flexibility also offers the possibility of matching, more precisely than hitherto, the capability of the manufacturing process with the requirements of the market.

To carry this extrapolation one stage further, the departure from the traditional separation of raw and refined sugar operations, together with the introduction of specific purification processes, like enzymatic starch removal and syrup clarification, into the raw sugar factory must inevitably lead to increased interest in the possibility that sugar of suitable quality for a wide spectrum of consumer markets can be manufactured without the necessity of remelt refining operations.

Conclusion

The impact of modern chemical technology on the South African sugar industry has served to highlight a most important change occurring in the relationship between raw and refining operations. The possibility that, one day, all cane sugar will be refined or processed to the consumer product on site at the raw sugar factory cannot be discounted. Certainly the beet sugar industry enjoys the advantage that the manufacture of its end product is centred in its own market so that long-distance sea transportation is unnecessary. The European, American and Japanese cane sugar refiners must face the prospect that modern transportation developments will soon be able to offer a technical solution to the geographical problem. The commercial problem will be more difficult to solve.

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