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PROCESS FLOW IN THE SUGAR INDUSTRY[1]

by

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SUMMARY

The term process is defined with special reference to sugar industry usage.

The route chosen between raw material and finished product will depend on many factors sometimes of local significance, at other times related to some outside source of technological expertise.

A basic flow sheet of seven generally recognised steps is used as a framework for discussion of range of choice available and criteria for optimisation calculations.

The place of decolourizing procedures in the production of white sugars is outlined.

Juice purification in the treatment of beet or cane extracts is discussed with reference to the simple basic process of defecation.

A. General

The term process when used strictly within the context of science or technology should refer to a step in a manufacturing procedure which involves a chemical reaction as distinct from a physical change. In the production of crystalline sucrose there is very little in the way of process treatment involved, most steps involving essentially physical changes or unit operations. These will be discussed in detail in the next paper.

The only steps involving a desired chemical change are those of precipitation and perhaps ion-exchange.

From a broader point of view as defined in a common dictionary, the word process refers to any change which may take place during the course of manufacture and it is with this general understanding in mind that the term will be used in this paper.

B. Product

The product will usually be crystalline sucrose but there are many variations to this. There are numerous variations in crystal size or quality. Sometimes sucrose is sold in the form of a thick syrup or "liquid" sugar. A further variation of this would be a mixed syrup of sucrose and hydrolysed sucrose made with the object of being able to transport a more concentrated form of sugar syrup.

The nature of the market largely dictates the nature of the product although there is room for "educating" a potential market to accept a new product.

It is really only the terminal stages of the process which are influenced by the nature of the product, whereas the primary stages are influenced by the nature of the raw material.

There is a large area of common ground with intermediate stages irrespective of nature of raw material or specific character of the product.

Whilst considering crystalline products we might differentiate between the so-called raw sugar which is to be further processed in a refinery and the various market grades of sugar which are to be sold directly to consumers.

The basic questions therefore are:-

1. What type of product should be defined?
2. Why have we determined this type of product?

When these two questions are satisfactorily answered we are then in a position to consider the terminal processing stages, the alternatives available and the criteria for making appropriate decisions.

C. Raw Material

Historically the sugar cane is the oldest type of raw material source for sucrose. The sugar cane originated in the island of New Guinea but was probably never used there for even the most primitive methods of sucrose production although it may well have been valued for the sweetness and flavour of its juice for drinking purposes.

The sugar cane gradually spread eastwards and northwards through India to western Asia and then to Mediterranean countries. It crossed the Altanic to the West Indies, Central and South America and to Hawaii. It reached Africa and was brought to Australia by white settlers. The earliest and simpliest forms of making sugar in crystalline form may well have originated in the south-east coastal province of China - in Fukien, or possibly in North Vietnam.

But growing sugar cane had definite climatic limitations and whilst the European colonial powers profited from the sugar cane plantations in their colonies they began to develop a sense of insecurity as their desire for sugar grew into a need, as a luxury article changed to a necessary commodity.

There were other tropical plants with sweet sap of which many varieties of palm are the best example. The palm may be grown successfully to higher latitudes than the sugar cane but the increase is only marginal in terms of European desires.

Root vegetables appeared to provide the best temperate climate plant and at one time it almost looked as though the carrot might fill this need. What became known as the sugar beet, however, showed sufficient advantages at the time to throw the scales in its favour and to result in its development to the present day state of the art.

Meantime the palm has not been entirely overlooked and there are many tropical areas where palm juice is processed in primitive village-scale "factories" to provide for local needs. The best palm trees do have some advantages - their life is 50 years or more, they need little fertilizing or irrigation, other crops can be grown around their base and they are resistant to pests and most diseases. There are quite serious harvesting problems since the sap must be collected from the flowering top of the palm but the yield in tonnes of sugar per hectare can be quite good. The quality of sap or juice is comparable with poor quality sugar cane juice.

Other plant materials such as sorghum have, from time to time, been suggested as being suitable for making sucrose. They might be used alone or to supplement juices from the more conventional sources.

The basic questions are therefore:-

1. What raw material should be employed for sucrose production ?
2. How best should it be grown and harvested?
3. Why has the decision been made for the type selected?

We need also to bear in mind the competitive character of dextrose produced by the hydrolysis of starch which is a widely grown plant material.

D. Flow Sheet

For the purpose of this paper we can restrict our serious consideration to the sugar cane and sugar beet.

If we start with the harvested raw material as delivered to the factory we can produce the following generalised flow sheet:-

Preparation of cane or beet

|

Extraction of juice - Disposal of fibre

|

Purification of juice - Disposal of "mud"

|

Concentration of juice to give syrup

|

Crystallization from syrup

Crystal Sucrose / \ Molasses

Certain variations are possible within this general flow sheet. Variations in the nature of differences in the basic unit operations will be considered in detail in the next paper.

The type of flow sheet variation which is practised for one reason or another involves something of the following:-

The development of individual small juice factories which operate only to the juice extraction and purification stage. These have historically been used in the cane industry under primitive developing conditions. The objects seem to have been to minimise on capital expenditure at the expense of transport costs.

What might be considered as a logical development of this idea is the establishment of syrup mills. There is a big gap in the time scale between the disappearance of juice mills - which were at one time common in Australia and no doubt elsewhere also - and the appearance of syrup mills which is now taking shape in Venezuela. In the syrup mills the sugar cane juice is concentrated to syrup consistency at the extraction site making use of the waste fibre available for steam generation and carrying out the major concentration stage. The syrup is then transported to a central crystallizing plant which itself is attached to juice extracting and concentrating units. Again it is a matter of optimising costs which can be influenced by specific local factors.

In principle comparable modifications could be operated in the sugar beet industry.

These two flow sheet modifications are however only of minor significance. A factor of major significance related to the nature of the product - whether it should be market grade crystal or raw sugar.

Raw sugar as the major product has been the historical development of the cane industry under colonial administration.

Under those conditions the object was to produce sugar in a transportable form from the colonies in tropical areas where the sugar cane could be grown to the mother country where it could be refined and provide employment in the mother country for carrying out the appropriate operations.

The local sugar needs of the colonial country itself were marginal and given very little consideration by the colonial power.

With the progressive development of independent countries there has not been a corresponding change in structure of the sugar industry with the possible exception of a greater cognisance of local needs.

The raw sugar market, absorbing the products of cane growing countries, has continued to dominate world trade in sugar.

The sugar beet industry tended to produce a marketable grade of crystalline sucrose in the same factory as the juice extraction and concentration. Where production exceeded the capacity of the local market the surplus would find its way into the world commodity pool of raw sugar ultimately to be absorbed by refineries either with or without associated processing of raw from sugar cane sources.

Two main types of market have developed for the raw sugar product. One seeks raw sugar of highest quality but with a ceiling set by import duty control to leave a limited margin for refinery operation. This encourages high capacity refinery operation with the object of minimising overhead costs.

The other seeks a lower quality raw sugar (but not too low) and thus does a higher proportion of processing in the more industrialized country. Also a larger volume of molasses becomes available for by-product processing.

A further possible development in this direction would be to enlarge on the syrup mill concept and transport by water-borne liquid tanker concentrated syrup from cane growing areas to high density centres of population where the maximum amount of processing could thereby be performed.

One might then envisage the stage at which such processing is carried out at sea on vessels comparable with floating fish processing factories. The syrup taken on board at its source would be processed en-route arriving in the form of crystal product and molasses available for immediate market delivery. Some changes in import regulations would be needed to accommodate such a novelty.

An important change which has taken place over the past 25 to 30 years has been a substantial increase in knowledge of how to store and handle sugar of refined quality. It is now known that it can be produced, stored and handled in tropical and equatorial climatic conditions with the very best quality criteria being maintained.

There are now factories in various countries which produce the very best "refined" quality crystal sucrose in the same factory as that in which the cane is milled.

There is no technical reason why this practice should not be universally adopted. There are however numerous economic factors which restrict its rate of implementation.

E. Near-White Sugars

The term "near-white" is used to include those sugars which are good enough to meet many of the retail market requirements but not quite good enough to meet the needs of food processors in the jam, beverage and fruit preserving industries.

The "near-white" sugars appear from both sugar beet and sugar cane sources. The sugar cane products are sometimes referred to as plantation or mill whites indicating that they are produced at the site of the milling factory. The quantity is substantial in developing countries. The quality is such that they pick up moisture more readily in a humid atmosphere and hence have a lower keeping quality. Their colour tends to vary between a grey and a very pale yellow. Colour development during storage is more noticeable than with higher quality refined sugar. They are believed to be noticeably less sweet in crystal form. Syrups are not clear and colourless and therefore not suitable for beverage manufacture or for preserving fruit. Slight flavours reduce suitability in these applications as also for jam making.

The basic flow sheet is developed to enable one or more of the various market grades of crystal sugar to be produced.

These developments are all chemical or physico-chemical techniques for removing colour from the syrup before crystallisation. The following basic procedures are employed either singly or in association with one or more of the other techniques. If only a single technique is employed the product sugar is of near-white quality. The fully "refined" quality requires two, three or even four stages of decolourizing procedures.

F. Decolourizing Procedures

1. Sulphitation
2. Phosphatation
3. Carbonatation
4. Vegetable carbon treatment
5. Bone char treatment

6. Ion exchange resin treatment
7. Special procedures of mainly local interest only

Sulphitation is one of the oldest techniques involving the bubbling of gaseous SO_2 either through juice or syrup. It may be done in one stage or two stages. When sulphiting juices it may be done before lime defecation or after or similtaneously. It is now recognised that it removes only a relatively small proportion of colour (probably ≯30%), is costly and the product crystals tend to recolour. Traces of SO_2 residual in product crystal are an undesirable food component. The chief advantage appears to be the ability of SO_2 to restrict the normal thermal degradation reactions, hence there may be less ultimate colour in the syrups.

Phosphatation is uncommon and expensive but generally effective in producing a clear syrup even though actual colour removal may not be particularly significant. Modern developments involve froth flotation of a calcium phosphate precipitate generated by adding phosphoric acid and lime at the syrup stage.

Carbonatation involves the substantial addition of calcium hydroxide to juice or syrup followed by the precipitation of calcium carbonate by bubbling carbon dioxide bearing gases through the heavily limed juice or syrup. The precipitated $CaCO_3$ can remove significant proportions of colour (45-65%), but there can be difficulty in filtering the precipitate if certain types of colloidal impurities inhibit the growth of the calcite crystals. This phenomenon is commonly referred to as the "filterability" and starch is thought to be an important impurity in reducing filterability.

Heavy liming can result in alkaline degradation of sugars to result in producing some of the very colours it is being desired to remove.

Activated vegetable carbons have been widely used as a means of removing colour from syrups. The proportion of colour removed depends upon the activity of the carbon and this is a variable property depending upon the capabilities of the manfuacturer. Vegetable carbon is not re-used or re-activated and hence is costly and careful costing of this colour removal step is important.

Bone char is probably the oldest of the decolouring procedures used in the sugar industry and has the distinct advantage of being amenable to regeneration by thermal treatment. The capital cost of such plant is, however, significant and careful control of conditions is necessary to ensure effective re-activation. Bone-char decolouring is a very effective treatment when all stages work well, but it can be significantly less effective if a high standard of control at all stages is not maintained. The initial raw material is less costly than for vegetable carbon and activation is rather more straightforward.

Ion exchange resin beds are relatively recent comers in this field and progressive development has been taking place over the past 25 years with further development yet to come. The most common application is simply for colour removal from syrup which has already had most of its colour removed by one or more other techniques. Juice treatment can be practised but is less common. Colour removal efficiencies of the order of 80% can generally be expected with some claims for higher values and some admissions of lower values.

Regeneration is by chemical means and is costly and also produces an effluent for which there may be some disposal problems. A number of variants have been employed for regeneration and intensive study of this aspect is still proceeding.

The decolouring beds are essentially of anion exchange character. The employment of double bed or mixed bed processes with the object of de-ionising sugar juices or syrups has been the subject of intensive study and still poses a number of problems.

G. Crystallization as a Decolouring Technique

It is worth observing that crystallization is fundamentally a very good purification procedure in any industry dealing with crystalline substances especially in the chemicals industry. In sucrose crystallisation the purification step is likewise significant. In the author's experience this has been most noticeable in the production of near-white sugars where it is not unusual to separate a crystal of 99.85% purity (i.e. impurities of 0.15%) from a massecuite of 85% purity (i.e. impurities of 15%). This represents a 99% removal of impurities which is substantially better than the classical chemical procedures. In raw sugar production it is common experience to produce a crystal of 99% purity from a massecuite of 85% purity or an impurity removal of 93.3%. There are recognisable reasons for this difference and exploitation of these factors could result in more effective use of the crystallisation step for producing pure crystal sugar. Crystallisation is effective in reducing all types of impurities whereas the various decolouring procedures have only minimal effects on impurity components chemically unrelated to the colouring substances.

H. Crystal Purity Control

Countries importing raw sugar usually impose heavy customs duties for sugars exceeding a specified polarization value e.g. 97.5 or 99 or some other figure as the case may be. It is well known to chemists that polarization is only a physical measurement having no specific reference necessarily to any single chemical entity. It is possible to produce a sugar of high purity but low polarization by suitable surface treatment of sugar crystals with a hydrolysed syrup - or "inverted syrup". This in fact is being done by at least one country with the object of copiug with an otherwise difficult impurity problem disliked by the refineries who form the market for their raw sugar.

This is a case of chemical manipulation within the limits of the legal framework, the ultimate working out of which on a broader scale is at present difficult to predict.

Questions:

1. What purification procedures should be adopted?
2. How should these be applied in a particular situation?
3. Why have we selected such procedures?

I. Juice Purification

The purification procedures just outlined are essentially those employed for producing a grade of sucrose crystal suitable for the retail market. Before any one of these might be applied there is invariably a juice purification step in the flow sheet. This is essential even if the final product is only raw sugar to be subjected to later stages of refining.

Juice purification in the sugar cane industry consists essentially of the precipitation of a calcium phosphate complex which has quite strong ability to remove colloidal material as well as coloured substances. This is a very effective step, a universally adopted step and one which is relatively simple to operate. But we do not really know a great deal about the mechanism of what happens.

It is known that it is important to have a minimum amount of phosphate ion in the raw juice as it comes from the cane, and there are occasions when supplementation may be economically justified. Studies in Australia have concluded that, whereas juice from noble canes could be treated relatively simply with a single stage of liming and heating the juices from hybrid canes have been more resistant. Present day canes in most countries are almost invariably hybrid varieties.

Several variations of more complex liming systems have been developed successfully to improve the basic clarification stage. Typical of these are fractional liming - usually two stage addition with various modifications of the temperature at which the lime is added.

Heating the juice at the liming stage is essential for effective clarification. The most suitable temperature has been found to be about 105^{o}C and unless this is achieved inadequate clarification is an invariable result.

Among the benefits of the heating procedure are coagulation of the precipitate as well as of other colloidal substances, liberation of air bubbles attached to the precipitate which otherwise inhibit settling, dehydration of hydrated hydrophyllic colloids as well as effective sterilization of the juice itself.

An important component of the precipitate is the calcium phosphate known as hydroxy-apatite. As precipitated it appears to have very strong adsorptive properties. It is also known that the hydroxy group is exchangeable with anions in solution and like the anion exchange resins no doubt has a strong predilection for anionic colour components of the juice. There is much yet to be learned about the chemical and physico-chemical mechanisms of the simple clarifying procedures.

Lime addition was initially on a mass proportional basis or some variation thereof as is still commonly the case for lime addition prior to carbonatation. Progressively this has been replaced by pH control as means for the factory measurement of pH have become more meaningful and more reliable. This now is almost invariably the control procedure adopted with either manual or automatic adjustment devices. The best pH value to which liming should be carried seems to vary from place to place and sometimes from one variety to another, or from one part of a season to another. In other words the character of the juice itself has some influence on determining the actual pH to which liming should be carried.

Also the time at which the pH is actually measured after the addition of the lime must be taken into account as the pH does change with time. The precipitation reaction is not instantaneous, the rate at which it proceeds can readily be measured in recognisable time units.

The simple procedure of lime addition associated with heating of sugar cane juices is commonly known as the defecation process. This is commonly compounded with some associated step introduced to obtain better purification at this stage. One example is the pre-coagulation of starch before the liming procedure. By combining temperature control and holding time in a tank preceding the liming stage a useful proportion of starch may be eliminated from juices carrying that component. Starch bearing cane juices are by no means uncommon in many countries.

Where sugars of better quality than the normal raw sugars are produced

Then one or other of the chemical decolouring techniques may be performed at this stage. Sulphitation is one very common example of this when near white sugars are to be produced for the retail market. The sulphitation may be carried out before liming, after liming, simultaneously or [illegible]tionally with various well recognised effects.

[illegible] purification in the sugar beet industry is not quite so straightforward [illegible] it is almost invariable practice [illegible] for the production [illegible] retail market quality sugar in the one process [illegible] chiefly for this [illegible] more complex juice purification procedures are adopted involving [illegible] double carbonatation with or without sulphitation [illegible] one of its [illegible] method of [illegible]

The [illegible] measurement of the real effectiveness [illegible] purification procedure is an exercise involving [illegible] significant [illegible] The most commonly adopted chemical technique [illegible] recording [illegible] before and after purification [illegible] very limited value because of the small differences involved, and the magnitude of sampling and experimental error.

Better [illegible] achieved by measuring [illegible] purity or [illegible] of the [illegible] juices. Techniques for these measurements have progressively improved and greater reliance can now be placed upon them. Unfortunately [illegible] much more difficult to perform [illegible] measurement [illegible] with [illegible] specifying the efficiency of the process. It [illegible] measurement [illegible] in terms of the effectiveness of the process.

Questions

1. What [illegible] the simple [illegible] "defecation" process
2. How [illegible] the defecation process [illegible] carried out
3. What are the restrictions of this process
4. Why are we [illegible] its application?

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