## SUGAR SERIES

Vol. 1. Standard Fabrication Practices for Cane Sugar Mills (Delden)

Vol. 2. Manufacture and Refining of Raw Cane Sugar (Baikow) sugar series, 1

# standard fabrication practices for cane sugar mills

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# PREFACE

This manual serves two purposes:

Firstly, to reach those who are employed in the cane sugar industry and, though not directly in touch with the fabrication process, nevertheless should be acquainted with the facts — for instance: electrical, mechanical, civil and accounting personnel. These people are not interested in the more sophisticated existing technical fabrication books, which are mainly aimed at those working in the fabrication process itself.

Secondly, to serve those employed in the cane sugar industry and working in the fabrication process — mainly the operational staff and practical workers. Many neither have nor need the highly specialized technological background required in this industry, although they may have either a general technical education or one pertaining to non-related industries. To serve the latter category, many chapters, such as "evaporator cleaning" and "low-grade crystallization," are written in the style of an operating manual. In fact, this entire book has been styled with factory operation in mind and to serve as an operation manual. At the same time, it contains enough information about the processes that the layman may learn how sugar is made.

In only a few countries do specialized schools for sugar technologists still exist. We believe that the best way to educate new technologists is through practice with the aid of older colleagues, and with efficient manuals at their disposal. The purpose of this book is not to replace others, but to enlarge upon some of the material in order to improve the technical skill of new personnel. Specialized schools become scarcer every day, probably because the sugar industry is less attractive to new graduates than other industries. It is true that salaries are always low compared with other enterprises, and working hours are extremely unattractive during the grinding season, with no free week-ends. Employment is often seasonal, in many countries of the world.

There are many misconceptions in the sugar industry, either due to wrong terminology or because of the revival of older and often obsolete systems — this is usually unintentional and results from ignorance of the older literature. A few examples will be mentioned to emphasize this point:

The pump that eliminates non-condensable air and gases from a vacuum system is actually an air pump, although the name generally given to it is "vacuum pump". One case is known where this misnomer proved very costly, because it was deduced that a low vacuum could be improved by buying a second pump. This was not the case. The vacuum fault was due to the presence of too many leaks in the badly maintained vacuum pans. After a thorough repair of the leaks, even the original air pump was far too large.

In about 1955, a "new discovery" was made by some South American sugarmen concerning the 2-boiling system. They were ignorant of the fact that the same system had been abandoned more than 40 - 50 years earlier, because a low syrup purity was needed. With the years the syrup purity improved, together with the system, and once the purity exceeded 80, the 3-boiling system became more desirable. The revival of the 2-boiling system was made possible by using water-cooled crystallizers for the A-massecuite. This kind of equipment was not available during the earlier application. Thus the new method proved to be merely an improvement on an old one.

Another point to note is that many new chemical products serving a specific purpose are marketed, but they lack documented experimental details. The only merit is that various recommendations about its use are gathered from scientists in various countries. This practice is not satisfactory. For instance, if a certain product is supposed to prevent or retard scale formation of an evaporator calandria, its effect can be demonstrated through heat-transmission measurement. This is much more convincing than a letter of recommendation saying: "The scale feels softer and was easier to remove than before use of the product. It was many days before it became as thick as before, and therefore the time between cleanings increased".

One reason why the older history of the industry is not universally known is that many excellent early publications are no longer available. This is a definite shortcoming, since most can still be regarded as standard manuals. Examples are:

H.C. Prinsen Geerligs, *Cane Sugar and its Manufacture,* 1930.
L.A. Tromp, *Machinery and Equipment of the Cane Sugar Factory,* 1946.
Francis Maxwell, *Modern Milling of Sugar Cane,* 1932.
Noell Deer, *Cane Sugar,* 1921.

All these books were published by Norman Rodgers, London.

As far as the technical history is concerned, I myself have the experience of 52 years in this industry. There are few persons today who have had personal experience of making "muscovado on sugar floors", before centrifugals were used. This was when "centrifugal sugar" commanded a higher price than drip muscovado, since it was of superior quality. Electricity was either unknown or used exclusively for a few carbonwire light bulbs at the most critical locations in the factory. It was generated by a small power plant, producing a few kilowatts of d.c. current. Nearly all pumps were of the duplex-piston type, of which the steam valve was manipulated by the man in charge from a platform or other floor, by means of steel wires, ingeniously connected to speed up or slow down the pump. Cane came to the mill in bundles of about 50 full-length stalks, which were hand-loaded onto the cane carrier mounted a few feet below the floor level. The number of men employed depended on the mill capacity and could vary from about 20 to 60 per shift in most cases.

In Java, the uniformity of the grinding rate depended mainly on the correct organization of the so-called "kolongan", the group of hand loaders. In the early days of simple belt-driven centrifugals, the basket size was limited to 30" × 18", a mechanical limit set by the high centrifugal force. Each machine had one operator: in Java operators were women. Modern centrifugals have a basket size 54" × 40". The filling capacity of the old ones was 3.3 cu ft of massecuite, while the latter can hold 25 cu ft, or nearly 8 times as much. Further, they are fully automatic and require only one supervisor for the complete battery.

Since writing a book requires time and preparation, I wish to acknowledge gratefully that this opportunity was given to me by the Industrial Consultant and Management Company of Coral Gables, Florida, during my regular services for this Company. I wish to dedicate this book to the younger generation and I hope that my experience will prove helpful to them. I also wish to express a word of appreciation to my fellow workers, in all cane-producing countries in general, as well as those in our Company in particular. I must also express my special thanks to my wife, Mrs. Wilhelmina T. van Hutten-Delden, for the preparation, typing and proof-reading of the manuscript, to which she dedicated so much of her time.

Miami, 1981 Edward Delden

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# GLOSSARY

**CANE**

Net or gross cane. The sugar cane to be processed for extraction of its sucrose content. Net cane is cane free from adherent impurities. Gross cane is cane that contains a determined percentage of trash, stone, dirt, etc.

**BAGASSE**

What is left of the cane after the juice containing the majority of sucrose is separated. Its components are fiber, pith, water, solids (which also contain the lost sucrose).

**FIBER**

All water-insoluble solids in the cane.

**JUICE**

1. *First expressed juice*
   Juice separated from the cane by the primary extracting mills, normally crusher + 1st mill or 1st mill (if there is no crusher). Also called *primary juice.*
2. *Last mill juice*
   Juice extracted from the bagasse by the last milling unit. Part of this juice is lost in the final bagasse (in fact the juice lost in bagasse is that produced by the last two rollers of the last milling unit).
3. *Diluted juice* also *mixed* or *raw juice*
   The juice of all milling units together with the added water, forming the juice forwarded to the factory for further processing.
4. *Normal juice* or *undiluted juice*
   Juice pressed out by the mill tandem, if no water is used for imbibition.
5. *Absolute juice*
   All water containing all soluble solids from the cane or *cane* minus *fiber.*
6. *Clear juice*
   The juice from the clarifier after decanted separation of the mud.
7. *Filter juice*
   The combined run-off of any kind of filter.
8. *Clarified juice,* or *evaporator juice*
   Mainly clear juice with any other juice ready to be evaporated.
9. *Syrup*
   The effluent of the evaporator combination, concentrated clarified juice.

**WATER**

*Imbibition water*

Water added to the last mill unit (or last two units), to dilute and displace juice left in the bagasse, to reduce sugar lost in it.

*Dilution water*

That portion of imbibition water that goes to the diluted juice. Imbibition water minus water staying in the bagasse.

*Maceration water*

This is found in Australia exclusively, where during the milling process, bagasse passes through a bath carrier (Meinecke system), normally under higher temperatures. The use of the word "maceration" is justified in Australia alone (Spencer/Meade, p. 622).

**EXTRACTION**

1. *Pol extraction*
   Pol in diluted juice percent pol in cane, or pol in cane minus pol lost in bagasse.
2. *Diluted juice extraction*
   Weight of diluted juice percent of weight of cane.
3. *Normal juice extraction*
   Weight of normal juice percent weight of cane. Diluted juice extraction minus dilution % cane.
4. *Absolute juice extraction*
   Weight of absolute juice % weight of cane, or 100 cane minus fiber % cane.
5. *Reduced pol extraction*
   Pol extraction recalculated on a standard fiber content in cane of 12½%. This makes possible comparison of factories having different fiber contents.

**FILTERCAKE**

The insoluble impurities separated from diluted juice by means of a filter process.

**MASSECUITE**

Further concentrated syrup. It is a mixture of crystals and molasses, before separation in centrifugals.It is classified with the letters A, B, C, according to the boiling order. In some countries, it is classified as first, second and third.

**MOLASSES**

The mother liquor separated from the grain of the massecuite. It is classified, as are the massecuites, by letter or number, except for the final molasses, which is also called black-strap molasses. Final effluent in the preparation of sugar through repeated crystallization.

**MAGMA**

A slurry prepared from C-sugar (separated from the final molasses) mostly with syrup. The magma is stored to serve as seed (or footing) for the A and B massecuites.

**FOOTING**

A grain mass, such as magma. On its grain, sucrose is deposited during the boiling process to form commercial sugar.

**SEED**

Same as footing, but the grain here is grown from finely powdered sugar. This smaller size grain is mainly used for starting a low-grade massecuite (mcC).

**RAW SUGAR**

Sugar as produced by a factory using the defecation process. The raw material for the refinery.

**REFINED SUGAR**

Sugar as produced by a refinery, after dissolving and purification of the received raw sugar.

**PLANTATION WHITE**

A rather white sugar as produced by either the sulphitation or the carbonatation process.

**CONDENSATE**

Condensed steam or vapor formed in the calandrias of heaters, evaporators or vacuum pans, after it has given off its latent heat for heating or boiling purpose. Depending on the pressure (or vacuum) in the calandria, it is divided into two categories:

(a) non-contaminated (when pressure in calandria)
(b) contaminated (when vacuum in calandria).

In juice heaters, the juice pressure is higher than the steam pressure. Its condensate therefore is considered to be contaminated.

**CONTAMINATED CONDENSATE**

Condensate which can be expected to contain sugar traces. Generally used as hot water in the different process stages requiring its use.

**NON-CONTAMINATED CONDENSATE**

This can be expected to be free from sugar contamination. Generally used as boiler feed water.

**STEAM**

(a.) Live steam (saturated or superheated).
(b.) Exhaust steam.

**LIVE STEAM**

Steam as produced by the boilers, at a pressure for which the boilers are designed. The higher the pressure, the more efficient the consumption of live steam. Generally used as motive force in driving equipment (turbines, reciprocating engines, etc.) and to generate electricity.

**EXHAUST STEAM**

Steam that has been used in prime movers and therefore has lost a large part of its pressure, which was converted into power (or electricity). Generally used for heating and boiling purposes in juice heaters, evaporators and vacuum pans.

**VAPORS**

Formed by using exhaust steam in a calandria to boil or evaporate liquid. Generally used for further boiling or heating. Classified with a number, according to the place the vessel occupies in the multiple-effect evaporator. For example: vapor II.

**MILK OF LIME**

A slurry prepared from water with slaked quick-lime, or with hydrated lime. Used as a clarification agent. Chemical composition: $Ca(OH)_2$ (calcium hydroxide). Generally it is used at a concentration of 5° to 15° Bé. The name is usually abbreviated to m.o.l.

**LIMED JUICE**

The diluted juice after addition of m.o.l.

# LABORATORY AND CHEMICAL EXPRESSIONS

**BRIX**

Percentage by weight of solids in *pure* sugar solutions, as determined by a brix hydrometer, therefore called apparent solids. Juices are not pure sugar solutions and the brix is not "true solids".

**REFRACTOMETRIC SOLIDS**

Percentage by weight of solids as determined by a refractometer. The difference between this and the hydrometer brix is that it increases as the impurity content increases.

**DRY SUBSTANCE SOLIDS**

What remains after drying a sample, as a percentage of original sample weight. Also called total solids.

**POL (ARIZATION)**

Reading on the scale of the polarimeter, indicating the apparent sucrose content of the sample to be analyzed. If the sample is a pure sugar solution, the pol equals the sucrose percentage. Pol is the direct polarization of a normal weight solution: 100 pol = 26 grams of sucrose in distilled water at 20 °C and made up to 100 ml.

**SUCROSE**

This is the true pol, taking into account the influence caused by the presence of invert on the polarization reading.

**CLERGET**

The method of double polarization to determine the invert influence on the polarization. It indicates the true pol or sucrose content.

**PURITY**

Purity is the pol divided by the brix × 100. It indicates what percentage of the solids is composed of sugar.

**APPARENT PURITY**

When pol and brix are used, the result is called apparent purity.

**REFRACTOMETRIC PURITY**

This is the purity using the pol and the refractometric brix.

**TRUE PURITY**

The dry substance solids and the Clerget (sucrose) are used as components.

**INVERT**

The reducing sugars, also wrongly called "glucose", which is only one of the components of the group of reducing sugars. Some components polarize positive, others negative. Generally the negatives win, hence the wrong name (glucose is negative).

**NON SUGARS**

That part of the solids (brix) not composed of sugar (brix − pol).

**ASH**

There are two forms:
(a.) carbonate ash
(b.) sulphate ash.

Normally expressed as sulphate ash. The analysis of sulphate ash is more dependable and simpler. Ash is all that remains after burning the sample in the presence of sulphuric acid, the inorganic impurities.

(c.) Conductometric ash determination can be reported as sulphate ash, applying a constant factor.

**R.S./ASH RATIO**

This is the quotient of reducing sugar to ash. It is used for judging refining quality of raw sugar and also in calculating the exhaustibility of final molasses.

**BOILING HOUSE RECOVERY**

Also known as B.H.R. or *RETENTION.* Pol in sugar % pol in mixed juice.

**OVERALL RECOVERY**

Also Recovery = retention × pol extraction. It therefore includes losses in the mill (or diffuser). Hence its name "overall".

**BOILING HOUSE EFFICIENCY**

B.H.E. This is the percentage of retention actually retained. The theoretical retention is calculated by either of the known formulas. The formulas are: Winter and Carp, S.J.M. (Noell Deerr), also existing tables.

**YIELD**

Commercial sugar produced % cane.

**YIELD 96°**

This is the yield converted in sugar of 96° pol. Standard sugar 96° = 97 purity and 1% moisture. Uses the Cobb table (Spencer # 36).

**YIELD ESG.**

This is yield converted into "equivalent standard granulated" (this is a theoretical sugar of 100% sucrose and 100 purity). Yields can also be expressed as lb/t or cane. If short tons are used, it is 20 × yield.

**RAW VALUE**

This is used in the U.S.A. to calculate tax (for U.S. quota), as required by U.S. Treasury Department. Defined by law: "Raw value means a standard unit of sugar, testing 96 sugar degrees by the polariscope. All taxes shall be imposed and all quotas shall be established in terms of raw values and for the purposes of quota and tax measurements, all sugar shall be translated into terms of raw value."

**EQUIVALENT 96 (RAW VALUE)**

$$= \frac{[(\text{Pol} - 92)\ 1.75] + 93}{100} \times \text{Tons sugar produced.}$$

**SAFETY FACTOR**

Relation between moisture and non-sugar content of raw sugar, as an indication of keeping quality of sugar in storage. It indicates whether a micro-organism is enabled to start deterioration, because of favorable moisture/food conditions. Moisture divided by 100 – pol must be 0.250 or less, as an acceptable safety factor.

# CHEMICALS

**BLUE**

Optical Brighteners, Ultramarin or Indanthren. Applied in the centrifugals as a complementary coloring to neutralize the yellowish hue plantation white sugar might have.

Indanthren is used as 50 g/t of sugar, of which only 0.01% adheres to the crystals (5 mg/t of sugar).

**CARAMEL**

Thermal decomposition of sugar, of dark brown color. Used as food color if pH is restored to neutral.

**CAUSTIC SODA**

NaOH. Used to descale evaporator heating surfaces (also in juice heaters, vacuum pans). Generally, by boiling a solution of about 4% by weight during a predetermined time.

**MURIATIC ACID**

HCl. Technical quality 38%. Sp.gr = 1.19. Used to descale heating surfaces, as above. Generally applied by boiling a solution of up to about 2% by weight.

**SULFAMIC ACID**

$NH_2HSO_3$. Sp.gr. = 2.1. Replacement of muriatic acid, because of ease of handling. Dry white crystalline powder. Is also less corrosive, non-hygroscopic.

**SODA ASH**

$Na_2CO_3$. As an additive to caustic soda. Helps to descale silicates, mainly present in last evaporator vessel as scale.

**INHIBITOR**

Commercial additive to muriatic acid, to retard acid reaction on iron of equipment. Forms protective coating on bare metal, not on scale.

# EQUIPMENT, MACHINERY

**CANE YARD**

Site is usually in the open air, where cane can be stored to cover the consumption during the night, until cane transport resumes the next morning.

**FEEDING TABLE**

This is an inclined feeder of cane to the carrier, having a leveler and transporting chains.

**CANE CARRIER**

This is used to transport cane to the milling tandem, and consists of chains and slats. Its width is normally equal to the mill size. Consists of two components: the auxiliary and the main carrier.

**MILL**

A cane-crushing unit, normally consisting of three rollers in a heavy steel housing. Cane first passes between the top and front rollers, then between the top and back rollers, to extract the juice.

**CRUSHERS**

A cane crushing unit, preceding the first mill to crush the cane prior to extraction of juice, for the purpose of improving the quantity of juice extracted. Normally consists of two rollers.

**SHREDDER**

This has the same purpose as the crusher, but a different principle. Consists of a drum, with a concentric shaft, on which hammers are mounted on arms.

**MILL TANDEM**

A complete mill complex, consisting of crusher (or shredder) and all mills, together with drives and reducing gears.

**CANE KNIVES**

These are mounted on cane carriers prior to entrance to mills, for preventing entire cane stalks from entering the mills, straightening and precutting the cane, for the purpose of improving juice extraction and saving driving power at the same time. Also of benefit to grinding capacity.

**INTERMEDIATE CARRIERS**

These transport the milled cane (bagasse) from one mill to the next.

**BAGASSE CARRIER**

This carries the bagasse from the last mill to the boilers, and its excess to storage.

**CUSH-CUSH**

This is a juice screener, to separate bagacillo from the juice of the mills. Juice passes through screens into tanks, while chains provided with brushes pass over the screens to carry off the retained bagacillo, and return it to the first intermediate carrier.

**BOILER**

Steam-generating unit, fired with bagasse and auxiliary fuel oil burners (sometimes fire wood is used).

**POWER PLANT**

This produces electricity by means of non-condensing steam turbines, which drive generators. For the off-season diesel-driven generators are mainly used, to produce a limited quantity of electricity.

**JUICE HEATER**

A heat exchanger in which juice is heated by using steam as a medium. Normally a multi-pass system. Juice flows through tubes, while steam passes along the outside of the tubes, in the cylindrical body. They can be used horizontally as well as vertically.

**CLARIFIER**

A large vertical cylindrical tank, where juice is given time for decantation, to separate the clear juice from the turbid, which still contains the mud. Juice flow is continuous.

**FILTER**

A device to separate the mud from the turbid juice; normally of the rotary-vacuum type. Can also be any kind of pressure filter, provided with filter-cloth, to let the juice pass and retain the mud on its surface.

**EVAPORATOR**

A series of vessels, in which excess water from the juice is evaporated to form a more concentrated liquid, now called syrup. The vessels work in series under increasing vacuum conditions, to reduce the boiling temperature gradually as the concentration increases step-wise. This prevents overheating of juice and loss of sucrose. The vessels together form a triple-, quadruple- or quintuple-effect evaporator.

**VACUUM PAN**

Similar to an evaporator vessel, a continuation of the evaporating process, but carried so far that crystallization occurs. Also boils under vacuum for reduced boiling temperature. The syrup is now transformed into massecuite (fillmass-strike-skipping), which is a mixture of grain (crystals) and mother liquor (molasses).

**CRYSTALLIZER**

A strike receiver in which the charge from the vacuum pan is stored before going to the centrifugals. Its purpose is cooling, to increase grain size and reduce sucrose left in molasses.

**CENTRIFUGAL**

A machine with a fast spinning drum and a screen inside, through which the molasses can pass while the crystals are retained. Separation is based on the difference in specific gravity, amplified by centrifugal force.

**DRYER**

A long drum-like rotating cylinder, where sugar is brought in contact with heated air, to reduce its moisture content.

**COOLER**

Same as a dryer, but air is dry and cooled to reduce temperature of sugar, heated by the dryer. This is to prevent caking during storage. The combination of dryer and cooler into one body is often called a Granulator.

# ABBREVIATIONS

## DIMENSIONS

| | |
|---|---|
| btu | British thermal unit |
| cal | calorie |
| cu ft | cubic feet |
| cu ft/day | cubic feet per day |
| cu ft/m | cubic feet per minute |
| cu ft/t | cubic feet per ton |
| fps | feet per second |
| gal | gallons |
| gpm | gallons per minute |
| g | gram |
| ha | hectare |
| Hg | vacuum |
| hl | hectoliter (100 l) |
| hp | horsepower |
| kcal | kilocalories |
| kg | kilogram |
| kg cm$^2$ | kilogram per square centimeter |
| atm | kilogram per square centimeter |
| bar | kilogram per square centimeter |
| lb | pound |
| lb/gal | pound per gallon |
| lb/h | pound per hour |
| lb/h/sq ft | pound per hour square foot |
| l | liter |
| m | meter |
| m$^2$ | square meter |
| m$^3$ | cubic meter |
| ml | milliliter |
| cc | cubic centimeter (same as ml) |
| mg | milligram |
| ppm | parts per million |
| psi | pounds per square inch |
| psia | pounds per square feet absolute |
| psig | pounds per square feet gauge |

| | |
|---|---|
| qq | quintal |
| rpm | revolutions per minute |
| st | short ton |
| sq ft | square foot |
| tcd | tons cane per day |
| tch | tons cane per hour |
| td | tons per day |
| th | tons per hour |

## LABORATORY

| | |
|---|---|
| app.pur | apparent purity |
| Bé | Baumé |
| B.H.E. | Boiling House Efficiency |
| bpr | Boiling Point Rise |
| bx | Brix |
| cp | centipoise |
| clerg | clerget |
| com | commercial |
| cryst | crystal |
| °C | degree Celsius (Centigrade) |
| °F | degree Fahrenheit |
| °S | degree Sucrose |
| °V | degree Ventzke |
| fm | final molasses |
| H.S | Heating Surface |
| mc | massecuite |
| M & E | made and estimated |
| m.o.l | milk of lime |
| p | poise |
| pol | polarization |
| pur | purity |
| rs(is) | Reducing Sugar (Invert. Sugar) |
| sol | solids |
| sp.gr | specific gravity |
| temp | temperature |
| tot.sug | total sugars |
| vol | volume |

| | |
|---|---|
| N.B.S. | National Bureau of Standards |
| S y A | Sugar y Azucar |
| I.S.J. | International Sugar Journal |
| ICUMSA | International Commission for Uniform Methods of Sugar Analysis |
| H.E.I. | Heat Exchange Institute |

CHAPTER 1

# STORAGE AND TRANSPORTATION OF CANE

Cane, being a plant, is subject to deterioration after it has been cut for transportation to the factory for processing. Deterioration starts immediately after cutting, and therefore storage time should always be kept to a minimum. Deterioration is accelerated by high temperature, light, loss of moisture and inversion, all of which factors are greater under tropical conditions. Losses in quality caused by delay in grinding are far higher than any mechanical or chemical losses occurring later in the process. For instance, four days' delay can cause a weight loss of 11% through evaporation (Rosenfield[1]). Tysdall[2] considers that a delay of 14 days generally causes a 48% loss of sugar in fresh cane. The first delay is in the field, where the cane grower cuts his cane and stockpiles it for collection and loading onto carts (truck, railroad, oxen, etc.). Close cooperation between loading crews and cutters is very important, as it is between factory management and cane grower.

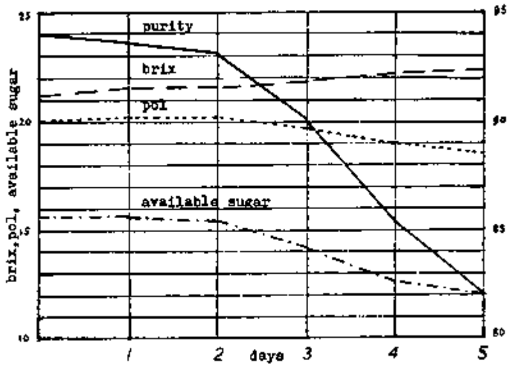
Undoubtedly, hand-cut cane is better suited for factory processing than mechanically harvested cane. Firstly, it is cleaner, precluding the need for washing. Secondly, purities are higher, because in general cane is cut lower to the ground by hand than by machine. The highest sugar content is known to be in the lower part of the cane stalk, the poorest part being the top.

Nevertheless, mechanical harvesting is here to stay, because it is faster. In fact, there are very few countries left where cane is still manually harvested and loaded. In many countries the personnel required for hand cutting is simply not available. Even in most labor-intensive countries, cane cutters are difficult to find, probably because of the low standard and image of the job. Where cane is machine-handled, washing is indispensable. Often, this is combined with stone removal, where the loading of cane is mechanical (push-raking, etc.). The main problem with machine handling of cane is usually damage to the field, jeopardizing future cane crop (ratoon). This occurs particularly when harvesting is done during the rainy season: then damage to next year's cane can be appreciable.

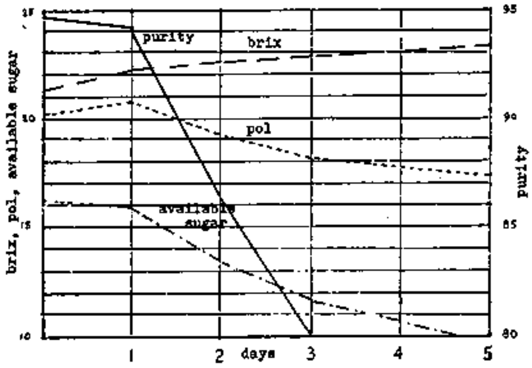
In Java, a country with very good efficiency programs, short afternoon meetings held between management, factory and cane transportation personnel determined the amount of cane to be cut the next day and kept storage to a minimum: this reduced time between cutting and grinding. Any measures taken to control storage are welcome because losses can run into high figures.

Another controlled factor, as important as storage, is the moment at which cane is cut with respect to its maturity, duration of optimum maturity and history of the cane in that particular environment.

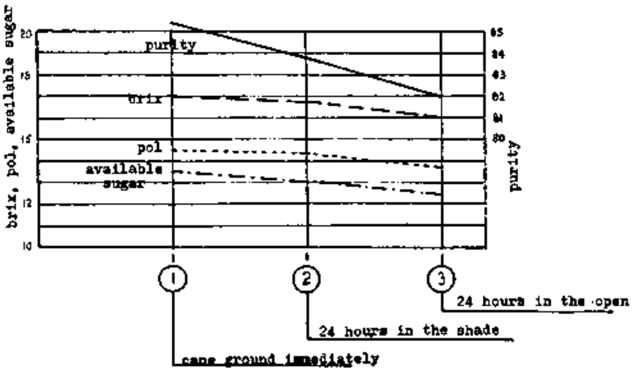
Maturity progress was checked every two weeks by analysis of sucrose and invert, and at maximum sucrose together with minimum invert orders were given for the field to be cut. It was then necessary to know the duration of optimum maturity. Some canes have a high plateau of three weeks, other varieties only 4-5 days. All this information has to be taken into account when establishing a cane-cutting program.



(a) Cane left 5 days in the shade



(b) Cane left 1 day in the open and 4 days in the shade



(c) Losses caused by delay of grinding compared to fresh cane.

Fig. 1 Deterioration of cane between cutting and processing.

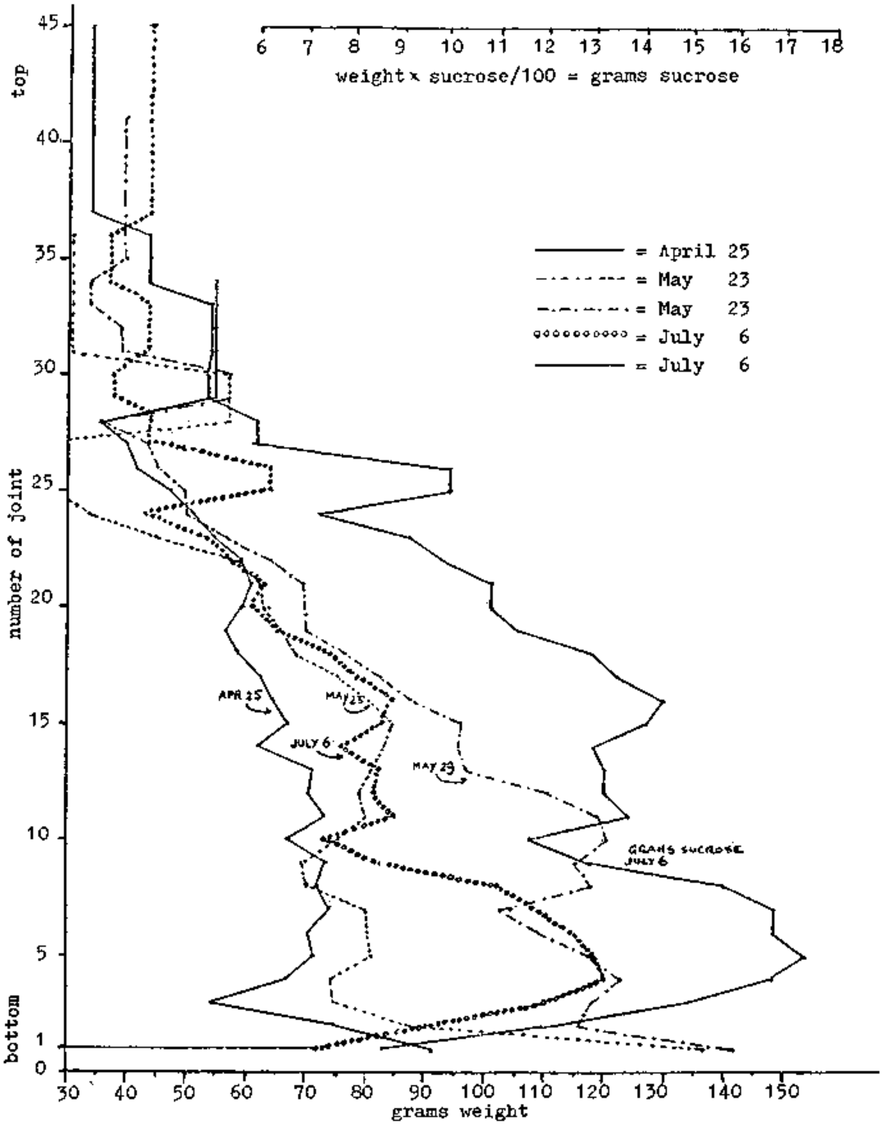


Fig. 2. Weight per joint of cane and grams sucrose per joint, at maturity on July 6. (From H.C. Prinsen Geerligs, *Cane Sugar and its Manufacture,* Norman Rodger, 1930)[3]

In Fig. 1, deterioration of cane during time elapsed between cutting and processing is clearly illustrated.

In Fig. 2, the sugar content and weight per internode of a cane stalk are given. It is shown that the richest part is near the bottom, while the top has some weight but hardly any sugar, even at the date of optimum maturity (July 6).[3]

In most countries, cane is cut during the morning hours, while transportation stops after dark. This makes it necessary to stockpile cane during the day, to be able to bridge the night until cane hauling resumes the next morning.

If a storage site has to be designed, it normally has a capacity of about 12 hours, but this also depends on local conditions. Stockpiled cane is estimated to weigh 25 lb per cu ft, if it consists of whole cane in bundles, and this figure is somewhat higher for chopped cane. The extent and height of the cane pile, as well as the weight per cu ft are important, because at close of day the laboratory chemist has to report ''cane in process'', to determine ''cane ground in 24 hours'', which equals ''cane weighed'' minus ''cane in stock''.

In times of high sugar prices, it is very desirable to continue grinding as soon as possible and as long as cane is available. The grinding season usually extends into the start of the rainy season. This is technically a bad situation, for two reasons:

(a) When rain falls, the cane starts growing again and uses its sucrose for this growing process. Yield decreases, pol in cane decreases, cane weight increases, juice brix decreases (the more water, the less solids in juice). Therefore there is more cane to grind, and more evaporation for the same results.

(b) Machines and traffic in the fields cause damage to the remaining root system and have an adverse effect on yield levels in future crops.

In countries where cane growth depends on irrigation (where there is no rainfall, such as Peru), maturity is achieved by withholding irrigation some time prior to harvesting. In other countries, it is brought about through dry weather together with cool nights. If increased production is required and the season lengthens, then expansion of the factory to increase its grinding capacity may be desirable.

In some places, such as Louisiana and Florida, temperatures below freeze point may occur at night. Frozen cane has to be processed as soon as possible, because after about four weeks, purity of juice and yield of sugar fall off rapidly. The cane, with brown leaves and dry stalks, looks as if it has been burnt. Later, in the boiling house, it is almost impossible to induce crystallization. The syrup will not liberate sucrose. Instead it is held in solution by organic compounds formed by freezing of the cane. In many cases, routine laboratory analysis to determine purity (brix and pol) indicates an acceptable purity value that turns out to be false. This is due to the presence of higher carbohydrates formed in the freezing process, which gives positive polarization as does sucrose.

## REFERENCES

1 Rosenfield, *International Sugar Journal,* Jan., 1937.
2 Tysdall, *Sugar Journal,* April 1957 and July 1959.
3 H.C. Prinsen Geerligs, *Cane Sugar and its Manufacture,* Norman Rodger, 1930.
4 *Ibid.*

## CHAPTER 2

# SEPARATION OF JUICE FROM CANE

There are two different systems of extracting the sugar containing juice from the cane. They are:

(a) by means of pressure in a number of mills provided with three rollers, through which the cane is forced. (A crusher is for cane preparation, not for extraction of juice.)

(b) by means of diffusion, extracting juice by applying heat and immersion in water and squeezing of the bagasse.

The oldest system uses mills, but there are disadvantages, the main ones being:

higher maintenance,
high power consumption,
relative lower sucrose extraction, due to re-absorption of juice by the final bagasse,
high initial cost.

Diffusion became possible after the process was made continuous rather than batch. This change happened in the 1950's. Diffusion is based on osmosis, and in the case of cane sugar, where there is a solution of sucrose contained in a cell membrane surrounded by a solution of lower concentration, sucrose passes through the membrane to the weaker solution.

Theoretically, the sucrose extraction of a diffuser can be nearly 100%. The disadvantage of diffusion is that the nature of the optimum cane preparation for material to be diffused is not yet known. If it is too fine, it makes the material impermeable during percolation; if too coarse, then extraction will suffer.

Retention must be long enough to allow cell membranes to rupture, as a result of surrounding hot juice of low density — osmosis alone accounts for only a small percentage of extraction. To minimize the risk of long retentions and inversion, milk of lime can be added in the diffuser to increase the pH to about 6. Higher sucrose extraction in the diffuser also means higher extraction of impurities. This reduces recovery in the boiling house later and can be a problem in mills where sugar is to be refined.

There are two basic concepts of diffuser function:

(1) Extract about 70% of juice in a mill before the diffuser and leave 30% of juice to be extracted in the diffuser.

(2) Extract all juices in a larger diffuser and prepare the cane correctly before it enters the diffuser.

The first system is of course logical in existing mills, where a diffuser is installed, either to increase capacity or to replace part of an older mill tandem. In the latter case, two mills are used after the diffuser to reduce the moisture in bagasse from about 80% to the normal level of 48%. With the water separated out from it, the so-called press water is screened, neutralized to pH 7, and after heating returned to the diffuser as maceration water.

Although many cane sugar factories are equipped with diffusers, the results, as regards sucrose extraction, are not too encouraging. If extraction reaches about 98%, then the amount of water to be applied is so large that evaporation is excessive and the steam is far more than the bagasse can generate. Consumption of fuel oil may cost more than the extra sucrose produced by increased extraction.

In mills as well as in diffusers, it is well established that the economical equilibrium of imbibition water applied to gain extraction is between 180 and 200% on fiber in cane. Above this, evaporation becomes excessive and causes high consumption of steam and therefore fuel.

## Importance of mill sanitation

To conserve the juice and prevent losses due to inversion or purity drop, it is best to reduce retention time to a minimum and keep the mills (or diffuser) as clean as possible by frequent washing with hot water and low pressure steam, as well as applying disinfectants to the circulating juice streams. The juice surrounding the mill tandem has a temperature which favors bacterial growth, and even small quantities of infected juice or bagasse bring about disastrous infection. Therefore, cleaning with hot water and steam should be repeated at least twice per shift and every time the milling is interrupted by down time.

In Fig. 3, taken from Prinsen Geerligs,[1] it is clear that juice purity of the last mill decreases rapidly, because of infection. It falls from 76 to under 60 in one week and returns to 77 after the mill cleaning on the seventh day.

It should be noted that in Java, where this graph was prepared, mills are stopped once a week for three hours for intensive cleaning. The graph also indicates that first mill juice does not deteriorate as fast, because of its large quantity, higher density and higher velocity through the tandem. Last mill juice, however, travels through all mills, has a lower brix, which is favorable for bacterial action, and its quantity is less, therefore retention is longer.

If disinfectants are used, the best places to add a dose are:

(1) in the discharge of the last mill and

(2) in all re-circulating maceration juices, which return to the preceding mills, using the juice as a carrier to spread the disinfectant to all mills.

Disinfectant can be added by gravity or by using a chemical pump which gives a measured dose. There are excellent disinfectants available, made by reputable chemical companies.

If the plant is shut down for cleaning or repairs, the mills can be disinfected using hot water and steam, followed by a general washing with formaldehyde solution. There are various mill disinfectant chemicals on the market, one well known one is Busan. Of course, all must be acceptable by the U.S.D.A. and the F.D.A., since they are mixed with food for direct consumption.

Normally, East Asian countries as well as Hawaii have a higher sucrose extraction than mills located in the Western Hemisphere (South-Central and North America). This is because there are two different approaches to grinding cane. These are: the

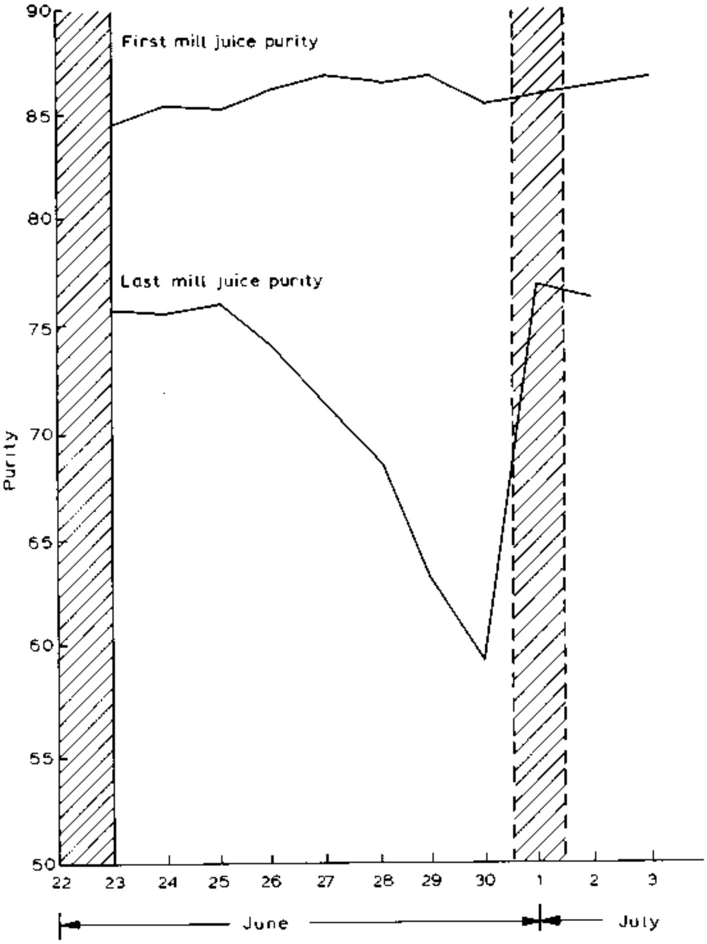


Fig. 3 Purity loss of last mill juice by infection of unwashed mills. (From Prinsen Geerligs[1])

European school of slow grinding with high pressure and the American school of fast grinding with medium pressure. The reason for this difference becomes clear, if we consider the geographical details as well as manpower. Most Asian island countries, such as Indonesia and Hawaii, have limited areas of cane, because they are small combined with high population density, making labor more available, this results in lower wage standards. The mills in those countries have the same cane area year after year, so there is no need to increase capacity. The only criterion is to extract as much sucrose from the cane as possible, normally 95-97%.

The American system has a different purpose. Here the criterion is to grind as much cane as possible in the time available, because milling capacity is constantly increasing. Every year the amount of cane planted also increases and so the aim is to economize as much as possible on higher labor costs, together with limited labor supply, to keep cost price of sugar to a minimum.

Here sucrose extraction is not the main target. Instead, it is to grind all available cane in the relatively short season. Here also, the capacity of the mills is continuously increasing. A good example are the mills in Florida and Mexico, where capacities increased over 200% in the last fifteen years. In general, these are countries with limited manpower and large cane-planting possibilities. Grinding in these countries is based on high mill speed and lower pressure to be able to "pass" sufficient cane. Sucrose extraction is normally between 91-94%, depending on tandem units and size compared with capacity.

## REFERENCES

1. H.C. Prinsen Geerligs, *Cane Sugar and its Manufacture,* Norman Rodger, 1930

## CHAPTER 3

# BAGASSE, BAGACILLO — ITS USE AND BEHAVIOR

The cane on the intermediate carriers between the mills is called bagasse, normally indicated by the number of the unit in the tandem, but it is also true that bagasse is the final byproduct leaving the mill tandem, after the juice has been separated from the cane. The composition of the bagasse is mainly fiber and moisture. It contains a certain amount of juice, which remains after extraction by the last mill. It therefore has the same quality as the last extracted juice. This juice is actually extracted by the last roll of the last mill. However, since separation of first and second juice of one mill is physically impossible, the small error introduced by taking last mill juice instead is generally accepted by all sugar countries in the world.

For all practical purposes, the weight of fiber in bagasse is equal to the fiber in cane. This is the basic concept of determining fiber in cane by the indirect method. In the case of bagasse, the pol and moisture contents are determined in the laboratory.

The total bagasse is fiber plus moisture plus solids contained in juice (brix of bagasse = pol divided by purity last mill juice). The total weight of bagasse is also known as cane plus water minus juice. These three latter quantities are determined by weighing. Bagasse is mainly used as fuel for the boilers. This provides a big advantage of the cane sugar mill over the beet sugar plant, as the latter does not produce fuel and has to operate on bought material (oil, gas, coal).

In a well designed mill, the bagasse produced is normally in excess of that required by the boilers to produce the necessary amount of steam, although efficiency of bagasse depends strongly on fiber content, moisture in bagasse, cane variety, preparation while grinding, and many other factors, such as sand content, type of furnace, etc.

Sometimes it is possible to utilize all or part of the bagasse for other purposes, such as paper and hardboard production and cattle-feed filler. Excess can also be baled and used at the beginning of the following year, or in some cases as fuel for locomotives, when cane hauling is done by railroad. In some places, excess bagasse is used to produce steam to drive power plants, and the surplus electricity can be sold. In the mill tandem and during the grinding process, a large quantity of very fine bagasse dust is formed, which is known world-wide as Bagacillo.

The main application for this Bagacillo is in its use in relatively small amounts as a filter aid for the rotary vacuum filters. It is mixed with the muddy juice to give "body" to the mud cake. The bagacillo is simply separated from the carrier through screens, by suction of a blower, which transports it to the mud mixer. It can also be separated using a rotary screen. In the design of a new mill, wind direction should always be taken into account, so that bagacillo in the air is blown away from the sugar end of the mill.

CHAPTER 4

# JUICE WEIGHING OR MEASURING

To be able to make a laboratory assessment of materials, some data must be determined. The quantities considered are:

(a) what comes in
(b) what is produced
(c) what is lost.

In the sugar mill we talk of sucrose, the product. To assess quantities, the weight of certain materials must be known, together with their analyses. It is obvious that the main material whose weight must be determined is the cane. Secondly, the other materials used in juice extraction and the weight of the products obtained in the mill must be known.

We therefore have:

weight of cane + weight of water = weight of juice + weight of bagasse

This is the basic quantity formula.

The weight of cane must of course be known for the purchase of the cane from the growers, or, if the growers belong to a cooperative mill, to determine their share. Thus, the weight of cane is the most important information, since other materials are always related to cane weight, and in nearly all countries cane weighing is compulsory and falls under government control.

Juice is normally weighed as mixed juice (also called raw or diluted juice). It can be weighed or measured, although weighing is more precise. If it is measured, samples of each measuring tank should be taken to obtain an average of the density of the measured juice and find the correct specific gravity. A flow meter can be used for this application, only if it is magnetic, since otherwise there is interference of insoluble solids present in this juice. Imbibition water must also be weighed, but here a flow meter can be used, as there is no material handling problem.

Under normal conditions, the factor relating the three previously mentioned weights of cane, juice and water is bagasse, calculated through the difference:

bagasse = cane + water − juice

It is desirable that the weight of bagasse should also be determined by weighing. If it is, there is a check on the reliability of each weight. Weighing bagasse is not too complicated if a so-called ''weightometer'' is used. The bagasse carrier is interrupted and the carrier of the weightometer is inserted between the two. The load on the instruments carrier is recorded and totalized, giving a continuous weight-reading and a digital integrated total. Weighing of bagasse is very convenient where it is used for purposes other than fuel.

## CHAPTER 5

# LIMING

As seen later under clarification processes, all of these processes uses lime as the basic clarification medium, and only the quantities and the preparation are different. Lime can be used in either of the two commercial forms: quick lime, CaO, or hydrated lime $Ca(OH)_2$.

Before World War II, quick lime was usually used, but lately hydrated lime has taken its place, and it has many conveniences not offered by quick lime. In all cases and whatever type used, the lime applied in the clarification process is in the form of milk of lime, which is a suspension of $Ca(OH)_2$ in water.

## (a) Quick lime

Quick lime is prepared by burning limestone in the presence of coke. Limestone, being mainly $CaCO_3$, gives off $CO_2$ when heated in a kiln:

$$CaCO_3 \longrightarrow CO_2 + CaO$$

The burnt CaO has some impurities, which are unburnt particles and dead burnt (overheated) particles, some silica and magnesium.

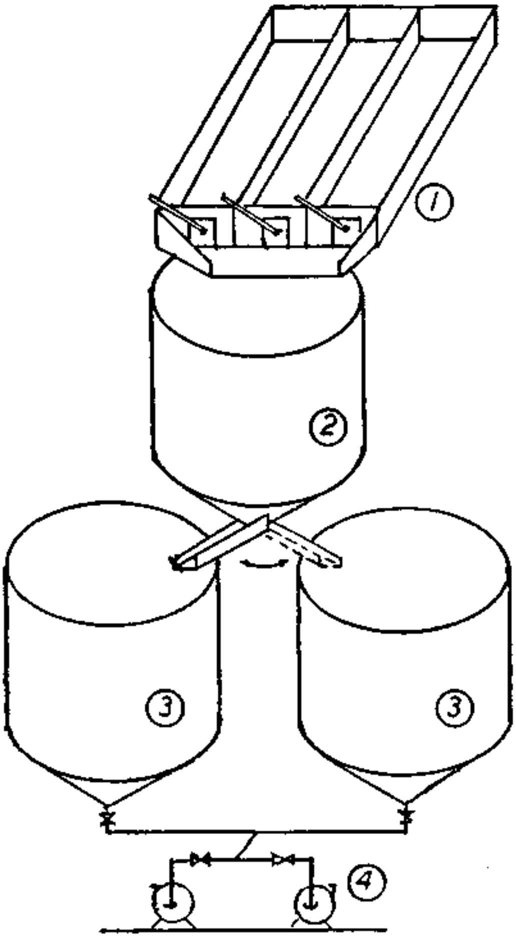
A good quick lime has 90-95% CaO, not more than 1% Mg (this could cause trouble in clarification if higher), and should not contain more than 1% of iron and aluminum oxides (to avoid deposits in evaporators). A physical test can be accomplished by mixing a sample with half its weight of water. It should become very hot in a few minutes, and mixing a sample with ten times its weight of water should produce a soft cream. In this form it still contains larger particles, which are CaO, in which water has not as yet penetrated completely. It takes some time to dissolve.

The lime is first treated in a slaker, where it remains for some time to give the larger particles the opportunity to absorb water. After a reasonable time it is transfered to a storage tank, where water is added to complete the correct density of the milk of lime. This density is normally 15 °Bé or lower. 10 °Bé is also used in many mills and even 3 °Bé or 5 °Bé is sometimes used in combination with automatic pH control.

The slaker can have the same physical dimensions as the storage tank. To increase effectiveness most of the larger particles can be broken up as follows:

Provide a flat rectangular tank, divided into three compartments, one for each daily shift, in which the lime for the next day is spread out and some water added by hosing.

The next day this lime is dropped in a cylindrical tank provided with a stirrer. This tank is on a lower level than the flat tank, such that the lime can be raked into the round tank. Here more water is added. The resulting milk of lime will be of about 25 °Bé.



① three-compartment pre-slaking tank

② cylindrical tank with agitator, for slaking

③ milk of lime finishing tank to adjust density and for recirculation, with agitator

④ milk of lime recirculation pumps

Fig. 4 Slaking of quicklime with 24 hours retention time. The instalation is vertical; material flows by gravity.

*Note.* When using hydrated lime, slaking is not required. In this case, lime can be diluted to the correct density in just one step. Therefore, only tanks No. 3 are required.

From here, again by gravity, the milk of lime is finally fed to a similar cylindrical tank, in which the required end Bé of the milk of lime is maintained. From this tank a pump moves the milk of lime through a recirculating pipe line from which the quantity required by the process is taken.

At the end of the shift, the lime prepared the previous day is all used. A new batch is prepared daily.

During the many years in which lime was used as a clarification agent, numerous experiments were performed, in which lime was applied to cold juice and hot juice in separate doses; to cold juice in part and then the rest to hot juice; before evaporation; after evaporation; in solid form; in liquid form at various densities; in the form of calcium saccharate; etc.

These experiments were mainly for the purpose of obtaining better floc formation for a more efficient clarification, or for reducing incrustation of the evaporators, or both.

The experiment of liming after evaporation was to evaporate acid juice, which does not form incrustation, and at the same time lime a reduced quantity of liquid in the form of syrup, which is roughly 25% of the juice weight. If clarification becomes difficult, other chemicals are often used to improve separation of mud, in combination with the lime.

Normally, phosphates (tricalcium phosphate) are added to increase the density (specific gravity) of the mud floc during its formation. A more modern method is the use of poly-electrolytes as the floculating medium. The quality of the water used to dilute the lime is as important as the quality of the lime itself, since they are both added to the juice and will increase the non-sugar solids in the juice, thus reducing the juice purity. The water to be used should be hot condensate from evaporator vessels under vacuum (#3, 4 or 5). The most accurate liming is the one where the pH is automatically controlled.

In the defecation process, the addition of lime is mainly used to neutralize the natural acidity of cane juice. If the juice stays acid, inversion (loss of sucrose) can take place and if juice is over-limed, it will be too alkaline and decomposition of glucose into organic acids will occur, causing a darkening of the juice (by reacting on the metal of the tanks and pipes). Iron salts of organic acids are mostly dark in color.

Over-liming also is molassigenic. It increases the amount of molasses produced; it also increases incrustation of evaporators. Results of clarification and the use of lime are largely dependent on quality and variety of cane, soil characteristics, equipment efficiency, applied temperatures, cane maturity, etc. The correct method is liming to neutral. If results are not satisfactory, phosphates or electrolytes (Separan) can be added to help.

There are various clarification processes, resulting in difference of produced sugar. These will be discussed later.

## (b) Heating

If we consider the most common system of liming cold juice and heating limed juice, the temperature of the juice obtained is important. This means that heating at too low a temperature results in bad clarification and bad sugar. Temperature must be well above boiling point and the excess temperature, obtained under pressure conditions, must be released before the juice enters the clarifier. Therefore heating can only be done in pressurized closed juice heaters. The pressure is formed by the pump capacity, which forces the juice through the heater.

Normally, juice passes through the tubes in a heater body, while the heating medium (steam) surrounds the tubes.

To be able to design a heater of reasonable dimensions, we must consider a system where the juice makes various passes back and forth through the tube under a designed liquid velocity to optimize heat transfer from medium (steam) to liquid (juice) and to minimize tube incrustation.

To make possible the use of vapor at different pressures, produced by different evaporator vessels, and to keep heater dimensions of reasonable size, heating is done in more than one stage, normally two stages, but three is also possible.

Although the velocity of the juice through the tubes is kept rather high (not less than 6 fps), deposition of incrustation cannot be avoided and heaters have to be cleaned after a few days use. Therefore, stand-by equipment is required.

After the juice has been heated beyond its boiling point, it passes through a flash tank where the excess heat above boiling point is liberated, because of the pressure drop. Visible vapor escape from the roof outlet of the flash tank is a sign that juice heating is correct.

Automatic temperature control of the juice leaving the last stage of heating is installed in all modern sugar mills; this is a very simple control loop. Juice heaters are designed to be either horizontal or vertical, the latter being used mostly in the beet factory, probably because there are more heaters involved. Through the use of vertical units, the area occupied can be smaller.

With cane, nearly all heaters are horizontal (American and British concept). French, Dutch and German heaters tend to be vertical. For some reason, horizontal heaters have a much higher heat-transfer coefficient (an average of 20% more), apparently owing to the steam distribution. Horizontal heaters have a limited tube length, because if tubes are too long, they need additional support to prevent sagging. By using shorter tubes (say up to 16 feet), there are more passes and therefore the diameter of the body is larger. If diameter exceeds 4 feet, the heater must be horizontal, never vertical. Cleaning of a vertical heater with soda can cause hazards, because the soda will remain in [illegible] lower header and must be drained by hand. This is not the case in horizontal h[illegible]s.

Condensate of juice heaters should ne[illegible] be used as boiler feed water, because the juice pressure is much higher than that of the steam. In the case of a leaking tube, juice enters the steam space, rather than the converse which is the case in vacuum pans and evaporators.

Cleaning is done mainly by circulation of caustic soda solution, together with alternate dry heating with steam, followed by cooling with cold water. Most of the deposit will be freed from the tube wall owing to the temperature change. It can be blown out by means of an air hose.

### (c) Filter

The use of rotary vacuum filters for mud filtration is almost universal in cane sugar mills. Historically, the first filters were percolation filters, filled with sand. Then frame plate presses became widely used. After the first World War, various pressure filters of more sophisticated designs were popular, for example: Kelly, Sweetland, Vallez, etc.

The main disadvantage of all pressure filters is that the filter station is a very dirty place because of the mud cake present and the use of high-pressure water hoses for washing off the filter cloth. Indeed, the use of rotary vacuum filters was a tremendous improvement. However, a vacuum filter is really not a filter; it is a strainer.

The disadvantage is that the filtered juice is not good enough to go forward in the process and be sent directly to the evaporator, to be mixed with clarified juice. It has to be returned to the liming tank and re-circulated completely, to participate again in the liming, clarification and filtering. The quantity of this juice is about 15-17% of the mixed juice, and it is a burden on clarifier capacity. Many systems were tried out to treat the filter juice in such a way that re-circulation could be avoided, but the methods were rather costly and few mill owners were inclined to experiment with uncertain equipment applications.

The most common systems were:

(a) filter press with re-liming and re-heating of the juice and use of filter aid (Fas-Flo filter of Suchar);

(b) re-liming, re-heating and a small individual clarifier;

(c) making a real filter out of a vacuum filter and putting a cloth on the drum. This was done by Dorr Oliver (Rapifloc system) as well as Eimco (Eimco-belt), but results were not yet satisfactory.

Nevertheless, one or more of these applications will mature sometime and re-circulation of filter juice will then be outdated.

As the sucrose lost in the mud cake is a positive loss, it is necessary to know the quantity of mud produced and its sucrose content. The most positive method is to weigh out each truck load of mud leaving the mill yard. This is not possible if the mud is washed away in water, then run to the field as irrigation. The correct way to determine the quantity of mud cake produced and the sucrose lost in it will be considered later in laboratory procedures.

CHAPTER 6

# CLARIFICATION PROCESSES

All procedures mentioned refer to the normal raw sugar clarification system, called defecation. As mentioned before, the use of milk of lime is a very old technique dating back to ancient India. Apart from the different applications of milk of lime, use of other products is possible, with supposed advantages over the use of lime. However, soon after their appearance, these products slowly disappear from the market, simply because lime is the easiest, cheapest, most readily available, and most efficient clarifying agent. Also, many products are available only locally. Just a few examples are:

(1) Magox } Mg oxides
(2) Elguanite } Mg oxides
(3) Bentonite (Puerto Rico, AlMg silicate)
(4) Guasima Sap (Costa Rica, for direct white sugar)
(5) Separan a coagulant in addition to lime (polyelectrolyte)
(6) Trisodium phosphate (in addition to lime)
(7) Lime as saccharate (using part of raw juice)

Intermittently, a different method of application of milk of lime finds its way into the process. The results are often good under local circumstances and with specific cane varieties. It is known that with the introduction of the famous variety P.O.J. 2878, which originated in Java, clarification was very difficult. This brought about many variations of the way lime was added:

(a) in batch or continuously
(b) lime, heat
(c) heat, lime
(d) lime, heat, lime
(e) Heat, lime, heat
(f) lime, heat, lime, heat
(g) mixed with raw juice as saccharate
(h) long or short reaction tie
(i) settling in open tanks or continuous clarifiers
(j) compound clarification
(k) under various pH conditions.

There are so many variations, still in use or obsolete, but one example is sufficient. Let us describe the Java method used with the P.O.J. 2878[1] cane:

(1) All juice pre-limed to pH 6-6.5 (cold)
(2) 40% of the juice limed to pH 9.5 (cold)
(3) 60% of the juice heated to 215 °F
(4) The two parts mixed, giving a pH of 7.6-7.8 and a temperature of 150 °F.

If system (e) is applied to juice heating in two steps, the raw juice of pH about 5.4 is heated to about 160 °F, then limed and heated again. This has the advantage that the heaters can be switched over every eight hours, and they stay clean, because the untreated acid juice reacts as an acid cleaner. The milk of lime reacts chemically with the juice, and forms calcium salts of the organic acids in the juice, which are mainly insoluble. The physical reaction — floc formation and consequently formation of a precipitate — is more important.

The amount of lime added in the defecation process is 0.6-2 lb CaO per ton of cane, depending on the purity of the lime, the cane variety and other factors. A good quality quick lime has 90-95% CaO, while hydrated lime contains 76% CaO (molecular weight CaO = 56, $Ca(OH)_2 = 74$, therefore $\frac{56}{74} \times 100 = 76\%$).

Normally, hydrated lime is more expensive because more is needed and transportation costs are higher, but the equipment required is much simpler. The amount of milk of lime added to the juice depends on the density to which it has been prepared. If 10 °Bé is used (which is quite universal), one liter of milk of lime contains 8.74% CaO and about 91% water. If 1.5 lb CaO is prepared at 10 °Bé, it will give 17.16 lb milk of lime per ton of cane (CaO is 8.74% of weight at 10 °Bé). 17.16 lb/t cane = 0.86% on cane weight. Thus, if milk of lime is prepared at 10 °Bé, the weight can vary from 0.6 to 1% on weight of cane.

## Water for milk of lime

As said before, lime quality is obviously important because all impurities added are molasses-forming and add to the quantity produced, while reducing sugar yield. This is easy to understand and all the facts are well known, but what is also very important is the purity of the water used to prepare the milk of lime. This is not so well known, or is overlooked. *Always,* water for milk of lime preparation must be condensate of vacuum vessels of the evaporators (Nos. 3 and 4) or of the heaters. Slight sugar contamination is not important.

## Circulation of lime

In all sugar mills, the milk of lime pump circulates the slurry and the required quantity is drained from this loop under pressure. The milk of lime must be moved incessantly and must not stagnate in a pipeline. Consumption of milk of lime is relatively small compared with the quantity in circulation through the pipe system. It is important to keep the flow velocity high enough to prevent settling, but also low enough to prevent excessive pressure-drop resistance.

Real milk of lime consumption of a 5,000 tcd mill is about 3 gpm, while the pumps normally are either 25 gpm or 50 gpm. The flow velocity in the circulation pipe loop must be calculated at 3 ft per second, which is high enough to prevent settling but low enough to avoid high pressure drops.

Wherever an elbow is needed in the pipe, a cross-piece should be used, to enable both the horizontal and vertical runs of the line to be scraped in case lime deposition occurs.

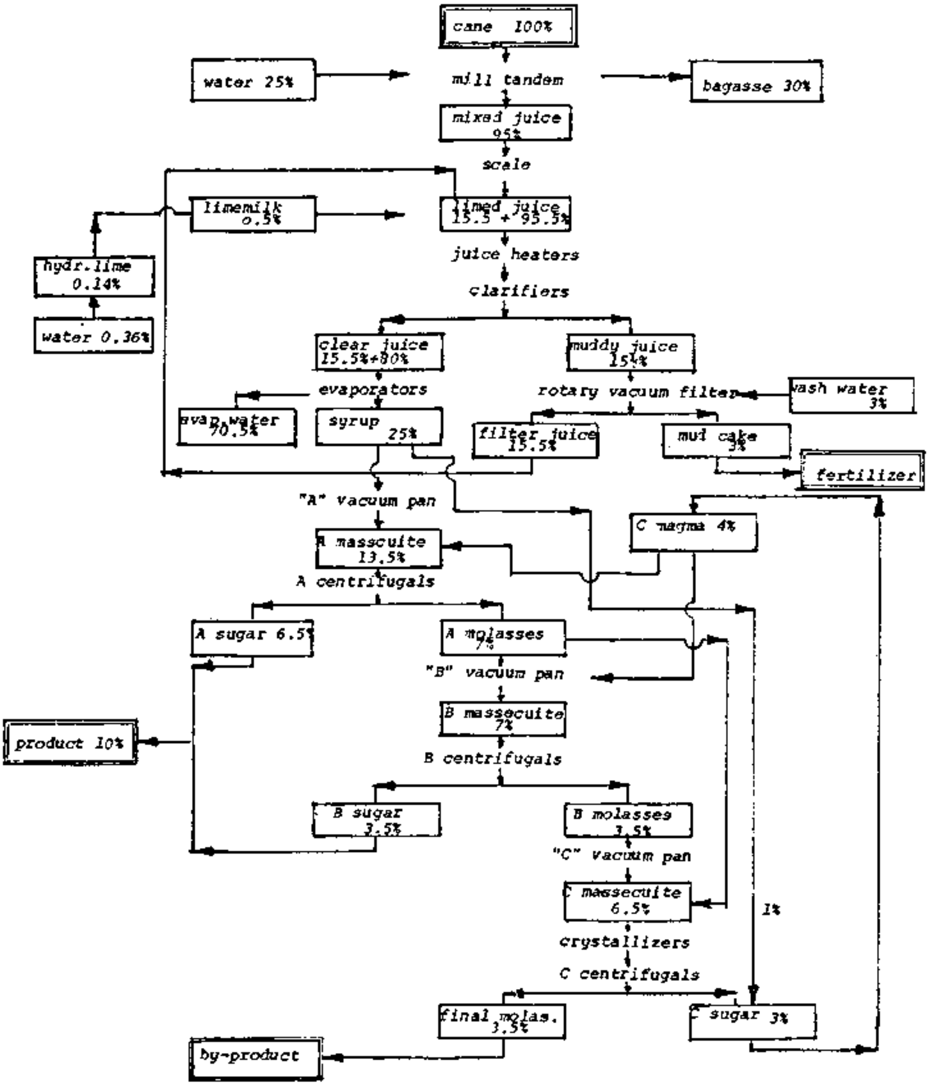


Fig. 5. Typical flow diagram of a raw sugar mill. Quantities depend on cane quality. Average percentages.

## Various clarification processes

The defecation process produces raw sugar. This is because the amount of lime used as a clarification agent does not remove enough non-sugars to produce a white sugar. In order to achieve this, other systems were developed. The application of these systems was logical, superimposed on the basis of the defecation process.

It was clear that the milk of lime added to the juice neutralized its natural acidity and, in so doing, precipitated many impurities. This precipitate increased when heat was applied to the juice. It was also observed that not all impurities could be eliminated. The logical solution then was to increase the quantity of lime added.

The only problem was in neutralizing the alkalinity at a later stage: herein lies the secret of the different systems used to produce a whiter product called "plantation white". This is a rather white crystalline sugar made in one process directly from the cane, without the need to send the raw sugar to a separate refinery.

The first step was to increase the milk of lime application to about four times the quantity required by the defecation process, from 2.4 to 8 lb/t of cane (0.12-0.4% on cane), and neutralize the excess alkalinity using $SO_2$ gas, which also bleaches the juice, giving it a lighter color. This is the so-called "sulfitation process".

## REFERENCES

1. P. Honig, *Principles of Sugar Technology, Vol. I,* Elsevier, Amsterdam, 1953, p. 558/559.

CHAPTER 7

# SULFITATION PROCESS

This process is quite old, and was used in Europe in the beet sugar industry. It was first introduced for cane juice in Mauritius in 1865. From there it was taken to Java, where it became very popular and is still the general procedure, together with the carbonatation process which will be described later.

As we saw in the description of the defecation process, there are many variations on lime and heat treatment. This is also true for the sulfitation process, in which all kinds of sequences and heat treatments have been recommended:
lime first, then $SO_2$,
lime and $SO_2$ simultaneously,
part lime, $SO_2$, lime again, etc.
Also batch process and continuous process are possible.

The most established sulfitation treatment is:

(1) heat juice to 75 °C (167 °F)
(2) clarification using 352 lb CaO/100 t cane (0.18% on cane) and 176 lb/100 t cane of sulfur (0.09% on cane) on average
(3) secondary heating to 105 °C (220 °F)
(4) flash tank
(5) clarifier (subsider).

The heaters are alternated every shift of eight hours, to let acid raw juice clean the scale formed by the sulfitation juice. The pH of sulfured juice will then be about 7.4. This will decrease to about 7.1 in evaporator juice and 6.5 in syrup. As part of the sulfitation process, the syrup is also treated with $SO_2$ to a pH of about 5.4, before its use in the A massecuite.

As the sulfitation process is intended to be a white sugar process, the separation of sugar and molasses in the centrifugals is all done in two steps, the so-called double-purge system. This is practised with A and B as well as with C massecuite.

Afterwards, several secondary treatments were applied to increase the whiteness of the sugar:

(a) washing the sugar in the centrifugal, shortly before discharging it with a blue-dyeing water, using ultramarin or indanthrene mixed in condensate water. This is to complement the slightly yellow color with blue, to produce a whiter crystal, for the same reason that the jeweler shows a diamond to a client on blue velvet.

(b) complete re-melting of C magma and making crystallization strikes as seed for all massecuites, including A and B.

(c) a sugar dryer/cooler must be used before bagging the product. Because of the high pol, the safety factor cannot be obtained in the centrifugal as it could be with raw sugar. This factor is:

$$\frac{\text{moisture}}{100 - \text{pol}} < 0.250$$

and, since the pol is high, 100 − pol is only small and the required low moisture cannot be produced in the centrifugal. Hence the use of the dryer/cooler.

(d) also practised was the procedure of dissolving all A and B double-purge sugar in neutralized condensate, and from this melt $R_1$ and $R_2$ massecuites were made, the so-called semi-refined sugar. The run-off of the $R_2$ mc returned to syrup. This of course required more steam, pans, crystallizers, centrifugals, labor, and recirculation, but the result was a nearly refined sugar, which was probably still cheaper to produce than the carbonatation white and was of at least carbonatation quality, if not better.

In reality, sulfitation is a two-step reaction: (1) it neutralizes the raw juice, and (2) it neutralizes the excess lime in the juice. On this occasion, the elimination of non-sugars, especially organic non-sugars, takes place. Also, colloids are partly precipitated, by means of destruction of the colloidal stability. The stability of hydrophobic colloids is due to electrical charge of the particles, which prevents them from becoming attached to each other. If the charge is neutralized, they agglomerate and can be removed (sedimentation or filtration). These hydrophobic colloids are mainly inorganic compounds. For detailed explanation of the chemical and physical properties of juice clarification, the reader is referred to the various handbooks.

The above serves to illustrate the difference between the defecation and sulfitation process. The latter increases the elimination of impurities and produces a whiter sugar.

## Sulfur dioxide

This is produced by burning sulfur in an oven in presence of air ($O_2$):

$$S + O_2 = SO_2 + 70 \text{ kcal}$$

The reaction is exothermic giving off 2200 cal/kg of sulfur (3900 btu/lb of sulfur). The sulfur used for this process is found in two forms: either volcanic or in underground deposits. The volcanic sulfur comes mainly from Japan, Sicily or many local sources, such as Java. The underground sulfur deposits are found mainly in Mexico, Texas, Louisiana, Mississippi, Alabama. They are about 500 feet underground and are melted using hot water under high pressure, forcing the liquid sulfur through a tube to the surface.

Consumption of sulfur in the sugar industry is rather considerable. Before World War II, yearly consumption in Java was about 4500 tons, in Natal 6200 tons after World War II. In Java sulfur was consumed at a rate of 200 lb per 100 tons of cane, while in Natal in 1950 it was 270 lb/100 tons of cane. Its melting point is 120 °C, its boiling point is 445 °C. American and Sicilian sulfur have a high purity, as does the Japanese, but the latter sometimes contains small amounts of arsenic (according to F.D.A. regulations, this must not exceed 0.5 ppm).

There are two basic systems of adding $SO_2$ to the juice:

(1) the Quarez system, or sulfitation tower (column)
(2) the sulfur furnace under air pressure.

(1) The first is mainly used as an addition to the defecation process, with the purpose of using some $SO_2$ to bleach the juice and eliminate some inorganic non-sugars and some colloids.

The bleaching is mainly intended to rended most iron compounds colorless. The consumption of sulfur is much less than in the real sulfitation process. When the tower process is used to produce a better quality raw sugar, it is preferable to name the process "sulfo-defecation", to distinguish it from sulfitation clarification, mentioned under (2). In the sulfo-defecation tower process, the $SO_2$ gas is aspirated, sending the juice through a liquid ejector. The juice then falls through a column and the $SO_2$ gas enters at the bottom in counter-current. Consumption of sulfur for this system is 0.6-1 lb/t of cane.

(2) This is the system generally used in real sulfitation to produce plantation white sugar. It consists of (a) a sulfur furnace, (b) an air compressor with air dryer and air recipient, (c) a $SO_2$ gas scrubber, water-cooled, (d) a sulfitation vessel, batch or continuous. The air compressor delivers the air required to burn the sulfur and provide the $O_2$ to form $SO_2$. At the same time, the pressure of the air is used to transport the $SO_2$ gas to the sulfitation tank and propel the gas upwards through the column of juice in the tank. The main problem with making $SO_2$ gas by burning sulfur in a furnace supplied with air ($O_2$) is that under favorable conditions sulfur sublimates from the $SO_2$/air mixture. Therefore, there should always be an excess of air ($O_2$) to make a gas mixture of low $SO_2$ content, of under 14%. Above 16%, sublimation is likely to occur.

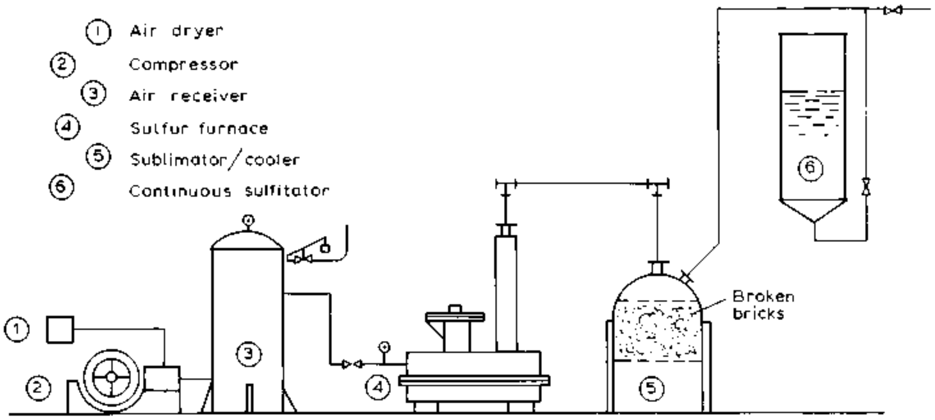


Fig. 6 (a). Arrangement of air pressure sulfitation equipment for continuous sulfitation, suitable for syrup treatment.

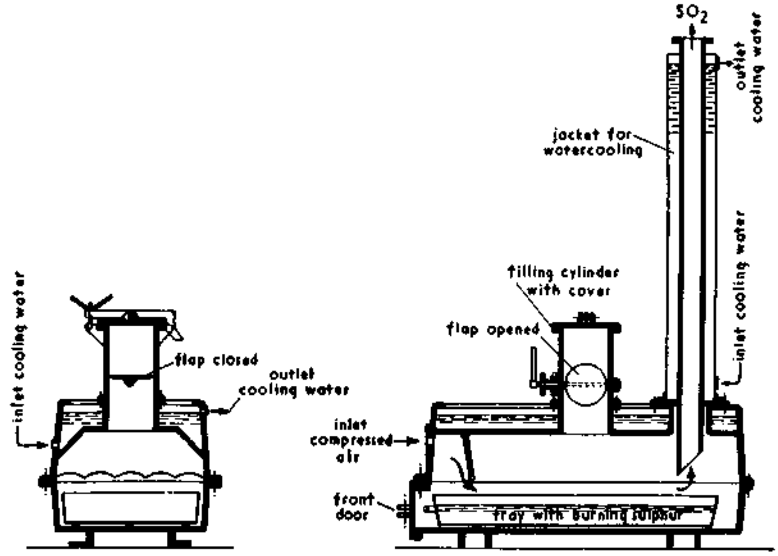


Fig. 6 (b). Typical sulfur furnace. (From Honig, Vol I, p. 645.)

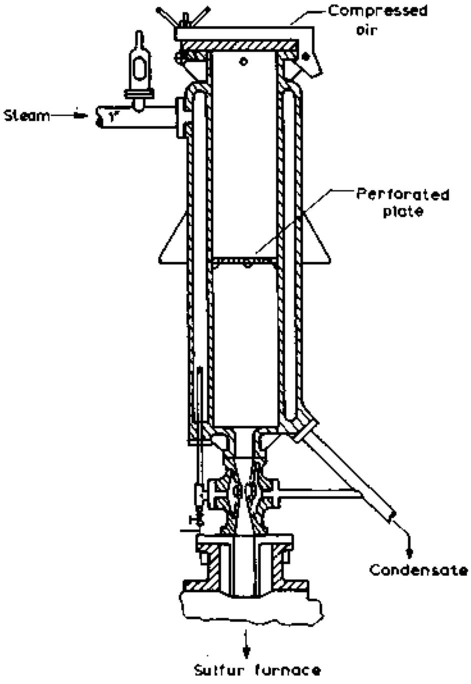


Fig. 7. Steam-jacketed sulfur filler and valve. It prevents sublimation caused by pressure fluctuations due to opening and closing the furnace for filling. The heated sulfur melts in the funnel and is admitted to the sulfur tray through the heated valve. No pressure loss occurs.

The top of the furnace, both the gas standpipe and the scrubber, should have a constant supply of cooling water. The lower the temperature of the gas in the pipeline, the less the chance of sublimation in that line. The reduced temperature also prevents formation of an excess of $SO_3$. This is important because in contact with water vapor, sulfuric acid will form, which attacks all pipelines. To avoid the presence of water vapor, the air admitted in the furnace should pass through a dryer before entering the compressor. The $SO_2$ contents of the gas should be kept at about 14%. If it becomes higher, it would be desirable to supply more air. Unfortunately, this is not possible since the compressor has a set capacity. For this reason, the burning surface should be reduced. This can be done by placing refractory bricks in the sulfur tray. The burner capacity is about 4 lb S/sq ft/h, or (4.31 lb/sq ft) = 20 kg/m$^2$ of tray area, if greater than 25 kg/m$^2$ sublimation is likely to occur.

It is very important that no conditions should change in the flow of $SO_2$ gas, for example fluctuating pressure. Therefore, the gas should always be turned on on a full sulfitation tank (not an empty or filling one). The weight of oxygen required to burn the S to $SO_2$ is equal to the weight of sulfur. The weight of air required is 4.3 × weight of sulfur (air contains 23% $O_2$), but there should be an air excess of 100%. The compressor should deliver 100 cu.ft/lb of S to burn, which also takes care of excess air.

## Sample calculation of a sulfur burner

| | |
|---|---|
| Assume grinding capacity of mill | 125 tch |
| Sulfur required (at 200 lb/100 t cane) | 250 lb/h |
| Sulfur burning capacity is 4.3 lb/sq ft/h | |
| Burning area required is 250/4.3 | 58 sq ft |
| Required 2 furnaces of 4′ × 8′ tray area giving | 64 sq ft |
| Air supply 100 cfm per lb/h of sulfur | |
| Air required 250 × 100/60 | 400 cfm |

or in units per 100 tch:

| | |
|---|---|
| Burning area required | 46 sq ft/100 tch |
| Sulfur burning capacity | 200 lb/100 tch |
| Air capacity 20,000 cfh | 333 cfm/100 tch |

As the process comprises mixed juice, milk of lime, $SO_2$ gas, temperature and time, numerous variations of the process are possible by varying temperature, time and acid or alkaline state, continuous or intermittent applications, etc.

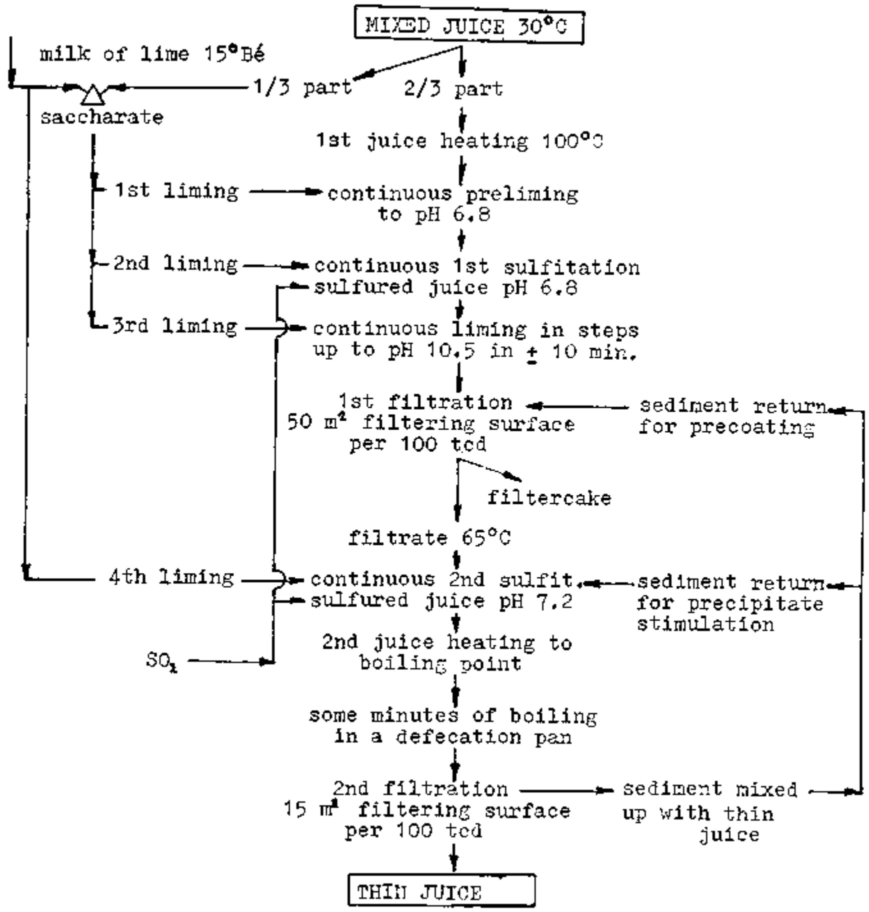


Fig. 8. Flowsheet of the double sulfitation process "Bogstra". (From Honig, Vol. I, p.642.)

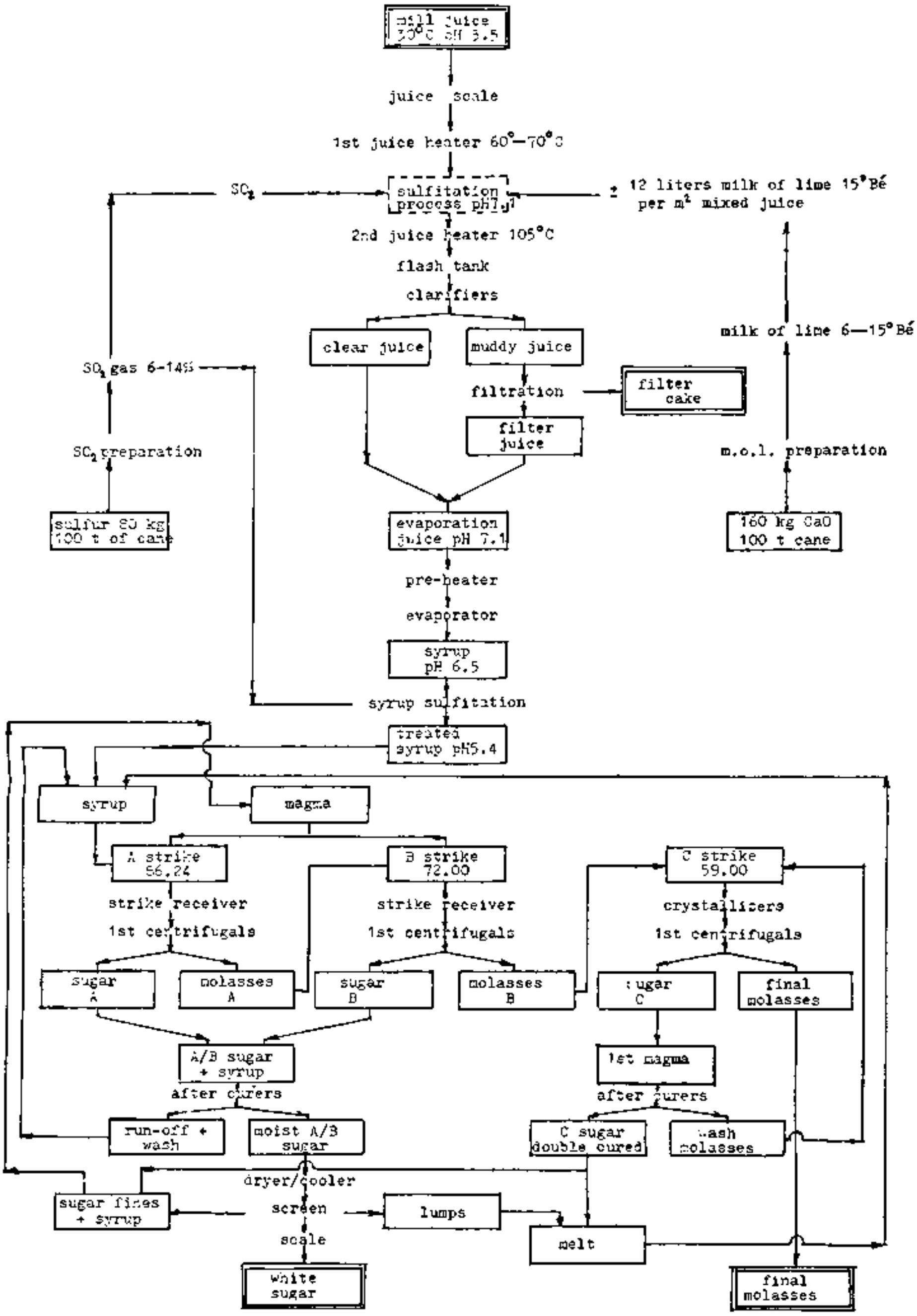


Fig. 9. Flowsheet of a sugar mill producing plantation white sugar by juice and syrup sulfitation and double curing of A, B, C sugar. (From Honig, Vol. I, p.585.)

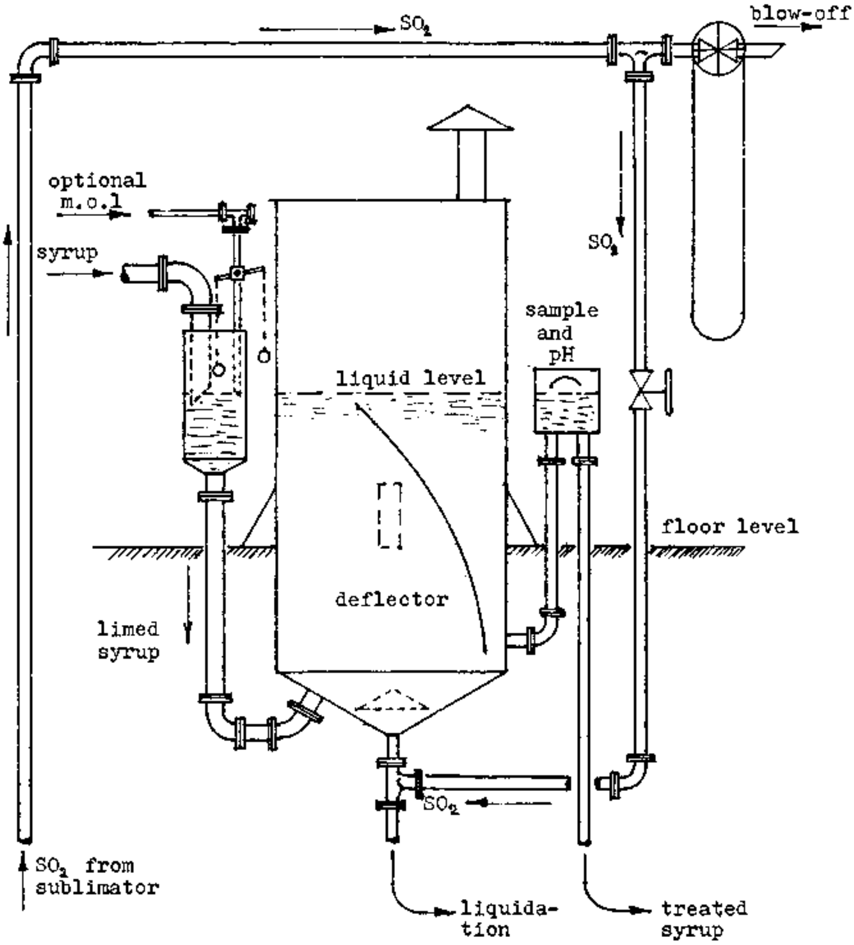


Fig. 10. Continuous sulfitation tank for syrup, provided with optional milk of lime dosification.

## CHAPTER 8

# CARBONATATION PROCESS

The main purpose of all clarification systems is, of course, elimination of impurities contained in the non-sugars in a soluble or insoluble state. The elimination capacity of the defecation process is limited to the production of raw sugar. The sulfitation and carbonatation processes, eliminating more non-sugars, are capable of producing the ''plantation white'' sugars.

The sulfitation process is actually a combination of two purposes. One is the defecation step of neutralizing the acidity of the juice by use of milk of lime, and the second is the neutralizing of the excess lime by means of $SO_2$ gas.

The carbonation goes even beyond this. Much more lime is added and neutralized with $CO_2$ gas. Here, of course, the amount of non-sugars removed is much greater and the sugar is of better quality. The following illustrates the differences between the three processes as regards the removal of non-sugar:

| | |
|---|---|
| Defecation | removal of about 6% of non-sugars |
| Sulfitation | removal of about 11.5% of non-sugars |
| Carbonatation | removal of about 28% of non-sugars |

Lime consumption expressed as CaO% cane:

| | | |
|---|---|---|
| Defecation | 0.03 — 0.10% | 0.6 — 2 lb/t cane |
| Sulfitation | 0.12 — 0.40% | 2.4 — 8 lb/t cane |
| Carbonatation | 1.50 — 3.00% | 30 — 60 lb/t cane |

The amount of lime used in the carbonation process is so large that it is not possible to buy sufficient in a prepared form, as is done in the defecation and sulfitation processes. If we take as an example a sugar mill processing 500,000 t of cane per season (medium-size mill), the total lime requirements are on average:

| | |
|---|---|
| defecation | 300 tons |
| sulfitation | 1200 tons |
| carbonatation | 10000 tons |

Thus, for the carbonatation process, a lime kiln is required for production of lime from limestone. By burning the stone, with coke as a fuel, $CO_2$ is formed. This is very convenient, since this gas is used to neutralize the lime excess to give a high rate of non-sugar removal.

## History of carbonatation

Originally, carbonatation derived from the beet sugar industry, where it was used because the mixed juice of beet can stand a much higher alkalinity than the cane juice, without producing dark colored juice and sugar and the problems that high alkalinity has on the crystallization process. Viscosity increases, as do the ash contents.

The process was developed in the early 1800's, but even in 1812 it was discovered that the high alkalinity due to the excess of lime was responsible for poor crystallization. In that year, $CO_2$ was applied for neutralizing the lime excess, with such great success that it became standard procedure to increase the lime dosification, heating to 90 °C, and to neutralize with $CO_2$ in open decantation tanks followed by filtration.

The name of the process is carbonatation. It is sometimes called carbonation, but this is less correct since this term is mainly used for addition of $CO_2$ gas to beverages.

Originally, in the beet industry, the lime was slaked in the juice, using the heat developed as a medium for heating the juice. This can be applied to beet, but not cane juice, as the latter contains reducing sugar which decomposes. In beet there are no reducing sugars present.

The first application of the carbonatation process was tried in Java in 1876. Here juice was heated to near boiling point after the excess lime had been added. It was then eliminated in two steps. The greater part was eliminated in the first saturation, then filtered and the second carbonatation eliminated the rest to obtain a final juice with a minimum of excess lime. This double carbonatation process returned to Europe, where it took about twenty years to be fully utilized in beet processing.

The advantage of the carbonatation process is the instantaneous excess of lime and $CO_2$ gas used, rendering precipitation of non-sugars combined with crystals of $CaCO_3$, which results in easy filtration. It was soon clear that the reactions were favorably improved when carried out at higher temperatures.

This is due to the fact that absorption of $CO_2$ in cold juice is poor. The biggest problem was that lime consumption is very high, being 1.5—3% CaO on cane, or expressed as limestone around 5% on cane. This is anywhere between 20 and 30 times the defecation lime requirement. Behavior of the process in beet is different from that of cane, because of the different nature of non-sugars and also the absence of reducing sugars in beet.

This permits much higher pH without disadvantage. For this reason it is important to have the R.S. in cane juice as low as possible. This is achieved by cutting the cane at the highest possible maturity. This maturity optimum gives the highest sucrose, together with the lowest reducing sugar.

The dominating factor in the carbonatation process is that high alkalinity together with high temperature cause decomposition of reducing sugar, resulting in acid formation, dark color, poor crystallization, high viscosity, etc. Nevertheless, the carbonatation process is attractive and will produce a white sugar just as it is produced in the beet industry.

It is clear that the carbonatation process in cane has been carefully studied and observed, especially in Java, where nearly all sugar produced was "plantation white". Of course, the sulfitation process was favored because of its simplicity and low cost, using about one tenth of the lime required by carbonatation. The only point in favor of carbonatation was the superior sugar quality: better non-sugar removal (nearly three times), higher sugar yield, better industrial value because of fewer impurities.

There are basically two systems:
(1) single carbonatation
(2) double carbonatation

(1) All lime is added in one step, neutralized and filtered once.

(2) In the first step, much of the lime is precipitated and filtered. In the second the filtered juice, still containing removable lime, is again subjected to $CO_2$ treatment and again filtered.

Filtering is most successful when carbonatation is done at higher temperature and high alkalinity is maintained for a short period. This is because at high pH (10-11), flocculation of phosphate occurs as a nucleus of $CaCO_3$, precipitation occurs, and also gum and pectine at high pH change into Ca pectinates (from potassium), which is a less hydrated gel, producing much better filtration.

It is found that high pH alone is not critical for decomposition of reducing sugar; the temperature level is more important. Therefore if this is kept at about 55 °C, a high alkalinity is no threat. If juice quality is extremely good, the temperature can be increased to 60 °C. This leads to better filtering and clearer juice.

The greatest advantage of using 55 °C is that the complex sucrose—Ca-carbonate—CaO compounds are not formed, and therefore foaming is not excessive.

The carbonatation procedure was developed by de Haan during the period 1914-1920 and is called the de Haan process. It gives optimum pH and temperature limits for maximum non-sugar removal, high filterability and minimum decomposition of reducing sugars. The conditions were: temperature at 55 °C and alkalinity 400 mg CaO/l (by titration with phenolphthalein). Later tests indicated that a higher alkalinity is preferable (1930-1940). Mechanical circulators were introduced and proportioning liming devices. Later, pre-liming was introduced to pH 10.5. In this case floc formation occurs within 2-4 minutes, if the temperature is 55 °C. The carbonatation process then starts and more lime is added; this transforms into crystalline $CaCO_3$, which surrounds the pre-liming floc. This process produces a better filterability. If the two processes are combined into a single step, then floc formation is disturbed and filterability is bad.

The sequence should be as follows:
(1) heat juice to 55 °C;
(2) add lime to pH 10.5, keep for 4 minutes to form floc and eliminate part of gums and pectin.
(3) add lime in adjusted quantity to 500 - 1000 mg CaO/l; this is necessary for absorbing the $CO_2$ and is simply done with Dupont titration paper;
(4) after all lime is added, a pH of 10-10.5 must be reached (400-800 mg CaO/l).

Limestone consumption is 25-30 kg/t cane (55-66 lb), while coke is about 10% of limestone or 2.5-3 kg (5.5-6.5 lb) t/cane. The large amount of lime makes it necessary to produce it locally in a lime kiln, as both products, lime and $CO_2$, must be used. The kiln gas contains 30-38% $CO_2$. There is always an excess of $CO_2$ for the process, as the exhaust contains about 10% $CO_2$.

After second carbonatation, a CaO content of 50 mg/l can be obtained. This is extremely low. The temperature in second carbonatation is held at over 65 °C, to prevent the formation of micro-organisms. They usually form in low-density juice at temperatures of 35 °-45 °C, such as press water. Floors must also be kept clean.

## Lime kiln

In the beet industry, as well as in cane factories using the carbonatation process, the consumption of lime is too high to allow it to be shipped daily from independent suppliers. Factories produce their own lime from limestone, using coke as a heating medium. They also utilize the $CO_2$ that is formed by burning the limestone to form CaO as follows:

$$\mathrm{CaCO_3} \rightleftarrows \mathrm{CaO} + \mathrm{CO_2}\nearrow$$

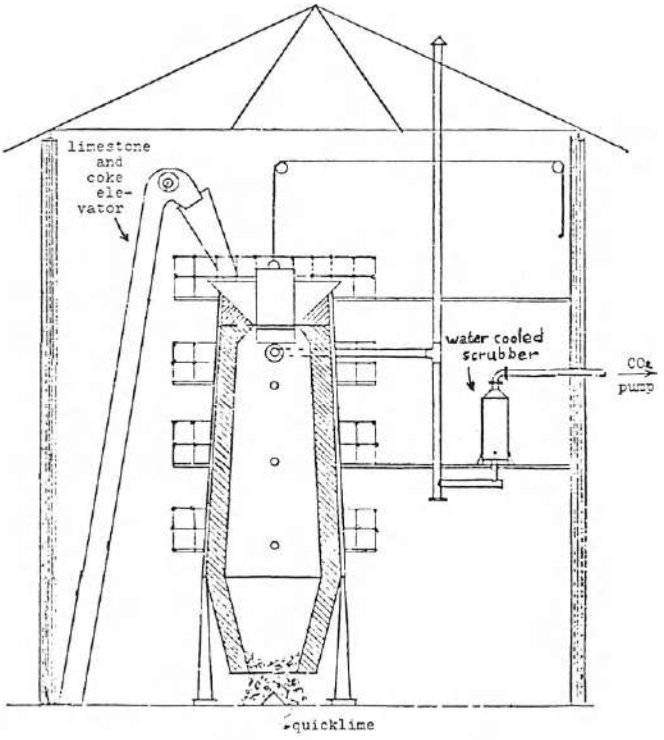


Fig. 11. Outline of a lime kiln. (From Honig, Vol. I, p.364.)

Besides the beet industry, the principal users of lime kilns are Java, Formosa, India and Natal. The lime kiln is filled with a mixture of limestone and coke. At the bottom, the burned CaO is being discharged, while new layers are added at the top. Limestone and coke are taken to the top by means of an elevator. The temperature in the kiln is from 1100°C to about 1300°C. This is necessary because the above chemical reaction is endothermic and requires about 42.5 kcal per mole (169 btu/mole). Overheating or heating for too long produce lime which is dead-burned. To ensure a correct temperature-time rate, the CaO at the bottom should be extracted automatically.

There are also automatic feeding devices. The pumps taking $CO_2$ out of the kiln must maintain a constant speed, because they also cause a draught of air through the kiln, which must be kept constant to allow a temperature control for correct burning.

The kiln capacity is about 1 ton of limestone per $m^3$ volume (61.5 lb/cu ft volume). In a vertical direction and from top to bottom, the kiln has the following zones:

(1) storage
(2) drying
(3) pre-heating
(4) calcination
(5) cooling.

The cooling is performed by entering air current. Normally, the ratio of width to height is about 1:5, depending on the limestone quality. Hard stone needs a greater height. Although higher ratios exist, there is a practical limit to the height of the kiln. The main points for kiln operation are the following:

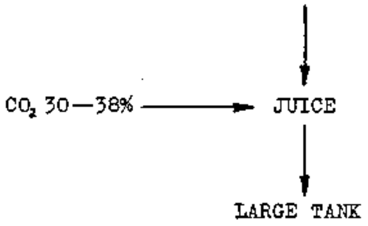
(1) ratio coke/limestone
(2) size of limestone lumps
(3) size of coke lumps

For decomposition of stone, 425 kcal/kg (767 btu/lb) are required. Coke has 7000 kcal/kg (12635 btu/lb). This gives a theoretical coke/limestone ratio of 16.5 or 6% coke on limestone, but there are some heat losses. In Java, the ratio is 13 (7.7%).

CaO leaving should be 50°C, and the $CO_2$ should be 50°-70°C at a concentration of 36-41%. Coke that is too small results in too high a temperature, but if it is large it does not mix well with the stone. Therefore the correct coke to stone size ratio is 1:2.

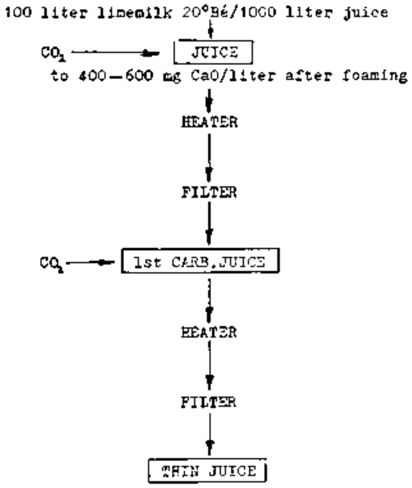
As a good control on the correct calcination in the kiln, the percentage of $CO_2$ should be determined regularly. This is very simple, using a Bunte (or Hempel) pipette, or an Orsat apparatus to determine both the $CO_2$ and $O_2$ proportions.

Although carbonatation is an excellent process, producing a very acceptable direct "plantation white" sugar, its equipment is expensive and its fabrication cost is much higher than that of defecation or sulfitation products.



size 2x juice + m.o.l. for foaming, which takes place at 1000—1500 mg CaO/l and stops at 400—800 mg CaO/l. $CO_2$ up to pH 8.3 in about 40—60 minutes per tank.

Fig. 12. Single carbonatation, as practiced up to 1915. Data for this diagram are taken from Honig, Vol. I, p.660.



Disadvantage: Too lengthy. Slow absorption of $CO_2$ in cold juice.
Improvement : titration of 1st carbonatation juice 20 ml + $H_2SO_4$ 1/28 N, 1 cc $H_2SO_4$ = 50 mg CaO/l for endpoint of 1st carb at 400 mg CaO. 2nd carb is simple, no foaming, high $CO_2$ absorption, short time.

Fig. 13. Double carbonatation. Data for this diagram are taken from Honig, Vol. I, p.661.

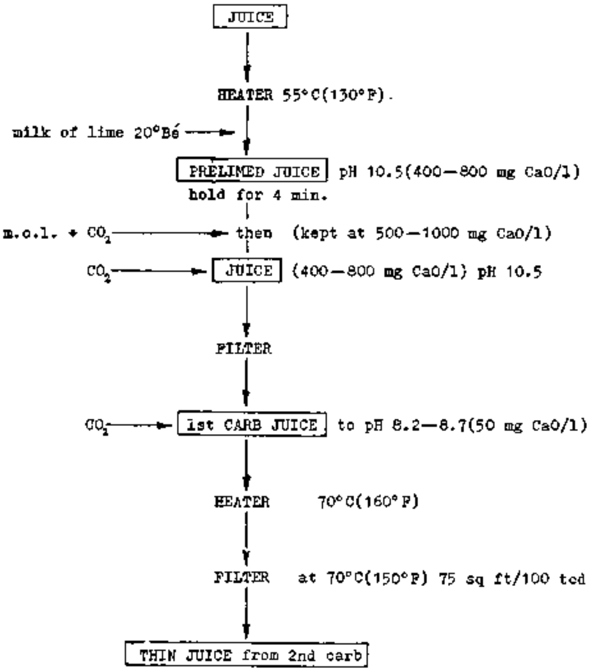


Fig. 14. Double carbonatation (modified de Haan system, 1947). Data for this diagram are taken from Honig, Vol. I, pp.665-666.

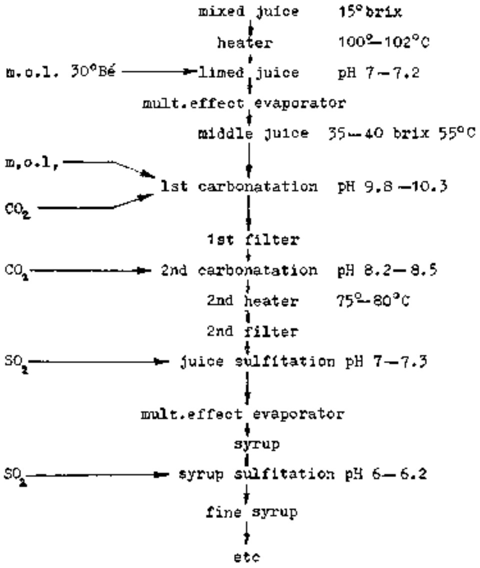


Fig. 15. Middle juice carbonatation. (From Honig, Vol. I, p.712)

CHAPTER 9

# SPECIAL CLARIFICATION AGENTS AND THEIR HISTORY

## (a) Phosphate

At times when juice was difficult to clarify and the normal variables, such as too low a temperature, incorrect pH, etc., were not the cause, it was normal to consider other additives to this kind of juice, to improve settling. One of the oldest was phosphoric acid and its calcium and sodium salts.

The original concept was that since the molecular weight is high, it could improve the specific gravity of the mud flocs in the dirty juice. (This should not be mistaken for the refinery application of phosphoric acid, where the precipitate is removed by flotation in the scum of Williamson-type clarifiers in liquor of about 63°Brix.)

It was found in the twenties that if the $P_2O_5$ content of the juice was low, clarification was bad. In Hawaii it was found by McAllep and Bomonti that juice containing less than 350 mg $P_2O_5$/l did not clarify properly unless phosphate was added. The commonest is "triple super-phosphate" containing 48% $P_2O_5$ dissolved in water. If diluted to 10°Bé, it is added at 30-100 mg/l of juice.

It is used worldwide, because it is fairly cheap and the result, a better clarified juice, shows immediately. It is available under many trade names, for example Sumaphos. It is also used to eliminate lime salts from refinery liquor and beet thin juice.

Of course, the general application of trisodium phosphate for the removal of hardness of boiler feed water should be mentioned, but it will not be dealt with further here.

## (b) Magnesium compounds

The use of magnesium is very old: it went under the name "dolomite" in the 19th century, after it had been slaked and boiled with water to form a hydrate and combined with lime, but it was found later that the filterability of the mud was much lower than with lime alone.

Another form used in the 1950's was the so-called Elguanite (MgO). It was mixed with cold juice and then heated to 180°F before filtering, first through a thickener, then through an Oliver rotary filter. The thickener filtrate is neutralized from pH 9.3-9.5 using phosphoric acid after heating to 200°F.

### Magox

This is MgO. It is the same as Elguanite, which is used in combination with lime. According to molecular weight, it is equivalent to 1.4 CaO and 1.84 $Ca(OH)_2$. It is not used to completely replace lime, because it is so expensive, but a combination is beneficial to reduce incrustation in evaporators. Factories that use it claim a purity rise in clarification, clearer juice and improved exhaustion of molasses. I myself tested it in Guatemala, but here, although the incrustation of the final evaporator vessel decreased, the third vessel was heavily scaled, switching the scale from 4 to 3.

Using Magox, the reaction time of the product with the heated juice should be watched closely by checking the pH value. Also, if the pH within the clarifier increases from top to bottom, the Magox had no time to react properly. At least 20-minutes reaction time between heating and reheating is required.

## (c) Clay

The use of clay dates back to 1861, as reported by Root.[1] Its clarification qualities are that it gives faster settling and more brilliant juices. However, the real mechanism of the effects of clay could never be properly explained, which is probably why its use did not survive.

The clay did not improve the clarification itself: thus non-sugar removal is required. It merely improved visual results in the form of clearer juice. During the history of the use of clay, all manner of quality properties were claimed, such as:

removal of colloids
improved raw-sugar quality
higher yields
faster boiling
reduced scaling

The actual results all depended on what kind of clay was used, and who was observing them.

One of the best known varieties of clay used was bentonite, which is a volcanic ash found near Fort Benton, Wyoming, although similar clays exist in other parts of the world. It is a white-grayish or greenish micro-crystalline clay of composition: $MgO\text{-}Al_2O_35SiOnH_2O$, in which $n = 5\text{-}8$. It has an absorption surface of 100-500 $m^2$ per gram of clay. According to Ramirez Silva,[3] the sodium bentonite form swollen in water gives a surface area for a cubic inch of dry powder of over 1 acre. Its greatest advantage might be its ability to carry cations that might become exchanged for other cations (or anions). It was marketed in 1949 by Ramirez Silva in Puerto Rico under the trade name of KWK Volclay.

In Hawaii, bentonite was tried on clarified juice, but settling of the floc was very difficult. Some benefits were claimed, such as improved filtration rate and refining quality of raw sugar. In Puerto Rico, the Silva process was used on refractory juices. Here bentonite was added to the mixed juice before liming. It was claimed to reduce lime % cane. Although benefits are claimed, there are no quantitive data available.

## (d) Bauxite

This hydrated $Al_2O_3$ has only been investigated rather recently, since World War II. It was not only tried in raw-sugar fabrication, but also in refinery processes, to replace bone char. Like the bone char, it can be reactivated. However, it was found that the quantity to be revivified is rather considerable, as 100 parts of brix require 100 parts of bauxite before reactivation. In this operation, it loses about 5% of its weight. The regeneration kiln would have been prohibitively large.

In the raw-sugar process, bauxite was tested by la Lande[4] in Brazil, where it was shown to remove 80% of color and 75% of the ash by single filtration through bauxite granules of 0.8-0.3 cm size of local origin, previously heated to 400 °C. In the refining process it was patented under the name of Sucro-Blanc, where it was used instead of bone char. This process no longer exists, although it was used in a refinery in Cuba after 1940.

### (e) Diatomaceous earth (Kieselguhr)

This is primarily a filter aid, especially in the refinery: its Spanish name is "tierra infusoria". It is a maritime fossil deposit, whose action is mainly mechanical, and whose clarifying (absorption) power is negligible. However, it does remove a small amount of colloids. Its use with raw sugar is rather limited; it serves only to improve the filterability of the juice. Its addition was normally 0.5-3 kg/m$^3$ mud (0.04-0.27 lb/100 lb mud) or roughly 1-6 lb/t mud. It is known in the market under tradenames such as Celite, Dicalite, Hyflo, Supercel, etc.

### (f) Charcoal and carbon

These are used exclusively in the refining process, not with raw sugar, although it was tried in sulfitation mills in Egypt, and in carbonatation and defecation mills in Java, in the early 50's.

### (g) Blankit

This is sodium hydrosulfite, $Na_2S_2O_4$, a strong reducing agent. It is used to reduce color in juice and later in the massecuites. The mechanism of the reaction is not known. It forms hydrogen in the solution and sodium sulfite. Unfortunately, bleaching by reduction cannot be permanent in a sugar solution, which re-oxidizes and consequently regains a darker color. Recently, it has not been used, but before World War I it was used in all sugar mills, making directly white sugar.

### (h) Poly-electrolytes

These are a rather new application (1950). They improve the floc settling rate and reduce the mud volume by as much as 50%. The amount used is 1-3 ppm of juice (0.002-0.006 lb/t cane).

The best application is in the flash tank, just before the juice enters the clarifier. Another application location is in the mud mixer before the mud goes to the rotary vacuum filter (in the so-called Rapifloc system). Examples of the trade names of these coagulants are Separan A-P 30 and Lytron 886.

For a certain juice condition the quantity to apply must be very exact: 1 ppm off can cause the cake to fall off, in which case 2 ppm is correct. The use of coagulants of the poly-electrolyte group is still too new to be exact as far as the correct quantities to be applied are concerned. Spencer Meade[5] recommend 5-20 ppm, while Hugot (2nd edition) mentions 1-3 ppm.[6] These last figures are probably more correct, as the book is of more recent date.

In any case, the correct application for each mill should be determined individually, because the price of the product is too high to permit indiscriminate use, and an excess is not only costly but also counterproductive.

## (i) Dye colors

Although these products are used in processes other than the clarification process itself, they nevertheless have the same function, which is to yield a product of better color (in this case not improving quality). The white sugar produced using the sulfitation or carbonatation processes are less white than a refined sugar. The residual contamination in the sugar, although minimal, causes a slight yellowish tint of the product's crystal. Neutralizing this tint by adding a blue color to it makes it appear whiter, as yellow and blue are complementary colors. It is just a matter of public whim to believe that slightly blue or whiter sugar is purer than yellowish. White always represents ''purity''. Originally, ultramarine was used at 0.1-1 gram per liter of water and applied to the sugar in the centrifugals, just before steaming and discharging. It is insoluble in water, and forms a suspension of a very fine powder. The concentration varies from mill to mill. Since World War II, ultramarine has mainly been substituted by organic dyes, such as indantren. Indantren is much more expensive than ultramarine, but the quantity required is so small that the unit price is negligible.

## (j) Caramel

There was a time when buyers in England wanted raw sugar of a high pol, although this was not permitted by law. In England a raw sugar has a pol of 98 or lower. Over 98, there are stiff penalties, which protect the national refiner.

To produce a sugar of high pol but acceptable by law, the high pol raw sugar was covered with a layer of caramel. This served two purposes:

(1) The pol was brought below 98 (caramel polarizes negative).
(2) The color was extremely dark, another requirement.

The only problem was not to increase the ash content. This was difficult, since the final-molasses caramel has a high ash. Therefore, the caramel was made of raw sugar washed specially for this purpose.

In a cast-iron open pan, on a slow fire, the sugar was heated and constantly agitated. Slowly the mass turned to a golden yellow, then light brown. The breaking point was determined by letting a drop of liquid fall into a glass of water. When the drop reached the bottom without disintegrating in the water, the batch was mature. Then the fire was extinguished and a small amount of milk of lime was added to increase the pH to about 6.5. Then water was added to a brix of about 50. This dark-colored caramel was used as an additive to the high pol sugar from the centrifugals, in a screw conveyor. If the pol became too high, the brix of the caramel had to be increased.

We should remember that the sugar from which the caramel was made first became inverted, and the pol was negative. Thus, a very dark raw sugar was produced, of 95-96 pol.

The only job left for the refinery was to wash the sugar in an affination process to restore the original high-pol sugar. This sugar was known on the world market as NA (New Assortment).

## (k) Other additives

In some countries, sugar of special grain size and colors were produced for certain market requirements. In former British Islands such as Barbados, Trinidad, etc., a sugar was made for the British market, called "Golden Brown". This was quite a large crystal, colored using a strontium salt solution. Also, a tin salt was sometimes used.

During the crop-restriction time in Cuba and after the yearly quota had been reached, the excess cane was ground to produce sugar for use as cattle feed. To ensure that this sugar did not reach the "black market", it was tinted green in the centrifugals using a vegetable dye dissolved in water.

Whatever dye materials or added products are used, they must be acceptable for food use, and in the U.S.A., must be approved by the U.S.D.A. and the F.D.A., a standard accepted in other sugar-producing countries.

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## CHAPTER 10

# ION-EXCHANGE

The application of the ion-exchange principle in cane-sugar mills is rather new but has potential. The process itself is not so new and has been applied widely in the beet industry and refineries.

The main reason for its slow acceptance is simply that cane mills are remote from big cities, and the chemicals required are not readily available in such places. Also, the costs of the chemicals are rather high, and they are available only through the chemical company that holds the rights to this specific equipment.

The process is used mainly in water softening. The chemicals used as ion-exchangers are of the synthetic organic type. There are resins which exchange the cation or base, and there are others which exchange the anion or acid. A well known resin used in water softening is zeolite. Ion-exchange eliminates non-sugar, hence its second name "demineralizer". The following is an example of the application of ion-exchange in a beet factory.

The function of the factory is to mix pulp with a certain amount of final molasses to produce dry pellets as cattle feed. To obtain the correct amount of final molasses, the syrup is demineralized to the point where just enough molasses is left to be produced, to be mixed with the pulp. The resin itself is insoluble. There is an exchange between the $H^+$ ion of the resin with the $K^+$ and $Na^+$ ions of the syrup (liquid). These cations are thus eliminated. The same happens with the anion exchange resins, where $OH^-$ ion exchanges for the $NH_2^-$amino ion.

For instance, if an NaCl (sodium chloride) solution is first passed through a cation exchanger, the $Na^+$ is exchanged for $H^+$ of the resin. This solution is now passed through an anion exchanger and the $Cl^-$ is removed and exchanged for $OH^-$. The result is an ion-free water. This is clearly illustrated in Fig. 16.

Regeneration of the exhausted resin can be achieved by treating the cation resin with acid and the anion resin with alkali. After some time, both capacities are renewed.

The NaCl solution enters the cation exchanger at the top. When, after some time, the effluent at the bottom contains $Na^+$ ions, it means that the resin "leaks" and efficiency decreases. Regeneration should now take place. If the exchanger is of the single-bed type, it should be liquidated, washed, back-washed, regenerated, rinsed, and new liquid admitted.

In treating sugar juices, nearly all components that normally form the final molasses can be eliminated. Not only can all inorganic non-sugar, but also organic ones such as amino acids be exchanged. There is only one important fact to be considered, and that is the pH. After first exchanging all $K^+$, $Ca^{++}$, and $Na^+$ for $H^+$ ions, the pH falls to about 2.0. To prevent inversion at this low pH, the juice must be cooled to slow down inversion velocity, to 20 °C or below For the short time between the cation and anion exchangers, inversion at this low temperature is insignificant.

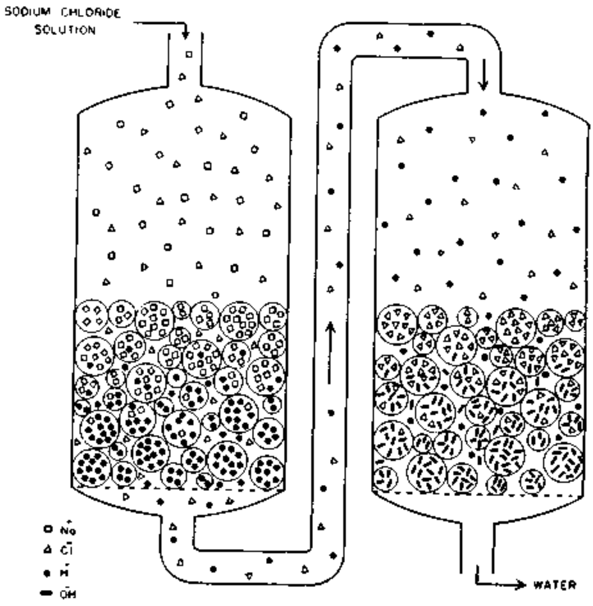

Fig. 16. Mechanism of ion exchange. Large spheres represent resins, cations on the left, anions on the right. In the first, sodium ions are replaced by hydrogen; then in the second, chloride ions are replaced by hydroxyl. The hydrogen and the hydroxyl combine to form water. Only water is left in the effluent. (From Honig, Vol. I, p.731).

Next, in the anion bed, the $Cl^-$ and $SO_4$ are removed and replaced by $OH^-$, which neutralizes the $H^+$ of the cation bed. Here the organic anions, such as aconitic, malic, etc., are also exchanged. The juice leaving is approximately neutral and most of the color is also removed. Only silica is not removed, being in the form of finely divided suspended particles. Thus, filtration after ion-exchange is normally desirable. The final effluent of the ion-exchange in cane sugar will contain sucrose, glucose, other sugars, and also some non-ionic organic non-sugars. It is therefore clear that effluent increases in purity through the elimination of impurities (non-sugar). This demineralization can be complete or partial as required.

Under normal conditions, the increase in purity from mixed juice to clarified juice is about 6.5 points. This varies according to the original juice purity and can be from three points for high-purity mixed juice to ten points in low-purity mixed juice. Because of reduction of molasses production (non-sugars are already eliminated), recovery increases on average by 5%.

The A and B massecuite produce a sugar that is nearly white. Color formation, normally caused by decomposition of glucose into amino acids which combine with metals forming dark impurities, does not take place here, because most of the amino acids are eliminated.

Another interesting point is that the small residual amount of molasses is not final molasses at all, because it has low ash; pol about 24 and glucose about 45. In other words, it becomes an edible syrup. Regeneration for the cation bed is through the use of sulfuric acid, or caustic soda (NaOH) or ($NH_2OH$) for the anion bed. The regeneration separates the eliminated impurities from the resins. From here they can be recovered if by-products are made from them. The material treated most successfully by ion-exchange is clarified juice. This was investigated in Hawaii. The impurities present in mixed juice, such as soil and suspended matter, preclude the use of an ion-exchange bed, because clogging occurs.

Clarified juice was cooled to about 20°C, then juice was passed through the exchanger twice: cation, anion, cation, anion.

This has the advantage that the first bed can be exhausted until it starts to leak, and then the second bed takes over. If this system is duplicated, the process becomes continuous and can be back-washed in another system.

As described above, the ion-exchange system is almost ideal: this is actually the case for real systems.

Only the resins required are expensive, and supplementary quantities as well as losses of resins keep the cost high. In addition, the quantity of juice to be treated in a normal size sugar mill is extremely high for such a system. This is why it is usually used for cases of partial removal, for instance 20% demineralization.

At the end of the cycle, the juice in the bed must be sweetened off (or replaced by water). This also causes a 10-20% dilution of the juice and therefore an increase in quantity. If performed otherwise, losses in sweet water are too high. Normally, sweetening off is stopped when brix reaches about 0.5. The results from the above-mentioned pilot tests in Hawaii, as described in Honig, Vol. I, p.744,[2] have been reproduced here. They show an average purity rise of 6.6, ash removal of 94.7% and color removal of 81%.

Sugar from A Massecuite had a pol of 99.8 (after drying)
Sugar from B Massecuite had a pol of 99.5 (after drying)
Magma from C Massecuite had a pol of 87.6

The analysis of the final molasses showed:

| | | Normal molasses |
|---|---|---|
| Solids | 86.5 | 86.5 |
| Approximate purity | 27.6 | 32.0 |
| Clerget purity | 33.8 | 40.0 |
| Clerget | 29.2 | 34.6 |
| reducing sugar | 44.1 | 20 |
| Ash | 0.93 | 10 |
| Brix (Sylmans) | 87.2 | 93.8 |
| Total sugars | 73.3 | 54.6 |
| Pol | 24.07 | 30.0 |
| | edible | not edible as it is |

Of course, the lower-sucrose contents of the exchange molasses went to the recovery of sucrose, which is about 5% higher than for untreated.

As mentioned before, the effectiveness of the resin decreases, and together with mechanical losses from back-washing (losses plus breakage) the total loss of resin should be calculated as being equal to complete renewal in one full year of operation, as in a refinery.

For regeneration purposes, the chemicals required are:

| | | |
|---|---|---|
| $H_2SO_4$ | (66°Bé) | 5½ lb/100 gal of juice |
| NaOH | (solid form) | 2½ lb/100 gal of juice. |

These are also considerable quantities if we consider that a 3000 tcd mill has an average clarified juice production of 700 gpm.

As the mechanics of the ion-exchange process are rather new, there is currently visible improvement. Instead of two separate exchangers (cation and anion), the mixed-bed system is used. The biggest advantage, of course, is to reduce time between the acid and alkaline stages of the juice, with a concomitant reduction in the risk of inversion. It is clear that ion-exchange cannot be used in factories remote from industrialized centers, because of transportation problems regarding chemicals required (and availability of water). Although expenses for maintenance and requisition are high, the advantages are:

(1) higher yield
(2) better sugar
(3) molasses, directly edible and in smaller amount
(4) no evaporator cleaning
(5) less pan work
(6) by-product separation

We have attempted to describe the ion-exchange system in some detail, because it is not very well known in the cane sugar industry, not simply because it is so expensive and requires large amounts of chemicals, but also because of the complete secrecy maintained by resin suppliers. There are only a few large suppliers, and they are very much afraid of professional espionage. They never supply even small samples of their resin and only rarely allow it to be seen. A typical case quoted in 1972 was as follows: ''The price is $100,000 to $1,000,000, depending on the quality and properties of the juice, which will be determined by our sugar technical salesman. If you decide to buy the installation, it will be sealed (black box) and must be maintained by our men (two men for the whole of South America, the Caribbean, etc.) They will carry out maintenance, repairs, etc. You simply buy the chemicals, feed the juice into the system, and receive the treated juice at the output side.''

This was an actual offer made by what is probably the largest ion-exchange company. The information given by the different companies regarding quantities of chemicals used is very unreliable and varies considerably. Also, as regards the consumption of resin, one company said: ''The amount consumed per year is negligible'' and another said: ''Expect a complete replacement each year''.

It is impossible to obtain a realistic estimate of what it will cost to perform a certain job in a cane sugar mill; one must simply take it or leave it.

Of course, we are talking here about juice treatment. For boiler-feed-water treatment, the function, sizes and expenses of a treatment plant are well known and there is no secrecy.

Many foreign makes are also available, but they are not recommended, because they depend on shipments of their products and resins.

Some operational data of a mixed bed unit are

Bed 4′ high, in a 10′ diameter tank (300 cu ft resin)
Flow rate of juice 320 cu ft/h = 40 gpm
Liquor cycle about 10 h
After treatment of 24,000 gal, regeneration must take place
Regeneration time 5-8 h
Life-time of resin estimated at 250 cycles.

Based on these data, it is clear that the size of a mixed-bed installation for an average sugar mill of say 3000 tcd is almost prohibitive, as juice production is of the order of 700 gpm.

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1. P. Honig, *Principles of Sugar Technology*, Vol. I, Elsevier, Amsterdam, 1953, p.731.
2. P. Honig, *Principles of Sugar Technology*, Vol. I, Elsevier, Amsterdam, 1953, p.744.

| Juice In | | | | | Juice Out | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Volume gal. | Solids % | Pol | Purity apparent | Ash % | Volume gal. | Solids % | Pol | Purity apparent | Ash % | Purity rise | Ash removal % | Color removal % |
| 1181 | 13.0 | 10.7 | 82.4 | .431 | 2401 | 9.0 | 8.1 | 89.9 | .014 | 7.5 | 95.8 | 86.9 |
| 476 | 12.8 | 10.1 | — | .442 | | 9.0 | 8.1 | 89.9 | .016 | — | 94.9 | 89.2 |
| 536 | 12.4 | 9.5 | — | .547 | | 8.8 | 7.8 | 89.2 | .015 | — | 96.6 | 84.0 |
| 294 | 12.5 | 9.7 | — | .485 | 563 | 8.4 | 7.5 | 88.9 | .014 | — | 96.4 | 88.6 |
| 1209 | 12.2 | 9.8 | 80.1 | .479 | 2032 | 8.5 | 7.6 | 89.3 | .015 | 9.2 | 96.2 | 78.0 |
| 582 | 12.8 | 10.3 | 80.6 | .470 | | 9.2 | 8.1 | 87.7 | .017 | 7.1 | 95.4 | 61.0 |
| 605 | 13.2 | 10.9 | 82.8 | .490 | 665 | 8.9 | 8.0 | 89.8 | .015 | 7.0 | 96.0 | 82.3 |
| 1021 | 12.2 | 9.9 | 80.6 | .465 | 2570 | 7.6 | 6.7 | 88.6 | .016 | 8.0 | 95.8 | 80.8 |
| 1086 | 12.8 | 10.4 | 81.5 | .461 | | 8.9 | 7.8 | 87.3 | .016 | 5.8 | 95.6 | 81.7 |
| 1144 | 12.7 | 10.5 | 82.4 | .461 | 1863 | 9.6 | 8.5 | 89.1 | .017 | 6.7 | 95.1 | 76.9 |
| 569 | 13.3 | 10.7 | 80.5 | .474 | | 9.9 | 8.8 | 88.9 | .019 | 8.4 | 94.6 | 83.7 |
| 1097 | 12.3 | 10.0 | 81.5 | .472 | 1309 | 8.4 | 7.4 | 88.3 | .018 | 6.8 | 94.4 | 82.8 |
| 971 | 12.8 | 10.8 | 84.5 | .473 | 1562 | 8.9 | 8.1 | 91.9 | .017 | 7.4 | 94.8 | 81.9 |
| 447 | 12.4 | 10.5 | 84.4 | .481 | | 9.4 | 8.6 | 91.3 | .019 | 6.9 | 94.8 | 85.3 |
| 1615 | 13.2 | 11.4 | 86.4 | .452 | 1929 | 10.0 | 9.4 | 93.7 | .019 | 7.3 | 94.5 | 83.6 |
| 1574 | 12.7 | 10.6 | 83.3 | .466 | 1777 | 9.6 | 8.4 | 88.0 | .023 | 4.7 | 93.5 | 73.4 |
| 1774 | 12.8 | 10.4 | 81.1 | .452 | 1968 | 10.3 | 9.0 | 87.3 | .018 | 6.2 | 95.0 | 78.2 |
| 1535 | 12.8 | 10.5 | 81.6 | .468 | 1698 | 9.4 | 8.4 | 89.3 | .020 | 7.7 | 94.2 | 84.4 |
| 1686 | 14.3 | 12.0 | 84.3 | .403 | 1906 | 11.6 | 10.4 | 89.3 | .022 | 5.0 | 93.3 | 92.8 |
| 1435 | 13.8 | 11.5 | 83.4 | .411 | 1697 | 8.3 | 7.3 | 88.5 | .019 | 5.1 | 94.0 | 77.7 |
| 1091 | 14.0 | 11.6 | 83.3 | .455 | 1280 | 10.8 | 9.6 | 88.8 | .022 | 5.5 | 92.3 | 83.0 |
| 1685 | 13.5 | 10.7 | 79.3 | .472 | 1934 | 8.5 | 7.4 | 87.5 | .020 | 8.2 | 93.3 | 75.8 |
| 1445 | 14.3 | 11.5 | 80.9 | .470 | 2116 | 10.5 | 9.1 | 86.4 | .021 | 5.5 | 93.9 | 77.1 |
| 1380 | 14.9 | 12.6 | 84.4 | .436 | 1562 | 9.4 | 8.4 | 89.1 | .020 | 4.7 | 92.7 | 74.9 |
| | | | | | | | | | Average | 6.6 | 94.7 | 81.0 |

Table 1. Two-pass ion-exchange treatment of clarified juice (From Honig, Vol. I, p.744.)[2]

## CHAPTER 11

# EVAPORATION

### Object of evaporation

From the mixed juice, impurities are removed as far as possible in the clarification process (clarifier, filter), with the result that a clarified juice is obtained, clear and free of impurities as far as required. The water has then to be evaporated to concentrate the sugar it contains. In the first step of this process, water is evaporated to a concentrated liquid state, while in the second step the concentration is carried further to the point where sugar crystallizes in the super-saturated solution. The first step is evaporation, the second is boiling. Both operations take place under vacuum to reduce the boiling temperature and prevent inversion of sucrose under high temperature and prolonged time.

The first step is to evaporate water from clarified juice to syrup or from about 15 °Brix to about 60°. This is about 75% evaporation. Thus, concentrated syrup represents about 25% of the clarified juice.

### History of evaporation

The basic law of heat transfer can be expressed as follows:

to turn ice ⟶ water ⟶ steam  heat must be applied
to turn steam ⟶ water ⟶ ice  heat is given off.

The physical development of evaporation followed along these lines. Chronologically, evaporation was achieved by applying heat:

(1) by open fire
(2) heating by steam
(3) applying vacuum to reduce boiling point
(4) use of latent heat following the law described above
(5) multiple-effect evaporation

In 1812, Charles Howard patented the vacuum pan (simple-effect evaporator). By 1827, about forty Howard pans were in use in England.

In 1824, in Marseille, Degrand used vacuum pans provided with steam coils and sight-glasses.

In 1825, Hallette, Pecqueur and Motelfarine all used heating steam of 150 °C (300 °F). The evaporation rate was 100 kg water per $m^2$ heating surface, equivalent to 6.25 lb/sq. ft.

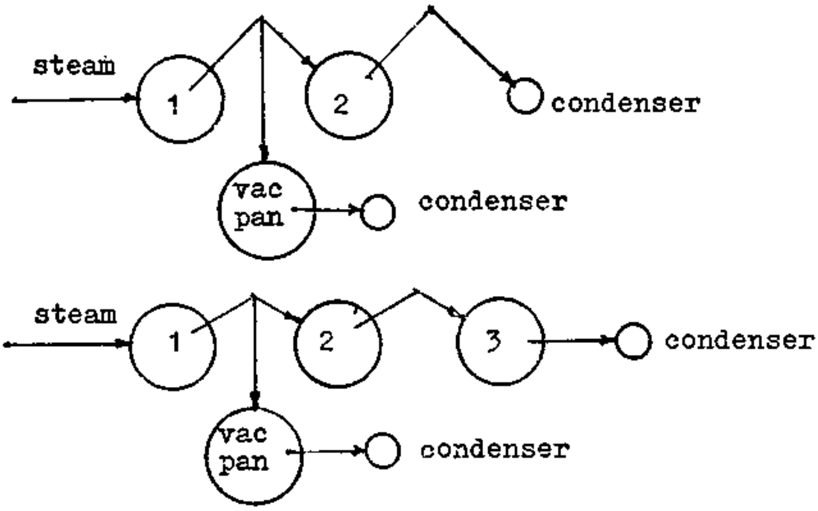
In 1828, Roth applied cold-water injection for condensing, instead of an air pump.

In 1833, Degrand, now employed by Durosne and Cail, used vapor to pre-heat juice before it entered the pan.

In 1834, the first double-effect was used, under the name Durosne.

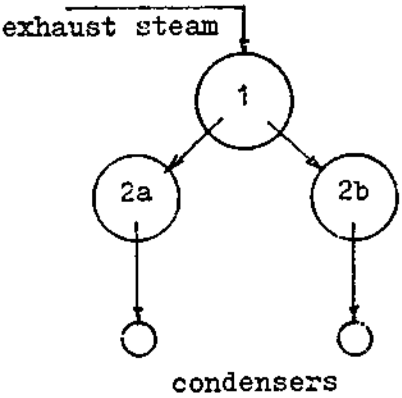
In 1837, there was further development of double- and triple-effects.

In 1843, Rillieux (born in New Orleans in 1806) patented his multiple-effect evaporators.



1843 Rillieux evaporators

Buckau Maschinen Fabrik (Germany) misunderstood the arrangement and made the following combination, which was imitated by Cail (France) and installed in Quincy, Douai, (France).



Robert made it vertical and designed the first triple-effect this way.[1]

## Technique of evaporation

To evaporate 100 kg water, the fuel consumption was as follows:

| | |
|---|---|
| Direct fire (coal) | 25 kg per 100 kg water |
| Steam | 21 kg per 100 kg water |
| Simple-effect vacuum | 13 kg per 100 kg water |
| Double-effect vacuum | 7 kg per 100 kg water |
| Triple-effect vacuum | 5 kg per 100 kg water |

Water evaporated per hour in:

| | |
|---|---|
| I-effect | 20-25 lb/h/sq ft |
| II-effect | 10-12 lb/h/sq ft |
| III-effect | 7.2-8.2 lb/h/sq ft |
| IV-effect | 5-6 lb/h/sq ft |
| V-effect | 4.1-5 lb/h/sq ft |

Rillieux gave the following capacities:

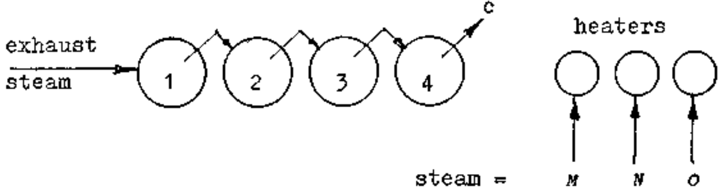
| | kg/$m^2$/h | lb/h/sq ft |
|---|---|---|
| I-effect | 100-125 | 20.44-25.55 |
| II-effect | 50-60 | 10.22-12.27 |
| III-effect | 35-40 | 7.16-8.18 |
| IV-effect | 25-30 | 5.11-6.13 |
| V-effect | 20-25 | 4.09-5.11 |

The three Rillieux principles are still in use for evaporator calculations. They are:

(1) In a multiple-effect evaporator, one unit of steam will evaporate $n$ units of water, where $n$ equals the number of vessels in the set.
(2) Using vapor from any vessel for heating juice heaters or vacuum pans, instead of (exhaust) steam, the saving in steam is equal to the amount of vapor used, divided by the number of vessels in the set, and multiplied by the number indicating the place occupied by the vessel (from which vapor is drawn).
(3) In any calandria in which vapor (or steam) is condensed, it is necessary to withdraw the accumulated non-condensable gases.

The gain between principle I and II equals:
$0.25S + M + N + 0 - 0.25S + 0.75M + 0.5N + 0.250) = 0.25N + 0.5N + 0.75O.$
Therefore the gain = vapor extracted for heaters divided by numbers of vessels and multiplied by number the vessel occupies.

*Explanation of principle I*



Steam needed:

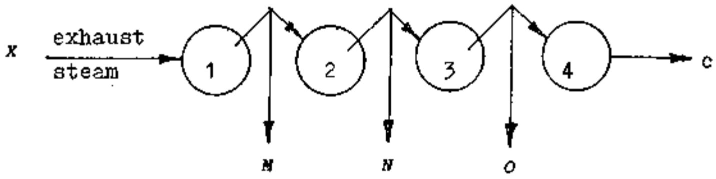
evaporator = $X$

heaters = $M + N + O$

water evaporated = $S$

$X = S/4$ total = $1/4\ S + M + N + O$

*Explanation of principle II*



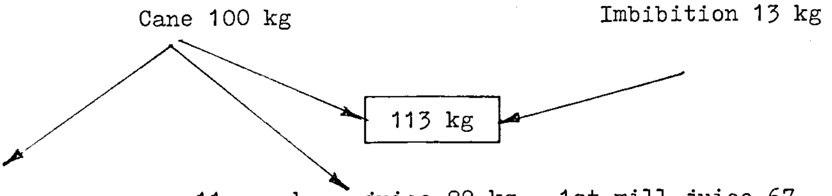
| | | |
|---|---|---|
| steam needed: | | |
| in | # 1 = | $X$ |
| drawn from | # 1 = | $M$ #2 = $N$ #3 = $O$ |
| evaporated | # 1 = | $X$ |
| | # 2 = | $X - M$ |
| | # 3 = | $X - M - N$ |
| | # 4 = | $X - M - N - O$ |
| evaporated total | = $S$ = | $X + (X - M) + (X - M - N) + (X - M - N - O)$ |
| | $S$ = | $4X - 3M - 2N - O$ |
| | $X$ = | $1/2\ S + 3/4\ M + 2/4\ N + 1/4\ O$ |

Steam consumption of heaters: given t steam = 115 °C (240 °F), Temperature of juice feed 26 °C (80 °F), juice weight = 100 kg.

metric $$\frac{100 \times 0.9\,(115-26)}{529.1} = 15.14 \text{ kg steam}$$

imperial $$\frac{220 \times 0.9\,(240-80)}{951.7} = 33.30 \text{ lb steam}$$

Typical flow of material in a mill in the year 1914:



| | | |
|---|---|---|
| fiber | 11 | kg |
| juice | 7.026 | kg |
| imbibition water | 5.374 | kg |
| | 23.40 | kg |

juice 89 kg =

| | | |
|---|---|---|
| 1st mill juice | 67 | kg |
| 2nd mill juice | 5 | kg |
| 3rd mill juice | 9.97 | kg |
| 3rd mill water | 7.63 | kg |
| | 89.60 | kg |

## Steam for heating

In an evaporator calandria, the heating medium is normally exhaust steam. The juice flows through the tubes, while the steam moves in the space outside the tubes. The surface area of the tubes represents the heating surface. This means that the steam is able to transfer heat to the juice through the metal surface. The steam comes in contact with the heating surface, and the temperature of the juice at the other side is lower than that of the steam. This causes a temperature reduction of the steam. Since there is a certain pressure, there is a fixed relation between the pressure and the temperature. If the temperature drops, the pressure must also drop, to restore the relationship. For instance, if the steam admitted is at 10 psi it is 240 °F. If by contact with colder juice the temperature drops to 230 °F, then the pressure will drop to 6 psi. This reduction is possible only if a certain amount of steam condenses. At the moment of entering, 1 lb of 10 psi steam contains 1160 btu total heat. After dropping to 6 psi and 230 °F, the latent heat is transferred to the colder juice (which will heat up), and the condensate water retains about 208 btu. The latent heat is therefore 952 btu. (1 btu is the heat required to heat 1 lb of water through 1 °F; 1 kg cal is the heat required to heat 1 kg of water through 1 °C; 1 kg cal = 3.968 btu.) If there is no condensation of steam, there is no heat transfer from steam to juice.

Therefore, superheated steam cannot be used for heating, because it has to lose the superheat first before it can start condensing. The heating surface can be defined as the surface in contact with the heating medium, not with the material to be heated, i.e. the outside diameter of the tubes.

In the Evaporator Test Code of the American Society of Mechanical Engineers (ASME) endorsed by the American Institute of Chemical Engineers (AICE), under article 29, it is stated: "Heating surface will be calculated as the surface in contact with steam or other heating medium." *Note.* This means the total outside area of the tubes, not the downtake, because this part is not filled with juice to be heated but is simply a juice conduit. Also the tube sheets are not considered heating surface, as the surface of the lower one is covered with a film of condensate anyway.

If we examine the steam tables, we find that the lower the steam pressure the higher the latent heat. In other words, the lower the pressure the more suitable the steam for heating purposes. Obviously, there must be other reasons why exhaust steam of, say 1 psi, is not normally used for heating, even though its latent heat is nearly 2% higher than from steam of 10 psi, which is often used.

The disadvantages of steam of very low pressure are the following.

(1) The temperature is so low that the slightest cooling by radiation of heat or through long-distance transportation causes condensation in the line and represents loss of steam. Extra traps are required to separate the condensate thus formed.

(2) The specific volume of steam of lower pressure increases so fast that piping for very low pressure is prohibitive. For instance:

1 lb of steam at 10 psi = 16.32 cu ft
1 lb of steam at 1 psi = 25 cu ft

This means that a 16″ diameter pipe of 10 psi has to be increased to 20″ diameter for steam of 1 psi, or a pipe of 40″ for 1 psi can be reduced to 32″ diameter for 10 psi.

(3) High demand of steam at a certain place makes the use of very low pressure impossible because of the excessive pipe diameter required. In many mills steam of 10 psi is often too low, for this reason, in which case pressures of 15-20 or 25 psi are used. Steam of 20 psi has half the volume of 1 psi. If it takes a 12″ diameter for 20 psi, it requires 18″ diameter to move the equivalent amount of steam at 1 psi.

There is always the possibility that the higher temperature of a higher-pressure steam will burn a sugar solution, forming dark decomposition through caramelization and organic acids. However, the higher temperature is not the only reason.

The second is exposure time to the increased temperature. Based on the principle of a shorter exposure time, special evaporators were designed, as we will see later. During the evaporation process the liquid boils. It circulates from the bottom upwards through the tubes and downwards through the downtake (centerwell).

Considering the juice movement in one tube during boiling, we see that while the liquid rises, the boiling increases for three reasons:

(1) It gathers more heat during upward travel.

(2) The pressure upwards decreases because of the hydrostatic head difference, and the vapor bubbles formed will increase in size. Both conditions together cause the juice to gain increasing velocity during its travel upwards in the tube. The boiling process will appear as shown in Fig. 17.

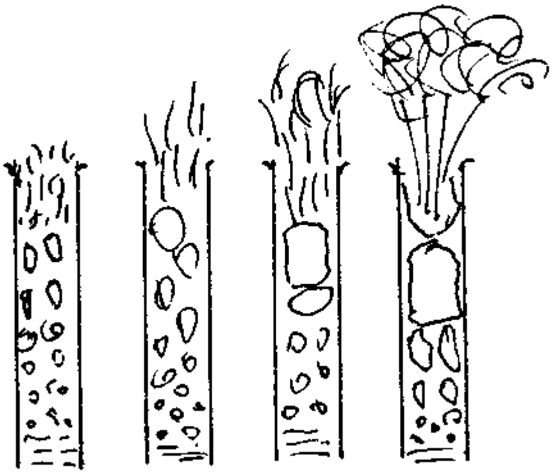


Fig. 17. Increased boiling reaction, bubble forming, velocity of vapor. (From Lyle[2])

(3) Temperature difference at the top and the bottom is a result of higher pressure at the bottom and lower at the top. When the liquid rises from the bottom with a higher temperature and reaches the top where a lower pressure exists, flashing takes place, giving the impression of a volcanic eruption from each tube.

## Entrainment

Too high a velocity can be the cause of entrainment of tiny juice particles escaping via the vapor duct to the calandria of the next vessel. There are three ways of reducing this effect:

(a) use of tubes of larger diameter
(b) increasing the height of the vapor belt
(c) more efficient entrainment separators (catchall).

(a) In an efficient design, the tubes of vessels 3 and 4 are of 2″ diameter, while those of 1 and 2 are 1½″ or 1¾″.

(b) Vapor belts normally have twice the height of the calandria.

(c) All kinds of entrainment separators are on the market, some more efficient than others. A good catchall not only separates all liquid from the vapor, but also causes a minimum pressure drop (resistance to flow). (See Fig. 18, showing additional external catchall.)

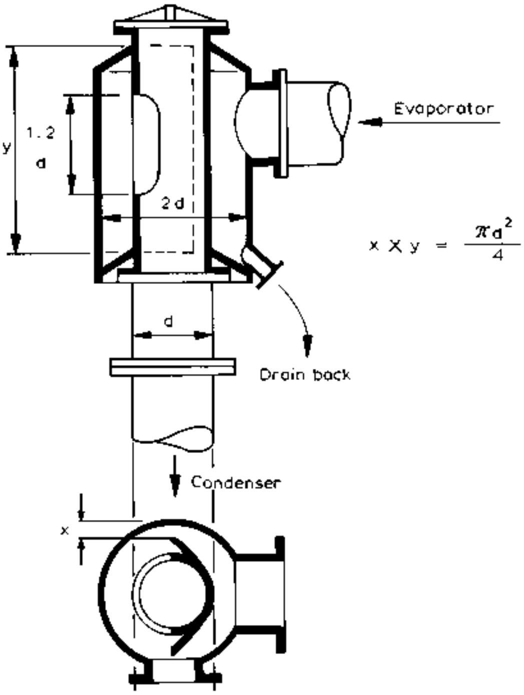


Fig. 18. External catchall. Designed by C. Perk, South Africa.

Another cause of excess velocity occurs when too low a liquid level exists in the vessel. The correct level is about one third of the tube height. A higher level reduces the evaporation rate, as does a lower one, in addition to increasing liquid velocity and entrainment. To maintain a level at 1/3 tube height by manual operation is almost impossible, because of the constant heavy fluctuation under boiling conditions. The level observed in the glass does not represent the real level in the tubes and is not a suitable guideline. Here, level controls of any kind are essential.

For reasons of possible entrainment, the tube length in standard vessels is limited to 8 ′. Normally, it is kept at 7 ′ or 7 ½ ′. The lowest temperature of the liquid in an evaporator is that corresponding to the vacuum in the last vessel. The vacuum is about 26″ Hg, corresponding to a boiling point of water at 125 °F. To this must be added bpr (boiling-point rise of juice), say 4 °, and, because of the hydrostatic head difference, say another 4 °, a total of 133 °F (56 °C).

The highest temperature is that of the exhaust steam in the first calandria. If the pressure is 10 psi, it is 240 °F. These two temperatures are the limits of the temperature scale of the process. Claassen[2] gives the temperature differences for a quadruple-effect evaporator using exhaust steam of 10 psi (240 °F), which is as follows:

| | t °F | absolute pressure | Gauge pressure |
|---|---|---|---|
| steam in I | 240 | 24.97 | 10 |
| juice in I | 227.5 | 20 | 5.2 |
| Δt | 12.5 | 5 | 4.8 |
| steam in II | 227.5 | 20 | 5.2 |
| juice in II | 211.5 | 14.69 | 0 |
| Δt | 16 | 5 | 5.2 |
| steam in III | 211.5 | 14.69 | 0 |
| juice in III | 182.5 | 7.9 | 16" Hg |
| Δt | 29 | 6.9 | |
| steam in IV | 182.5 | 7.9 | 16" Hg |
| juice in IV | 142.5 | 3.05 | 24" Hg |
| Δt | 40 | 5.00 | |

Table 2. Temperature differences for a quadruple effect evaporator. (From Claassen[3])

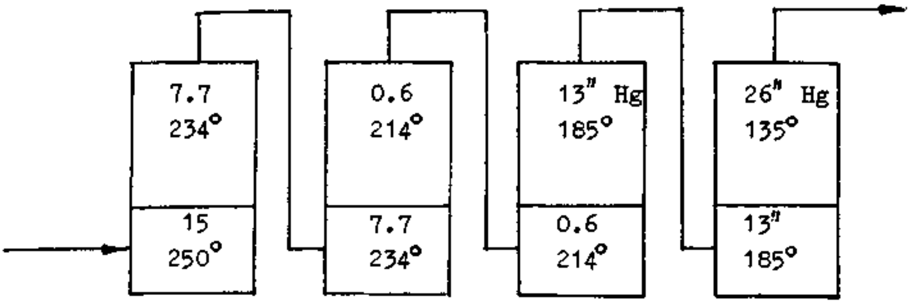


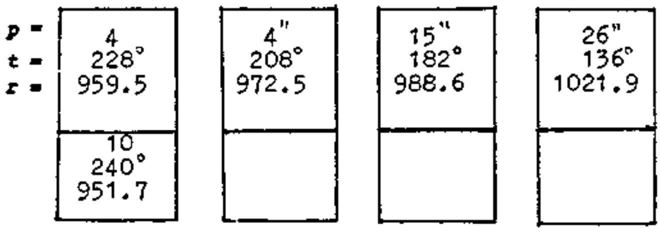
Fig. 19. Newer figures using 15 psi and 26" Hg.

For design purpose, the overall pressure drop is divided by the number of vessels, slightly decreasing towards the last. This is because of the increase of density of the liquid.

Table 3. Decreasing pressure drops in the design of a quadruple effect evaporator.

Assuming: exhaust steam pressure 10 psig = 25 psia
vacuum last vessel 26" Hg = 2 psia
overall pressure drop 23 psia

| divided as follows: | calandria<br>I | 11/40<br>I | 10½/40<br>II | 9½/40<br>III | 9/40<br>IV | 40/40<br>overall |
|---|---|---|---|---|---|---|
| % of drop | | 27.5% | 26.25% | 23.75% | 22.5% | 100% |
| pressure drop | | 6.32 | 6.04 | 5.46 | 5.18 | 23 |
| abs.pressure | 25 | 18.68 | 12.64 | 7.18 | 2.00 | |
| temperature | 240° | 224° | 204° | 178° | 126° | 114° |
| bpr + head | | 4° | 4° | 4° | 10° | |
| juice temp. | | 228° | 208° | 182° | 136° | |
| Δt° | | 12° | 16° | 22° | 42° | |



To calculate the evaporation coefficient of a vessel, the Dessin formula is normally used. It was developed because the heat-transfer coefficient is a number with a very small value. For instance, for the first vessel of a quadruple effect it is taken as 400 btu/sq ft/ °F, but in practice it is often much higher.

## Dessin formula[4]

(Imperial) $$C = \frac{(100-B)(T-130)}{16000} \quad \text{lb/h/ sq ft/ °F}$$

or (Metric) $$C = \frac{(100-B)(T-54)}{1000} \quad \text{kg/h/m}^2\text{/ °C}$$

$C$ = specific evaporation coefficient
$B$ = brix of juice leaving the vessel or average brix according to Coutanceau
$T$ = temperature of the heating steam.

The factor 16,000 is for good general conditions. If a greater safety margin is required, it can be replaced by 18,000, which takes into account a heavier scale formation, for instance in design of a new mill.

Alongside the Dessin formula, the formula for pre-evaporator capacity is also used:

$$C = 0.4\,\Delta t$$

$C$ = evaporation coefficient lb/h/sq ft
$\Delta t$ = temperature drop in °F between heating steam and vapor formed
The evaporation rate = specific evaporation coefficient (Dessin) multiplied by the temperature drop.

**CALCULATION**

Take the table of the preceding page, where the $\Delta t$ were: #1 = 12, #2 = 16, #3 = 22 and #4 = 42. The brix of each vessel is determined from evaporation totals and is related to grinding capacity. Assume the following brixes for this example: I = 17; II = 24; III = 35; IV = 60, juice = 13. Average brixes: b = 15; b = 20; b = 30; b = 48.

$$C_1 = \frac{(100 - 15)(240 - 130)}{18000} = 0.519 \times 12 = 6.23$$

$$C_2 = \frac{(100 - 20)(224 - 130)}{18000} = 0.418 \times 16 = 6.69$$

$$C_3 = \frac{(100 - 30)(204 - 130)}{18000} = 0.288 \times 22 = 6.34$$

$$C_4 = \frac{(100 - 48)(178 - 130)}{18000} = 0.139 \times 42 = 5.84$$

The next step is to calculate the heating surface of each vessel, using the above Dessin evaporation rates and a typical heat balance (as made for Atlantic before construction).

H.S.#1 $\frac{91852}{6.23} = 14743$ made for economical reason 13000 can be 14500

H.S.#2 $\frac{62926}{6.69} = 9406$ 9000 can be 9500

H.S.#3 $\frac{67407}{6.34} = 10632$ 10000 can be 10500

H.S.#4 $\frac{72324}{5.84} = 12384$ 11000 can be 12000

47165 43000 46500

The heating surface in vessel #1 is required for reheating juice; if the juice enters #1 with a temperature below its boiling point it has to be reheated to the boiling temperature before evaporation takes place.

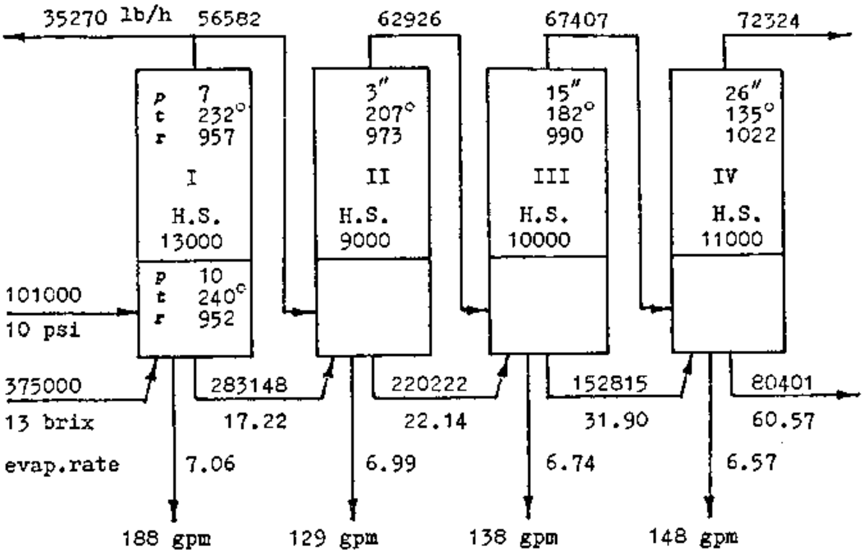


Fig. 20. Original evaporator designed for Atlantic Sugar Coop., Florida, before construction.

| | btu | lb/h | brix |
|---|---|---|---|
| 1.Steam 101,000 lb/h (10 psi) | 96,152,000 | 375,000 | 13.00 |
| deduct for heating 375000(232—210) | 8,250,000 | | |
| available for evaporation | 87,902,000 | | |
| evaporation 87902000/957 | | 91,852 | |
| transfer to #2 | | 283,148 | 17.22 |
| 2. vapor from #1 | 87,902,000 | | |
| to heater 35270 × 957 | 33,753,390 | | |
| left for #2 | 54,148,610 | | |
| add flash 283148(232—207) | 7,078,700 | | |
| available for evaporation | 61,227,310 | | |
| evaporation 61227310/973 | | 62,926 | |
| transfer to #3 | | 220,222 | 22.14 |
| 3. vapor from #2 | 61,227,310 | | |
| add flash 220222(207—182) | 5,505,550 | | |
| available for evaporation | 66,732,000 | | |
| evaporation 66732860/990 | | 67,407 | |
| transfer to #4 | | 152,815 | 31.90 |
| 4. vapor from #3 | 66,732,860 | | |
| add flash 152815(182—135) | 7,182,305 | | |
| available for evaporation | 73,915,165 | | |
| evaporation 73915165/1022 | | 72,324 | |
| syrup leaving last vessel | | 80,491 | 60.57 |

Cap 4500 tcd at 100% juice extraction of 13 brix

juice lb/h $= \frac{4500 \times 2000}{24} =$ 375,000

syrup produced$= \frac{375000 \times .13}{60.57} =$ 80,491

evaporated water 294,509(91852+62926+67407+72324)

Table 4. Evaporator heat balance Atlantic Sugar, Florida, (before construction).

The *H.S.* corresponding to the reheating is:

$H.S. = 0.6\, C\, (t_1 - t_0)$

$C$ = clarified juice in tons per hour

$t_1$ = boiling point of juice in first vessel

$t_0$ = temperature of entering juice

Example: juice 187.5 T/h

$t_1$ 232° F

$t_0$ 210° F

$H.S. = 0.6 \times 187.5(232 - 210) = 2475$ sq ft.

If there is a juice pre-heater in above case, the first vessel installed of 13000 sq ft is adequate, 14743 − 2475 = 12270 sq ft. Two identical quadruple effects were installed, so that cleaning could take place while the mill continued to grind.

As can be seen in the heat balance, the juice heating in vessel #1 is taken care of by using all steam to first heat the juice, then evaporate it. In other words, the heat required to heat the juice is deducted from the heat admitted. The difference is used for evaporation.

## Evaporator design

There are various combinations of evaporators. The basic evaporator set can be triple, quadruple or quintuple in effect. They consist of 3, 4 or 5 vessels. If installed in mills of identical capacities, they will do the same job. The difference is in steam economy. The least economical is of course the triple, the best is a quintuple.

A triple is used in mills where the fiber % cane is high. Here, it is good practice to be less economical in fuel (bagasse) consumption, because it is easier and cheaper to deal with an excess of steam instead of bagasse. Fiber % cane in Louisiana is about 17%. Therefore, all mills in Louisiana are equipped with triples. A quadruple is generally used, exceptions being where fiber is high or where mills are very small, say under 1000 tcd. Quintuples are seldom used in cane factories, although they are of general practice in beet sugar. This is easy to understand, as the fuel for steam generation in the beet industry must be purchased. The pulp is not suitable as fuel, as bagasse is in the cane industry.

If the 5-effect is used in cane, it is mostly in mills that are combined with a refinery, where the steam balance is unfavorable and economy in consumption is justified.

Since the existing mills always try to increase their grinding capacity, to reduce production cost by lowering their break-even point, it is nearly always necessary to modify evaporators, to satisfy the increased demand of evaporation. Rather than complete replacement, there are many possible solutions to increase capacity gradually.

### Bleed-off

1. Change a straight 4-effect to a vapor heating set. The first vessel produces enough vapor to heat the juice heaters in addition to the second vessel, the so-called bleed-off. The degree of bleed-off must be pre-determined. Most common is to the heaters alone. Some vacuum pans can also be switched to vapor I. Secondary heaters can be used while primary heaters use vapor II. When heaters use vapor I, the first vessel must be larger than the second. This can be expressed as follows:

Instead of using exhaust steam in the heaters this exhaust goes to the evaporator first, and then to the heaters, after evaporating about 1 lb of water for each lb of exhaust. The evaporation capacity is increased with the lb of exhaust steam required in the heaters.

### Vapor cell

2. Adding a vapor cell to the straight set. A vapor cell is a vessel in which juice is evaporated using exhaust steam. The produced vapor is "dead ended" and used entirely for the heaters. The concentrated juice goes to the conventional evaporator with a higher brix, thus increasing its capacity. It can also work with part of the juice. In this case, the concentrated juice goes to the first vessel, together with the non-concentrated remainder of the juice. The vapor cell can be single-, double- or even triple-effect, depending on the required economy and available exhaust-steam pressure.

### Pre-evaporator

3. In a mill where there is an exhaust-steam shortage, and where a considerable amount of live steam is used for make-up of exhaust shortage, the solution is to install a pre-evaporator.

A pre-evaporator is a vessel using reduced live steam to produce a vapor of pressure equal to that of the exhaust steam. This vapor is sent to the general exhaust line, the live steam having assisted as an evaporator medium, instead of having been mixed with exhaust steam without participating in the evaporation process. The word pre-evaporator is usually used wrongly. It is an exhaust-steam producer and live steam consumer. Most mills call a first-vessel with bleed-off a pre-evaporator, which it is not. It is just a larger first vessel with bleed-off, nothing more.

Since a pre-evaporator uses reduced live steam, the temperatures of the steam, the vapor and the juice are rather high. It is therefor a good idea to have a vessel with the least possible retention time for the juice. At the early stage of its application, the pre-evaporator was called a "Pauly" after the inventor of a long-tube vessel. It had increased juice velocity because of the long tubes, a separate catchall and a short retention time (under two minutes).

The Pauly was also called a semi-Kestner. Tubes have a length of about 12 ft, while the Kestner uses tubes of 24 feet. Hence the name semi-Kestner. (For a description of the Kestner, see p.69.) It is necessary that the long-tube vessels be provided with efficient catchalls or have high vapor spaces. The Pauly pre-evaporator had a separate catchall. In other words, it had a calandria body and a catchall body. This was done to reduce the excessive height of the vessel if the catchall were built on top of the calandria.

Because of the higher juice velocity, scaling of this kind of vessel is less, requiring cleaning once only during the crop season.

This advantage led to the idea of using a Kestner as a pre-evaporator, as discussed later. Cleaning of these vessels was done only during the off-season, not during the crop.

## Operational criteria

Before starting the crop, one must ensure that the combined evaporator machinery does not leak air such that an efficient vacuum sequence cannot be maintained; otherwise the purpose of concentrating juice into syrup is hardly possible.

Before the crop starts and steam has already been produced, a vacuum must be formed in the system, first in the last vessel and then in the preceding ones by opening the valve of incondensable gas.

If the system is cold and full of air (incondensable), the formation of a vacuum in the whole system using the condenser and vacuum pump (or multi-jet spray pumpless equipment) takes a very long time. This is not the case in a vacuum pan after discharging, because the pan is full of vapor from steam-out, which is condensable and a vacuum is formed in a few minutes.

After a vacuum of 20″ or more has been reached throughout the whole system, the valve to the condenser has to be closed, and the time and vacuum of each vessel noted on the test record. At 5-minute intervals, the vacuums must be rechecked. This continues until one of the vacuums reaches 10″.

A vacuum drop of 1″ in five minutes is considered acceptable for vacuum pans. For evaporators it is a little better, because most of the leakage is around the proofstick and the many feed valves of a vacuum pan, which the evaporator does not have. Of course, the incondensable-gas valves must be closed before the readings; otherwise the individual vacuums are not really individual.

It is permissible to make the test with all the joints freshly sprayed with water, since under working conditions they will also be wet. The only difference between the test and operating conditions is that the metal is cold during testing and hot when operating.

It is hard to determine the value of the difference, but in general the air leaks are smaller when hot. Therefore, since the test is made cold, the normal operating conditions are better than the test results.

It is important, at the beginning of the crop, to start the vacuum as soon as the steam pressure allows operation of injection water and vacuum pumps, since producing a vacuum takes many hours. It is worthless to try testing with a vacuum lower than 20″ because of the lower differential pressure. If we get a loss of 1″ during the first five minutes, then the drop in five minutes at 10″ vacuum will be considerably less than 1″ and would therefore give the wrong information.

## Incondensable gas elimination

The lower the vapor pressure, the heavier the incondensalbe load. Elimination is very important, especially in the last two vessels. If insufficient, the calandria will soon be completely filled with incondensable gas. On the other hand, if the pipe diameter is too large, the loss of steam or vapor is considerable and destroys the vacuum, as all vents are connected to vapor spaces or to the condenser directly.

A correct size piping for an evaporator of 4 - 5000 sq ft vessels will be:

# 1 = ¾″ to air
# 2 = 1″ to vapor space of # 2
# 3 = 1.25″ to vapor space of # 3
# 4 = 1.50″ to condenser vapor inlet.

All must be provided with a needle valve or ball valve for precise regulation. The best system, however, uses thermosteam traps. These traps close as soon as steam (or vapor) passes and open when the colder air (gas) escapes. Normally, the temperature difference between the vapor in the calandria and the air escaping is about 5 °F. This makes it possible to judge air elimination, using thermometers. Ideally, thermotraps and thermometers would be used for control of the trap efficiency.

It should be borne in mind that elimination of air and excess of elimination are both very important factors for efficient operation.

*Note:* The temperature difference between steam and air in vacuum pans is higher than in evaporators, because a pan uses a higher pressure difference between the heating medium and vacuum. The $\Delta t$ here is about 10 °F. It is important to know that even a slight air leak has a serious effect, taking into consideration that the specific volume of air at 26″ Hg is 174 cu ft/lb. This also shows that excess vapor from the air piping puts a serious load on the condenser.

Sometimes, all air vents are piped to the condenser. This should not be done; each air vent should go to the vapor space of its own vessel, to reduce excess pressure drops.

## Juice feeding

The normal process is feeding juice from the bottom and also extracting from there. There are evaporators designed to feed above the tube sheet, but this is dangerous as regards carry-over (entrainment). Besides, it goes against the natural route of circulation. The boiling movement is from bottom to top, not vice versa.

The normal procedure of determining the juicepipe diameter is to calculate the one between # 1 and # 2, and make all other connections equal to this one. The diameter is based on a juice velocity of 4 fps for a 4-effect. Theoretically, the juice piping towards the end can be smaller as the quantity of liquid decreases, but this is not actually true, because the flash taking place in the pipe entering an ambient of lower pressure would accelerate the juice too much if the diameter were too small.

Normally, the juice enters through a ring or a deflector plate at the bottom. The way the juice enters can be important to the behavior of carry-over, but exactly how is not known. We have had cases of entrainment in new installations, and by simply changing the juice-entrance arrangement, the problem of carry-over was solved. It seems that under certain circumstances, the juice "spouts" through the tubes.

The best arrangement is the so-called sealed downtake originally introduced by Chapman. In this system, the juice entering the centerwell (downtake) is the only juice that can leave the vessel. It is a much better system than the old one in which short-circuit can take place. This means a freshly entered juice can go straight out without traveling through the tubes. In the sealed downtakes, the juice leaving must have gone through the tubes at least once, participating in evaporation.

There are variations on the Chapman circulation: the semi-sealed downtake where the funnel is about 1″ free from the downtake. In this arrangement, there is a small short-circuit of juice of a higher temperature, because of the hydrostatic head increase at that lower level. Another variation is to place the funnel halfway up the downtake.

Now and then, variations on the admittance of the juice to the vessels are invented, but all become obsolete, so that the usual current arrangement is the Chapman sealed downtake and its variations of the higher-placed funnel, semi-sealed downtake, etc.

If the evaporator does not function correctly and its defects have to be investigated, the first necessity of course is to check the brixes of the juice in each vessel. Therefore, a sampling device to extract a juice sample is as necessary as a manometer on a steam boiler.

Nevertheless, there are very few factories that have such an accessory. This shows lack of knowledge of operation facilities. The expense involved in installing samplers is negligible (see Fig. 21). By setting up a heat balance and knowing both the theoretical and actual brixes, the defect(s) can be localized sooner.

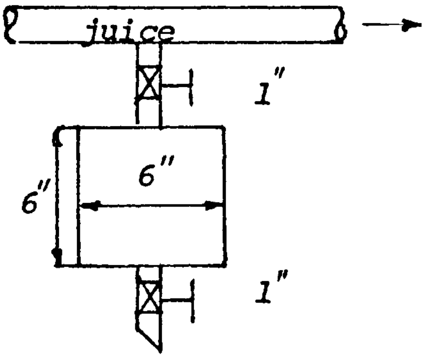


Fig. 21. Juice sampler for evaporator

## Long-tube evaporators (Film evaporators)

We have already mentioned the Pauly or semi-Kestner, which has a tube length of about 12 feet and is normally used as a pre-evaporator. The idea behind its application is to increase juice velocity and to reduce retention time; at the same time a higher steam temperature (pressure) can be used, so that the vapor produced will have the same pressure as the exhaust steam. The retention time of the juice in the Pauly is less than two minutes. The Kestner has tubes length of 21 - 24 feet, while the juice has a much higher velocity than in a Pauly and the retention time is reduced to about 30 seconds.

The quantity of juice stored in a Kestner is very small (about 50 cu ft), as the level seldom exceeds three feet. Heat transmission is high, because evaporation is caused by climbing film in the tubes, and a high temperature difference between heating steam (high pressure) and thin layer (small quantity) of juice to be heated. Normally, the heating steam is about 25 psi or a little more. Its temperatures i 268 °F. The juice film has a temperature close to 268 °F, but retention takes only 30 seconds, during which no decomposition of the juice takes place.

The real advantage of the system is that the retention time is also too short for scale formation. Therefore, a Kestner seldom requires cleaning during the crop season, and if it does, the cause is usually incorrect level operation or frequent grinding interruptions.

There are Kestners built with the separator body on top and on the side (as a separate vessel). The latter is a better arrangement. Because of the facility it creates in changing tubes of 24 ft long, it enables tubes to be changed from the top. In the case of a single body, tubes must be introduced through the bottom. It therefore requires a floor height of at least 25 feet to enable installation of tubes from below.

Evaporation rates are almost double the rates of conventional evaporators. This reduces the heating surface to be installed to about half normal.

The climbing film exists only when juice is boiling. It is obvious that the juice entering the Kestner should be pre-heated, as the vessel itself has scarcely any juice retention. It also requires a rather large clarified juice tank to ensure a constant supply to it, as it must not be allowed to run dry.

As the brix increases through the stages of evaporator effects, the heavier liquids are less likely to form climbing films. Although there are 4-effects composed of 4 Kestners, their normal application is mainly as first and/or second vessels exclusively. Because of the ability to work with higher temperatures (and short retention), they are well suited to forming 4-effect pressure evaporators. While a conventional evaporator needs a vacuum at the end, the pressure evaporator works with a low pressure at the end.

It starts with a high pressure, for example:

| | Steam | I | II | III | IV |
|---|---|---|---|---|---|
| psig | 35 | 25 | 17 | 9 | 2 |
| temperature | 280° | 267° | 254° | 237° | 219° |
| latent heat | 924 | 933 | 942 | 954 | 966 |

This kind of pressure evaporation is limited to the beet industry, where it is safer, because of the absence of invert sugar.

As a rule, Kestner tubes are 2″ diameter, although sometimes 1.25″ is also used in smaller units. The choice of 2″ tubes is because they are stiffer, a necessity in the case of such long tubes. The law of loss by hydrostatic head does not apply to Kestner, because the tube is completely occupied by vapor bubbles and the liquid column is interrupted. There is no hydrostatic head loss.

## Rectifier

A rectifier is a simple effect evaporator for adjusting the syrup to a predetermined brix. If a mill produces syrup to be further processed in other factories, it is normally concentrated to 72 brix for two reasons:

(a) to reduce volume as much as possible (storage, transportation reduction)

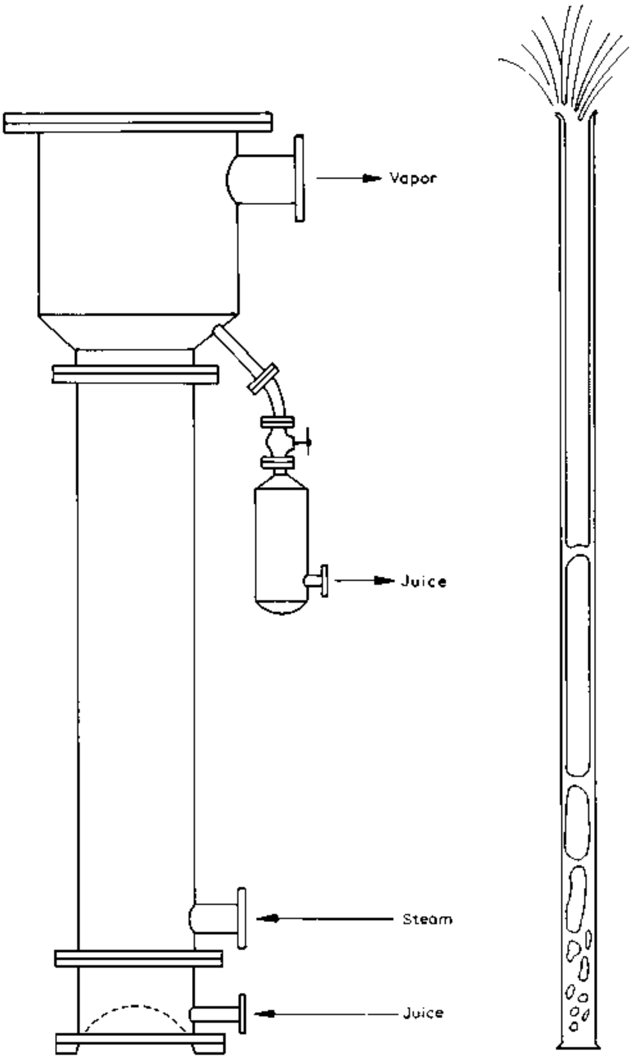


Fig. 22. Kestner long tube evaporator and climbing film in Kestner tube. (From Lyle[6])

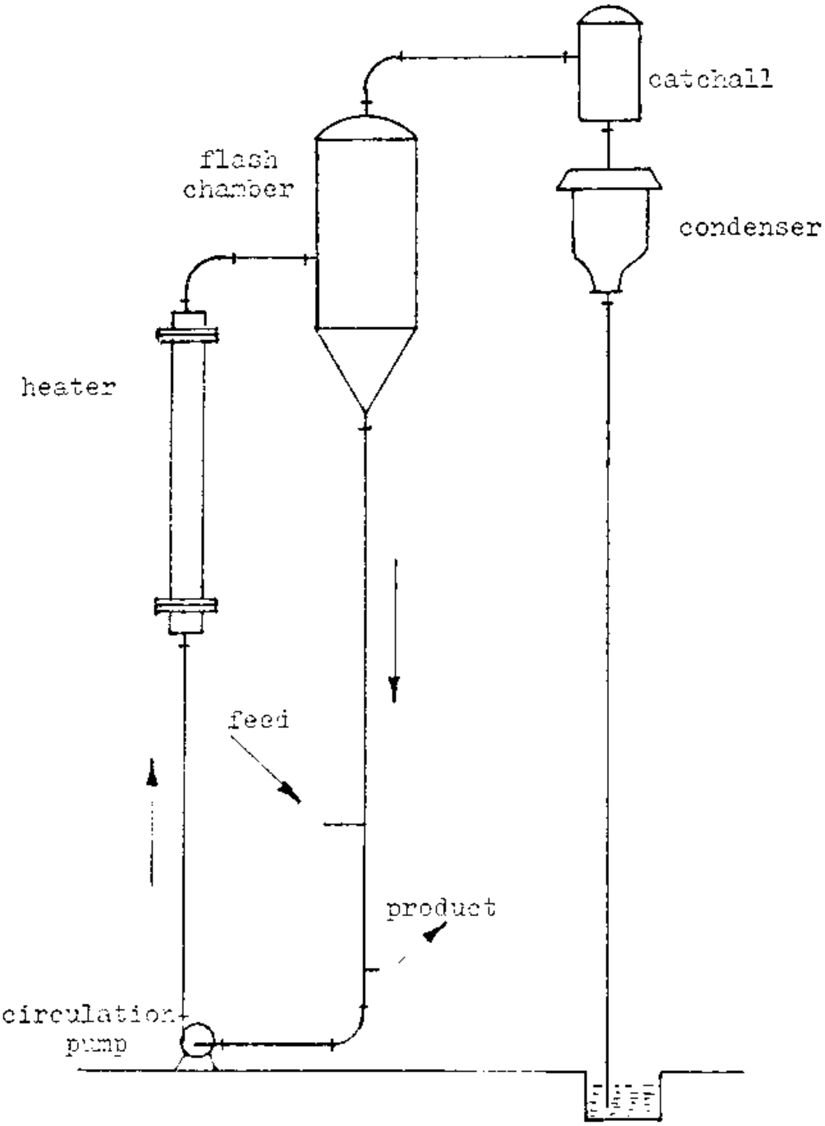


Fig. 23. Concentrator/rectifier of the flash evaporation type.

(b) to increase storage safety. The higher the brix, the more stable and resistant to infections it is. Rectification is a general practice in the beet industry. This is because of fuel economy and constant steam-consumption requirements in the boiling house. A common type of rectifier is the flash-evaporator[6]. It consists of a juice heater from where it flashes off its excess temperature in a vapor space under 26" -27" of vacuum. The process is controled by a brix control, which opens and closes the steam to the heater section, while the syrup flow is kept constant. The syrup is recirculated in the system by means of a recirculation pump. Only syrup of the correct brix is discharged from it.

## Juice Purity

It is quite common that the purity of the juice increases during the evaporation process by a total of about 0.8. This is mainly due to:

(a) a loss of non-sugars (brix) in gas form, such as carbon dioxide, ammonia ($CO_2$ and $NH_3$)

(b) incrustation on heating surface (very small)

(c) decomposition of invert, causing less negative pol and an apparent rise in polarization.

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## CHAPTER 12

# EVAPORATOR CLEANING

When an evaporator has to be cleaned periodically, the interval time varies (from a few days to three weeks), depending on the local properties of the juice. The right moment is determined in practice by:

(1) the increased consumption of steam, or the failure of boilers to produce the increased requirement

(2) the decreasing brix of the produced syrup and the resulting inability to maintain the grinding rate

(3) day to day reduction of the grinding rate, and a combination of the imbibition water, the low steam pressure and the low brix of syrup.

In most mills, these conditions do not occur, because evaporator cleaning takes place once a week, at the weekend when cane delivery to the mill is low, or, as in Florida, the mill has a double set of evaporators, and switches from one set to the other without interruption of grinding. Here the intervals are very short (normally 3-4 days).

## Downtime

If the mill has to close down for cleaning, it is a sound idea to reduce the lost time to a minimum, but without sacrifice of cleaning efficiency.

The downtime for cleaning can be divided into two parts:

(1) the actual cleaning operation (boiling caustic soda, boiling the acid, or scraping and brushing the tubes).

(2) the secondary operations, such as flushing out with water,discharging wash water, filling with water, waiting for boiling to begin, filling with soda and acid, etc.

## Incrustation

It is clear that the chemical composition of the scale is different in each vessel, because of the difference in temperature and juice concentration in each, and the dependence on the clarification system.

In general, it can be said that the scale in the first and second vessels is mainly of organic origin, while in vessels 3 and 4 it is inorganic.

If the cleaning is done chemically in the normal way, it consists of caustic soda boiling followed by muriatic (or sulfamic) acid boiling. The soda is capable of eliminating all organic scale including oxalates and silicates. The acid eliminates carbonates, sulfites, phosphates and inorganic scale. The soda boiling in the last vessels is beneficial, although it does not dissolve the inorganic scale. This is because it makes the scale swell, and it also causes pitting so that the acid treatment later applied will be more penetrating and effective.

There is no way to avoid scaling, although it is increased largely by overliming in the clarification, by using a bad quality lime, by insufficient milk of lime preparation, etc. As scale deposit is heaviest where juice velocity is lowest, it is clear that the scale is thicker at the bottom of the tube and thinnest at the top.

## Cleaning systems (chemical)

As already indicated, the almost universal system is cleaning with soda and acid. There are many variations not only in the chemicals, but also in their application. We will explore this sytem first, being most important. The products used are:

### 1. Caustic soda

This is added to the vessels already containing water, or the solution is prepared and pumped to the vessels. Concentration is normally 2-5%. The longer the boiling time, the better, but there is an economical limit. This time is usually 5-8 hours.

Soda cannot be boiled violently because of foaming. It is just kept at boiling point. The soda is very effective in vessels 1, 2, where nearly all scale is organic, but its effect on 3 and 4 is also important, because it dissolves the silicate in the scale and leaves the untouched inorganics very porous by elimination of silicates, which makes it easier for the acid to attack them later. The caustic soda is available in three commercial forms:

(a) solids in drums of 700 lb and 200 lb
(b) in flakes in drums of 400 lb (and 100 lb and 50 lb)
(c) in liquid form of 50% by weight.

The solid form is very difficult to handle. The drum has to be cut in half after being beaten with a sledgehammer to break the solid mass. Flakes are much easier to handle, although this form is more expensive. The liquid form is by far the easiest to handle. It requires two tanks: one for storage of the new product, and another for recirculation of used solution. The easiest way to install these tanks is by positioning the receiving tank on top of the recirculation tank. The spent solution can then easily be replenished with new material by simply dropping a measured quantity into it.

The most common soda concentration is 4% by weight. We can express this in easier numbers:

A 5000 sq ft H.S. conventional vessel has about 300 cu ft volume to the upper tubesheet, equivalent to 18500 lb of water, of which 4% is 740 lb of NaOH. This is equal to about 150 lb per 1000 sq ft H.S. This is an easy number to remember and use. This solution is kept boiling for at least 5 hours to a maximum of 8 hours.

Table 5 Caustic Soda Solutions at 60 °F (15.5 °C)

| NaOH % | Specific gravity | Bé | Brix | NaOH g/l | NaOH lb/gal | Weight lb/gal |
|---|---|---|---|---|---|---|
| 2 | 1.023 | 3.26 | 5.8 | 20.46 | 0.17 | 8.53 |
| 4 | 1.045 | 6.24 | 11.2 | 41.80 | 0.35 | 8.71 |
| 5 | 1.056 | 7.69 | 13.8 | 52.80 | 0.44 | 8.80 |

2. **Muriatic acid**

This is the commercial form of crude hydrochloric acid, of 20° Be (1.16 s.g. and 36 brix) 1 gal = 9.67 lb. It contains 31% HCl and is used in concentrations of 0.25% up 1-3% (in Florida). The concentration can be kept lower in vessels 1 and 2, higher in 3 and even higher in 4. Taking same size vessel as above, the acid amount should be about 180 lb for a 5000 sq ft vessel, equivalent to 720 lb in total. Dividing as indicated above the result would be:

| | I | II | III | IV | total |
|---|---|---|---|---|---|
| acid lb | 110 | 110 | 220 | 280 | 720 |
| per 1000 sq ft | 22 | 22 | 44 | 56 | 36 |

Acid is boiled for a maximum of 1-2 hours. Longer boiling is not effective, as all acid is boiled off in two hours anyway. The acid solution can be boiled more vigorously than the soda solution, as it does not foam. To insure that the acid is completely spent, a titration can be made after one hour of boiling, and if any acid remains boiling can be continued until a second titration with NaOH indicates that no more HCl is present. If this takes place after 1.5 hours, for instance, then the boiling time is fixed at 1.5 hour in this factory. Before cleaning starts, the pH of the acid solution must be under 3 and never higher than 5.5 (zero cleaning action).

3. **Soda ash**

To assist the soda in eliminating silicates in the last vessel, a quantity of soda ash ($Na_2CO_3$) can be added. This can be done in this vessel individually (through the manhole). The quantity added is best determined by experience. In Louisiana, about 25% on the soda is used.

4. **Inhibitor**

Inhibitor is normally added to the acid before boiling is started. This prevents the acid from attacking the metal itself. There are inhibitors in the market; the best known is Rodine 213, used as indicated in the following example.

*Use of Rodine 213 in a calandria of volume of about 4000 gal of water*

| | gal | lb |
|---|---|---|
| $H_2O$ | 4000 | 33200 |
| HCl | 65 | 621 |
| rodine | 0.25 | 2.2 |

Note: based on recommended application of 3 gal per 1000 gal 20°Bé acid, used at 200°F.

If no inhibitor is available, molasses can be added. It too has a definite inhibiting effect.

## Variations on chemical cleaning

The main variations are those concerning time and chemical concentration. Others are variations in application and chemicals. Time and concentration vary according to local requirements: in some countries excellent results are obtained by boiling 2% soda for four hours, while in other places it requires eight hours using a 5% solution. In other words, these factors are purely empirical.

The main variation in application is to circulate by pump concentrated caustic soda solution of about 30°Bé as a spray, using a perforated ring tube above the calandria. The circulation time is about 2 hours. The calandria is heated with exhaust steam. This variation is not new — it was applied long before World War II. The results are satisfactory, but again, in different locations the effectiveness varies. The disadvantage is that the spent solution must be analyzed quantitatively and replenished accordingly.

In some regions, satisfactory results have been obtained by inverting the soda-acid sequence to acid-soda. By far the most variations were those found using different chemicals. The best substitutions were:

(a) Sulfamic acid instead of muriatic acid. Its advantage is that it is in powder form and as long as it is dry it is quite safe to handle. The price is somewhat higher, but transportation is much easier than for liquid acid and breakage is eliminated. It is also less corrosive than HCl.

(b) Another well-known product is fluoride, especially in cases of high silica contents. It is commercially known as Diamante 72 (Cuba).

(c) For cleaning during the off-season, a diluted solution of molasses is left to ferment. It is diluted to about 18 brix at ambient temperature. The pH drops to under 4. This solution can be left for some time. It can be followed by a light chemical cleaning just before start-up, or the tubes can be brushed mechanically.

(d) There are also vegetable products in use for scale softening, which do not dissolve it. One well-known one has the trade name of Algo. It is even used in very dilute solutions such as 0.05% (500 ppm). It can soften the scale so much that in some cases it can simply be washed away (with water jet or air jet).

(e) A rather new chemical of the sequestering type is also used. Its name is Versene or EDTA, according to its chemical composition, which is ethylene diaminetetraacetic acid. It can be regenerated using sulfuric acid or caustic soda to adjust the pH as required for its application. It is very expensive: about twenty times the price of muriatic acid. To its price must be added the acid and soda used for regeneration.

### Technique of chemical cleaning

It is clear that the real cleaning procedure consists of the boiling of the caustic soda and muriatic acid (both solutions). As we have seen before, the time consumed by these two operations is about eight hours in total. All necessary secondary operations can be considered as lost time as far as real cleaning is concerned. The sequence of a complete cleaning is as follows:

1. liquidation of juice
2. fill with water to wash out juice
3. discharge wash water
4. fill with soda solution from tank
5. boil soda
6. discharge soda back to tank (or ditch)
7. fill with wash water I
8. discharge wash water I
9. fill with wash water II
10. discharge wash water II
11. fill with water for acid
12. add acid
13. boil acid
14. discharge acid waste to ditch
15. fill with wash water
17. open manholes
18. inspect tubes cleanness visually
19. close and prepare for grinding
20. (occasionally) test calandria for leaking tubes

The cleaning stages are 5 and 13. Water fillings take place at 2, 7, 9, 11, 15, a total of 5 stages. Discharges (either water or chemicals) are 3, 6, 8, 10, 14, 16, a total of 6 stages. It is clear that admission of water and discharge of liquids occur so frequently that provision for gaining time in these operations is essential. It cannot be done simply using a 2″ pipe to admit water by gravity. Nevertheless, this example is taken from actual practice. Filling one vessel took about 15-20 minutes (1-1.5 hour per quadruple) and was repeated 5 times; the lost time for filling with water alone was 5-7.5 hours. There is only one correct water service, namely by using the injection water pump. This does not create any problem, because the evaporator is out of service and the injection water pump is not required. Such a pump is capable of delivering anywhere from 2000-5000 gpm, depending on the mill capacity and evaporator size.

A 8″ diameter pipe header should run along the evaporator from the highest possible point of the vertical delivery pipe of this pump to the condenser. From this 8″ header, an individual 6″ line (4″ for a small evaporator) should be provided to supply water to each vessel individually. One vessel can now be filled to the upper tube sheet in a few minutes, and the whole 4-effect in less than ten minutes, including valve opening and closing. The combination of five times takes about 30-40 minutes.

The second most frequent manoeuvre is to discharge to the ditch. Here again, there is no problem in making the drain pipe of ample size, not less than 6″. If the discharge ditch is far away, a header should be installed and it should be given enough inclination for rapid discharge. No valves are required in this header, and so the pipe size is not tied to the valve cost. The advantage of sufficient pipe size, besides drainage-time reduction, is that heavy drainage causes whirling inside the vessel, keeping the chemicals and solids in suspension.

After the soda treatment, it is essential that the vessel is washed twice before acid is boiled, because a residue of soda would neutralize the acid and no cleaning effect of the acid would take place. This experience is known from practice. For this reason, solid soda can only be used if there is ample time available before the cleaning to prepare the solution, say 3-7 days. If not, flakes must be used although they are more expensive. In many Latin American countries, liquid soda is not available, because it requires special tank trucks.

## Steam cracking

One important operation has not been mentioned yet because it does not involve chemicals or other products. After the soda boiling is finished, the contents are discharged, and before admitting the first wash water, the heating steam of the calandria is turned on. This will heat all tubes and surrounding metal to a moderate temperature, just by contact and radiation losses of the steam.

After a while, the steam is turned off and the cold water of the injection water pump is turned on immediately. It causes instant cooling of all hot metal and a slight shrinkage is the result. This is usually enough to loosen a large portion of the scale.

The same operation is repeated after the acid boiling. Under point 17 (open manholes), the manhole in the bottom is opened to collect all fallen scale lying on the bottom plate. After it is taken out, the bottom can be cleaned by means of a water hose. This so-called cracking is rather effective and takes a reasonable short time.

## Steam for cleaning

All calandrias should be provided with a 4″ diameter supply of exhaust steam. This line must have a reliable shut-off valve and a main valve in the take-off place. The vessels normally using exhaust steam can use their regular shut-off valve and do not need a 4″ connection. Only the calandrias supplied with vapor need the extra steam connections.

*Note:* It is not good practice to have live steam of working pressure or reduced intermediate pressure (mostly 80-100 psi) anywhere around the evaporator. If this is the case, the inspection requires all vessels and their accessories to be tested as live-steam apparatus. This makes all pipelines and valves more expensive (higher pressure fittings), and all calandrias must be tested on the steam pressure. Extension lights for inspection of the inside of the calandria should be made for low voltage (24 V), as 110 V is fatal around wet steel bodies.

## Mechanical cleaning

In most labor-intensive countries, where labor is cheaper and readily available, mechnical cleaning is preferred to complete chemical cleaning. Boiling of caustic soda is always practised. Mechanical scraping and brushing replaces the acid treatment only. In more and more cases, factories are abandoning mechanical cleaning in favor of acid treatment. There are many reasons for this:

(a) Labor is becoming more expensive and scarcer. In most countries workers are reluctant to perform this kind of uncomfortable labor.

(b) Piece-work like this is mostly judged and estimated by a labor union official to make sure that the price gradually increases.

(c) A certain (rather large) number of tubes will never be cleaned. Those near the body plates (inside diameter) are avoided because the scale on the plates, being as rough as coral and barnacle, damages the workers' hands. Soon these tubes are completely eliminated as they become solid with scale.

(d) Those tubes that are regularly scraped or brushed lose their wall thickness because of damage, and tube testing for leaks is a constant necessity and is time-consuming.

(e) Acid boiling, especially when an inhibitor is used, is a simple and fairly quick operation, avoiding all the labor relations problems, non-availability of labor force and inefficient cleaning operation.

(f) The ever-present danger of having people working inside the vessel and the possibility of steam leaking or erroneous opening of the steam supply, the necessity of keeping the men wet using hoses, the problem of only one manhole for the men leaving and entering, the use of many extension lights, the limitation of only a few electric descalers, and a permanent shortage of rollers and brushes.

Sample calculation of time

Assume evaporator heating surface 30,000 sq ft, consisting of 1.5" diameter tubes 7-ft long. Total number of tubes is 10909. If incrustation is rather heavy, one man can do 15 tubes per hour. If less heavy, a maximum of 50 tubes per hour can be reached. Take an average of 25. Cleanig requires 10909/25 = 436 man-hours. Assume 5 men cleaning in each vessel = 20 men. Cleaning time 436/20 = 22 hours and descalers required are 20. If 20 men are cleaning, there are 20 on stand-by (to change every 30 minutes). Three shifts are required, meaning a total of 120 men.

*Note:* If in one factory cleaning is done in, say, 10 hours using a total of 20 men, the cleaning *must* be incomplete: it simply cannot be done effectively under those conditions.

*Conclusion:* Nothing is easier than chemical cleaning. Mechanical cleaning should be abandoned.

## Cleaning of steam side

Sometimes the steam chest itself is dirty, which means that a deposit on the outside of the tubes is formed. This is mainly caused by exhaust steam coming from steam engines, where oil mixes with the steam. The best way to clean, during the off-season, is to float a layer of kerosene on water, alternately raising and lowering the level by slowly feeding or draining the water. Of course, this inconvenience occurs only in the vessel(s) heated by exhaust steam.

## Vacuum pan cleaning

In a raw sugar factory, occasional bioling of 5-10 gallons of acid in a pan half full of water is enough to remove scale in the pan used for graining with magma and feeding of syrup. The B and C pans do not need chemical cleaning during the crop. Boiling water will be sufficient. In the refinery, pans are or can be cleaned with a mixture of magnesium chloride and a little caustic soda. Bemis used 300 lb $MgCl_2$ with 2 lb soda in 3600 gallons of water, with good results.

## Prevention of scale

The cleaning of evaporators is a problem even when done chemically, and in most mills it is a main source of lost time. Thus it is logical that scale-preventive products or devices are very desirable. These products are numerous, the devices only a few, and they rely on producing an electric or magnetic field.

The inventors claim that the salts producing the scale deposit are ionized and remain suspended in the juice, rather than forming scale. Two of these patents, the C.E.P.I. and the Superstat, are known. Some mills claim good results, others not. Chemicals to be added to the juice are more commonly in use. Some of the best known are: Wrikorg-C, which is added to the juice leaving the clarifier. Its composition is tetraphosphoglucosate of lime; Fabcon I-12, which is also added to the juice entering the last vessel.

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## CHAPTER 13

# MEASUREMENT OF HEAT-TRANSFER COEFFICIENT

There is very little proof of the effectiveness of additives. The normal story is that stoppage for cleaning used to be necessary every ten days, but now after using ''our'' product it is every 12 days! The scale is much easier to remove, because it is softer, etc. Nobody produces scientific data, such as better heat transfer or the same heat transmission after a longer time delay. Nevertheless, measurement of heat transfer is not very complicated. The reason why very few factories have the equipment is that they clean once a week anyway, and cleaning too early does not matter. Other factories have stand-by evaporators and switch over during grinding and clean without shut-down.

Moreover, it is not clear whether it is a matter of maximum scale or minimum steam consumption. In other words, should cleaning be postponed until scale demands cleaning or should cleaning be done as soon as steam requirement to the evaporator increases, before scale build-up is at maximum?

Nevertheless, measurement of heat transfer is of interest if the effectiveness of an additive has to be judged. Since the last vessel always has the heaviest scale and dominates the cleaning requirement of the evaporator as a whole, we are only interested in measuring the heat transmission in the last vessel. If we measure heat transfer we can:

(1) determine the moment of cleaning
(2) show whether or not cleaning was efficient
(3) judge, the effectiveness of new products.

To define heat transfer, let us consider a clean vessel first, rather than a 100%-scaled one. If a caladria is really scale-free, heat transfer from the steam to the juice is at a maximum, which means that steam condenses readily, juice reaches a maximum temperature and the condensate quantity is high and at its minimum temperature. On the other hand, if scaling is heavy, transfer is bad, juice stays relatively cool, condensate is a small quantity and temperature is high. This indicates that the quantity of condensate and the temperatures of the vapor, juice and condensate are the factors which will inform us about heat transfer.

Let: temperature of juice be = $t_j\,°C$
temperature of vapor in calandria = $t_v\,°C$
temperature of condensate = $t_c\,°C$
heating surface of vessel = $S\ m^2$
quantity of condensate = $v\ l/min$

Heat-transfer coefficient (cal/m²/°C/h) =

$$\frac{v \times 60 \times (\text{total heat at } t_v - t_c)}{S \times (t_v - t_j)}$$

To measure the three required temperatures and the flow of condensate, the easiest way is using three thermometers and a flowmeter for the condensate quantity. The measurement of the juice temperature is not so reliable. For this reason, Ing. J.H. Spoelstra of Stork in the Netherlands devised an improved formula, converting the temperature of the juice into the temperature of the vapor on top of the juice.

Apparent heat-transfer coefficient $K$ in cal/m$^2$/°C/h.

$$K = \frac{C\ (\text{total heat at } t_s\ -\ {}_c)}{H.S.(t_s - t_v)}$$

$C$ = condensate in kg/h
$H.S.$ = heating surface in m$^2$
total heat at $t_s$ = enthalpy of heating steam cal/kg from table
$t_s$ = temperature of heating steam °C
$t_c$ = temperature of condensate °C
$t_v$ = temperature of vapor in vessel °C (also from table)

Estimating $t_s = 80\text{-}86$ and $\Delta t = (t_s - t_c) = 4\text{-}7$, then total heat at $t_s - t_c$ varies from 552-558, or average = 555.
now:

$$K = \frac{555 \times C}{H.S.\ (t_s - t_v)} \qquad \text{(Spoelstra)}$$

*Note.* If the condensate flow is measured with a flowmeter or a rotameter in gpm, then

$$\text{flow in kg/h} = \frac{\text{gpm} \times 8.33 \times 60}{2.2} = 227.1 \times \text{gpm}$$

## Practical use of heat-transfer coefficient

From the first day after cleaning, the temperatures and flow of condensate are measured at a convenient fixed time daily. The calculated results are marked on a graph: day and date scale on the $x$ scale (absciss) and the heat transfer on the $y$ scale (ordinate).

Once this graph is maintained, we know what the best coefficient must be after cleaning and where to stop for cleaning again at the lowest point. At the same time, "cane ground" will be noted on a cumulative basis, so that cane ground from cleaning to cleaning is known. If a new product for cleaning or a preventive type is tried out, it will show in the graph, either as more cane ground, or a longer run through slower scale formation.

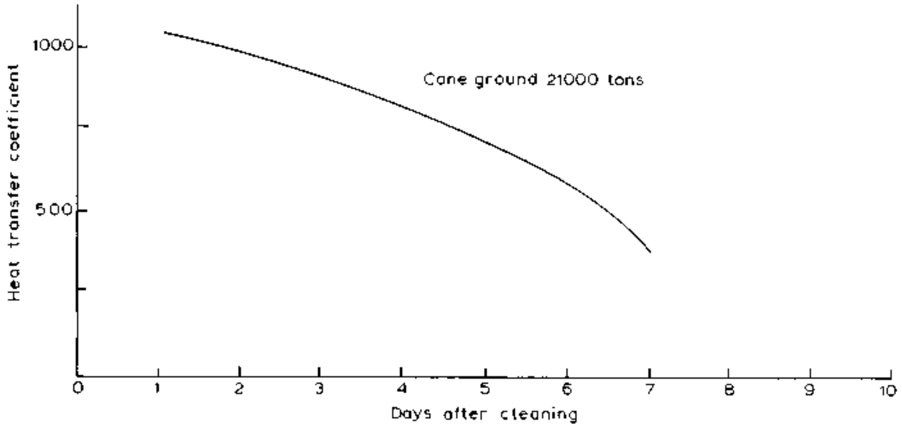

Fig. 24(a). Heat transfer coefficient during the time between cleanings.

and a test run is made for a new product for scale prevention.

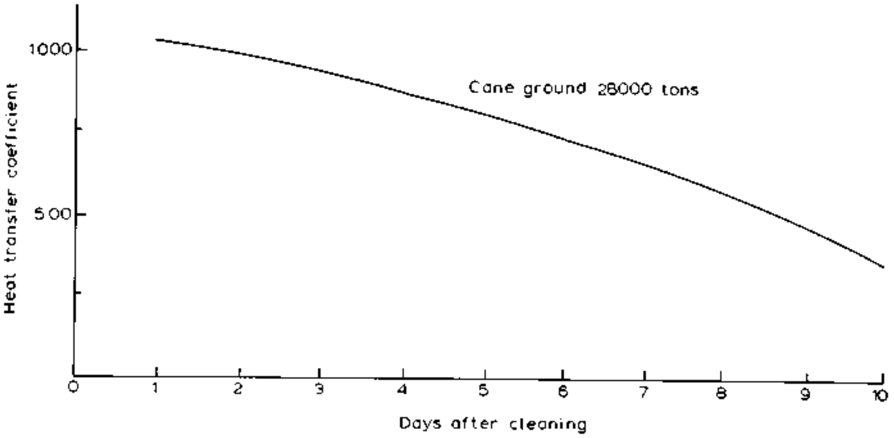

Fig. 24(b). Heat transfer coefficient during the time between cleanings.

Suppose the test graph looks as shown in Fig. 24(b). We can convincingly say that the product has a positive merit. The coefficient indicated that cleaning occurs nearly three days later than normal. Therefore, cane ground during this run was 7000 t more. This reduction of cleaning means, for instance, two fewer cleanings in the crop, or 36 hours less lost time. The payroll alone in 36 hours is $7500. Deduct from this, cost of product and installation expenses. Yield increase through reduction of crop duration is not taken into consideration, nor is the reduced depreciation on equipment.

*Note.* If after 1 day of cleaning the coefficient starts at a lower level than normal, it indicates that more soda and/or acid must be used next time.

## Cleaning shut-down

In most countries, the week-ends are used for repairs and cleaning. That is because of less cane cutting or even complete stoppage of cane cutting in the field. Depending on the local customs, the week-end stop can be from 12 to 36 hours and can be on Saturday, Sunday or even Monday.

In countries where no stoppage occurs, the factory is usually provided with a stand-by evaporator set, to avoid any downtime at all for cleaning. Alternatively, there are stand-by vessels connected in the set such that each vessel can be disconnected temporarily for cleaning. The latter system is not very desirable, because of the complications required in pipe connections and extra valves of large dimensions (also very expensive). In such cases, the best set-up is to have a stand-by last vessel only. By cleaning the last one more frequently, the run can be increased, say from 8 to 14 days. But, again, two valves are required to connect each final vessel to the condenser, and here we have valves from 30″-42″ depending on the mill capacity. The price of those two valves is not much less than another vessel. Besides, a valve this size with a positive shut-off has still to be invented.

The general rule for any evaporator installation is that it must be as simple as possible. Any sophistication using extra pipe connections and requiring valves is an invitation for trouble. We have seen many problems in evaporators with too many "tricks", and on more than one occasion operation efficiency has been increased by eliminating extra equipment, not by adding to it.

Very few factories do not stop at week-ends and for cleaning whenever required. Nevertheless, in many factories it has been found convenient to have a cleaning stop, because the downtime is well used for performing accumulated small repairs, such as changing packings, repairing leaks, changing impellers of pumps, even changing rolls in the mills, etc.

It is absolutely necessary during the crop time to have all abnormalities noted down by the shift engineers and superintendents, to be able to make a work program during the stop.

## Miscellaneous on bleed-off

It is normal procedure to bleed-off vapor I and vapor II for the second and first stage of juice heating respectively, with vapor II from ambient to about 175 °F and with vapor I from 175 °F to 220 °F. Of course, the juice heaters must also be provided with exhaust steam, because during start-up the heaters must function before the evaporators are in use.

This in itself constitutes a problem. We have seen cases, where for some reason (slow grinding, etc.), vapor production was momentarily low, and the operator opened up both valves, vapor and exhaust steam, on the heaters. When questioned, he explains: ''This will help the vapor to perform the task.'' In fact, the opening of the exhaust steam will equalize the pressure at both calandria and vapor belt of the first vessel, which stops evaporation, since $\Delta t$ is lost. The situation is even worse when vacuum pans also receive vapor I. A vacuum-pan operation is one with constant fluctuation. Not only is the cycle itself ''stop and go'', but the consumption of vapor during the process falls off rapidly.

If a certain amount of vapor bleed-off is sent to the vacuum pans, it takes a very capable pan-man to switch from one pan to another constantly, to equalize the bleed-off as much as possible. Whenever possible, bleed-off from vessel I or II to the vacuum pans should be avoided. Consumption of vapor by juice heaters is much more continuous.

We have seen evaporators so generously designed as far as capacity is concerned, with bleed-off from vessel I to all vacuum pans, that exhaust steam had to be throttled heavily to keep the density of the syrup within bounds. This causes a reduced evaporation in vessel I, which is then unable to produce all the vapor required for the boiling operation.

As in this particular case there was no other heating medium available at the pans, this inconvenience caused much downtime and very limited production, the opposite to what was intended, just because the evaporator was too large.

## Controls for evaporators

*Level.* As already indicated, a level control on each vessel is absolutely necessary, because visually maintaining a correct level is not possible, to say nothing of balancing the tie-in of one vessel with the next or the preceding one.

*Steam to vessel I.* To evaporate a certain quantity of water, a fixed amount of exhaust steam must be admitted to the first calandria. The problem is that the juice flow to the first vessel is far from constant, but the fluctuations cannot be detected.

Some varieties of cane have more juice than others. Switching from one variety to another goes undetected. Grinding rate constantly fluctuates. Small stops (chokes, etc.) occur repeatedly and go undetected as far as the evaporator feed is concerned. The only way to ''feel'' such fluctuations is by use of instruments.

For any instrument controlling steam flow to calandria I, all other factors influencing consumption must be as constant as possible. For instance:

(a) The pressure of the exhaust steam must be kept constant by using a valve to reduce live steam to a preset exhaust steam pressure for supplementing, for the case where pressure is low.

(b) There must be an automatic blow-off valve for exhaust steam, in case pressure is too high.

(c) There must be an interlock between these two, so that live steam make-up cannot be blown-off at the same time.

(d) A constant pressure must be maintained in the vapor space of vessel I, also using make-up or blow-off if necessary.

(e) There must be a controled level in the clarified juice tank to feed the evaporator, to secure a constant supply and exclude air to the vessel.

When all conditions are favorable, the vapor-space pressure should throttle the steam supply to the calandria. Let use suppose there is an undetected reduction in juice supply. If the steam is left as it is, the level will lower, the pressure of vapor will increase, and evaporation in vessel II will rise, lowering the level. If there is an increase in juice supply, there will not be enough steam and so the level increases, the vapor pressure drops, evaporation in vessel II decreases, etc, until syrup brix drops. The vapor pressure in vessel I has to be the signal to the steam control in calandria I. If pressure drops, it should open wider to admit more steam. If pressure increases, it should close more to admit less steam.

Control of the amount of injection water to the condenser ensures a constant vacuum. Vapor to the condenser varies and water supply should vary accordingly. If this is the case, the vacuum will be constant. Here the temperature of the waste water in the tail pipe must control the graduation of the injection-water valve.

If an evaporator is equipped with all features mentioned above, viz:

(1) level controls
(2) exhaust steam to calandria I
(3) make-up of live steam to exhaust
(4) blow-off of exhaust
(5) water to condenser

then there is no need to control syrup density, because this must come naturally as a result of all controled conditions. If this is not the case, the design is wrong.

Control of syrup density is a very difficult instrumentation problem and is not too reliable. Moreover, it is expensive. If required, the most reliable system is the so-called U-tube for full syrup flow (not just a sample flow). It is a U-tube which is in balance when liquid is distilled water. By using syrup, the degree of unbalance is amplified and measured. Such an instrument costs over $10,000.

The next step is measurement of heat transfer in vessel IV, which completes the instrumentation.

If the factory has no instrumentation at all, it can be installed in steps:
(a) level control
(b) steam control on vessel I
(c) vacuum control
(d) heat-transfer measurement.

We assume live steam supplement and blow-off of exhaust exist, which is the case in most mills.

One can assume that all calandrias and vapor belts have pressure gauges and the last vessel also has a mercury column. Quite often thermometers are also mounted.

## Soda and acid facilities

*Caustic soda* requires two tanks:
(a) one for new soda, either liquid or prepared from flakes
(b) one for used-soda storage.

Both are mounted outside with (a) on top of (b).

The dissolving tank must have a steam coil to heat the liquid for dissolving and provide circulation. Additional circulation can be maintained by means of compressed air or a mixer. The latter is better. Solid soda should not be used, only flakes or liquid.

The circulation tank should have sufficient capacity to store the combined quantity of each vessel filled to the upper tube-sheet, i.e. about a total of 2500 cu ft for a mill of about 5000 tcd.

*Example.* Consider a horizontal cylindrical tank 11′ × 26′. It must be provided with a pump of ample capacity to keep the filling time to a minimum, say about 350 gpm at 120′ head, 25 hp.

*Acid* tank must be completely rubber-lined or made of fiber glass. The simplest system uses a pump (special material) to take acid through a pvc pipe header with valve to each vessel. The connection from the vessel to the header is through a hose with quick coupling. Instead of measuring the quantity of acid to each vessel, it is easier to have a pump of, say, 25 gpm supplying acid during a measured time, using a timer.

Another method of transporation is using compressed air to lift acid to a constant-head tank above the evaporators and feeding measured quantities to the vessels by gravity. The latter system is somewhat more dangerous.

When using sulfamic acid, it can be added to each vessel through the man-hole from pre-measured containers, one for each vessel.

## Taking advantage of sensible heat of condensates

If the steam in the calandria condenses, the heat of the condensate is the sensible heat the water contains at the pressure it has.

Suppose the exhaust steam is at 10 psi, $t$ = 240 °F, total heat 1160 btu, equal to latent heat plus sensible heat of 951.7 + 208.3. The vapor I is at 4 psi, 228 °F, so total heat is 1155.7 = (959.5 + 196.2).

If we allow the condensate of calandria I to come in contact with calandria II, it will flash off its excess of sensible heat, 208.3 − 196.2 = 12.1 btu/lb. This operation can be repeated from one vessel to the next. All the heat given off goes to the vapor as additional aid to evaporation.

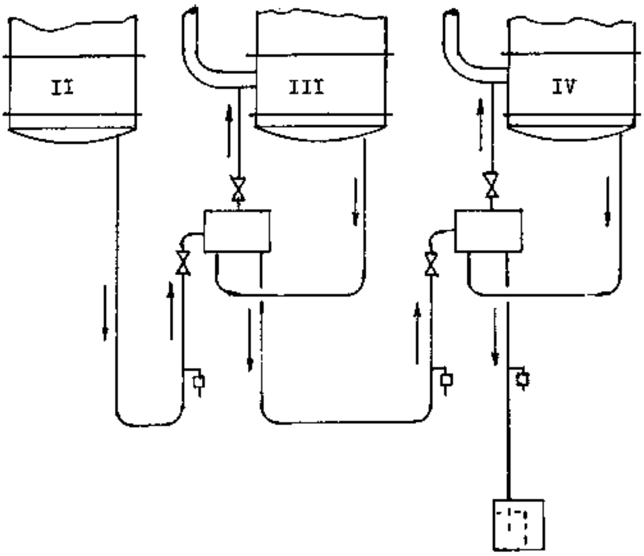

Fig. 25. Condensate flash system in which the heat given off is used for evaporation. Condensate II flashes to calandria III and condensate II and II to calandria IV.

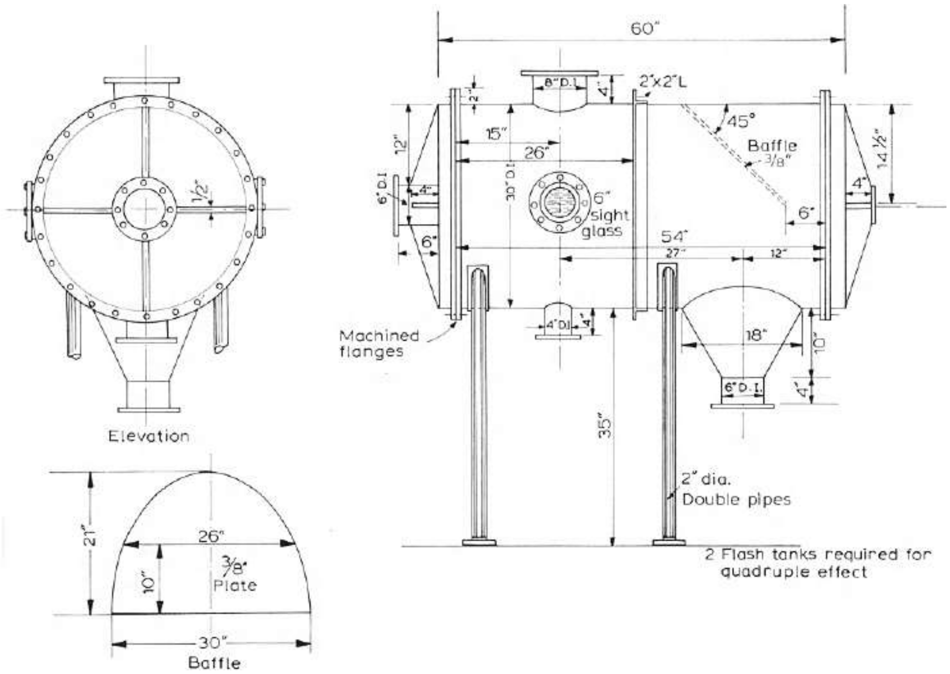

Fig. 25a. Condensate flash tanks for a quadruple effect evaporator of 43000 sq ft heating surface.

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CHAPTER 14

# BOILING HOUSE OPERATION

## Introduction

The purpose of the second concentration stage of the syrup after it has left the evaporators, is to produce granulated sugar (grain or crystals). By producing grain, the sucrose contained in the syrup is largely eliminated, leaving behind the impurities (non-sugars), which end up in the final (black-strap) molasses. This is a by-product from which, economically speaking, no sugar can be recovered. The syrup as it leaves the evaporation has a purity of 80-86 (under normal conditions).

If the sucrose is crystallized, it is not possible to reach complete exhaustion (elimination), from its high level of sugar contents to the low level left behind in the exhausted final molasses, in just one step of crystallization. In other words, the process of crystallization has to be repeated to step down from about 85 purity to about 27, contained in the molasses. The normal procedure in the cane industry is three times, making A strikes, B strikes and C strikes.

If purities are really high, say 88-92, even four times may be necessary. Higher purity syrup means more sugar and less molasses production. Lower purity of syrup means less sugar and more molasses production. The average purity of final molasses is 30-32. So if a syrup of 32 purity is produced (hypothetically), there will be *no* sugar, *only* molasses, but if a syrup has 100 purity, it will be *entirely* sugar with *no* molasses. The higher the purity actually is, the more sugar and less molasses are produced.

The best way to know which part of the solids present in the syrup will go to the commercial sugar and which part to the final molasses is by considering the following simple calculation, which gives the proportions:

(1) solids in sugar % solids in syrup =

$$\frac{\text{purity syrup} - \text{purity molasses}}{\text{purity sugar} - \text{purity molasses}} \times 100$$

(2) solids in final molasses % solids in syrup = 100 − solids in sugar

*Example* purity syrup = 82.00
purity sugar = 98.40
purity molasses = 33

$$\text{\% solids in sugar} = \frac{82.00 - 33.00}{98.40 - 33.00} \times 100 = 74.92\%$$

$$\text{\% solids in molasses} = 100 - 74.92 = 25.08\%$$

If the solids and the brix of both sugar and molasses are known, the physical quantities can easily be calculated.

If the normal system is that of "3 boilings", it is clear that a 2-boiling and a 4-boiling system also exist.

The 2-boiling will be applied in factories which normally have relatively low purities, while the 4-boiling (as already explained) is used in high-purity regions. Massecuite (strike or fill-mass) is indicated with letters or numbers, to indicate its sequence, for instance:

A massecuite (or first)
B massecuite (or second)
C massecuite (or third).

The latter is also called low-grade massecuite, to indicate that it is the final one. After crystallization takes place, the massecuite is composed of sugar grain and liquor.

In the cane industry, this liquor is called molasses, indicated by the same letter (or number) as the massecuite. Therefore an A massecuite is composed of A sugar and A molasses. The A molasses will produce the B massecuite, which is B sugar and B molasses. In turn, the B molasses produces the C mc (official abbreviation of massecuite) composed of C sugar and final molasses, which leaves the process as a by-product.

## Vacuum pans

A vacuum pan, being a continuation of the evaporator, is also a vessel provided with a calandria for steam heating and a condenser for vacuum. The only difference is that it is a single-effect vessel. As the constitution of material to be handled is different from that of syrup, certain constructional differences are necessary to enable the pan to cope with higher-density and more viscous materials. The vacuum pan, just like the evaporators, went through various development stages. It was invented in 1813 by Howard (see Fig. 26).

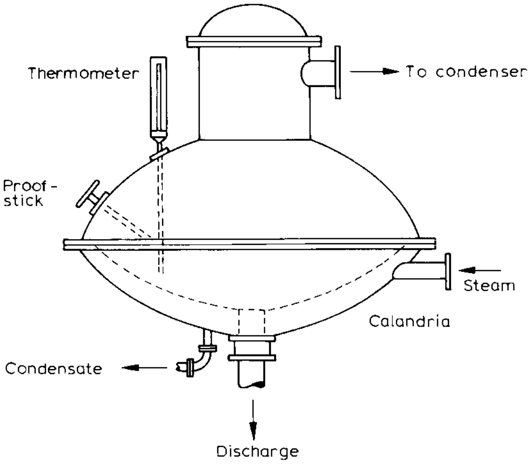

Fig. 26. Original 1813 Howard vacuum pan. For more details, see also Oliver Lyle, *Efficient Use of Steam*, H.M. Stationery Office, London, 11th imp., 1974, p.324.

In its early stage, the whole pan was made of copper in a flattened globe shape. Heating was achieved through various steam coils. As the working level slowly increased during the boiling process, steam was admitted to the coils, one after another, as soon as it became submerged by massecuite.

Although there are many mechanical variations, the main types are:

(1) coil pans

(2) calandria pans.

The coil pan has steam coils heated by live steam, because the coils with their various spirals are so long that if low-pressure steam were used, the last portion of the coils would not be heated, as all steam would have condensed before the end.

The ratio of heating surface to volume is low as the coils were normally 4″-6″ diameter. Circulation of the massecuite, however, is very good, since there is very little flow obstruction.

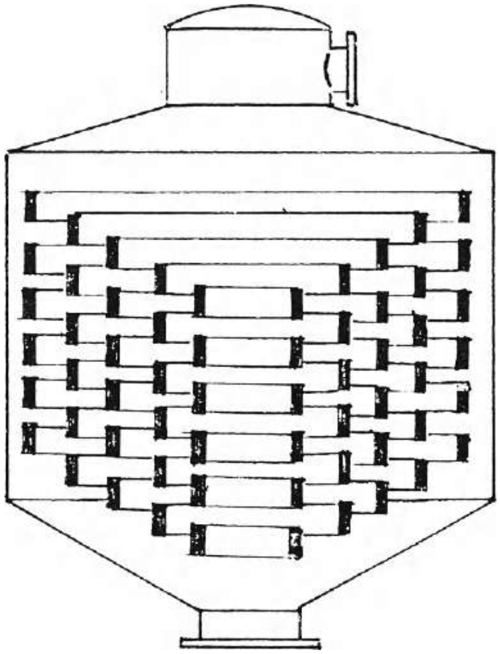

Fig. 27. Ribbon coil pan, can be used with low pressure steam.

This low ratio was the driving force for later improvements. One, for instance, was an application of flattened coils of 5″ diameter to a size of about 3″ × 6″. By arranging the coils in a series of rings instead of a continuous spiral, it was possible to use low-pressure steam. Each ring was short enough to allow the use of exhaust steam. The proportion of H.S. to volume in such pans is about 1.5 sq ft per cu ft (0.492 $m^2$/hl) (see Fig. 27).

Coil pans are no longer fabricated in the Western Hemisphere. In Europe they were maintained longer, especially in the beet industry and in far Eastern countries under European influence.

The calandria pan is the one universally used, although there are many variations such as:

(a) calandria with central downtake
(b) calandria with diametral downtake
(c) calandria with inclined tube-sheets
(d) floating calandria
(e) floating calandria with inclined tube sheets
(f) low head pans
(g) standard pan with agitator
(h) low head pan with agitator
(i) horizontal vacuum pan
(j) conical bottom (or dished)
(k) stream-flow bottom (dished).

*Note.* (See Fig. 28)
All variations have some justification, some more than others, but there are a few outstanding designs. These are a, f, g, h, j, k. Of course j and k can be combined with a, f, g, h. All others are exceptions. We shall therefore describe the standard straight pan, the low-head pan and agitators.

(a) The straight-sided pan is still the most universal. Its design is simple, and its price the lowest of all. The merit of a good design is good massecuite circulation; in other words, constant movement of massecuite from bottom to top and back. If this is not the case, the mass at the bottom overheats and becomes a dark color (inversion also). This defect was soon recognized and was the reason behind the designs f, g, h.

Firstly there are general rules, such as:

(1) tubes not smaller than 3.50″ or 4″ diameter
(2) tubes of rather short length
(3) pan diameter large
(4) working level rather low to prevent deficient circulation.

Keeping these rules in mind, it is clear why the low-head-pan design was developed. It produces the same quantity of massecuite as the conventional pan, but at a lower level, because of an increased belt diameter. Consequently, the circulation is improved and the temperature difference between top and bottom of the massecuite will be smaller. This kind of pan normally has a H.S. ratio of 2 to 1 (0.66 $m^2$/hl). Only for low grade is the ratio kept somewhat lower (about 1.4-1.6 sq. ft./cu. ft).

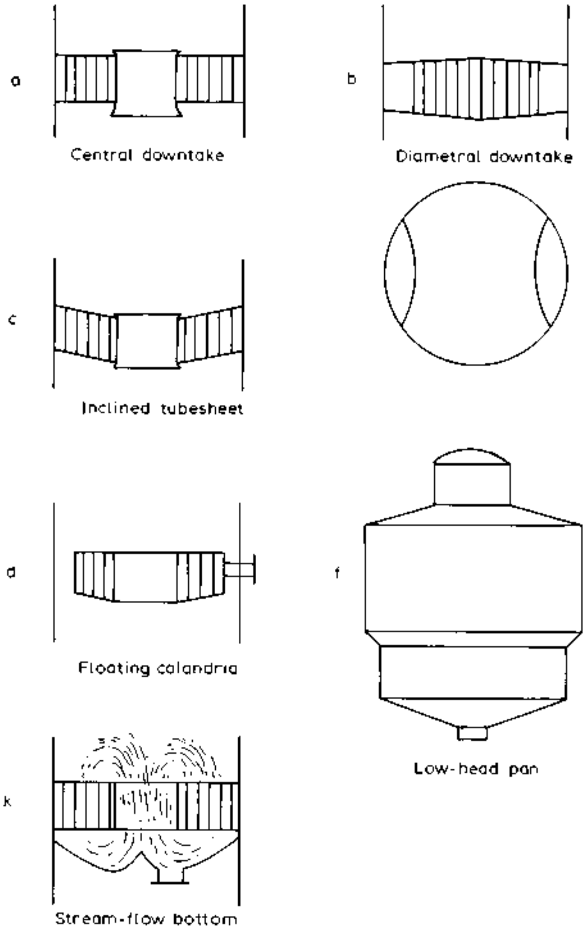

Fig. 28. Some variations of calandria and pan design.

The strike level of a low-head pan is much lower than in a straight pan. For example, a 1200 cu. ft strike made in a straight pan, assuming the calandria and bottom volume is 500 cu. ft, has 700 cu. ft above the calandria. Assume a diameter of 12′ for the calandria and 14′ for the belt.

(1) If belts were straight and 12′, the massecuite height would have been 6.2′.

(2) If belts were low-head and 14′, the massecuite height would have been 4.55′ only, or 20″ lower (50 cm), corresponding to about a 2.50″Hg higher vacuum at the bottom. The advantage is obvious: the strike duration is much shorter because the time for tightening increases rapidly at higher levels.

The hydrostatic head can be so important that the massecuite at the bottom can be undersaturated, in which case the grain dissolves again when it circulates downward. This occurs when the vacuum is high.

When sugar crystals start dissolving, the corners are the first places to disappear. Thus, if the sugar in the massecuite shows round crystals, it indicates that the vacuum is too high. A lower vacuum will result in sharp-edged crystals. This behavior was the main motive for development of the low-head pan. The grain remained sharp-edged, while the pan could work at a higher vacuum, which has the advantage of reducing the boiling time.

As circulation is required to reduce boiling time and decrease undersaturation by having a higher temperature at the bottom, mechanical circulators were added to both the straight or the low-head pan (g and h). At the same time, to reduce resistance to circulation, flow can be held at a minimum by designing a streamlined bottom as under k, together with the circulator.

As can be expected, a mechanical circulator has the best efficiency at the end of the strike, when the material is already quite heavy and natural circulation is at a minimum. At the beginning, when viscosity and density are rather low, natural circulation alone is satisfactory.

The large changes in density justify use of a 2-speed circulator, the lower speed for the highest densities. There also is a propellor of variable pitch on the market. There is one disadvantage, namely the rather high power consumption. According to Webre[2], the power to be installed must be 0.07 hp/cu.ft capacity (0.25 hp/hl) which means a 100 hp motor for a 1400 cu ft pan (400 hl). The speed for C massecuite must be about 50 rpm. Studies performed by Webre show that a circulator is easily justified. In a calandria pan of modern design, he found a massecuite velocity through the tubes of
1.53 fps during the first hour and
0.15 fps during the third hour,
reducing continuously to 0.01 after 6 hours.

Other advantages of mechanical circulation are:
(1) blending in of newly fed material
(2) a relationship between the density and electrical load on the motor
(3) circulation can be controled (rpm, pitch)
(4) temperature differences between top and bottom are lower because of fast and thorough mixing
(5) better crystal movement through the massecuite
(6) steam pressure is no longer the main source of circulation, therefore better results with low pressures
(7) improved color because of shorter residence in high-temperature zone.

If the intention is to use a pan on vapor produced by the first evaporator (or vapor cell), the heating-surface ratio must be larger than 2 to 1, preferably 2.5-3 sq ft/cu ft. If not, the circulation is insufficient, as it is directly proportional to the temperature difference between contents and heating media in the pan. At the low pressure of the vapor, the $\Delta t$ is smaller, therefore circulation is less. Mechanical-construction details make it barely possible to build pans of such a high ratio. The normal procedure in this case is to have a lower ratio, although as high as possible, and improve failing circulation by means of a mechanical circulator.

Use of vapors as a heating media in vacuum pans is always a problem
(a) for the reason mentioned above,
(b) because of heavy fluctuations in consumption, which is a constant problem as far as smooth operation of the evaporator is concerned.

It can be organized, but it requires a very able pan operator to constantly switch the right pan to vapor use and back to exhaust at the right moment.

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## CHAPTER 15

# SEEDING AND CRYSTALLIZATION

Before a choice of boiling system can be made, it is necessary first to know how the graining takes place. Most commonly used is the 3-boiling system in which A, B and C massecuites are required to exhaust the original syrup stepwise, producing sugar and final molasses. In this case, three kinds of sugar are produced, of which the A and B form the commerical product, while the low-grade (C) is too dark, small and impure to be considered a suitable commercial product.

As we shall see later, the C sugar must be small-grained to be able to exhaust the final molasses. This makes it possible to use C sugar to nucleate the commercial grain as a "seed", forming the heart of the grain on which sucrose will be deposited to make it grow to the commercial size.

We should point out here that the C-sugar grain becomes the heart of the A and B sugar, and should therefore be reasonably free from adhering final molasses; in other words, it should be purged clean.

For the purpose of this application of C sugar, it is mingled or blended with a certain amount of syrup, to bring it to a rather low massecuite density of about 90 brix, so that its movement can be handled with a pump, taking it from the centrifugals to the seed-storage crystallizer on the pan floor. The mixture is normally called magma (mingle or einwurf).

First, the size must be developed to produce the correct commercial size at the end. This cannot be done in one straight pan operation. The amount of magma going to the pan must cover the calandria completely, before steam can be admitted. This quantity is about one third of the pan capacity. Simply feeding the remaining two-thirds of the pan in the form of syrup does not result in a satisfactory grain size.

When this is complete, the pan strike (usually) must be divided in two half strikes, and each of these halves must be completed for a second time to reach its grain size. This is called "cut-over".

At the beginning of the crop, A and B massecuites must be produced, when no magma is yet available. In such a case, the grain is produced by crystallization and grown by feeding syrup to it. Because of the extremely fine grain at the start, it has to be cut-over many times, but each time the total number of grains remaining in the strike is halved. This results in large grains but in a smaller quantity. With this in mind, the original crop of grain must be abundant, to guarantee sufficient quantity, after cutting-over maybe three or four times.

Of course, the same rules of increased grain size and decreased number of grains is also valid for magma, but the number of cut-overs is fewer.

Many studies have been made in relation to crystal size and surface area and these appear in handbooks. Nevertheless, we should draw attention to important points of these studies. Thieme in Java first studied crystal volume related to dimension, as the latter is determined by the number of screen used.

$V$ = volume     $a$ = side dimension

$$V = 0.7\, a^3$$

$W$ = weight of crystal in mg, 1.59 = specific gracity

$$W = 1.59 \times 0.7a^3 = 1.11a^3$$

$f$ = surface area (mm)

$$f = 4.127\, (W^2)^{1/3}$$

The above values were used to calculate tables. The important part is to know how much the surface area increases with respect to number and size of original grain.

Table 6. Calculated weight, surface, area and volume of sugar crystals. (From E.C. Gillett, *Low Grade Sugar Crystallization,* California and Hawaiian Sugar Refining Corp. Ltd. 1948, p27-28.

| Mesh No. | Tyler opening mm $a$ | Crystal weight mg $W = 1.1a^3$ | Number of crystals per mg $1/W$ | Area mm $f = 4.127W^{2/3}$ | Volume mm $V = 0.7a^3$ | Area per mg $f/W$ |
|---|---|---|---|---|---|---|
| 16 | 0.991 | 1.08 | 0.93 | 4.34 | 0.681 | 4.02 |
| 100 | 0.147 | 0.00352 | 284 | 0.0955 | 0.00222 | 27.2 |
| 250 | 0.061 | 0.000252 | 3970 | 0.0165 | 0.000159 | 65.5 |
| 325 | 0.043 | 0.000088 | 11400 | 0.00817 | 0.0000555 | 93.0 |

We see that as the powdered sugar gets smaller, the numbers of crystals increase rapidly, just like the surface area per mg. This is important for the rapid absorption of sucrose on the surface. The surface per unit weight of grain size #325 is nearly 25 times as large as the #16. It pays to make powdered sugar as small as possible, because the sugar-absorption potential is proportional to the surface area per unit weight.

The magma grain is used as a seed for the A and B massecuite, allowing it to grow to commercial grain size by feeding sugar-rich material to it, which deposits its sugar on the seed crystals. Of course, this cannot be done in the process of making the C massecuite, the producer of magma. The grain of the magma, or the C sugar, has to be produced by crystalization.

We therefore speak of "crystallization" if grain is formed for C massecuite, and of "seeding" if magma is used for A and B massecuite. Deposits are needed both for crystallization and for magma. They are usually called seed crystallizer and magma crystallizer (receiver). A third one is also needed, containing the so-called "developed magma". This is magma after a cut-over. A pan starts with a magma footing and is completed by feeding syrup to it. When the pan is full, the grain has grown, but is still too small for commercial purpose. Half of the strike (or one third) is kept in the pan and the rest dropped into the developed-magma receiver, for later use.

The remainder in the pan is again completed and reaches commercial size, normally on the second cycle. Crystallization, which is preparation of footing for C massecuite, is done by growing grain on sugar in powder form added to a supersaturated ambient of syrup or molasses (or a mixture of both).

Until about 1930 this process was rather primitive because of lack of control media. As more and more reliable instruments became available, the process became more scientific and today is a standard procedure, giving consistently excellent results.

The original system consisted of letting the grain come by itself. Then sugar-containing liquid (mostly syrup) was concentrated to supersaturation, judged by sampling with the proof stick, until at a certain moment it appeared full of grain. The operator would then decide when enough grain was present. At that moment, new formation would be prevented by suddenly reducing the supersaturation, either by admitting water to the pan or decreasing the vacuum and closing the steam. If water was used, it would be used carefully in order not to dissolve the still very small and weak grain.

On the other hand, concentrating again could lead to a second formation of grain, this time smaller than that already grown. If this is the case, it is given the name of false grain (reproduction, secondary grain, smear). The latter name comes from the opaque color it imparts to the liquid. The skill of the operator is called on, in feeding water in the right proportion to maintain supersaturation and avoid over-concentration. Such manipulation provides the time required by the grain to move around (circulation) and pick up sucrose from the supersaturated liquid, which makes the grain grow.

Circulation is due to admitting steam to the calandria, and so it is not an easy task to keep all the required conditions proportionally within bounds: steam, circulation, water feed, supersaturation, dissolution of grain, false grain formation, constant vacuum, etc. For this reason, it was quite valid to speak of the "Art" — it really was an Art, considering that none of the operators ever knew anything about supersaturation, crystal size, etc. They only knew that the grain had to grow and that it requires time. All operations were destined to keep the mass within bounds between the devil and the deep blue sea! It was not surprising that in those old days, more than 50% of the C massecuite did not purge well, because of the presence of false grain, and even more so because centrifugals were far less efficient then than they are now. The first attempt to improve on crystallization was to "shock" the supersaturated liquid. This was done by introducing a small quantity of grain into the pan, not to add to the grain, but just to cause a "shock". It can be done at a lower supersaturation level than in the old method, having the advantage that the danger of false grain is not yet present. It takes place in the metastable zone, not in the labile zone, as is required by the "waiting" method. It is not absolutely necessary to shock with sugar grain. It can also be done by admitting air into the pan, i.e. any kind of "shock". Ultrasonic waves may be used, for instance.

The shock system was also used before instruments were introduced. The testing here was done also by sampling from the proof stick by the string test. Although the danger of false grain is lower here, it is not the only problem. Once grain is formed, there is also the danger of conglomeration. Conglomeration takes place before false grain is formed. It is known under different names, mounted grain, rolled grain, etc. It is a new irregular shape of grain, consisting of a couple of good grains grown together, approximately in the shape of a piece of rock. Once formed, it will never separate and grow as if it were a healthy grain. A conglomerate grain occludes impurities and dirt — it cannot be properly washed in the centrifugal. It is therefore a source of low purity, high color, and bad filtrability. It forms more easily in a high-purity ambient, such as pure syrup.

This is one of the reasons why crystallization for C massecuite should never be started on syrup. A mixture of syrup and A molasses at a purity of about70 is best for preventing false grain and conglomeration. At the same time, the crystallization is slower and provides a better safety margin as far as the time to grow the grain is concerned. It does not run out of control.

Irregularity of grain size can result from a number of defects, such as:

(1) fluctuation in vacuum (causing variations in temperature and therefore supersaturation)

(2) evaporating too fast, so that supersaturation increases without allowing time for sucrose deposition on grain

(3) air leakage in the pan

(4) feeding cold liquids at a lower temperature than that of the content of the pan.

All these defects can be causes of false grain formation and conglomeration under favorable conditions. After the grain has been formed, it is once again the skill of the operator to stop further formation.

## Pan-Seeding

The newest and by far the best method of grain formation is pan seeding, which is nowadays easily controled by means of instrumentation and uniformity of seeding powder to be used. The principle is to introduce to the pan, at the right point of supersaturation, a pre-determined quantity of powdered sugar. Each tiny powder grain will serve as the center of a future grain of commercial size. If this procedure is correctly controled by instruments, it is absolutely uniform in performance from strike to strike. It no longer depends on the "Art" of the operator.

## Powdered-sugar preparation

In most mills, the powder is prepared in a ball mill, in which the sugar is ground, suspended in alcohol as a carrying medium. The capacity of a ball mill is very small and it has to grind sugar 24 hours daily. The degree of grinding is very satisfactory. A hammer mill has a much larger capacity, but does not grind as finely as a ball mill.

The amount of powder required varies with individual grain size. The finer the powder, the less is needed to introduce a pre-determined quantity of grains into the pan. In any case, the quantity required is determined in practice, and once the right results have been obtained, it should not vary. Using a hammer mill, the daily requirement can be prepared in 1-2 hours. To prevent caking, it is best to grind a few grains of rice together with the sugar and store it in a glass-stoppered bottle, until it is used.

Although the quantity required increases with particle size, it is no problem to use a few pounds more for each crystallization, as the sugar is made in the mill and is not lost when used. Observed through the microscope, the ground grains have the shape of a chip of crystal, rather than the shape of a boulder. This is important, because broken grains grow much better than round-shaped dust around the sugar dryer of a refinery. This dust should never be used for seeding.

By growing the grain, the odd-shaped chips will grow first into correct crystal shapes before any other form of growth takes place. The process is much slower if amorphous dust is used and the crystal shape is never well pronounced.

## Application of powdered sugar

At the correct moment, the powder has to be injected into the pan. To make it simpler, the powder is mixed with propyl alcohol as a vehicle. Sugar is almost insoluble in alcohol. The pan must be provided with a funnel, in which the alcohol-suspended powder is poured and waits to enter the pan. It is kept suspended by means of a small electrically-driven laboratory mixer.

To enter the pan, a fast-opening valve of 1″ or 1.50″ diameter is mounted at the bottom of the funnel. As soon as the suspended powder is admitted to the pan, the valve closes to avoid admitting air into the pan, which might cause local false-grain formation. If the hammer mill is new, it is a good idea to pass a sample of its powder through a Tyler sieve to determine its average grain size.

The crystallization process is a function of many variables, but most can be eliminated with proper care. They are variations in:

(1) vacuum
(2) purity
(3) temperature
(4) supersaturation (or boiling-point rise).

(1) In practice, it is found that varying the vacuum is not easy. In most countries, the same conclusion (that keeping it constant is much more effective and easier) has been reached. The pan should have a control on the water inlet to the condenser, which opens or closes in accordance with water temperature in the tail pipe, to keep the vacuum constant.

(2) The purity of the syrup molasses mixture in which crystallization will take place must be kept constant and should not exceed 70. The most effective mixture is syrup and A molasses in the correct proportion, according to the individual purity of each component.

*Example:*

syrup = 82, A molasses = 64, mixture = 70.
quantity of syrup = $X$
$X \times 82 + (100 - X)64 = 100 \times 70$
$18X = 100(70 - 64) = 600$
$X = 33.33$
syrup = 1/3
A molasses = 2/3. Mixture will be of 70 purity.

*Note:* The purities of the syrup and A molasses and also the sugar and B molasses, must be readily available to the pan operators.
AN INTERCOM BETWEEN LABORATORY AND THE PAN FLOOR IS VITAL.

(3) If the vacuum is constant, the temperature of the massecuite will be constant if there are no large fluctuations in steam pressure.

(4) The supersaturation or boiling-point rise (bpr) must be measured by one of the many available control instruments.

Measurement consists of:

(a) brix, using a refractometer mounted on the pan

(b) bpr, using a control container of water, compared with the mass in the pan, both under same vacuum conditions

(c) direct supersaturation as a function of boiling point

(d) load of electricity (consumption of the motor) moving a mechanical circulator.

(e) electric-conductivity instrument. The conductivity of the liquid in the pan is proportional to the water content and inversely proportional to the density.

All the above-mentioned instruments indicate correctly if the purity of the pan load is kept constant. The simplest and least expensive instrument is that mentioned under (e), the so-called cuitometer. It has two electrodes inserted in the pan, either in the bottom or just above the tube-sheet. It must be supplied with a constant voltage. It therefore has a built-in voltage regulator.

The second variable is the purity, which is already kept constant. The only variable left is supersaturation. The reading can be put at any point of the scale by means of a rheostat. When the correct supersaturation is reached, it is indicated by a certain point on the scale and at this point the seed is injected. That is all there is to it. The same instrument is also used for indicating continuous feeding of the pan. In this case it is used for all three stages of the boiling system, A, B and C massecuite.

## Crystallization procedure in practice

The conditions required during the crystallization process are known basically. What needs to be established are simple instructions, easy to understand and remember, for executing the whole process without the use of complicated and time-consuming details. During normal grinding there is no time for science!

It is already clear that the variables, purity and vacuum, must be kept constant. The pan must be filled to slightly above the upper tube-sheet with the mixture of syrup and A molasses prepared to a purity of 70 (mixing has already been explained). To know the purities, the laboratory must have the latest syrup and molasses to hand, and must be in communication with the boiling house (pan operator) for this purpose. Steam is turned on and evaporation starts. After some concentration has occurred, the cuitometer is switched on. As concentration progresses, the reading of the cuitometer decreases and finally reaches the previously determined reading. At this point, the powder has to be injected.

To facilitate powder injection, the pan must be provided with an adequate funnel, say 8″ diameter × 16″ high, with a conical bottom and connected to the pan with a 1½″ (1″ on small pans) piping and a quick-opening valve. Such a valve has a spring-loaded handle for opening and is of course normally closed. Every effort must be made to prevent air from entering the pan along with the seed powder.

The powdered sugar is suspended in iso-propyl alcohol and is kept in suspension by mounting a laboratory mixer with a clamp on the funnel side. The correct mixer for this application is "Lightnin" electric laboratory stirrer, model F, variable speed 300-1600 rpm, 1/30 hp, shaft 5/16″ × 12″ with a 2″ three blade propeller, provided with tank clamp, # 19950 B of the Curtin catalogue. Just before injecting the powder, the mixer is taken away and the funnel covered with a loose lid to prevent excess air suction.

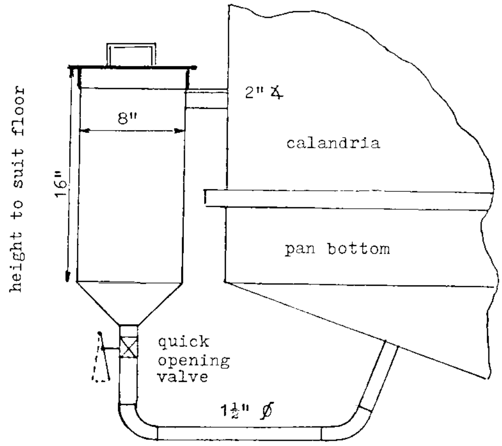

Fig. 29. Funnel on vacuum pan for seeding.

The alcohol, which carries the powder, explodes slightly on entering the pan, because of the pan vacuum and temperature. This kind of explosion carries the powder quickly throughout the whole mass. As regards the entry of the explosive mixture, the best site is at the bottom because, if connection to the vessel is above the tube-sheet, part of the grain might spout up and disappear in the vapor line to the condenser.

The suspension of powder in alcohol is normally 4-5 lb of powder per 1 gallon of alcohol (100 grams per 200 ml). In countries where alcohol is expensive and gasoline cheaper, gasoline can be used (e.g. in Venezuela).

Each factory has to determine the quantity of powder required for crystallization, since this varies from mill to mill. A good start, for instance is: 3 g per hl of final C massecuite, equivalent to 100 g for 120 cu ft. If crystallization is made for 3 strikes, the powder must be related to the total volume of 3 pan loads. Suppose the pans are 1400 cu ft, then powder required is:

$$\frac{4200}{120} \times 100 = 3500 \text{ g} = 3.5 \text{ kg} = 7.7 \text{ lb.}$$

During further concentration of the footing, the reading on the cuitometer slowly falls. If the reading reaches the point where powder should be injected (moment of seeding), the following manipulations should be executed:

(1) close off steam almost fully — just leave the valve cracked (1/4 turn)
(2) inject the powder
(3) manipulate the ''movement'' water.

Let us condsider these manipulations individually.

(1) If steam enters the calandria, it will evaporate water from the footing, thus increasing the supersaturation. At this point we do not want the supersaturation changed; on the other hand, we do need some circulation in the pan, because the grain we are about to inject must travel around to meet the sucrose present in the liquid at its supersaturation point. This sucrose deposits on the grain and causes growth. The larger the grain surface area, the easier it will be for the sucrose to find a grain surface. It eliminates the need for the sucrose to form new grain (false grain) hurriedly, because there is enough grain surface available.

(2) Just before injecting the powder suspended in alcohol (kept blended in the seed funnel), the electric mixer is removed. When the injection takes place by holding the level of the quick-opening valve in the open position, the funnel is lightly covered with a lid to prevent entry of excess air. After all seed is gone, a small amount of water (say 1 liter) is admitted through the funnel, to clean the suction pipe of remnants of seed.

(3) To maintain the required circulation, a very small amount of steam is allowed to enter the calandria (valve open only 1/4 turn), and to compensate for the unavoidable slight evaporation, a small amount of water is introduced into the pan (this is where a mechanical circulator is useful). On the feeder manifold of the pan, a 1/2″ diameter pipe is installed to allow feeding of hot water to the pan. The exact quantity must be regulated by means of a needle valve in the 1/2″ line.

The amount of water needed to compensate for the evaporation caused by the steam admitted is determined by the reading of the cuitometer. This must indicate a constant supersaturation. This hot water flowing through the 1/2″ line is called ''movement'' water (see also Honig II, p.279). Its purpose is two-fold:

(1) to compensate for evaporation caused by the steam, which is admitted to maintain circulation;

(2) to produce a secondary circulation of its own through the formation of steam bubbles rising through the mass. Movement water should be hot, because any cold material entering at this stage, will locally produce false grain.

Even after the seed has entered the pan, the grain is not yet visible with the naked eye. The supersaturation is kept at the same reading on the cuitometer by admitting or throttling off movement water. This situation is maintained for 30 minutes. If a proofstick sample is taken at the end of the 30-minute waiting time, the grain has then become clearly visible and resembles millions of tiny diamonds. Under a microscope (magnification 25 × to 40 ×), the grain shape can be investigated for uniformity, separation and freedom from conglomerates (twins). If false grain is present (smaller than the original grain) — hence the name ''secondary grain'' — it should be eliminated now by washing. If it is very bad, the whole batch should be dissolved and crystallization restarted. This is better than trying to continue with a bad footing. False grain will form only if a fault has occurred, perhaps with the vacuum or the steam, etc. If the process is well managed, there cannot be any false grain.

After the half-hour growing time and visual inspection of the grain, it is time to exhaust the surrounding liquid in the pan even further. If this liquid is kept too rich in sucrose, the danger of later formation of conglomerates and false grain is high.

There are two main components of the crystallization process: time and sucrose deposit. These two factors must be kept in equilibrium. Deposition of sucrose on the surface of the existing grain takes time and if time threatens to be too short it must be prolonged by adding a small amount of water. It can be observed by testing the liquid (from the proofstick). If it is still very sticky, it has excess of free sucrose, in Spanish called ''sobrante''.

The first step after the waiting time is to open up the steam just a little. Now, using the large water valve of the pan, give the strike a moderate ''drink'' of water for time prolongation. Follow the reading on the cuitometer and go to a moderate higher number, which corresponds to a lower brix. Suppose seeding took place at 30, then water to about 55-60 will be correct. After closing off the water at that point, the brix increases slowly and the reading decreases. Go back to a seeding point of about 30.

Now ''open up'' the strike again with a second drink of water, this time going a little higher than before, say 80. Again concentrate to slightly above the seeding reading, perhaps 40. At this point, take a proofstick sample to test the exhaustion of the liquid. After most of its sucrose has been lost to the grain, it feels thinner and less viscous. If this is the case, open up more steam and start feeding A molasses to the footing. By now, the amount of grain must be very abundant and very small. This is to secure a maximum of crystal surface, which ensures de-sugarizing of the liquid and the least risk of false grain and conglomerates.

When the pan is full it will contain a footing for three consecutive C strikes. One third is kept in the pan for the first of the three strikes, while two-thirds are discharged into the seed crystallizer (receiver), for future use. The original footing had a purity of 70 (mixing, in our example, one-third syrup of 82 with two-thirds A molasses of 64 purity). After the pan is completed with A molasses, we have a complete footing for C massecuite of about 66 purity. To make a C massecuite, the footing for it will be one-third of the above complete seed, completed with two-thirds of the pan capacity of B molasses.

Assuming that the B molasses has 54 purity, we have

$$0.33 \times 66 + 0.67 \times 54 = 57.96$$

about 58 purity of the finished C massecuite. An indicating cuitometer is sufficient, but if required a recorder can be connected to it and a strip chart record of each strike can be obtained.

When feeding first A molasses and later B molasses to the seed footing, the strike should never be fed "open", it must always be kept "tight". Opening up brings the risk of false grain formation at the moment of re-tightening, because of loss of equilibrium of factors: density and time. Keeping the mass tight is very easily done on the cuitometer. Once the pan is full, the final tightening takes less time and is without danger of false grain, because through keeping the strike tight at all times, the liquor is well exhausted.

## Quality of C sugar as magma

The C sugar is mainly used as footing for commercial A and B products. It is very important that it be as pure as practically possible, since it forms the heart of each individual commercial sugar grain. Moreover, the impurity of the C sugar is the lowest possible product, namely final molasses. To illustrate the influence of the final molasses recirculation in the C sugar, let us work out two examples, one a clean and one a less clean C sugar.

Assume that the theoretical best C sugar quality is:
pol = 97, moisture = 1%, purity = 98
Compare with a good C sugar of:
pol = 92, moisture = 1½%, purity = 93.40
and a poorer quality C sugar of:
pol = 86.25, moisture = 2%, purity = 88,
both with a purity of final molasses = 33.

Then:

$$\%\text{ final molasses in good C sugar} = x \times 33 + (100 - x)\,98 = 100 \times 93.40$$

$$x = 7.08\% \qquad \text{and}$$

$$\%\text{ final molasses in lower C sugar} = x \times 33 + (100 - x)\,98 = 100 \times 88$$

$$x = 15.38\%$$

If purity of C sugar is 5.40 lower, then the recirculated final molasses is more than double the amount. The result is that the quality and the polarization of the commercial sugar is much less when the lower quality C sugar is used as a footing. This point was emphasized, because *it is absolutely vital to produce the best possible C sugar, as it is the main component of a good quality product.* Moreover, recirculation of a waste product in larger proportions also causes increase in viscosity, color and formation of molasses (melassigenic). Later we shall see what can be done in the centrifugal station to optimize elimination of molasses recirculation.

## Recirculation

As a general rule, recirculation of any molasses, whether A, B, or final molasses, into its own or previous massecuite is detrimental and should always be prevented. The process is to make sugar from sugar cane by a straightforward series of procedures. Anything flowing against the forward direction is a retrograde step. Sometimes it cannot be avoided; for instance, the return of the filter juice to the limed juice. For this reason, many schemes for cleaning the filter juice have been introduced, to avoid returning it to an earlier stage of the process. Some slight recirculation of final molasses carried back with the C sugar cannot be prevented, but it must be kept to an absolute minimum.

From the above, the importance of the C massecuite boilings can be seen. If they are made properly, the production of the highest quality commercial sugar as well as the best possible exhaustion of the final molasses is guaranteed.

## Boiling systems

The choice of the boiling system to be adopted by a certain mill depends mainly on:

(1) the initial purity of the syrup
(2) the purity drops between the various massecuites and their molasses.

(1) If the syrup purity is high, many steps are required to gradually reach the final molasses purity. As a rule, it can be said that:

syrup purities up to 78 allow a 2-boiling system
syrup purities up to 86 allow a 3-boiling system
syrup purities above 86 require a 4-boiling system.

(2) The purity drop can be improved in various ways:

(a) Provide more crystal area, by making the grain somewhat smaller and more abundant (better deposit of sucrose).

(b) provide forced cooling of massecuite after discharging from the pan and before purging, to increase supersaturation and deposition of sucrose on the grain. Forced cooling is mandatory in the 2-boiling system.

(c) Increase the brix of the finished massecuite.

To demonstrate the difference between a good and a bad purity drop of a massecuite, assume the following data:

| | |
|---|---|
| massecuite purity | 82 |
| sugar purity | 98.50 |
| bad purity drop | 15 |
| good purity drop | 20 |
| brix massecuite | 92 |

$$\textit{bad case:}\quad \%\ \text{crystal yield} = \frac{82 - (82 - 15)}{98.50 - (82 - 15)} \times 92 = 43.81\%$$

$$\textit{good case:}\quad \%\ \text{crystal yield} = \frac{82 - (82 - 20)}{98.50 - (82 - 20)} \times 92 = 50.41\%$$

This means that the good purity drop contains about 7% more grain, which is recovered from the sucrose in the molasses. In other words, the molasses is exhausted better and less has to be done in the next boiling step.

The physical conditions of the boiling house should be such that a high final brix will still enable the discharge of the massecuite in a reasonable time: enough gravity flow should be provided by means of reasonable height of the pan floor above ground level.

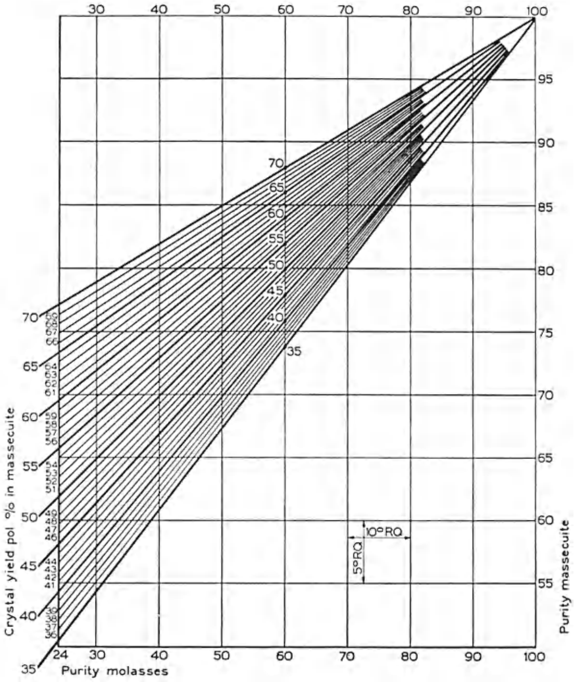

Fig. 30. Crystal yield as a relation of the purity drop of a massecuite. (From Honig, Vol. II, p.279)

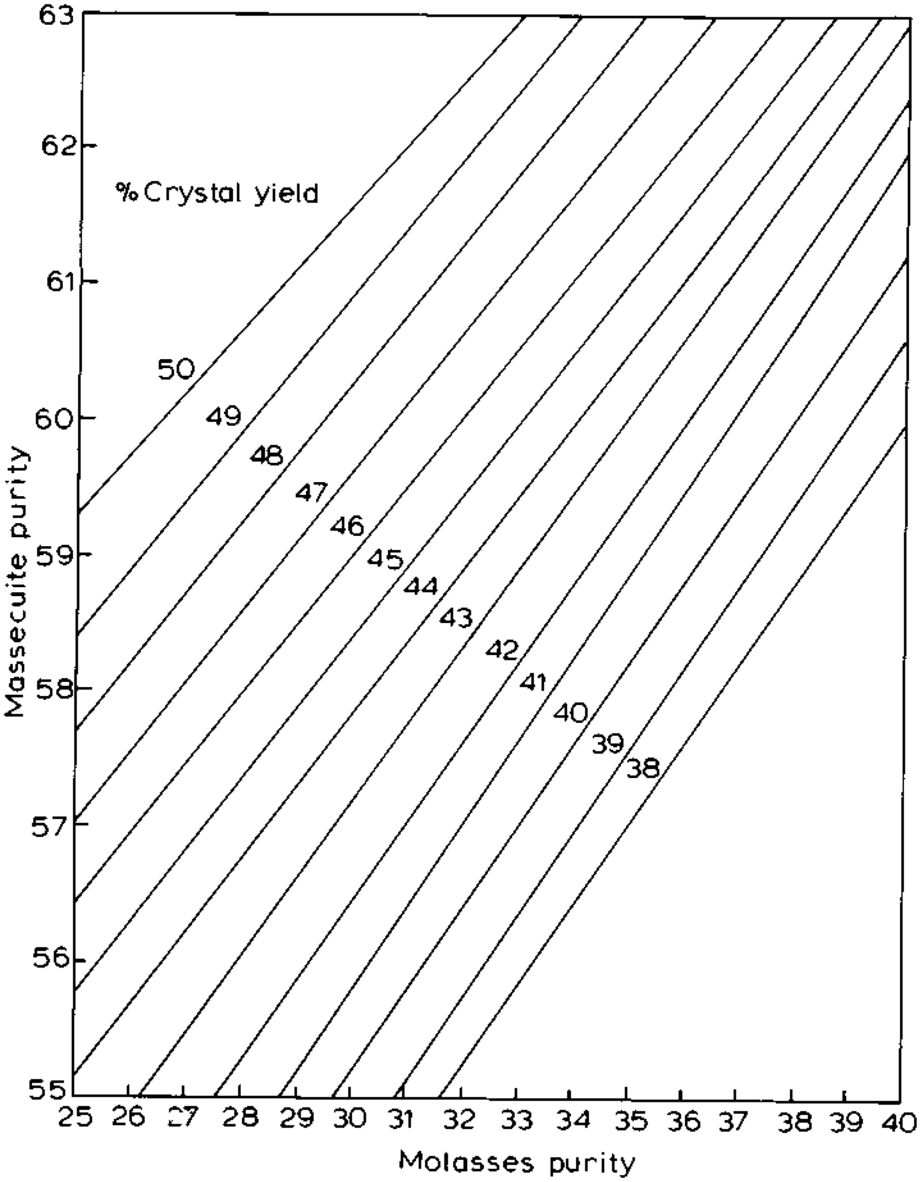

Fig. 31. Enlarged portion of Fig. 30 for purities of C massecuite. (From Honig, Vol. II, p.326)

CHAPTER 16

# TWO-BOILING SYSTEM

Although the system is old, its application in a modern way is rather new, say about twenty years old. This is due to the effective new ways of cooling massecuite, which is an integral part of the system and has improved much, together with the instrumentation of the crystallization procedure. The 2-boiling system is mainly applied in mills where syrup purity is under 80. It has advantages, such as:

reduced steam consumption

20% less pan capacity required

improved sugar quality, because B sugar does not exist — all commercial sugar is A sugar.

It should therefore be considered in mills with steam deficiency and shortage of pan capacity.

If in such mills the syrup purity is over 80, then some sacrifice should be considered, such as increased sucrose losses in final molasses and recirculation of A molasses in the A strikes. This depends on which is less desirable, steam and pan shortage, or increased sucrose losses.

The A massecuite is produced by using about 20% by weight of C magma and 80% of syrup. This proportion results in the correct size of the grain. After discharging the A massecuite into the crystallizer, it must be cooled for a short time. The crystallizer, of course, is provided with one of the many systems of water-cooling elements, but preferably it should be a continuous rapid-cooling type, such as the Werkspoor.

A purity drop of about 20 points or more can be expected; in other words, if the A massecuite has a maximum purity of 80, the molasses from it can be expected to have a maximum of 60 purity. The material which the crystallization of the C massecuite comprises must in this system be pure A molasses (not mixed with syrup to 70 purity). Only the required amount of powder is added to it. This means that the C massecuite purity is the same as the A molasses purity.

It is proven that the grain made in A molasses alone as footing is purer than that made in an ambient of higher purity (or a mixture of A molasses and syrup). This is probably due to the slower growing of the grain in a low purity ambient.[1]

## REFERENCES

P. Honig, *Principles of Sugar Technology,* Vol. II, Elsevier, Amsterdam 1959, p.220.

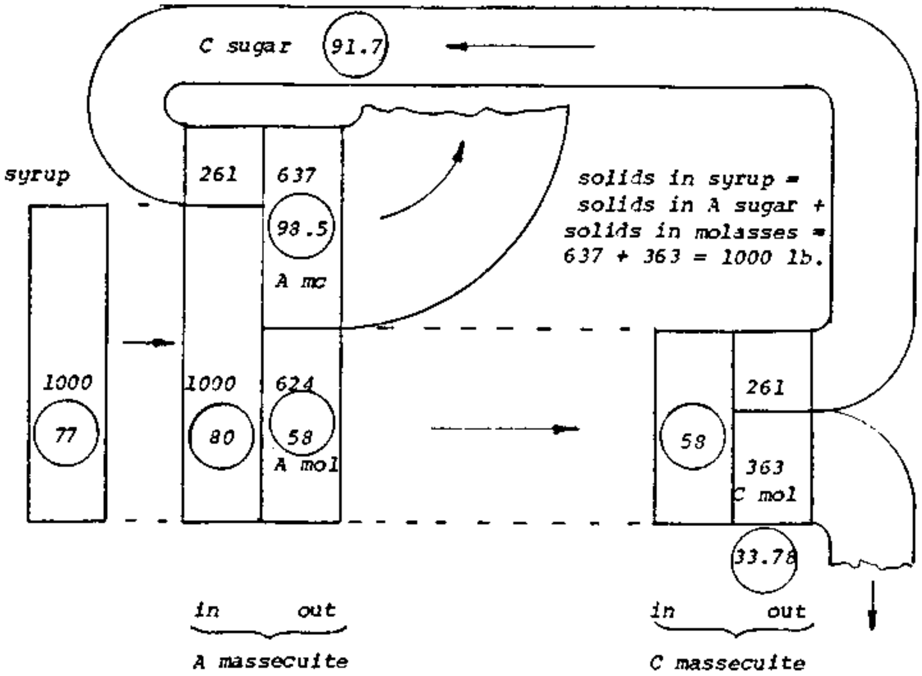

Fig. 32. Typical solids flow diagram for a 2-boiling system. In circles are the purities, quantities in pounds.

CHAPTER 17

# THREE-BOILING SYSTEM

The 3-boiling system employs the A and B massecuites as commercial sugar producers, while the C massecuite produces the seed for the A and B strikes and the final molasses. This system was introduced in Java in 1910 by Pasma.[1] When first used, it became clear that the C sugar needed two steps for development to commercial size. It therefore required a receiver (crystallizer) for developed magma, for storage for future use. This system can be applied safely if syrup purity is up to 85. Above this value it becomes necessary to have cooling elements in all A and B crystallizers, to increase the purity drop as much as possible.

In extreme cases, when the purity of the syrup exceeds 90, only the 4-boiling system is possible, since in such a case four steps are necessary to reduce from over 90 to about 30-33 purity of the final molasses. This can be the case where C sugar is remelted and not used as seed for the A and B strikes. The purity of such melt is 86 or higher. As we see, it can tip the balance between applying the 3- or the 4-boiling system. If the carbonatation process is applied, the 4-boiling system is mandatory, because of higher purities throughout.

We show a flow diagram (Fig. 33) of a 3-boiling system having rapid-cooling crystallizers for A and B massecuites, and all C sugar is melted and added to the syrup. Initial purity is 84.3.

## REFERENCES

1. P. Honig, *Principles of Sugar Technology*, Vol. II, Elsevier, Amsterdam 1959, p.328.

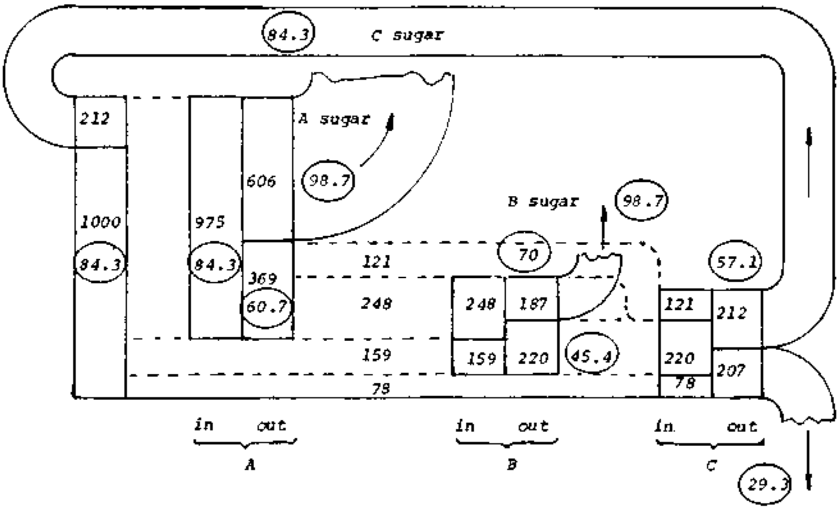

Fig. 33. Solids flow diagram for a 3-boiling system, dissolving all C sugar and rapid-cooling crystallizers for A and B massecuites. Quantities for this diagram were derived from Honig, Vol. III, p.482.

## CHAPTER 18

# HANDLING OF A AND B MOLASSES

The A and B molasses as delivered by the centrifugals cannot be used as feed to the pans without prior preparation. It comes from the centrifugals at about 88 brix and is probably contaminated with small grain, which passed through the screen and through holes in the screen. Some small grain (former false grain, but increased in size) is unavoidable and is present even if the strikes are prepared with the utmost care. Also, on cooling, new false grain can be formed in the tanks.

To enable the pan operator to use the molasses and be sure that all small grain is dissolved, the crude molasses should be:

(1) diluted to 70 brix, when most of the grain will dissolve

(2) heated to a temperature slightly superior to the temperature of the material in the pan (about 140 °F, 60 °C). All of the remaining small grain will be eliminated. At the same time, the feed to the pan, having the same temperature, will not produce a shock in the supersaturated content of the pan and will not cause new formation of false grain.

For dilution of the molasses, contaminated condensate should be used exclusively. This is the condensate from heaters and vacuum vessels of the evaporator. It is normally used as the general hot-water supply. The dilution should be combined with heating and mixing to be most effective and, of course, should be automatic. A reliable system is shown in Fig. 34 and can be described as follows. The receiving tank under the centrifugals is provided with a scale consisting of two small tanks. One is continuously filled with the molasses sample from the pressure line of the pump, the other has a tare consisting of loose bolts and nuts. The sample volume is about one gallon (9-11 lb). The sample overflows continuously into the tank.

In addition to this scale, the tank has a level control and a steam heater working on a thermostat. By initially filling the sample tank of 1 gln the density of the molasses is still too high, dilution is still required. The sample is heavier than the counterweight, the beam trips and the sample is lower. In this position it opens the counter-balanced water valve which admits hot condensate to the tank.

Another system is dilution by timer, such as those incorporated in Western-States centrifugals. This system, like any other, requires intense mixing of water and molasses. The correct dilution of molasses, together with proper heating and mixing is a procedure seriously overlooked in most mills. Nevertheless, it is of utmost importance for efficient boiling-house operation.

It is surprising that in many mills, small but important details are lacking, especially in the boiling house. It shows that the technique of boiling is not well understood, and most of the blame lies with the operators themselves, since for years they have been unwilling to train or teach people. They claim that their work is an art, and, strangely, this attitude is worldwide. In Java, for instance, sugar boilers were Chinese, simply because a Chinese is considered to be more of an "artisan". The "art" disappeared when instrumentation took over, but outsiders were still under the spell of the "art". Of course, sugar boiling is still one of the more sophisticated skills in the sugar industry, and even more so if the mill has to produce specialty sugars, such as extra large grain, special colors, fondant, etc.

Storage of A and B molasses, together with syrup storage in the vacuum pan supply tanks located on the pan-floor, has always been a problem, because of the tremendous weight and space required. There are many advantages in having the pan-floor at a high level of about 60′ above the main floor, but the load of the storage tanks is one of the limiting factors.

Recently, outside tanks have been used to store A and B molasses, while on the pan-floor there are only three tanks, one for A, one for B, and one for syrup. The outside tank has a high-capacity pump controled by the level of the pan-floor tank. Thus, the supply tank is always full. It is provided with a heater to maintain the molasses at 140°. The outside tank is of the same type as the final molasses storage tank: round, sloping roof, level indicator (pneumercator), and is insulated to prevent heat losses. This solution has many advantages, especially in countries where earthquakes frequently occur. In these countries, gravity installations are limited, because of excessive structural requirements and subsequent danger. The steam heater starts working and keeps the liquid in circulation. (A noiseless Schutte and Koerting steam jet heater is the right type for this application, see Schutte and Koerting, Fig. 301 of Bulletin 3A, sizes from 1/2″ to 4″.)

At the same time as it heats, it mixes the water and molasses vigorously. When the pump starts receiving diluted molasses, the brix decreases, the weight decreases, and the scale balances, closing or throttling the water supply to the tank.

In actual practice, in a mill in Peru, the brix of the molasses was maintained at 70-72 brix without failure and without supervision.

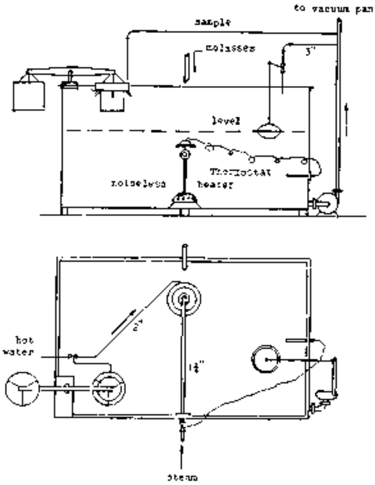

Fig. 34. Automatic molasses dilution and heating device.

## CHAPTER 19

# DOUBLE MAGMA, COMPLETE CRYSTALLIZATION, ETC.

In some countries and in individual mills, the double magma system is used. It originates from the bad influence which B sugar has on the overall quality of the commercial product. This was especially true in the past, because now-a-days centrifugal efficiency is so improved that there is no reason why B sugar should have much less quality than A sugar. Of course, the intrinsic qualities are less, such as ash content, but color and pol can be equal to A sugar.

In years past, the way to eliminate the B sugar in mills having too high a purity for a two-boiling system was to use the C sugar as seed for the B massecuite and the B sugar as seed for the A massecuite. It should be remembered that such a system requires extra pan capacity, and of course, more steam.

Excess C sugar as well as excess B sugar, left over after use as seed, must be melted and returned to the process. The problem is to do this in a continuous, automatic way, otherwise it requires an attendant full-time, i.e. a man in three shifts. First, it should be decided where the excess magma is going: either to clarified juice before evaporation, or to syrup in the pan supply tanks. The advantage of returning it to clarified juice is that dissolving is faster and easier, because of the low brix of the juice. It does not do any harm to evaporation: on the contrary, it increases the intitial brix and actually reduces evaporation requirement.

*Example:* (quantity exaggerated)

Assume clarified juice 1000 lb of 15 brix has 150 lb solids;
syrup of 60 brix = 250 lb of 150 lb solids;
evaporation is 1000 − 250 = 750 lb.

Return 100 lb C sugar: 100 lb = 98 lb solids plus
1000 lb juice 150 lb solids giving
1100 lb mixture having 248 lb solids of which

$$\text{brix} = \frac{248}{110} \times 100 = 22.55 \text{ brix}$$

$$\text{corresponding to } \frac{248}{60} \times 100 = 413 \text{ lb syrup}$$

made from 1100 lb mixture.
evaporation = 1100 − 413 = 687 lb from 1100 lb

$$\text{corresponding to } \frac{687}{1100} \times 1000 = 624.5 \text{ lb evaporation per}$$

1000 lb.

To free the return of magma from supervision, we proceed as follows: A large overflow is provided in the magma crystallizer. If the level exceeds the overflow level, it is collected in a vertical cylindrical tank installed right under the overflow. A good size tank for this purpose is 8′ diameter × 6′ high, (300 cu ft = 2250 gln = 8.5 hl). It is provided with a mixer and a level control, as well as a clarified juice and a syrup supply. At a certain level again it can overflow to the clarified juice tank (by gravity). If it has to be sent to syrup supply, it must be pumped.

In case all C sugar is melted, all footings must be crystallized as if it were C massecuite. This has to be done during the first days of the crop, because of lack of magma, with the difference that the footing, unlike the C massecuite case, is done in syrup, not in a 70-purity liquid.

## Cut-over

All pans are interconnected through the cut-over piping. Diameter is 8″ or 10″, depending on pan size. By means of this system, any pan of the set can cut part of the content to any other pan. Besides, it also serves as a suction line for magma, developed magma or crystallization seed to any of the pans. The cut-over pipe is right under the pans and each pan or receiver is connected to it through a valve.

Always after the cut-over has been used, it must be cleaned with low-pressure steam (exhaust) to prevent mixing of material left over in it. The condensed cleaning-out steam can return to raw juice, or have a special small receiving tank or, normally the case, return to the C magma mixer under the centrifugals. It should certainly not go to the A and B crystallizer, because of bad color and mixed grain sizes.

Cutting-over is regulated by the vacuum in the pans; in other words, if we wish to cut-over half a pan load from pan 1 to pan 2, then vacuum is raised in the empty pan 2 and partly broken in the full pan 1. If the pan has to discharge to the magma receivers, vacuum must be broken entirely. Return of receiver content to a pan is also a vacuum operation.

*Note:* The steam used for steaming-out should always be of low pressure, either exhaust steam or *reduced* live steam, because the action is "washing" not "pushing" the condensate of the steam does the job. If reduced live steam is used, it is to make it possible to pass more lb/h than by using exhaust. Normally, the individual steam-out piping is 3/4″ or 1″ at most. Steam-out piping must be insulated to guard against accidental touching.

CHAPTER 20

# MOLASSES CENTRIFUGATION

Whichever boiling system is applied makes no difference to the fact that all impurities (non-sugars) are directed toward the final molasses in which they will be expelled from the process. This means that they are physically present in the A molasses, later in the B molasses, and finally in the final molasses, where they belong. The concentration increases because the purity (sugar) decreases, and gradually they represent a higher percentage of the total weight.

If it were possible to separate some of the impurities in the earlier stages, such as A or B molasses, it would alleviate much of the low-grade work and would produce an improvement in C sugar quality and better efficiency of the C centrifugals. It is logical to try elimination in the smallest quantity of material, having the highest concentration of non-sugars, before reaching the low-grade production. Obviously this is B molasses.

Elimination of suspended and insoluble solids in the B molasses can be performed by means of high-speed centrifuges. This equipment should not be mistakenly called a centrifugal, which is a different apparatus. A high-speed centrifuge is like a medical centrifuge and those used to separate bacteria. It has a speed of up to 60,000 rpm and separation is by means of centrifugal force on materials of different specific gravity. At 20,000 rpm this gravity is multiplied to about 13000 × gravity, in the laboratory model.

There are a few manufacturers of this kind of equipment. The best known are Alpha Laval, Titan of Westfalia, and Sharpless. All work on a time cycle. After a predetermined time, the feed is turned off, the bowls open slightly and a water jet washes out the accumulated solids. They close again and feed is turned on. Some prefer to use them on A molasses, although the quantity is much greater, but the viscosity is lower than that of B molasses, so that through-put is increased.

In any case, whatever the material, the idea is to eliminate non-sugars before they reach the C massecuite. The results are better C sugar and less molasses, less viscous magma in A and B massecuite as a footing, better commercial sugar quality.

The centrifuge can be used for two purposes:

(1) separation of solids from slurry
(2) clarification of liquids, eliminating solids.

They are rather expensive pieces of equipment, but at the same time very efficient. The principle is as shown in Fig. 35.

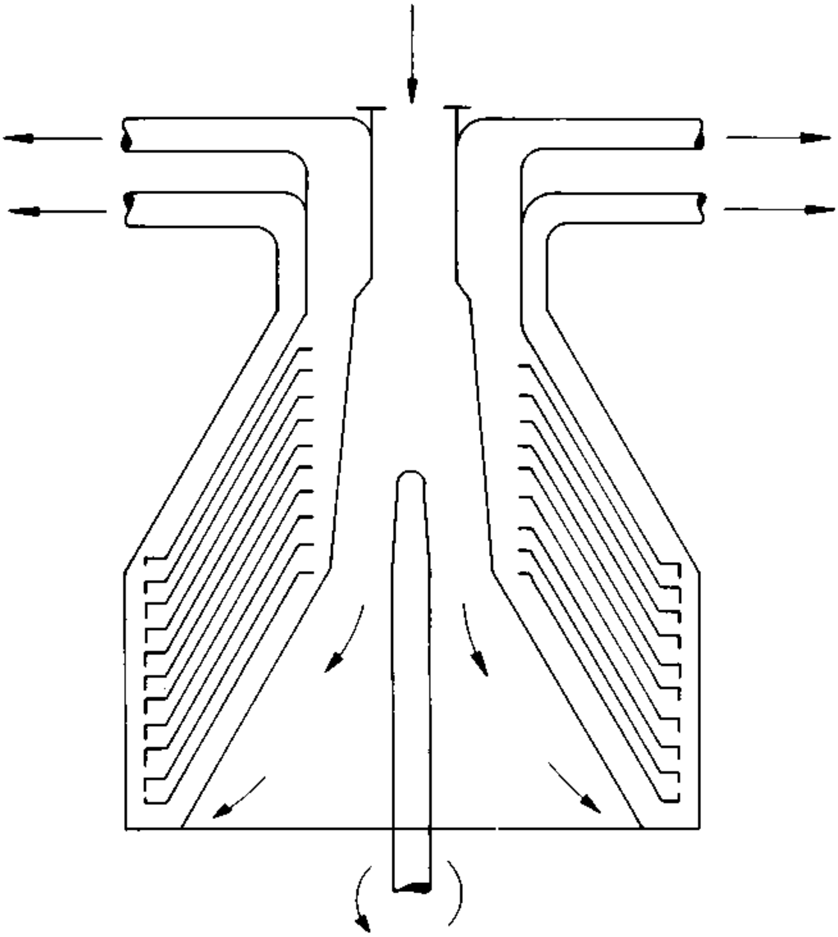

Fig. 35. Principle of separation by gravity in a high-speed centrifuge.

## CHAPTER 21

# CRYSTALLIZERS

In a low-purity ambient, such as C massecuite, the deposition of sucrose on the existing grain is very slow. It is dependent on both supersaturation and time. Cooling takes place and supersaturation increases at lower temperature, but also the viscosity increases. This makes separation of grain and molasses in the centrifugals more difficult and incomplete. The solution is last-minute reheating to reduce viscosity.

Originally, crystallizers were long horizontal vessels, either round or U-shaped (also V-shaped) in which the massecuite cooled slowly. In tropical countries this kind of cooling could normally last 80 or more hours, even up to 240 hours. The result was that the number of crystallizers used to be very large, occupying a long area under the pan-floor. The problem was that normally one (or two) pans were used for C massecuite and long inclined canals were required to run the discharged mass to any of the crystallizers. In order to give such a long trough sufficient inclination to enable the mass to flow, considerable height was necessary between the pan bottom and the crystallizer top. If this was not possible to arrange, the massecuite had to be pumped, although pumping massecuite should be considered an emergency operation.

The equipment described was rather deficient, because in most mills the brix of the C massecuite was kept low for the purpose of adequate flow condition. A low final brix of C massecuite is a sure cause of high sucrose losses in final molasses, because of lower crystal yield.

Therefore, technical progress was then aimed at:

(1) reducing the number of crystallizers (shorter overall length of the combination);

(2) increasing the height of the pan-floor to obtain better discharge inclination;

(3) finding better ways to more efficient cooling, which is basically the same as (1);

(4) if pumps had to be used, taking a positive-displacement type that does the least damage to the grain.

With these improvements in mind, let us follow the chronological development of solving the problems.

Around 1925, many types of cooling provisions flooded the market. The earliest types (even used before 1925) were the round crystallizers provided with outside spray piping to cool the body plate itself from the outside. The next development was stationary interior piping with cold water flowing in and heated water flowing out (such as Kopke, Volkert, etc.). Then followed many kinds of rotating cooling elements. For this kind, the shaft had to be hollow (pipe) and be used as the header for the water supply and discharge. (Various systems used were Ragot, Karlik, Herrison, Blanchard, Turl, etc.) Most widely used is the Blanchard, of rather simple construction. The best innovation is of course, the continuous type of crystallizer such as Werkspoor or Stearns Roger. For instance, for a 5000 tcd factory, two of these crystallizers are sufficient to handle all C massecuite.

In most new factories, the pan-floor is about 60′ above ground level. This gives enough vertical space to allow a massecuite receiver under the pan and above the crystallizers. Then, there is enough space under the crystallizers to install the centrifugals.

Most mills of inadequate height were found in countries where earthquakes are frequent. However, construction materials and designs have changed so much that gravity construction of a 60′ high pan-floor is no longer an objection to earthquake safety. Nevertheless, wherever the pan-floor height can be reduced without creating problems to the process requirements it is highly recommendable.

For this reason, inclined canal troughs are no longer used to discharge massecuite from the pans, because:

(a) it is difficult to prevent overflowing

(b) a reasonable inclination is always needed to maintain acceptable flow velocities.

Discharge of the pans to the crystallizers is now exclusively done by means of pipelines and guillotine-type valves (also called knife valves) operated from the pan-floor by either a hydraulic or air control. The reduction in height achieved using this system is appreciable.

A second reduction is to substitute all old-fashioned, enormous pan-discharge valves by knife valves for vacuum service. The latter kind are less than 3″ wide, while many old discharge valves were from 2′-3′wide. The use of pipe-line discharge makes spilling impossible and the pan contents can be unloaded in less time and with heavier density, because the hydrostatic column of the pan volume is used to help push the massecuite out. This is not the case when canals are used and flow is regulated by throttling the discharge valve.

## Crystallizer purpose

After the strike has been discharged into a crystallizer, the purpose is to cool. This means an increase of supersaturation and prolonged sucrose deposition on the existing grain. This causes a larger purity drop (purity massecuite − purity molasses), and consequently a larger crystal yield and less molasses. The limit is when the viscosity increases so much because of the lower temperature that grain growing is barely possible.

In practice, the temperature limit is about 40°-45 °C. The more efficient the heat transmission of the cooling elements, the sooner the temperature limit is reached. The continuous Werkspoor crystallizer has the highest heat transmission. Cooling for about 13 hours is more or less correct for this type. Blanchard-type elements can cool efficiently in 18-24 hours. The heat-transfer coefficient is proportional to the rpm of the elements. The speed of rotation should never exceed 1 rpm. Normally 1/2 rpm is used. Using this rate the heat-transfer coefficient of a Werkspoor crystallizer is

7-10 btu/sq ft/°F/h = 34-40 cal/$m^2$/°C/h.

and for a Blanchard about

2.5 btu/sq ft/°F/h = 12 cal/$m^2$/°C/h.

**Cooling water required**

The amount of cooling water required can, for all practical purposes, be considered to be 1 cu ft per cu ft of massecuite.

Assume 1400 cu ft of massecuite requires 1400 cu ft of water in, say, 18 hours, or:

$$\frac{1400 \times 7.48}{18 \times 60} = 10\,\text{gpm}$$

for each crystallizer. Massecuites of higher purity require much less time for cooling than the C massecuite. Normally, the time elapsed from discharging an A massecuite in a crystallizer and running it through the mixer of the centrifugals, will be sufficient for reasonable cooling. However, if the crystallizer is provided with cooling elements, the purity-drop increase will be about 5 points for A massecuite and 4 points for B massecuite.

In other words, if A massecuite had a normal purity drop of about 18, it will increase to 23. If massecuite purity is 80 and cooling elements are provided, the molasses will have a purity of about 57. The increase in commercial sugar will be appreciable and the amount of molasses to be re-boiled will decrease by the amount the sugar gains.

In recent years, nearly all centrifugals for C massecuite are continuous and it is only logical to make the cooling in crystallizers continuous also. Most sugar mills which already have many C crystallizers have modified the arrangement and are using the original equipment as a continuous single unit of cooling.

The original arrangement as in Fig. 36 A, was changed to a continuous complex as in Fig. 36 B.

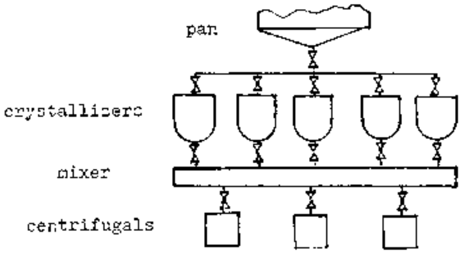

Fig. 36A. Individual C crystallizers. Original arrangement.

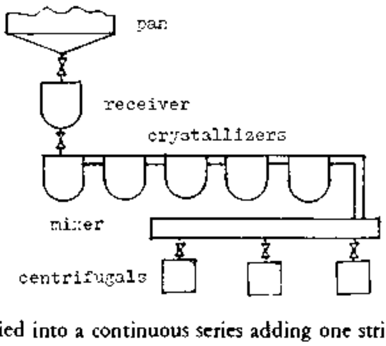

Fig. 36B. The same, modified into a continuous series adding one strike receiver.

To avoid short circuit in the continuous arrangement, a baffle is placed half-way in the crystallizer's upper portion to force the massecuite to dip under it and emerge again. The advantage of the continuous set-up is that all units are full, while in the batch arrangement one must be empty to receive the new strike, and one is being discharged, a discount of two units.

In set-up B, all units are on cold-water cooling, while the last one works on hot water to reheat before going to the mixer in which the final reheating takes place by means of the Steven's coil (see later). Cooling from about 70° to 40 °C is considered sufficient, with reheating to 50°-51 °C to reduce viscosity and obtain cleaner separation of grain and molasses. Cooling below 40 °C does not justify the long extra time involved, because exhaustion below 40 °C is too slow.

### Water circulation

The water used for circulation in the cooling system should be treated water; otherwise, the system will scale and cooling will be inadequate. The only way to treat this water is to use it in closed circuit, to prevent disinfectant loss. This water together with the cooling water of mill bearings, pump circulation, etc., belongs to the "closed-circuit cooling water", which has its own cooling tower. It amounts to about 200-300 gpm. The only attention of the crystallizer, besides the normal mechanical attention such as oil, grease, etc., is to see that no water leaks into the massecuite.

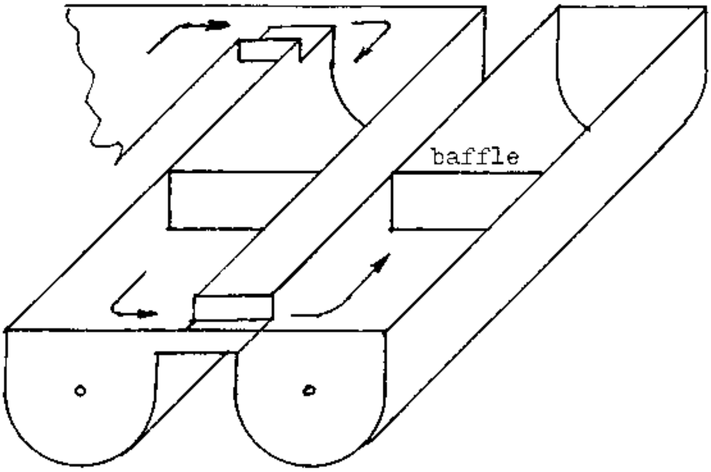

Fig. 37. Detail of continuous overflow arrangement of crystallizers.

## Massecuite dilution or reheating

After the massecuite has cooled to about 40 °C, it is normally too viscous to be efficiently purged. Viscosity doubles with every temperature reduction of about 10 °C. Reducing viscosity can be done by either:

(1) diluting with water or diluted molasses, or

(2) reheating for a short time, prior to purging (see Hugot, p.279)[2]

(1) If water is used to dilute, then theoretically the water starts diluting the molasses, and when the molasses is still undersaturated, it starts re-dissolving sugar from the grain. It is clear that, if only the correct amount of water is added, no damage will be done. But the important question is: whose responsibility will it be to measure first the water and then add it slowly, so that there will never be any local excess? It is also clear that this system is bound to get out of hand, and all the care given to the massecuite in the pan will be lost in an unguarded moment. So there is one golden rule: NO WATER WHATSOEVER IN CRYSTALLIZERS.

This was known long ago, and for this reason molasses was diluted to about 30 brix in dosification tanks and added slowly. But the same question of who is responsible is again relevant, because the mill is grinding, everyone is busy, and no one can be spared simply to supervise the addition of molasses to the crystallizers.

(2) The solution we are left with is: reheating. Basically, the effect is the same as dilution, but it is less sudden and much easier to control. Even accidental loss of control is drastically reduced. Besides, reheating is easily cut-off at the right moment.

Figure 38 shows a graph of viscosity against temperature for molasses. It shows that in general terms the viscosity doubles when the temperature is reduced by about 10 °C.

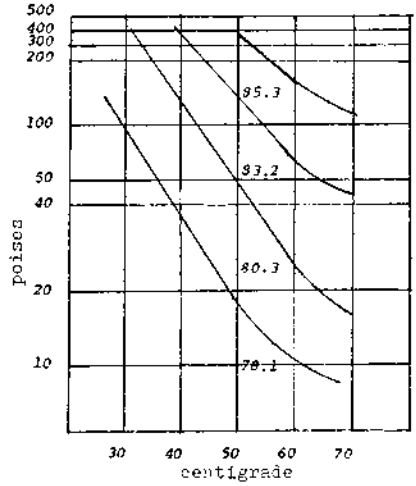

Fig. 38. Curve of Behne, for viscosity/temperature of molasses at same purity but at different solids. (From Honig, Vol. II, p.495)

REFERENCES

1. P. Honig, *Principles of Sugar Technology*, Vol. II, Elsevier, Amsterdam, 1959, p.472.
2. E. Hugot, *Handbook of Cane Sugar Engineering*, Elsevier, Amsterdam, 1960, p.279.

CHAPTER 22

# CENTRIFUGAL STATION

The purpose of the centrifugal station is to separate crystals from molasses by means of gravity difference due to centrifugal force. Although centrifugals have existed for many years, they are nevertheless one of the latest equipment improvements of the 20th century. Before centrifugals were used, the massecuite was poured into tightly woven baskets, which were placed on a large concrete floor in the open air. This curing had the following effects:

(1) The mass cooled, supersaturation increased, and some deposit of sucrose from the molasses took place onto the existing crystal surface.

(2) The molasses slowly leaked out of the baskets leaving the crystals behind. The tropical daytime sun heated the leaking molasses enough to keep it flowing toward the collecting pit, whence it was collected and brought back to the pans for making the next grade of massecuite.

Many mills in S.E. Asia based on this system were still working before World War I (1914). The finished sugar from the baskets was surrounded by a rather heavy molasses film. The pol fluctuated widely, depending on the curing time. Normally, it was 90-95. It had a dark golden color and a rather high moisture content. The original name of this sugar on the world market was "muscovado". Even as late as 1928, many "muscovado" floors still existed in Java, although by that time all mills had centrifugals. The B sugar made from the drip molasses was darker and smaller in size, but was still a commercial product, sold mainly to India. The name was no longer "muscovado", but "molasses sugar".

## Centrifugals

In the early stages of development, the limitations of the machine were of a mechanical nature. The rotation speed depended on the limited roller-bearing suspension, while acceleration was slow, because of the flat-belt drive. Also, braking at the end of the cycle was deficient because of overheating of brake linings. Finally, the basket diameter was small, because of lack of proper high-tension construction materials, which were often unfit to withstand extreme centrifugal forces.

In the development, the first machines had a basket diameter of just 30 inches. Gradually, the technique progressed, and now the diameter is up to 54 inches at higher speeds, and all stages are automatically controled:

To know what the improvements are, we have to go back to the operation sequence of the old-fashioned machine. The earliest machines were driven by a flat belt from a central horizontal shaft behind the battery. The shaft was driven by a steam engine, turbine or electric motor. The power required to maintain the speed is rather low, but the power for the initial torque is very high. Thus, an able foreman was required to make sure that a certain starting sequence was maintained.

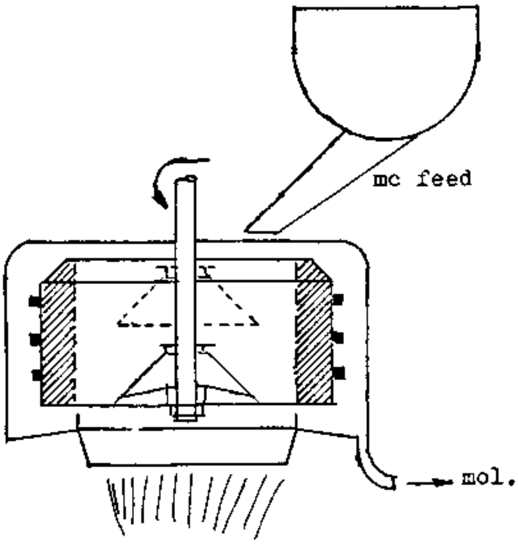

Fig. 39. Principle of centrifugal separation of grain from molasses.

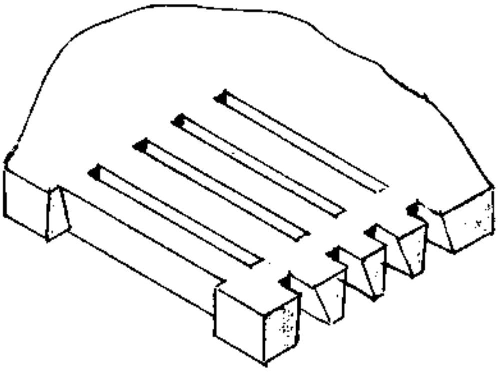

Fig. 40. Enlarged profile of slots in screen.

Normal defects were:

(1) all machines lost speed when one started up;
(2) the initial torque was very slow to achieve, because of belt slippage;
(3) braking was very slow;
(4) discharging was done by hand using a wooden shovel.

## Improvements

An early improvement was the water-driven machine. It worked on the principle of a Pelton wheel, a type of water turbine. It had two water-feeding nozzles, one large for start-up and one smaller for maintenance of speed. The starting nozzle was turned off automatically after some minutes, in order to help maintain water pressure as much as possible. There were two main targets for improvement:

(1) very fast acceleration at the beginning
(2) a speed high enough to generate heat from friction with the air.

The massecuite enters the basket at a pre-determined temperature. If acceleration is slow, the basket acts as a fan and cools the massecuite. Thus the viscosity increases, contrary to the requirements. If the speed increases fast, a point is reached when friction heat equals the temperature loss by fan action, and at even higher speed the massecuite heats up by excess of friction heat. The faster the speed-up, the less chance there is of taking heat from the massecuite in the basket. (We shall see later that in modern continuous centrifugals, a small amount of steam is admitted to overcome heat loss).

By admitting massecuite into the basket and accelerating rapidly, the majority of the molasses is spun off immediately. This is called in Spanish ''romper la purga'', to break the purging. If acceleration is slow, this does not take place, because of higher viscosity, corresponding to lower temperature. As can be seen in Fig. 39, the massecuite in the basket forms a wall leaning against the screen and is about 6″-7″ thick.

A 48″ × 30″ centrifugal achieving 1200 rpm has a gravity factor of 982 × ; thus 1 lb of massecuite in the basket will weigh 982 lb. This multiplication is the driving force for separating the molasses from the grain. The basket wall has holes of about 1/8″. Inside the basket is a lining for the purpose of maintaining a space between the basket and the screen. This lining is mostly of the ''Appel'' type, perforated and corrugated. The older type is ''Liebermann'', which is a cushion of spiral wound wires. Inside the lining is the screen, normally provided with longitudinal slots, which are wider at the back than the front. They open up from about 0.3 mm in the front, to 0.7 mm in the back, and are about 4 mm long. The larger the open area of a screen, the better and faster the purging, but, at the same time, a screen with a large open area is much weaker and its life is shorter.

Table 7. Comparison of old and modern centrifugals

| 1920 old machines | 1970 modern machines |
|---|---|
| basket diam. 30″ × 18″ high | basket diam. 54″ × 40″ high |
| capacity 3.3 cu ft | capacity 23.6 cu ft |
| low torque, slow acceleration | high torque, fast acceleration |
| flat-belt drive | electric motor drive |
| deficient mechanical brake | regenerative electric brake plus mechanical for low speed |
| discharge by hand with paddle | automatic plow |
| about 5-7 cycles/hour | 20 cycles/hour |
| equivalent: 30 manual machines | 1 automatic 54″ × 40″ |
| about 16.5 cu ft mc/hour | 460 cu ft mc/hour |

After the first improvement of water-turbine drive, the direct-coupled electric motor came into general use and rendered the Pelton wheel and belt drive obsolete. Besides, an electric drive makes automatic control much easier. In most countries using old-fashioned equipment, one operator handled two machines; in labor-intensive countries each machine had one operator. A modern automatic station has one supervisor (sometimes with a helper) for all machines.

## Mechanics of purging in batch machine

Suppose the massecuite is purged in a 48″-diameter machine. The massecuite layer in the basket is 7″ thick. The grain lying against the screen spins at 48″ diameter, while the inside spins in a circle of 34″ (48 − 2 × 7). It is clear that the centrifugal force at the outside far exceeds that at the inside. This difference causes the molasses to find its way through the 7″ layer and rushes out through the holes in the screen. The molasses nearest to the screen is always subject to the highest centrifugal force. This means that at any given moment during the purging, the crystals nearest to the screen are the cleanest, while any remnant of molasses is found mainly at the inside. If a sample is taken across the wall thickness, the pol of the sugar at the outside is higher than that of the inside. In other words, if the average pol of the sugar is 97, that outside might be 99 and at the inside 95. The higher the gravity factor, the smaller the difference in pol. This problem was immediately recognized and many technologists tried to find a solution.

It is obvious that use of a thin wall of massecuite was tried. It solves the problem, but the capacity of the station became too small. The best solution was the so-called double-purge system: discharge the centrifugals, mix the sugar again with syrup (or molasses), and purge it for a second time. This is "double-purge", "repurge", "fore and after workers", etc. We shall return to this system later.

*Note:* In raw-sugar fabrication, the thickness problem is not important, because raw-sugar has a pol range of 96-98.5 leaving enough flexibility.

## Low-grade centrifugals

Since about 1964, nearly all C massecuite centrifugals have been replaced by continuous centrifugals, worldwide. This rapid progress was made possible by the improvement of the quality of C massecuite by using instrumentation during the crystallization stage and improved crystallizer work. The continuous machine does not have the big power-requirement surges which the batch machine has, for start up.

### Description

The basket is conical and placed either horizontally or vertically in the machine. The massecuite is fed to the center and rises along the conical wall, by centrifugal force. As the feed is such that the massecuite layer is about 1/8″ thick, it becomes thinner as it travels along the cone, because of increasing diameter. When the massecuite finally leaves the cone, it is in a layer so thin that it does not exceed one grain in thickness; in other words, each grain is purged individually.

The cone is lined with a special screen of chromium-nickel alloy with round holes about 0.005″ in diameter (0.127 mm). There is, of course, some damage to the grain, because it rolls over and over, like boulders in a river. The shape inevitably becomes rounded and the grain also suffers from hitting the wall as it is fed into the center-cup of the basket. This rounding is not serious, as the grain is used mainly as footing for A and B, and the rounded shape grows square again during the growing period. However, this was the main drawback in the use of a continuous centrifugal for commercial sugar, where the damage is irreparable. The layer of massecuite in the conical basket loses heat very fast, because it is so thin. Heat must be added continuously by means of a small spray of hot water and/or steam.

Although most makes are of the vertical-basket type, there is one that is horizontal (Allis Chalmers, no longer produced). The horizontal design is logical, because crystal movement is in the direction of gravity, not against it, as is the case in the vertical machine. The construction is also more compact. Here again, there are screens with a capacity depending on the open area. The highest open area goes with the weakest screen.

## Double purge

As pointed out before, a low purity in low-grade sugar means that a considerable amount of final molasses is returned to the A and B massecuite. To prevent this, the C sugar was purged twice, once normally to separate C sugar from the final molasses, then mixed with a small amount of syrup (or A molasses) as a washing medium and again purged in a second set of centrifugals. The molasses separated in the second stage is called ''repurge molasses'' and goes to B molasses. The name ''fore and after workers'' is explained in this step. Normally the pol of the repurge C sugar is about 92-94 and contains very little residual final molasses.

Double purge of C sugar is practised in many mills, although the use of continuous centrifugals improved the quality of C sugar so much that it is now considered obsolete. As explained before, each grain is individually purged, which is not the case in batch centrifugals. It is feasible to obtain C sugar of 92 pol in continuous machines without using double purge.

When "plantation white" is produced by either sulfitation or carbonatation, all strikes A, B and C, are double purged as part of the process technique. It shows that so-called "sulfitation white" in American countries, is not plantation white; it is just a little whiter raw sugar. In the sulfitation-remelt process, the A and B are double-purged, then remelted in neutralized condensate and re-boiled to form $R_1$ and $R_2$ semi-refined strikes. The difference from refined sugar is that here no carbon is used.

CHAPTER 23

# EXHAUSTION OF FINAL MOLASSES

Without further investigation, it is scarcely possible to predict the exhaustibility of a final molasses. For instance, it is quite possible that mill A has very good exhaustion, although the molasses purity is 36, while mill B is not as good and has a purity of 32. There must be other factors, not directly visible, that determine the minimum obtainable purity.

As early as 1892, Prinsen Geerligs had begun to find rules to determine exhaustion. It is known that the purity of final molasses of cane is in the range 28-38, while that of beet is always 55-65. The only difference between the two is that the latter has no reducing sugars. Therefore, the sucrose represents the total sugar content. In cane, it is sucrose plus reducing sugar and also amounts to about 55. It is therefore clear that the reducing-sugar content is one of the factors, determining exhaustibility.

It is important to finish the C strike with a high brix, in which case the molasses brix is also high. The difference between a higher and a lower brix is the water content. More water admits more sucrose into solution. Therefore, a high brix is required for optimum exhaustibility. The water has reducing sugars in solution, so there is less room for sucrose.

Many studies have been made, and all are based on highly theoretical principles and calculations. An absolute minimum purity cannot be reached, because water cannot be withdrawn completely. As crystallizer capacity in a mill is limited, laboratory exhaustibility tests come out lower than in practice in the mill. Therefore, the exhaustibility test indicates the ideal purity, and is called the "target purity". The factory never reaches the target purity, but the difference between the results and the target should be minimized.

As is well known, the concentration of non-sugars in final molasses is the main reason why apparent purity and brix are not really representative, as far as purity and solids are concerned. Using these values, additional variables are introduced into the calculations, with results that are less reliable and do reduce the value of the target purity. Therefore, true solids are used instead of brix, and sucrose will be clerget. Further data needed are sulfated ash content and reducing sugars (R.S.). The true solids can be calculated from the brix,if sulfated ash is known. Clerget and reducing sugars are routine, so the only extra analysis required is the ash.

## Formula of Sylmans

In 1932, Sylmans of the Java Experimental Station in Pasuruan published his formulae for calculating the true solids from the brix and ash. Before entering into details, we should explain what true solids are — the residue after evaporating all water present. It is found in the laboratory by weighing 5 g, for example, and diluting this with some water to make it more liquid. In a capsule, some sand or filter-paper fragments are dried and tared, then the molasses added and put in the oven to dry. After cooling and weighing, the dry solids from 5 g of molasses are known. This procedure is explained in detail to show that it is an analysis that takes time and is not routine.

Sylmans gave three formulae for defecation, sulfitation and carbonatation molasses of 90 different sugar factories:

*Defecation* true solids = picnometric brix − 0.72 sulfated ash
*Sulfitation* true solids = picnometric brix − 0.86 sulfated ash
*Carbonatation* true solids = picnometric brix − 0.74 sulfated ash.

The formula for defecation was checked out against true solids in Cuba over a complete crop season and, instead of picnometric brix, the normal routine hydrometric brix was used (on molasses diluted 1:1). The Sylmans factor of 0.72 was found to be correct. Therefore: true solids = brix − 0.72 sulfated ash

As an example:
brix = 90.50 ash = 11
true solids = 90.50 − 7.92 = 82.58%

## Formula of Douwes Dekker

The study was completed by Douwes Dekker in 1940, who found that the most important factors determining the exhaustibility were:

(1) ash % non-sugars, and
(2) reducing sugars % non-sugars.

He studied 150 final molasses in 1938-39 and devised a formula giving the target purity of each molasses. Again, he gave different formulae for the three clarification processes in addition to one generally applicable formula, which will be further explained here:

target true purity = $35.886 - 0.08088x_1 + 0.26047x_2$
where $x_1$ = reducing sugar % non-sugars
$x_2$ = sulfated ash % non-sugars
true purity = clerget/true solids × 100
non-sugars = true solids − clerget

Although it is the target purity, it should be stated that it can only be approached, seldom obtained, because in practice a final molasses is never completely grain-free. The importance is mainly in comparison. If, in the same mill, today shows a difference of two points, it means that it is better than yesterday's difference of four points. If the comparison is between different mills, it can be shown that, for instance, in mill A an apparent purity of 36 might indicate a better exhaustion than 31 in mill B.

Why do we still use apparent purity for final molasses? Because it is a very simple analysis and although it does not have an absolute significance, it provides daily comparison, since it contains the same imperfection every day. The target true purity should be determined from the accumulated bi-weekly sample (twice-monthly). Because of the special analysis involved, it cannot be performed daily. It is important enough to be done in *all* mills, as there is no other way of knowing what is lost in molasses and what the losses should be.

## Formula of Honig

Honig wanted to use a formula on routine laboratory figures and based his version on apparent purity, hydrometric brix and pol (not on true solids and Clerget). Of course, it cannot be very accurate, because the brix has no constant relation to the true solids; it depends on the ash (see Sylmans formula). Also, the relation pol to clerget depends on the amount of reducing sugar, but it is worth mentioning for its simplicity.

Apparent target purity = $24.0 - 0.11x_1 + 0.26x_2$
$x_1$ = reducing sugars % non-sugar
$x_2$ = ash % non-sugar.

As the ash changes very little from one day to another, it can be determined weekly and used during one week.

*Example: Honig*

$$\left.\begin{array}{ll} \text{brix} & = 90.50 \\ \text{pol} & = 27.15 \end{array}\right\} \quad \text{non-sugar} = 63.35$$

reducing sugar = 19
ash = 11

$$x_1 = \frac{19}{63.35} \times 100 = 29.99 \qquad x_2 = \frac{11}{63.35} \times 100 = 17.36$$

$$\text{A.T.P.} = 24 - 0.11 \times 29.99 + 0.26 \times 17.36 = 25.21$$

*Example: Douwes Dekker*

Assume: (a) clerget = 42
(b) true solids (Sylmans) = 82.58
(c) non-sugars (b) − (a) = 40.58
(d) ash = 11
(e) reducing sugars = 19

$$x_1 = \frac{19}{40.58} \times 100 = 46.82 \qquad x_2 = \frac{11}{40.58} \times 100 = 27.11$$

$$\begin{array}{lll} \text{True target purity} = & 35.886 - 0.08088 \times 46.82 & \\ & + 0.26047 \times 27.11 = & 39.156 \\ \text{true obtained purity} = & 42/82.58 \times 100 = & 50.86 \end{array}$$

$$\text{State of exhaustion (Honig, Vol. II, p.529)} = \frac{100 - 50.86}{100 - 39.136} = 0.81$$

## Points of consideration

(a) Cooling lower than 45 °-40 °C has very little effect on further exhaustion of the molasses.

(b) The concentration (brix) of the C massecuite on discharging from the pan has the greatest effect on obtaining low purity of molasses (maximum crystal yield). In other words, an increase of impurities % water of 0.2 units results in a decrease of one point in molasses purity.

(c) The quality of the C massecuite and the exhaustion of final molasses are the most important conditions in the boiling house.

(d) The accounting of the lowgrade materials and products in the laboratory should be as complete as possible.

(e) After leaving the pan, the lowgrade strike should *never* be diluted with water or molasses. It should be reheated shortly before purging to reduce viscosity, resulting in cleaner C sugar and easier separation.

(f) At least once per 8 hour shift, the molasses leaving each machine should be examined manually to determine if it contains grain. At the same time, the collective sample should be checked visually on a glass plate for possible false grain.

(g) After leaving the centrifugals, final molasses should *never* be heated. In the past, fermentation and even explosion have occurred in storage tanks, and all cases concerned re-heated molasses.

If molasses have to be diluted on delivery to transportation facility, sometimes the case on request of the buyer, it should be pumped to a receiving tank, in which it will be blended with the correct amount of water, well mixed and then pumped to the truck or other vehicle.

Molasses leaving the centrifugals should preferably be weighted, and the storage tank should have a device to measure its contents, for example, a pneumercator. The weighing of the molasses gives the total weight of molasses produced, while the pneumercator keeps track of shipments.

Many sugar mills do not have a molasses scale. This is a serious defect, not only for the purpose of laboratory control, but also from a commercial point of view. If sugar is sold, it would be ridiculous not to weigh the sold product, but molasses, which also has considerable value, is only estimated and seldom weighed. A mill grinding 500,000 t cane per season, produces about 2,500,000 gal of molasses. At $0.20 per gal, this represents $500,000 well worth weighing or at least measuring.

The uses of final molasses are many. Of course, the best known is the use for distilling purposes for producing alcohol and rum. It is also used as cattle feed, mixed with other products and often pelletized. Many by-products can be derived from it, if there is a market for them. Finally, it can be used as a road stabilizer, to produce a semi-sold road deck, free of dust and rather impermeable.

## REFERENCES

1. H.C. Prinsen Geerligs, *Cane Sugar and its Manufacture,* Norman Rodger, London, 1924.
2. P. Honig, *Principles of Sugar Technology,* Vol. II, Elsevier, Amsterdam, 1959, p.531.
3. P. Honig, *Principles of Sugar Technology,* Vol. II, Elsevier, Amsterdam, 1959, p.535.
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CHAPTER 24

# SUGAR HANDLING

If raw sugar is produced, it is usually unnecessary to give the product any special treatment before bagging or storage in bulk. The keeping quality is a function of the polarization and the moisture content.

One needs no specialized knowledge to be aware that excessive moisture can cause fermentation of the molasses film around the grain and that this is an ideal condition for bacterial culture and micro-biological deterioration. What then are acceptable limits for keeping quality? The best figure is the safety factor:

$$\frac{\text{moisture}}{100 - \text{pol}} = 0.250 \text{ or less}$$

This formula shows that the higher the pol, the lower the moisture must be. At the limit, the centrifugals cannot deliver a sugar with a lower moisture, because of the fixed gravity factor. In this case, the sugar must be dried in a dryer to reach the safety factor. This is the case, for instance, of refined sugar with nearly 100 pol.

A good moisture figure from an efficient centrifugal is 0.30%. With this moisture, the pol to yield a sugar safety factor of 0.250 is 98.8:

$$0.250 = \frac{0.3}{100 - 98.85}$$

In general, it can be assumed that if a sugar of a pol 98.5 or higher is produced, the factory needs a dryer, because the moisture left in the sugar must be lower than the moisture the centrifugals can produce.

## Dryer and cooler

The dryer normally used is the rotating-drum type, such as Roto-Louvre. The sugar to be dried passes through it in a forward-moving falling curtain, while hot air is blown in to remove the moisture. Before discharging the air, it is guided to a cyclone in which the sugar dust particles it contains are separated. If the dried sugar is stored in bulk or bagged at the temperature at which it leaves the dryer, it will cake together after it cools. For this reason, the sugar must pass through a cooler, a piece of equipment similar to the dryer, but here cold air is blown through the sugar curtain.

Generally, the drying and cooling stages are combined in one longer drum, of which the first part is a dryer using hot air and the second part served by cold air is the cooler. Such a machine is normally called a granulator.

## Drying and cooling mechanism

Sugar crystals have three different water contents:

(1) moisture on the surface as part of the molasses film
(2) moisture occluded in the growing process of the grain in the vacuum pan
(3) water required chemically to build the crystals (crystallization water)

The process of drying can only eliminate a large part of the surface moisture. The occluded water and crystallization water, as well as a small part of the surface moisture, always stay behind.

We know that 26 g of pure sucrose dissolved in water and made up to 100 ml is a solution of 100 pol. As water is present, it means that 26 g of pure sucrose is in reality not 26 g, because it still contains some water. In other words, the pol can never be 100.

After most of the moisture is eliminated in the dryer, the pol of the sugar increases, because the standard 26 g contain more sugar and less water. As a rule, 0.1% moisture reduction results in an increase of 0.1 pol.

The caking of sugar leaving the dryer in a hot condition is probably due to the reduced viscosity of the molasses film of high density (low water). On further cooling, the crystals seem to be glued together and the increasing viscosity helps to keep it lumped.

After water is eliminated, the molasses film, now having a high brix, stays behind on the grain surface. The molasses at such high brix is hygroscopic. It will reabsorb some moisture from the air, until an equilibrium is reached. This equilibrium can be partially controled by conditioning the air in the warehouse. There are no rules for this, because it varies from place to place, country to country. In general, it can be said that the air in the warehouse should be kept at the lowest possible relative humidity, so that re-absorption of moisture is low.

Cooling of the sugar after drying should reduce the temperature to below 110°F (43°C). No caking will occur then. The cooler should be working with cool and dry air. The air from both dryer and cooler passes through a Roto-clone-type separator in which the dust contained in the air is precipitated and dissolved by means of a water spray and the syrup formed is collected in a small tank in which the lumps of sugar separated by a screen in the dryer are also dissolved to form together a "tailing" solution. It is pumped back to syrup or clarified juice tank.

## Storage

In a warehouse, sugar is stored either in bags or in bulk.

### In bags

If in bags, it is important that no moisture from the floor is absorbed by the lowest layer of bags. To prevent this, the floor is covered with a sheet of heavy tar-paper, with the tar-surface on the floor and the "Kraft" side up. Another, more costly method, is the use of wooden pallets. This is essential if the transportation of the bags from the sugar floor is done by means of a fork lift.

The advantage of pallets on the floor is that is permits air circulation under the lower sugar bags, which prevents stagnant moisture accumulation. The disadvantage is that it limits the height of the layers of bags, because of the load limitaion for which the pallets are made.

For loading as well as unloading the warehouse, light-weight portable bag carriers are used in combination with an inclined loader, which is adjustable in angle. If the warehouse is large, inspection lanes should separate individual mounds of bags.

A big problem in a sugar warehouse, for bags as well as for bulk sugar, is that during cooler nights the roof cools and causes condensation of vapor under it. After reheating during the morning hours, drops fall down on the top layer of the bags. It is therefore necessary to cover the top layer with canvas tarpaulins, or Kraft paper with a tar layer. Of course, it is even better to prevent condensation by insulating the roof externally. This also has another advantage, that it reduces considerably the heat fluctuations of the corrugated roof plates. These fluctuations cause leaks at places where the bolts pass through the plates; the constant expansion and contraction of the metal open up the bolt holes. The roof insulation itself prevents leaking and at the same time evens out the temperature differences.

If the loading doors are opened, to load rail-road cars or trucks, it should preferably be done during the hours of the lowest relative humidity. This is normally in the mid-morning hours and early afternoon. When loading is finished, the doors should be firmly closed. It is essential that the relative humidity within the warehouse never exceeds 65%. At this percentage, sugar in bags will not absorb moisture nor will it lose moisture. The doors should be opened when outside relative humidity is below 65% and kept tightly closed when higher. High and large stacks of bags present less outside surface and reduce moisture re-absorption, while small and low stacks increase the outside surface and the risk of re-absorption is greater.

The sugar warehouse should be separated from the factory building. The latter generates a high humidity in the air, which is the opposite of what the warehouse needs.

The sugar in bags weighs 50-53 lbs/cu ft, whereas in bulk, the average weight is 60-63 lb/cu ft, because of self-accommodation and compacting of crystals to void proportion. According to Spencer Meade, the specific weight at 20-ft depth is 62.3 lb/cu ft and is accommodated by face-to-face packing of the crystals (minimum void).

### In bulk

A bulk warehouse generally has low side-walls and a roof at the same angle as the angle of repose of a sugar stack, which is between 40° and 50°, depending on the percentage of moisture left as a film. Theoretically, the angle is 45°, but in practice it is more like 40°, and 50° when sugar is rather wet. The low side-walls must be strong to resist the horizontal component of the load against them. Vertical silos are also used for storage.

The best way of reclaiming sugar is by means of a drag conveyor, lengthwise in the middle of the stack. In general, keeping qualities of a raw sugar are better in bulk than in bags. Water damage has less influence on bulk sugar, probably because of reduced exposed surface. Fire hazard seems to be less, the evidence being that insurance premiums are lower for bulk storage. Handling costs are significantly less than for bag handling, and ship loading is much faster and costs much less to the navigation company.

### Bags

For many, many years, the main source of bags has been India. The material of which the bags are fabricated is "guni" or "burlap". The suppliers dictate the price, which has always been quite high. Because of price-consciousness, mills tried to wash and re-use old bags, but somehow the results did not justify the laundering. It seemed that in washing, the properties of the "guni" changed, and the re-used bag was not good for carrying on the bare back and shoulders of the stevedore. Most probably it is the wax and natural oils in the "guni" material that make it comfortable in contact with the skin.

This oil and wax protect the sugar better too, because sugar in washed bags absorbs moisture from the surroundings much more readily. If bags are washed, they should be washed so thoroughly that no sugar traces are left in the final rinse, because such traces are highly hygroscopic and can cause infections later.

Because of the high price of bags, each country has tried to fabricate bags from different fiber-producing plants, such as Kenaf, agave, etc. But stevedores maintain that all bags not originating in India burn the skin and are not suitable for handling in the traditional way.

## Instrumentation

Each warehouse should have an instrument to indicate relative humidity, both inside and outside. Preferably, it should be of the conventional wet-and-dry-bulb type. For each warehouse, a graph should be prepared of % R.H. during the morning, at noon, and at night as an average of each month of the year. Ideally, of course, there would be an indicator for indoor R.H. and a recorder for outdoor R.H. or recorders for both.

## Scales

If sugar is stored in bulk, a bulk scale must be an integral part of the equipment, because there is no other way of knowing the weight of sugar to be loaded. There are various makes on the market, of which the best known are the Richardson automatic bulk scale and the Servo-Balans automatic scale. The latter is considered to be the "Rolls Royce" of scales. It is very reliable and accurate.

*Other warehouses* are those for packaged, refined sugar and specialties such as soft sugar, brown or yellow, with a high moisture content. The refined-sugar storage is usually air-conditioned and/or heated.

## Transportation

Sugar in bulk requires specially equipped rail-road cars or trucks, and also special equipment at the receiving end (e.g. a refinery).

### REFERENCES

1 Spencer-Meade, *Cane Sugar Handbook*, 9th edn., Wiley, New York, 1963, p.259.

CHAPTER 25

# INSULATION OF EQUIPMENT

The materials used for insulation and lagging of equipment are many. Examples are Kieselguhr or diatomite, cork, asbestos, magnesia-asbestos, animal hair, glass wool, etc. Cork is excellent, but not for heat, and is mainly used in refrigeration. Magnesia-asbestos is normally used in a sugar mill. It should not be used above 600°C, but this never occurs in the sugar industry. Most often, 85% magnesia-asbestos is used (85% magnesia carbonate and 15% asbestos). Application can be either as a plaster or in molded form for pipes, flanges and slabs for tanks, etc. For bigger vessels such as evaporators and vacuum pans, blankets of glass wool have been used recently, saving labor. If vessels have to be lagged while working (hot), a plastic material must be used, such as Wyolite. Nowadays, after lagging, the apparatus will be covered with aluminum sheets for a neat finish and it provides a reflecting surface as well, which does not require painting.

In the Far East, rope made from fiber of the coconut shell, the so-called "Tali klapa", was used. This was replaced recently by the more convenient magnesia-asbestos varieties. It was about ½" in diameter and was used to wind around steam and exhaust-steam lines. It was then covered with a plaster of cow-dung and finally coated with a bandage of cheese-cloth material. After this, it was painted with calcarium. It was the cheapest insulation of reasonable low heat conductivity available for those countries.

*Thickness* of lagging depends on pipe diameter and internal temperature. Nearly all temperatures in a sugar mill are below 400°F (with the exception of modern high-pressure boilers). Using 85% magnesia-asbestos, as a rule, lagging can be of a thickness of:

| | |
|---|---|
| 1"-1½" | for pipes 3"-6" |
| 1"-2" | for pipes 6"-10" |
| 2"-2½" | for pipes over 10" and flat plates. |

It it is very important not to lose any heat, the thickness should be increased — for instance, for a clarifier or a hot-water tank.

## What should be insulated?

It pays to insulate anything that has a temperature of 60°F above the ambient temperature, such as tank, pipe-lines, containers, vessels, etc.[1] In a sugar mill, the equipment is:

( 1) all steam pipes (for live, reduced, exhaust steam, vapors), with the exception of the vapor line from last vessel to the condenser: here no heat has to be conserved
( 2) all hot water and hot juice lines, except some condensate lines.
( 3) all steam-out lines (for safety purposes)
( 4) juice heaters

( 5) clarifiers
( 6) mud-circulation tank
( 7) clarified-juice tank
( 8) all evaporators vessels, I and II are more important than III and IV, because of the decreasing temperature difference
( 9) all vacuum pans, with the exception of vapor piping to the condensers
(10) all sides and bottoms of syrup and molasses supply tanks
(11) C massecuite centrifugal mixer with the Stevens coil
(12) all touchable hot equipment (for safety purposes), including caustic-soda piping, evaporator drains to the ditch, etc.

## REFERENCES

1. Oliver Lyle, *Efficient Use of Steam,* HMSO, London, 11th Impression, 1974, p.757.

## CHAPTER 26

# VACUUM EQUIPMENT

There are three main stations in need of vacuum:

(1) rotary vacuum filters (Dorr Oliver and Eimco)
(2) evaporators
(3) vacuum pans

(1) Rotary filters are provided with vacuum equipment when bought from the manufacturer, normally consisting of a condenser and a rotary water-sealed vacuum pump, such as Nash, Elmo, etc. It can also be a steam or water ejector. In this case most of the material to be evacuated to form a vacuum is air. Therefore a pump is better than an ejector.

(2) Evaporators require one condenser and its auxiliary equipment for each set, whether triple-, quadruple- or quintuple-effect. The condenser is connected to the vapor pipe of the last vessel (also called syrup vessel). Here the equipment to be used depends on the availability of either steam, water or electricity.

If abundant water is available, then the choice is multi-jet-spray condenser. If steam is more easily available, then a barometric condenser with a two-stage steam ejector with inter-condenser is a better choice. If economy in both is indicated, then the correct thing to install is a barometric condenser with an air pump.

(3) For vacuum pans, the same criteria are valid as for the evaporator condenser.

Where the water supply is rather limited (and that is in most cases), a cooling pond or cooling tower is required to receive used injection water and render it re-usable after cooling it as much as possible. Physical water losses are compensated by cold water supplied by the make-up water pump.

CHAPTER 27

# PRINCIPLES OF CONDENSING EQUIPMENT

Formation of vacuum is actually condensing of produced vapor, which is reducing the volume of the vapor to its equivalent volume in the form of water. A condenser is a closed cylindrical tank to which the vapor to be condensed is admitted, and cold water is applied in "rain or curtain" form, to make easy contact with the vapor. On contact, the vapor cools and condenses. The heat contained in the vapor is freed and absorbed by the water, which was originally cool and now heats up.

The ratio of water to vapor, as well as the initial temperatures of both, determine the quantity of water of a given temperature that is required to condense the quantity of vapor. If the quantity of water is too small, it heats up too much and will generate vapor of its own (too high a temperature), thus reducing the obtainable vacuum.

The condenser duty is the total heat to be absorbed by the water in btu/h. The basic formula is:

$$\text{quantity of water in gpm} = \frac{\text{condenser duty}}{500 \times \text{temperature rise in } ^\circ\text{F}}$$

The heat to be absorbed is an average of 950 btu/lb to 1000 btu/lb (for older type steam service). Condenser duty = this heat × lb/h vapor to condenser.

The terminal difference of a condenser is the difference between the temperature of the vapor to be condensed and that of the water after it had absorbed heat from the vapor. If these two temperatures are the same, the efficiency of the condenser is 100%. The terminal difference is a function of the condenser design and operating conditions. The minimum terminal difference to apply is 5 °F.

However, the vapor as released by the evaporator or vacuum pan also contains a certain amount of air and gases, which are non-condensable. They come from the heating medium, the juice itself and from leaks of the equipment. These non-condensables must be eliminated from the condenser by means of a pump or other suction system. If the quantity of non-condensables is rather large, the terminal difference is larger than 5 °F, up to 10 °F, and condenser efficiency decreases. Of course, the condenser size is a limiting factor to the amount of injection water it can handle.

Table 8.
Relation between diameter of condenser and quantity of injection water for counter-flow condensers

| maximum gpm | I.D. (inches) |
|---|---|
| 900 | 36 |
| 1600 | 48 |
| 2500 | 60 |
| 3000 | 66 |
| 3600 | 72 |
| 4200 | 78 |
| 4900 | 84 |
| 6400 | 96 |

To determine the vapor-inlet size to the condenser, the Heat Exchange Institute[1] gives, for 26″ vacuum (4″ absolute), a vapor velocity of 260 ft/s, calculated from the formula:

$$v^2 p = 400$$

$v$ = vapor velocity in fps, $p$ = vapor density in lb/cu ft.

There are three basic condenser designs:

(a) Counter-current condenser. In this, water enters at the top, vapor enters near the bottom. The water rains down on the vapor. The mixture of water and condensed vapor leaves through the tail-pipe.

To provoke an efficient curtain-and-rain effect of the descending injection water, there are trays and counter-trays built within the condenser shell to prevent an ineffective water stream. Each manufacturer has his own tray design, and most are efficient. A general condition for installation of such a condenser is that the trays should be as level as possible, to ensure an even water overflow, which prevents all the water falling at one side and none at the other side (see Fig. 41).

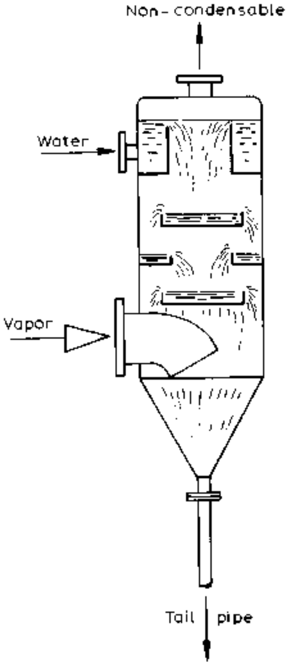
(b) Parallel-flow condenser. In this, both vapor and injection water enter near the top and flow down the vessel together. The non-condensables are eliminated near the bottom under a splash deflector. The non-condensables of the counter-current leave the vessel at a lower temperature. In the case of the parallel-flow, the temperature is highei and an air-cooler is required to reduce the volume before going to the air pump (or ejector). This will increase the pump efficiency. The air-cooler is an expansion vessel under the same vacuum as the condenser. The expansion under vacuum of the non-condensables makes it lose heat (see Fig. 42).

(c) Jet condenser. The jet condenser can be jet alone (for small capacities) or jet plus spray. The spray is responsible for the condensation of the vapor, while the jet eliminates the non-condensables by entrainment (ejector action). There are two water inlets, one for the spray nozzles and one for the jet nozzles. The spray is the top entrance, the jet is the lower one. The vessel is shaped such that it is most effective for ejector action.

Water consumption of this kind of condensor is of course higher than that of the other barometric types, but no air pump is required, so there are neither moving parts nor power consumption.

Only the injection water pump is larger, because more water is used to feed the jet part of the condenser. On average, water required by a multi-jet spray (M.J.S.) condenser is about 15% more than that required by a counter-current condenser, mainly depending on the quantity of non-condensables to be entrained (see Fig. 43).

Both the counter-current and the parallel current flow condensers, produce a dry air, while the M.J.S. and other types of jet condensers produce a wet air, because air is mixed with the water used for the jets.



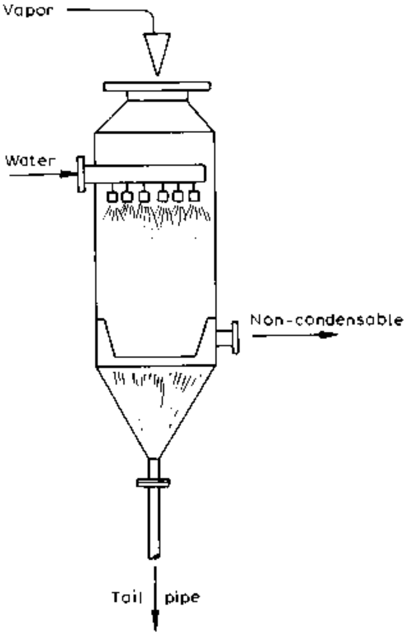


Fig. 41. Principle of counter flow condenser.

Fig. 42. Principle of parallel-flow condenser.

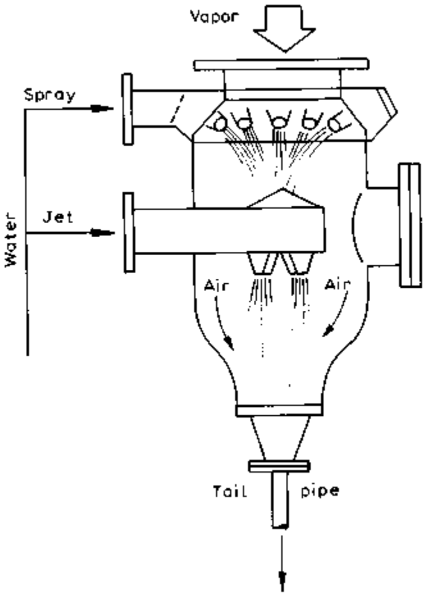


Fig. 43. Principle of Multi-Jet-Spray condenser (M.J.S. type).

*Tail-pipe height.* The tail-pipe is the outlet of used injection water together with the condensed vapor. To form a barometric seal, the length of the pipe (which contains water) must be equivalent to the suction lift of the vacuum in the condenser. In other words, if the vacuum is 26″ Hg, and the maximum barometric pressure is 31″ (at sea level), the "minimum effective height" of the tail-pipe is 35.2′ (Table BT-6 of Heat Exchange Institute Standards)[2]. The tail-pipe should preferably run straight down to the hot-well seal, but if this is impossible, an off-set less than 45° is acceptable. An off-set below 90° is incorrect. The length of the tail-pipe is from the water level in the hot-well up to the connection of the pipe to the condenser (condenser height does not count).

## Barometric and low-level-type condenser

If the lay-out of the plant is such that the condenser is at a lower level that cannot provide a barometric height of 35 feet, the tail-pipe will be too short and a pump must be used to remove the water, to prevent flooding of the condenser. If the tail-pipe is long enough to be of the barometric type, only a water seal at the bottom is required. Discharge is then by gravity. Figure 44 shows the arrangement of the hot- and cold-well.

If the factory is situated near the sea-shore, it is possible to use sea-water as injection water. In this case, there is no need for a cooling-pond, to re-use the same water after cooling. Sea-water will be used once only. As long as the water in the condenser does not stagnate, there is no objection to the use of salt water, but the pump material must be chosen for contact with salt water.

Diameter calculation of the tail-pipe is based on the water velocity of 5 fps. The tail-pipe should immerse in the hot-well not less than 12 inches from the hot-well bottom and also no less than 12 inches under the water level. The hot-well capacity should not be less than 1.5 times the volume of the water column in the tail-pipe.

### Non-condensables elimination

The means of extracting the non-condensables are the following:

(1) air-pump (vacuum pump is really a misnomer). It can be reciprocating or a rotary pump.

(2) a water ejector, in which water jets are used to entrain the air.

(3) a steam ejector, which is similar to the water ejector, only the medium here is steam, not water.

(4) a multi-jet spray (M.J.S.) condenser, which has a built-in water ejector. It uses the spray to condense the vapor and the jet to entrain the air.

The choice of one of the above devices depends on the ample availability of the required medium:

| | |
|---|---|
| air-pump: | electricity or steam |
| water ejector: | water |
| steam ejector: | steam |
| M.J.S. condenser: | water |

Air-pumps, especially the reciprocating kind, need spare parts and maintenance. Ejectors need very little maintenance attention, because there are no moving parts. To maintain about 26″ Hg, steam ejectors are normally of the two-stage type, consisting of the primary ejector, delivering the aspirated air to an inter-condenser, and thence to the secondary (smaller) ejector. In the inter-condenser, it is cooled and dried to reduce volume. The steam used is lost.

The water used in a separate water ejector does not absorb heat and can be returned to the cold-well if so required. It can also be sea-water.

### Cooling pond or tower

In most factories, a water supply is not sufficiently abundant to allow the injection water to be discarded after one passage through the condensers. It should be cooled and used repeatedly.

Cooling of rather large quantities of water at about 122 °F (50 °C) to about 95 °F (35 °C) requires an extensive area in which the water can be atomized in the open air to lose its excess heat and leave the area at the required lower temperature. The principle is that the ambient air has a low enough relative humidity, permitting absorption of the heat from the water as it expands and partly evaporates.

Although the original quantity of water is increased by the quantity of condensed vapor, evaporation losses and spillage make it necessary to add make-up water to the water returning from the cooling pond on its way to the process again. The make-up is about 15% of the total. The quantity of water required depends on a combination of factors, an important one being the initial temperature of the water supplied to the cold-well.

For instance:

case I, inlet temperature = 18 °C
outlet temperature = 50 °C
vacuum = 25″ Hg

case II, inlet temperature = 25 °C
outlet temperature
and vacuum unchanged.

According to the Norris Tables,[4] the weight (lb) of water required to condense 1 lb of evaporation is:

*case I* (18 °C) = 18.9 lb/lb

*case II* (25 °C) = 23.9 lb/lb
or 5 lb/lb more, or 26% more.

## Principle

The cooling pond (spray pond) itself is a large shallow concrete basin. The water to be cooled is pumped (sometimes it flows by gravity) to it and passes through a header to a parallel row of pipes on which sprays are mounted. Water leaves the spray nozzles as a fountain. During its travel in the air, it cools by giving part of its heat content to the ambient air.

In the majority of sugar mills, the cooling pond is too small, because as grinding capacity increases yearly, expansion of the pond is seldom undertaken. The reason is probably that it is unusual to enlarge a concrete structure. The area of the pond is very important, because it is necessary that the fountains from the spray nozzles are sufficiently separated to secure a free circulation of air between them. All sugar handbooks give unit capacities in lb/sq ft/h. They vary from about 120 to 160 lb water per sq ft/h. Hugot[5] gives an average figure of 154, or
lb/h water to be treated divided by 154 = pond area.

In tropical countries (i.e. most cane-growing countries), it is a disadvantage to make the area too large, because reheating of cooled water by direct exposure to the sun reduces the cooling efficiency considerably. For the same reason, the depth should not be excessive, since this causes long retention time. It should be enough to supply the reclaiming pumps with a positive and safe quantity, but at the same time deposit capacity should be kept to a minimum. A depth of up to 3 ft is all that is needed. If possible, it should be less. To the calculated area indicated above, the margins must be added. That is the distance from the last spray line at both sides, one at the leeward side, and one at the windward side. The leeward side is larger because of the carry-over by the wind. Windward needs about 12 ft and leeward side about 24 ft.

The spray nozzles are mounted on "stars" having 5 nozzles each (see Fig. 45). The length of the arms of the stars depends on the angle of spray of the nozzle. All kinds of angle characteristics are commercially available.

The height of the fountain-like spray depends on the pressure of the water at the nozzle. Normally, this pressure is about 7 psi or 16 ft of water head. If the condensers in the factory are mounted high enough, it is possible that the required 16 ft of water pressure can be given by gravity head. This means that in addition to the 16 ft there must be 35.2 ft as tail-pipe length, a total of about 55 ft above ground level. Added to this height comes the condenser (see Fig. 46).

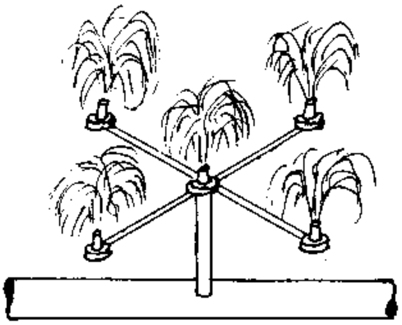


Fig. 45. Nozzle arrangement per star.

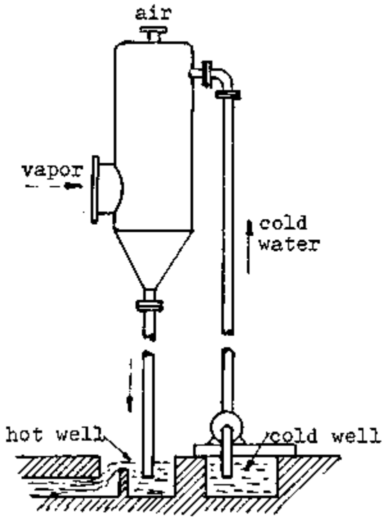


Fig. 44. Arrangement of a barometric condenser.

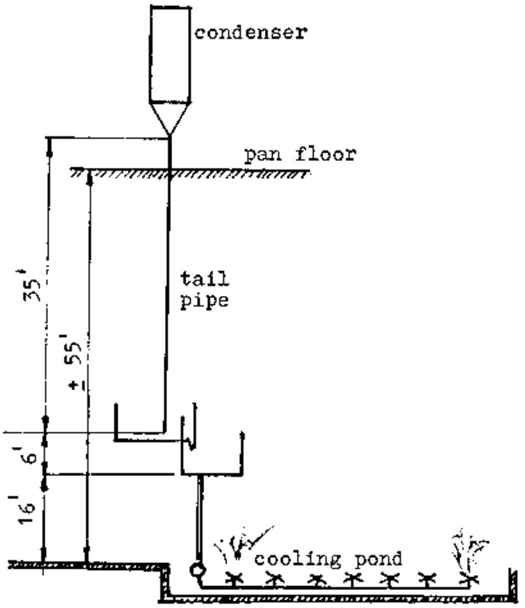


Fig. 46. Complete gravity feed of water to the cooling pond.

If this height is not available, the water has to be pumped to the cooling pond. The pump capacity must be somewhat larger than the injection water pump, because the quantity of condensate must be added to it. The number of nozzles needed is calculated by dividing the total amount of water to the pond by the capacity of the nozzle at the head of water at the nozzle. By further dividing the number of nozzles by 5, the total number of "stars" required is known.

Normal cooling-pond nozzles have a capacity of about 25 gpm at 16 ft of head of water (7 psi). 25 gpm = 12450 lb/h.

**Sample calculation of cooling pond**

Assume:

| | |
|---|---|
| water to the pond | 10,000 gpm |
| equivalent | 5,000,000 lb/h |
| nozzle capacity | 12,450 lb/h |
| pond capacity | 154 lb/sq ft/h |
| number of nozzles = 5,000,000/12450 = | 400 |
| (nozzles mounted in stars of 5) | |
| number of stars = 400/5 = | 80 |
| pond area = 5,000,000/154 = 32468 = | 32,000 sq ft |
| available area for each nozzle | 80 sq ft |
| available area for each star | 400 sq ft |
| assume: length × width = 256 × 125 | 32,000 sq ft |
| distance between stars lengthwise | 15 ft |
| on length of 256 ft are 17 such distances: | |
| number of stars | 16 |
| total width | 125 ft |
| discount for leeward and windward side | 24 ft |
| | 12 ft |
| width between parallel pipes | 89 ft |
| distance between pipes 89/5 | 18 ft |

In places where the wind is rather strong during the grinding season, as in Venezuela, it is better to make the margins at leeward and windward sides larger to prevent heavy water losses. In Venezuela, louvre-type walls are built on the leeward side.

Injection water is seldom treated with disinfectants, because losses are too high and also the quantity is too large. Disinfectant additions would not be practical. For this reason, cooling towers are not very popular. They foul up easily because of contamination and algae formation. Modern towers have louvres made of aluminum or stainless steel. Nevertheless, infection is troublesome and requires much attention. *Note:* for closed-circuit cooling water of mill bearings, crystallizers, pumps, etc., towers are used but water for this application is treated.

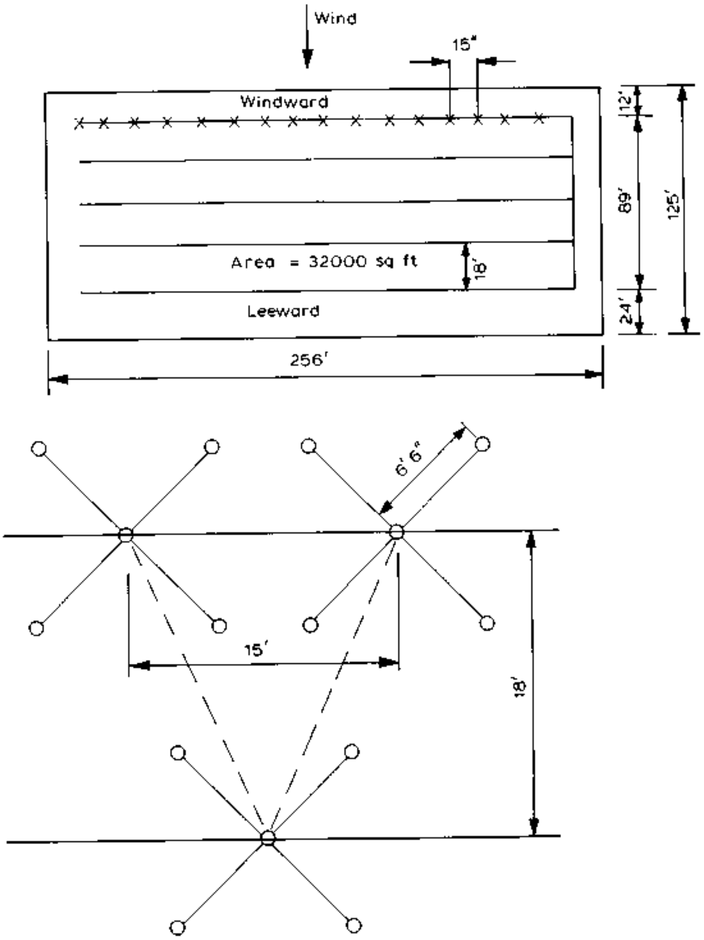


Fig. 47. Cooling pond with nozzle arrangement and star details.

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2. Ibid., p.11.
3. Ibid., p.12.
4. Spencer-Meade, *Cane Sugar Handbook*, 9th edn., Wiley, New York, 1963, p.816.
5. E. Hugot, *Handbook of Cane Sugar Engineering*, Elsevier, Amsterdam, 1960, p.647.

CHAPTER 28

# STEAM

There is a basic difference between the production of steam for a cane-sugar mill and for a beet-sugar house. The cane mill produces nearly all of its required fuel for the boilers in the form of bagasse, while the beet-sugar house has to produce steam from imported fuels. Here the by-product pulp (cosette), the equivalent of the bagasse of the cane factory, cannot be utilized as a fuel. It is therefore essential to the beet-sugar industry to produce and conserve steam in the most economical way, to save on fuel expenses.

Normally speaking, the cane raw-sugar industry produces just about the right amount of bagasse needed to produce the necessary quantity of steam. In many countries more bagasse is produced than is needed, mainly depending on the fiber content of the cane. It is therefore quite possible that in certain countries, where there is high fiber content, the use and production of steam is deliberately less efficient. This is because it is easier to deal with steam than with an excess of bagasse volume, which is expensive to move and dangerous (accidental fires).

In such cases, there are various ways to reduce efficiency:

(1) the use of medium-pressure steam instead of more efficient higher pressures

(2) the use of saturated or slightly superheated steam instead of real superheated steam

(3) the use of triple-effect evaporator instead of a quadruple-effect

(4) the use of only exhaust steam rather than vapors, for the juice heaters and the vacuum pans.

All are factors to help remove excess bagasse. Of course, all this is taboo in the beet industry. There the boiler-steam pressure is not lower than 350 psig and about 150 °F superheat or more. The evaporators are either quadruples or quintuples, and all variations of vapor cells or pre-evaporators are applied with vapor bleeding of up to the third vessel of a 4-effect evaporator, to increase the steam economy to its maximum. Here the boiler design itself is also important in reaching the highest possible efficiency.

In the cane industry in high-fiber regions, it is often possible to install cheaper boilers, because no refinements are necessary, such as water-walls, soot blowers, travelling grates, automatic blow-off, continuous ash removal, air pre-heaters, economizers, and many more conveniences.

The steam pressure usually used is 250 psig, and 300 psig is normally considered to be the upper limit. In many old mills still using reciprocating steam engines, the pressure cannot exceed 125 psig. If such mills are modernized, there is a need for a higher pressure, but the 125 psig must be maintained as long as these engines are used. In many cases there are two working pressures: 125 and the more modern 200 or 250 psig.

From the point of view of the process itself, the steam used is mainly exhaust and only a certain amount of live steam, enough to supplement possible shortage of exhaust steam. This part of the live steam must be reduced to the exhaust steam pressure. Some live steam is also used for steam-out of massecuite piping, valves, magma, molasses pumps, etc., but for this application it should be used below 100 psi (80 psi is better still). At this pressure, only the cheaper fittings are required for 125 psi maximum.

## Steam-out

As already indicated before, steam-out live steam must be reduced to about 80-100 psi. However, steaming-out of vacuum pans requires a more detailed explanation.

After each strike it is mandatory to clean the pan thoroughly so that no grain stays behind when the new strike is started. After the pan has been discharged, remnants of massecuite stay behind in blind corners and on the flat surface of the tube sheet. To clear this out, the pan has to be washed. This means that no high-pressure steam should ever be used. Steam of higher pressure is difficult to condense, because of the high temperature difference, and dry steam does not wash. Condensation of the steam is needed, together with just a little "push" to reach all hidden corners. Also, high-pressure steam leaves immediately through the open foot valve, without even participating in the cleaning process.

Using exhaust steam at the pressure used in this particular mill (8, 10, 15 or 20 psi), together with a hot-water atomizer in the top of the pan, is the fastest and most efficient cleaning action. In fact, this set-up resembles a condenser action: the water spray partly condenses the exhaust steam and the washing action takes place at about 212 °F. There is enough steam left to replace most of the air in the pan, so that when the foot valve is closed after finishing steam-out and the vacuum is turned on, the steam condenses immediately because of decreasing temperature and vacuum is formed in a very short time. If the volume of the pan were occupied by air, it would take a long time before the vacuum reaches 26″, as the contents are non-condensable and must be eliminated by pump or jets.

The hot-water atomizer required can be purchased with the necessary spray angle to match the pan diameter. If the pan diameter is very large, it may be necessary to install two or three atomizers, in which case the spray cones overlap, as illustrated in Fig. 48.

The pump required to supply water to the nozzles can be mounted on the pan floor and must only be started during a steam-out. Pump capacity of 75 gpm is more than enough and suction head is positive, as water comes from the elevated hot-water tank. The steam-out exhaust-steam line should be provided with double valves, because a small leak through one valve (if there were only one) is not acceptable. It can ruin the strike, because of pressure difference from about 10 psi to 26″ vacuum. A line size of 4 inches for steam-out is adequate, if exhaust pressure is 8 psi or higher. Below that, 6 inches is recommended.

## Quantity and pressure of steam

We often hear complaints from fabrication personnel, especially on the pan-floor, that there is insufficient steam. If questioned about this, they may reply, "We have only two pounds pressure". This answer is inaccurate, because if there is no steam, this concerns the quantity, not the pressure.

Suppose the exhaust-steam pressure is 10 psi and there is not enough steam, then as soon as a new strike starts and steam is admitted, the requirement is larger than the supply, steam condenses in the calandria and the pressure drops from 10 psi to almost nothing.

If, however, enough steam enters, the pressure can almost be maintained: in the very beginning it might drop slightly, but it will come back after a few minutes. In this example, there is no shortage of pressure, but of quantity. This misunderstanding comes from misrepresenting both conditions, since pressure is routinely expressed as "pounds", as is quantity. If correct units were used, they would be "psi" or kg/cm$^2$, or atmosphere/or bar for pressure, and lb/h, t/h or kg/h, etc. for quantity.

Wherever possible, the use of live steam connected to evaporators or pans should be avoided, because in most countries such equipment must be tested according to the requirements for higher pressure. These requirements can be such that the construction cost of evaporators and pans would be much higher.

Generation of steam and its properties will not be discussed here, as it does not relate to the fabrication itself. Besides, there are excellent books about the sugar industry that deal with this subject in detail. Regardless of the procedure of generation of steam, it is nevertheless convenient to know some easy-to-remember basic numbers relating to the overall steam requirements of a mill. Many of these figures can be used for preliminary estimates for a new mill design, where no fabrication and cane data are yet available.

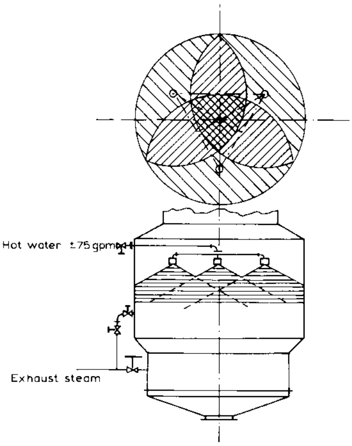


Fig. 48. Vacuum pan steam-out arrangement using water and steam, where three atomizers are required because of large pan diameter.

**Steam requirements**

(1) Live steam generation = 4.66 lb/h per lb of solids in diluted juice. If cane is used instead of diluted juice, and taking an average value for the brix of the juice and the juice extraction: 13 brix and 92 extraction, then:
required steam = 4.66 × 0.13 × 0.92 × cane in lb/h = 0.557 × cane or about 55% on cane.
For steam consumption Hugot[1] gives 52.5% on cane = 1215 lb/tch.

(2) Steam consumption of vacuum pans using a normal three-boiling system (magma as seed for A and B, including dilution of molasses). Steam to pans = 1.5 × water content of syrup.[2]

*Note.* Later, when quantities of massecuite are calculated, evaporation for each of the components can be determined, giving together the total evaporation of the pan-floor and the steam requirement.

(3) Steam to heaters in lb/h =

$$\frac{\text{weight of juice} \times \text{specific heat}}{\text{latent heat}} \times (t_{out} - t_{in})$$

weight of juice = diluted juice + filter juice
specific heat of juice = 0.9
latent heat = belonging to exhaust steam (or vapor) at existing pressure, for instance: 10 psi = 952 btu; 8 psi = 955 btu.

Figure 49 shows a typical steam and condensate balance of an actual new mill designed for a capacity of 3500 tcd. All data given are in lb/h and include the heat liberated by flash of the juice and the condensates of the evaporators. In this case, juice heaters use vapor II for first-stage and vapor I for second-stage heating. Live steam of 300 psi is reduced in two steps:

(a) from 300 to 120 psi

(b) from 120 to 18 psi as make-up of exhaust steam, and exhaust steam of 18 psi can pass through a reducer to make-up the 0.5 psi vapor II to the first-stage heaters. The 120 psi is exclusively used for the centrifugals, sugar dryer, filters and A and B molasses reheating.

The reduction is done in two steps for two reasons:

(1) the need to use steam of intermediate pressure (120 psi)

(2) the reduction in one step from 300 to 18 would cause very high velocity of the steam through the reducing valve, because of the high pressure drop resulting in increased specific volume of the steam. This would give a very-high-frequency whistling sound and cause "wire-drawing wear" on the valve. The boiler-feed water in this case comes from vessels I and II of the evaporator and the vacuum pans. A small make-up is required (about 10%).

**Use of vapor from evaporators**

If vapor is used for more efficient steam economy, it can be used for the juice heaters or one or more vacuum pans or both. The economy obtained is obvious: the exhaust steam, instead of being used directly for this purpose, is first used to

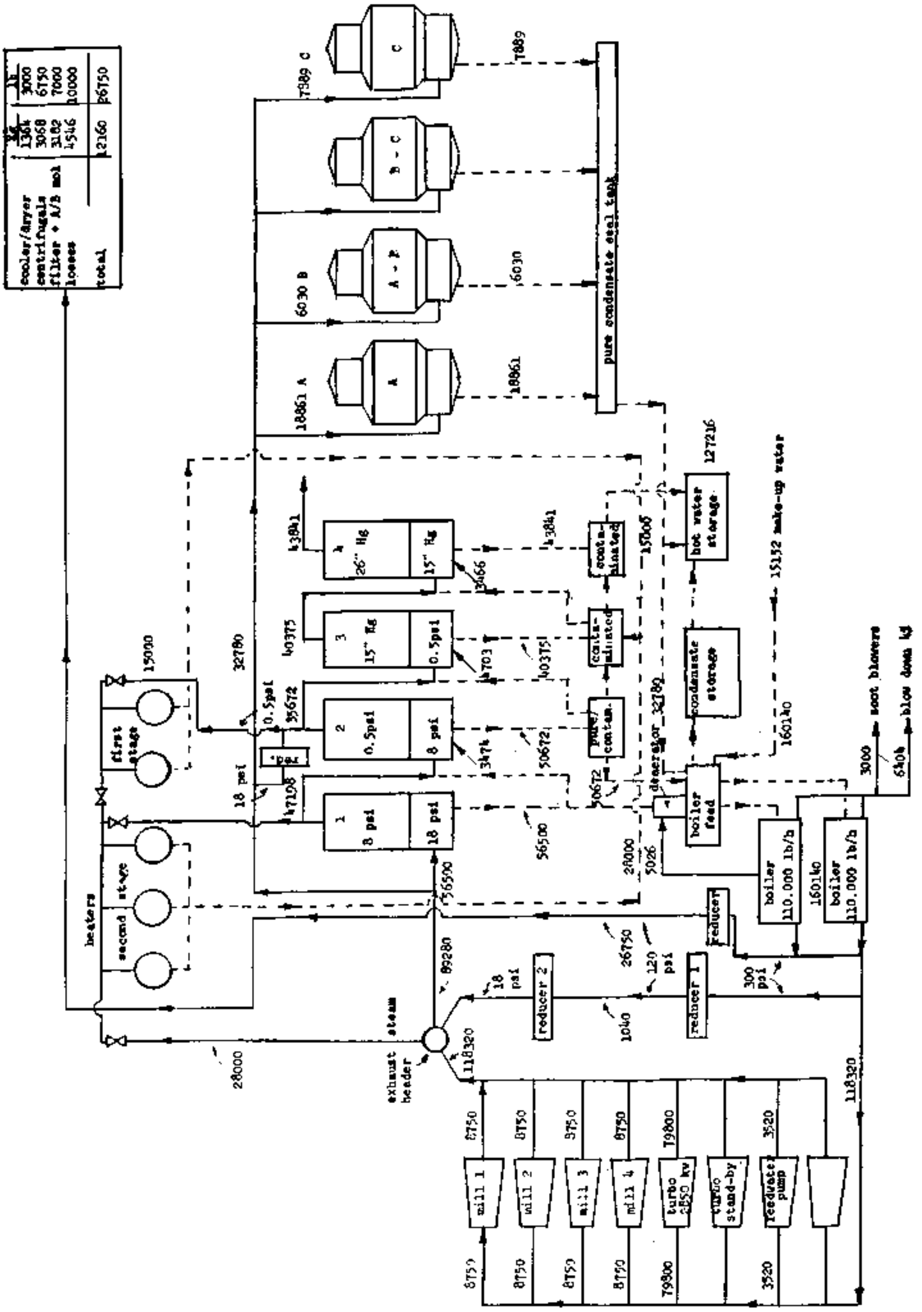


Fig. 49. Typical steam and condensate balance for a mill of grinding capacity of 3500 tcd. All quantities in lb/h.

evaporate and the vapor produced is used for heating instead. This means that the evaporation is done "free". The exhaust steam works twice instead of just once. The vapor generally comes from a larger first vessel, a pre-evaporator or a vapor-cell. This vessel has a larger heating surface than the second, to provide evaporating capacity to produce the required excess of vapor.

It is also clear that once the set is designed to provide vapor to heaters or pans, the extra vapor produced must be drawn off, otherwise the evaporator cannot function correctly and economically. It is of course easier on the operation if the vapor consumption drawn off remains constant and does not fluctuate. If it does fluctuate, the evaporation suffers and cannot be efficient.

The steam (or vapor) consumption of juice heaters is a continuous and smooth operation: if grinding is constant, a nearly constant flow of juice has to be heated from a constant starting temperature to a constant end temperature.

This is not the case with vacuum pans, as the operation is batch and not continuous. A pan can start off using 20,000 lb/h steam, and after 10 minutes its requirement may be only 3000 lb/h, gradually reducing to practically zero.

It requires very able and skilled operators to keep the steam demand as even as possible, by switching from one pan to the other and keeping a sound sequence going. The fluctuations can be somewhat evened out, by make-up of the vapor if the pressure is low, and blowing-off to atmosphere if it exceeds a pre-set value.

In general, it is not good practice to have vacuum pans working on vapor, because of the ever-present fluctuations. Of course, this is not the case in the beet industry, where it is essential to economize on fuel. Normally speaking, the heaters alone on vapor bleed-off provide enough economy for a standard raw-sugar operation. Another reason for not having pans on vapor is that the vapor pressure is lower than the exhaust steam used to produce this vapor. The lower pressure also produces less circulation in the pans, as circulation is directly related to the difference in temperature of the heating medium and the material in the pan. If there is less circulation, strike duration increases.

If vapor must be used on the pan-floor, then only two pans should be connected, one of which operates on vapor and can be alternated with the second, to keep consumption as smooth as possible.

*Note:* If the heaters work on vapor, an exhaust-steam connection must also be available, because as the mill starts up, the heaters function before the evaporators do, and no vapor is yet available.

*Boiler feed water* is mainly condensate and has to be corrected for acidity (pH) and checked for sugar contents (leaking evaporator tubes). If water of second vessel is also used, it is important to prevent carry-over of vapor I. If this vapor has carry-over of juice particles, it goes to the calandria of vessel 2 and ends up in the condensate. A level control is vital in such a case, to prevent accidental high juice levels. The boiler-feed make-up water must be treated to make it suitable for feed-water use. Most often, a rather small demineralizer (ion-exchanger) is used and the water is stored in quite a large tank, to ensure ample supply of good quality water. It can also be kept for the beginning of the next season to initiate boiler operation before fresh condensate is produced by the evaporators. Treated water tanks are mostly in the range of 200,000 gal or larger.

## REFERENCES

1. E. Hugot, *Handbook of Cane Sugar Engineering,* Elsevier, Amsterdam, 1960, p.755.
2. E. Hugot, *Handbook of Cane Sugar Engineering,* Elsevier, Amsterdam, 1960, p.498.

## CHAPTER 29

# WATER SUPPLY FOR FABRICATION PURPOSES

Both hot and cold water are required, as well as raw water for condenser injection.

### Raw water

This can be river water, well-water, even sea-water. It is used for injection of the condensers, general cleaning and sometimes for fire hoses. In some cases, it is used to transport mud to the cane field. The only requirement for its use in condensers is that it must be free from insoluble solids, such as leaves, wood chips, small fish, etc. Therefore it must pass through screens before it is delivered to the plant. Most efficient screens for this purpose are travelling screens, as they barely require any manpower. If cane is washed, it can also be done with raw water.

### Cold water

Cold water is used for cooling mill bearings, for pump seals, and crystallizer cooling elements. This water is chemically treated to keep it free from algae and other contaminants. In order not to lose treatment chemicals and to keep the quality high, it is applied through a closed-circuit system, which includes a cooling tower, pumps and storage tanks. As the amount of make-up required due to losses through leaking and evaporation is only small, its origin can be from the boiler-feed storage tank, which contains treated water.

### Hot water

Its origin is from third and last evaporator vessels and juice heaters. As already explained, condensate of heaters should never be considered to be uncontaminated, because the pressure of the juice is normally higher than the pressure of the heating medium, and leaking is always in the direction of the condensate, not of the juice. A slight sucrose contamination, intolerable in feed water, presents no problems in the processes for which it is used:

( 1) imbibition
( 2) lime preparation
( 3) mill sanitation
( 4) molasses dilution
( 5) crystallizer reheating
( 6) C massecuite reheating (Stevens coil)
( 7) centrifugal wash
( 8) remelting of lumps, sugar, etc.
( 9) vacuum pan operation
(10) miscellaneous occasional uses.

Hot water used for imbibition has to be cooled slightly; otherwise if it is too hot, it might provoke chokes in the mill. In order not to lose heat in this case, the water can be pumped through a heat exchanger, where cold diluted juice is applied as a cooling medium. The juice picks up part of the heat of the water — the juice has to be heated later anyway. In practice, the temperature limit of imbibition water is about 70°C (158°F).

Lime should always be prepared using condensate. As it is mixed with the juice, introduction of soluble as well as non-soluble solids should be avoided. Using high quality lime, together with high quality water, will benefit optimum clarification conditions. Hot water is better for breaking up the particle size of the lime.

Mill sanitation consists of cleaning unreachable corners periodically, using exhaust steam and hot water. In this case, steam is preferred to water, because of dilution of the juice by water, which does not form part of the process (as does imbibition water). In some places, the use of water is unavoidable.

Dilution of A and B molasses (and sometimes syrup if the brix is too high) can only be done with hot water. Cold water simply does not mix readily with the molasses; it stays on the surface or goes to the bottom of the tank. Crystallizer and C massecuite reheating use hot water as a heating medium in heat-exchange equipment, without any physical contact between the water and the materials to be heated. Condensate for this purpose keeps the inside of the heating surface clean, because of its slightly acid condition and low mineral content.

Water used in vacuum pans is for dissolving false grain or preventing formation of false grain by reducing supersaturation and extending the time factor. It is obvious that this water should have a temperature equal to or higher than the strike temperature. In the steam-and-condensate-balance graph, the hot water for the process is 127216 lb/h, equivalent to about 850 lb/tch or 36 lb/tcd about 45% of all condensate, equivalent to 105 gal/tch and 4½ gal/tcd.

Miscellaneous uses are, for instance, periodical wash-out of syrup and molasses supply tanks, wash water of rotary vacuum filters. This latter application requires a booster pump to bring its pressure to 35-40 psi, the minimum pressure required for efficiently atomizing water from the spray nozzles. Lower pressure causes the water from the nozzle to form a spout, which cuts the mud cake and does not wash. In many mills this detail is overlooked. It is such a simple detail, and correction pays for itself in the form of lower sucrose loss in mud. Each mill should have a spare nozzle pipe with nozzles, to alternate every cleaning stop. This precaution, plus the booster for correct water pressure, guarantee the lowest possible sucrose losses in mud. To illustrate its importance, consider the following averages:

cane ground in season = 500,000 t cane  
mud % cane 2% = 10,000 t mud cake  
pol before precautions 2% = 200 t sucrose  
pol after precautions 1% = 100 t sucrose  
available sugar in t pol 50% = 50 t available.

CHAPTER 30

# PUMPS

We do not intend to deal with the mechanics of pumps in this book, but we shall consider a few details. The once common reciprocating steam-driven pumps are no longer used. They are uneconomical steam consumers and require high maintenance. Latterly, the use of centrifugal pumps has become almost universal. There are a few materials in the sugar mill that are not suitable for pumping by a centrifugal pump. In general, materials of high brix and high viscosity fall in this category. Usually, the highest brix that can be dealt with by a centrifugal pump is about 65. Above this figure, positive displacement pumps are used. There are various types of displacement pumps. In the sugar industry, the commonest are:

(a) gear pumps
(b) screw pumps (Moino type)
(c) Rota pumps (Vane type)

The gear and screw pumps are mainly used for high density material such as A and B molasses and final molasses, while the Rota type is used for massecuite, magma; all are crystal-containing material. Gear and screw pumps have a lower efficiency than centrifugal pumps and the outlet cannot be closed, as it can in the latter.

For massecuite, the Vane-type pump is the only one that does not destroy the grain. It consists of an elliptical body rotating in a round housing. The suction half is separated from the delivery compartment by a vane resting on the elliptical body and is held closed by a spring action or an external counterweight. The only attention required by the pump is a steaming out when pumping is interrupted. No stray metal should be allowed to enter the pump housing. To avoid this, a screen is placed in front of the pump. This pump requires positive suction head.

Although the rotor turns at about 40 rpm, delivery capacity can be varied slightly by a slight change in rpm. This type of pump is rather expensive, because it requires a motor-reducer and/or V-belt transmission. Their use is limited to grain-containing materials.

Air pumps, if they are individual for each pan, are mostly of the rotary type, such as Nash, Elmo, etc. If bigger units are used for general vacuum systems, they are often the reciprocating type, either steam-driven or with an electric motor. The individual rotary type can be conveniently mounted behind each pan, for easier handling by the pan operator. The circuit breaker is mounted on the pan panel.

As the capacity of,a pump is often somewhat larger than required (there is a safety factor for peak loads), it is nearly always necessary to have a level control on the pump supply tank; otherwise, the tank runs dry and the pump will suck air. There are many types of level controls, most of those in use now are the d.p. type (differential pressure).

However, the old-fashioned float-operated "open and close" valve is a very reliable and simple way of maintaining a liquid level in the tank. If the level is high, the float rises and closes the bypass, which prevents liquid already pumped from returning to the tank. Thus, all liquid is delivered to its destination. If the level is low, the float lowers and opens the bypass. Liquid already pumped will return to the tank. In this way a preset level is maintained in the tank. If air reaches the pump, delivery is interrupted and the pump must be primed to restart.

It is good practice to have a manometer on the outlet of each pump. Another requirement is a check valve at each pump outlet. If the pump has to be stopped, it prevents material in the delivery line from running back into the pump, which is forced to rotate in the reverse direction by the pressure of the liquid column on the impeller. When the pump has to be repaired, it can be taken apart without losing the liquid in the delivery line, which is held back by the check valve.

Table 9.
Pipe-size capacity range in gpm for schedule 40 steel pipe

| Cap (gpm) | Size (in) | Cap (gpm) | Size (in) | Cap (gpm) | Size (in) |
|---|---|---|---|---|---|
| 0-5 | 0.25 | 50-350 | 3 | 1800-11000 | 18 |
| 1.5-10 | 0.375 | 100-600 | 4 | 2000-14000 | 20 |
| 2-16 | 0.50 | 160-1000 | 5 | 3000-19000 | 24 |
| 4-28 | 0.75 | 220-1400 | 6 | 5000-35000 | 30 |
| 6-50 | 1 | 400-2200 | 8 | 8000-50000 | 36 |
| 12-75 | 1¼ | 650-4000 | 10 | 10000-70000 | 42 |
| 16-100 | 1½ | 900-6000 | 12 | 16000-90000 | 48 |
| 25-160 | 2 | 1000-7000 | 14 | 18000-120000 | 54 |
| 35-240 | 2½ | 1400-9000 | 16 | 20000-140000 | 60 |

Table 10.
Normal velocities in pipes

| material | density average | fps |
|---|---|---|
| water | | 6 |
| juice | 0-20 brix | 5 |
| syrup | 40-65 brix | 3 |
| molasses | 70-90 brix | 2 |
| massecuite | 90-99 brix | 1 (or less) |

Table 11.

| material | fps |
|---|---|
| Superheated steam | 200 |
| Saturated steam | 100 |
| Exhaust steam | 130 |
| Vapor | 120 |
| Vapor under vacuum | 180 |
| Vapor to condenser | 200 (or more) |
| Compressed air | 80 |
| Air under vacuum | 50 |
| Sulfur dioxide gas $SO_2$ | 75 |
| Carbon dioxide gas $CO_2$ | 75 |
| Milk of lime | 6 |

## CHAPTER 31

# PIPING

It is sufficient for the purpose of this book to give the allowed velocities of materials present in a sugar mill. As a general rule, the higher the viscosity of the material, the lower the velocity must be. For instance, in the case of handling final molasses, the delivery line has a much larger diameter than the calculated value. This is to prevent high loss or head (or pressure drop), which demands excessive power of the pump. As a second general rule, the delivery velocity is always higher than the suction velocity. Hugot[1] gives both limits for materials in sugar mills in fps (Table 211, p.831).

Allowed steam and vapor velocities are important for calculating vapor piping between evaporators and to condensers. In general, the following velocities can be used:

| | |
|---|---|
| live steam | 120 fps |
| exhaust steam | 150 fps |
| vapor | 120 fps |
| vapor under vacuum | 200 fps |
| water | 6 fps |

For more detail, see Hugot,[2] p. 832 (Table 212). As regards vapor piping from one evaporator vessel to the next, it is essential that each vapor connection from vapor space to the calandria of the following vessel is provided with a butterfly valve. A butterfly valve is chosen for various reasons:

(1) In general, vapor lines are of a larger diameter and normal gate valves would be both too costly and also too heavy for the purpose.

(2) As the principal function is to prevent soda and acid vapors from entering the next calandria during cleaning, a less positive closing of a butterfly valve is sufficient.

(3) As each vessel has a chimney to the atmosphere for the purpose of boiling cleaning chemicals, there is hardly any pressure in the vapor lines, which makes the use of butterfly valves adequate.

(4) The butterfly valves for this purpose can be easily produced locally.

If no valve were mounted in the vapor line, the exhaust steam admitted to each calandria during boiling out would flow back through the line to the vapor space of the preceding vessel and would impede proper boiling.

## REFERENCES

1. E. Hugot, *Handbook of Cane Sugar Engineering,* Elsevier, Amsterdam, 1960, p.831.
2. E. Hugot, *Handbook of Cane Sugar Engineering,* Elsevier, Amsterdam, 1960, p.832.

## CHAPTER 32

# PRODUCTS OTHER THAN SUGAR

In nearly all countries, raw sugar production for export is limited by a predetermined quota. While the quotas can fluctuate, because of old stocks, price politics, political changes in governments, etc., the cane planted to produce the alloted quota cannot be changed on a short term basis, as it takes some years to change acreage.

In most countries, the local consumption quotas determined by the government do not fluctuate much on short term, unlike the export quotas. It quite often happens that after production and meeting of the sugar quotas, there is still cane available, which can be used to produce other sugar-containing products without breaching quota restrictions. One product produced in rather large quantities is raw sugar, treated with a vegetable dye to distinguish it from consumption sugar. This is sold as cattle feed at a reduced price.

## Native sugars

Many other products are made, and also used as sweeteners. In this category are firstly native, primitively made sugars, which have different names in each country, for instance:

| | |
|---|---|
| raspadura | Cuba, Santo Domingo |
| panela | Venezuela, Columbia |
| chancaca | Peru |
| rapadou | Haiti |
| gur | India |
| gula djawa | Indondesia |
| muscovado | The Philippines. |

Production of this native "raw sugar" is a home industry. The cane is cut in the morning and brought to the plant. Juice separation takes place after the cane for the daily production has been accumulated. The milling plant of the original process was a small vertical mill driven by a mule, bullock, horse, etc. Clarification of the juice was purely mechanical, by means of a ladle. The evaporation took place in large hemispherical cast iron kettles over an open log fire. When the right degree of concentration was reached, the hot and liquid concentrate was poured into molds. In Indonesia for instance, these molds were halves of coconut shells, hence the name "gula mangkok" — "cup sugar". Each country had its own shape and size of mold, but they were usually brick-sized.

As in the case in almost all industries, even this production method has been subject to progress. Now, almost everywhere, a small steamboiler is used to produce steam to move the still primitive mills, and steam is often used as a heating medium for evaporation.

### Muscovado process — the Phillipines

The massecuite is charged in 5 gallon (oil) cans and left for several days. Holes are then made in the bottom for molasses drainage. The remaining sugar has a pol from 71 to 82.

### Gur

In the fabrication of gur, the juice is heated and clarified with an extract of Dula roots (Hibiscus). The rising scum is ladled off, then further concentration takes place to about 93 brix.

## Inverted molasses

A second important product is inverted molasses, also called high-test molasses, which is made from cane instead of sugar, before or after the production quota is reached. The diluted juice is produced just as for sugar, but clarification is done with or without only a small amount of lime. The pH of the juice is low and the juice is cold.

Evaporators do not require cleaning, as no scale is formed in acid juice (no lime). Pan supply tanks or crystallizers are used to store the syrup of about 55 brix. Here the freshly prepared paste made of dry yeast is added to invert the sugar in the syrup. The quantity of yeast required is determined by the speed required to invert the sucrose, this speed being obtained according to the available capacity of deposit for inversion.

In the beginning of the inversion cycle, the reaction is slow, but later it proceeds more quickly because of the infection already present. To assist initial inversion, a small amount of hydrochloric acid can be added with the yeast.

To check progress of the inversion reaction, every hour the laboratory determines the pol of each tank and maintains a chart of the hourly pol reduction for each tank (or cyrstallizer). As soon as the pol approaches zero it can be discharged to be concentrated further to the required brix. If a certain pol is required, the inverted syrup can be mixed with an amount of untreated syrup to constitute a mixture of correct sugar contents.

The normal composition of high-test molasses (mieles invertidas) is:

| | |
|---|---|
| solids | about 85 |
| pol | about 27 |
| invert | about 50 |
| total sugars | about 77 |
| ash | about 2-2.5 |

After reaching final density, the molasses has to be cooled to arrest further reactions. Normally, there is no special equipment available for this purpose, as the process takes place in a regular raw sugar mill. Therefore, cooling can be achieved using a normal vacuum pan under vacuum as high as possible. No steam is turned on. A vacuum of about 28″ - 28.5″ is feasible. If necessary, air leaks can be maintained just to aid the cooling process. For instance, the foot valve can be cracked open to let a small quantity of air in, or a seed funnel can be kept open.

Discharge from the cooling pan can be made continuous by opening the cut-over valve slightly, to allow enough liquid to escape to maintain the pan level.

If colored sugars are required, the dyes used are of vegetable or synthetic origin, the latter of course being acceptable as food additives. The dye can be added in the last stage of the centrifugal cycle or blended with the white sugar in a screw conveyor before drying.

In Indonesia, yellow-colored sugar was traditionally used during times of mourning.

Production of caramel has already been described in this manual. It is used as an additive in producing the so-called N.A. (new assortment) sugar for England, and as a means of increasing color and reducing pol for import duty purposes.

Use of blue as a complementary color for slightly yellowish plantation white sugar has also been mentioned. It makes the sugar seem whiter.

In Honig[1], the quantity of indanthren used for this purpose is given as 50 g per ton sugar, of which only 5 mg per ton sugar adheres to the grain surface.

Furthermore, there are many variations of edible syrups, which are used as kitchen syrups, and can be blended with all kind of syrups made from sources other than sugar cane or beet. The color can also be custom-made for a particular market. For instance, syrup for the South of the U.S.A. is normally darker than that sent to the north-east of the country, where a lighter color is preferred. There a maple taste is quite popular, while in the South a distinctive cane-molasses taste sells better.

## REFERENCES

1. P. Honig, *Principles of Sugar Technology,* Vol. III, Elsevier, Amsterdam, 1963, p.498.

CHAPTER 33

# INSTRUMENTATION IN RAW SUGAR MILLS

We do not intend to detail all instruments in this chapter. Handbooks are available for this purpose. However, we will clarify the most effective and least complicated controls to be used in sugar mills in the developing countries. There, controls should be such that they really assist operators, but are not sophisticated, since skilled maintenance personnel is simply not available in many countries.

We have seen in some countries that a group of mills in the same area jointly employ a qualified repair man for instrument maintenance, and in some countries some companies also offer this kind of service. The reduction of instrumentation to a practical minimum depends on the country concerned and factors such as obtainability of spare parts from a reasonably near source, and this plays its part in the final selection.

As a general rule, in countries where wages are high, more instrumentation is used than in countries where wages are low (usually the developing countries). The lower wage level is also the reason why no instrument mechanics are available, as they are highly skilled and expensive compared with the average wage level.

## Cane scale

The most necessary and widely used control instruments are scales for cane, juice, water, sugar, etc. The cane scales are also used for the purchase of cane from independent growers. They must be exact and fraud-proof. These requirements alone complicate the simplicity, because the instruments must be provided with ticket-printing devices and accuracy falls under the jurisdiction of a government control. Therefore, in the off-season, much attention is given to factors that form part of accurate weight control, such as:

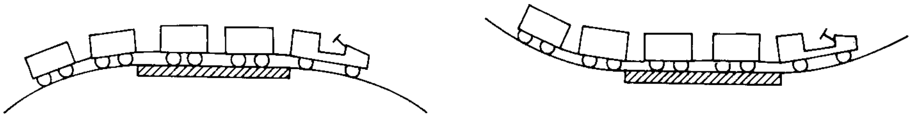
(a) determine tare of cane cars, trucks, etc.
(b) check level of approaches to the platform
(c) clean scale pit, lubricate joints, repair if necessary
(d) make check weighings with pre-determined check weights.

In more details, these factors are:

(a) tare weight of loading equipment can only be done after all cars, trucks, etc., have been completely overhauled. The tare weight should be painted on the equipment together with its number of sequence.

(b) The slope to and from the weighing platform is important, because there are many mills where cars are pulled by tractor. The scale weighs the car or cars standing on it, and subsequently cars are pulled on by a tractor and weighed, without uncoupling the train. The sketch shows, in somewhat exaggerated form, how this can introduce an error. See sketch on page 180.

(c) This does not need further explanation.



(d) As a check weight, each mill must have platforms on wheels with one or more old mill rollers on it. The weight must be painted on the platform. If the scale is for railroad cars, the check weight should be in the middle of the rails, and if the scale is for other kinds (trucks, cars) it should be placed at all four corners as well as the middle of the weighing platform. The weight checked must be the average of the five checks.

## Juice scale

Juice scales are nearly always automatic and are provided with printing devices. Juice scales are for weighing diluted juice (also called mixed juice or raw juice). Normal flow-meters cannot be used here, because of insoluble solids and air in the juice. An orifice plate clogs up and errors are unacceptably large. A special flow-meter, called the mass-flow-meter is made by one manufacturer. It is basically a rotameter (has a float), but the problem is that it measures everything passing through, including air, and it needs a level control on the supply tank, because if the mill stops and air passes through, it will be measured as though it were juice.

## Magnetic flow-meter

The third kind is a magnetic flow-meter. The sensing device is outside the pipeline, and there is no obstruction. The only requirement is that it demands a reasonably high velocity of liquid in the pipe. In other words, there must be a reduced diameter to increase the velocity, which requires increased power from the pump.

The International Commission of Uniform Methods (ICUMSA) states that "Juice must be weighed not measured", because measuring requires average brix (specific gravity) and temperature corrections to compute the weight. Volumetric determination of juice requires correction for occluded air and foam, which is done by leaving a tank for some time, the volume being restored by addition of a measured quantity of water. Automatic scales come in many variations, such as Maxwell-Boulogne, Foxboro, etc.

## Imbibition water

For this a flow-meter can be used, although most mills use scales. Again, ICUMSA says that weighing is preferable. Undoubtedly, this is done to render the fundamental equation as exact as possible. With the weight of cane, juice and imbibition water as exact as possible, the weight of bagasse (cane + water − juice) can be fairly reliable. This is important, because then the sucrose lost in bagasse is also more reliable.

Although this chapter concerns instrumentation, it is necessary here to explain the temperature control normally applied to imbibition water. A temperature of about 70 °C is preferred. This gives the best results as far as extraction and mechnical requirements are concerned (minimal slip or chokes). The simplest way to produce water of the required temperature is by mixing hot and cold water in the correct proportions. For this purpose a three-way mixing valve is quite convenient, similar to those used in bathrooms (but of a larger capacity). Another common system uses hot condensate, cooled in a heat exchanger, where the cooling medium is diluted juice from the mill tandem. The juice here becomes slightly heated, but this is convenient, since a little later it must be heated (in the juice heaters).

The quantity of cold juice which passes through the exchanger determines the final temperature of the cooled water. A temperature control can be used to open or close the cooling juice valve, as is done in juice heaters on the steam flow.

## Lime

One of the most widely used controls is the automatic pH control for the addition of lime to the juice. In many mills in developing countries, the pH control is not used, since it requires a skillful instrument maintenance to keep it in good condition. The electrodes need great attention, and a spare unit should be available, because they are fragile. The instrument is electronic and that fact alone makes skilled supervision a necessity.

Although pH control doubtlessly enhances clarification, milk of lime dosification can be maintained rather satisfactorily manually with one of the many available control-indicator devices and a laboratory-type pH meter.

It must be emphasized here that automatic pH control is preferable, but if it cannot be maintained properly, then it is inferior to manual regulation.

## Heater temperature

The next step in the fabrication process is control of the final juice-heater temperature. This is a simple control and should be present in all mills. It consists of a sensing bulb in the juice line leaving the heaters. This signal opens or closes the steam valve (heating medium). The steam valves on juice heaters are rather large, normally more than 10″ diameter, and this renders the control valve expensive. However, it is possible to control the flow with a much smaller valve, mounted in a by-pass.

Suppose the normal steam valve would have been 12" diameter. Then, instead of 12", a 10" valve is used plus a 6" valve in the by-pass. The 10" valve can be opened just enough to limit steam slightly and the shortage can be controled through the 6" valve (see Fig. 50).

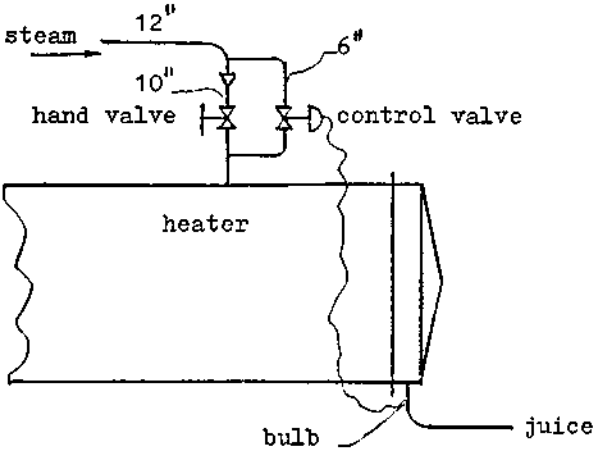


Fig. 50. Juice heater temperature control mounted in by-pass for reduced control valve size.

## Evaporators

Evaporator controls can be divided into two categories:

(a) indispensable controls
(b) convenience controls

The controls in category (a) are:

(1) level control on clarified juice tank
(2) make-up and blow-off on exhaust steam to first vessel
(3) level control on all vessels.

In category (b) they are:

(1) brix control on syrup produced (including recorder)
(2) flow-meter on steam to first vessel (including recorder, totalizer)
(3) condensate flow recorders.

Further considerations on those *under (a)* are the following:

(1) The level control on the clarified juice tank is important to ensure that no air is pumped into the vessel. As this air reaches the last vessel, its specific volume increases so much that even a small amount occupies a large part of the calandria, in which case the withdrawal pipes of the incondensable gases are unable to handle such large volumes.

(2) For continuous and correct operation of the evaporator station, it is necessary to keep the exhaust-steam pressure constant, by supplementing with live steam if the pressure is too low, and by blowing-off to the atmosphere if too high. Without a constant pressure of exhaust steam, the operational conditions fluctuate too much and results are poor.

(3) It is known that optimum evaporation takes place when the juice level in the tubes is maintained at about one third of the tube height (see Hugot[1]). Maintaining such levels manually is almost impossible. The levels indicated in the level glasses cannot be trusted because of violent variations and the time lag before these variations show up in the level glass.

Other factors cause level fluctuations, such as variations in steam supply, in vacuum, in condensate level, etc. For these reasons, an automatic level control is mandatory. Inclusion of level controls on all vessels is one of the best financial investments, as regards instrumentation.

On the points mentioned *under (b),* we have the following considerations.

(1) Brix control of syrup produced is rather a luxury, because if all controls mentioned *under (a)* are in perfect working conditions, and the heating surfaces of the evaporators are well proportioned for the mill capacity, then the brix of the syrup is bound to be good, unless the evaporator is scaled and has to be cleaned.

(2) A flow-meter on the steam consumption of the first vessel is convenient but forms part of a complete record on steam consumption and production. Steam consumption recording of evaporators alone does not serve the purpose. A complete control records production of boilers as a function of consumption of mills, power plant, make-up to exhaust steam to heaters, evaporators and vacuum pans.

(3) To complement steam recording, condensate flow is useful, but rather complicated. Here rotameters can serve the purpose.

In Chapter 12, the recording of condensate of the last vessel of the evaporators is mentioned as part of the determination of heat transfer.

## Vacuum pans

The most important control instrumentation is of course the supersaturation control, used for crystallization of seed for C massecuite. For measurement of supersaturation, there are many instruments based on different principles, comparing the boiling temperature of the liquid with the boiling temperature of water under the same vacuum. The temperature rise gives the supersaturation, provided that the purity does not vary from one strike to another.

There are many patents based on supersaturation determination, such as Holven's patent, worked out by Honeywell, and that of Ditmar-Jansse based on vapor pressure in the pan compared with vapor pressure of water in closed container in the pan.

Furthermore, there is the refractometer, mounted on the pan which shows the density directly proportional to supersaturation. Its application as a pan-mounted instrument is somewhat delicate, because of its prism being exposed to temperature changes due to boiling, steaming out and water circulation for cleaning.

The instrument most widely used is the cuitometer, a conductivity control. Its popularity is due to its simplicity and low price. It indicates the conductivity of the liquid in the pan. The conductivity of the crystals is negligible. The conductivity is inversely proportional to the density (and to the supersaturation), which means that a higher density gives a lower reading. The factors influencing the reading are massecuite temperature, purity, voltage, and electrode distance.

The temperature is almost constant, voltage is kept constant by means of a built-in regulator, the electrode distance is constant. The only variable is the purity, but, as explained earlier, the footing for a C massecuite seed must be kept unchanged at 70 purity, particularly when a cuitometer is used.

The only remaining variable then is density (or supersaturation), and that is the one we want to measure. The procedure of using a cuitometer is as follows.

As soon as the pan starts concentrating the original feed of 70 purity, the meter is turned on, ensuring that the potentiometer is on the reading regularly used. The scale has a range of 0-100, and the set-point indicator is on the number at which seed powder is always injected, say 40.

Concentration starts and the reading falls. Shortly before reaching the seeding point, the seed suspended in alcohol is transferred to the funnel and kept in suspension by means of a laboratory blender. When the seed point is reached, the seed is injected and the crystallization is executed further as explained earlier in the description of seeding technique on p.106.

The use of the cuitometer is simple enough to allow use of one on each pan. Hugot is of the same opinion (Hugot[2]). Used on the A or B pan, the feed can be maintained continuously by maintaining a constant instrument reading and by opening or closing the feed valve.

The only attention the meter needs is periodic cleaning of the electrodes, which become encrusted. They can be cleaned in the laboratory with a warm hydrochloric acid solution. The tips are silver-plated. If so desired, they can also be cleaned using fine sandpaper.

There are vacuum pans provided with completely automated operation (Honeywell, Fisher and Porter, etc.), but their use is mainly restricted to refineries. The reason is that in a raw sugar mill, pan operations are subjected to constant fluctuations (irregular grinding, stoppages, changing cane quality, etc.), whereas a refinery operates like clockwork and quality conditions are extremely uniform.

## Vacuum control

In addition to cuitometers on *all* pans, each pan should also have a vacuum control. The two controls together guarantee optimum efficiency of this station. The temperature of the water leaving the condenser through the tailpipe acts as a control for the water to be admitted to the system. In other words, a temperature-sensing bulb gives a signal to the water valve to open or close, to maintain a constant pre-set vacuum in the pan. At the same time, it admits just the amount of water required to keep the vacuum at that point.

If water temperature rises at noon, more water passes automatically through the condenser, whilst if the temperature falls at night, less water is required and the valve closes slightly.

## Crystallizers

Each C massecuite crystallizer should be provided with a thermometer of the large-dial type. If more sophisticated instrumentation can be afforded, a multi-point temperature indicator in the laboratory can be connected to each crystallizer by means of thermocouple extension wire (copper/constantan) and a thermo-couple probe in the crystallizer (also copper/constantan). By pushing a button on the indicator, the temperature in the cyrstallizer is indicated instantly.

## Vacuum-pan supply tanks

They should all have a dial thermometer, with a dial large enough to be easily visible from the pan front. The temperature should be maintained manually some degrees higher than the vacuum-pan temperature (about 150 °F or 65 °C).

## In general

Throughout the plant, manometers and thermometers should be mounted wherever necessary. These gauges should be removed and stored in the laboratory, during the off-season, to be cleaned and tested (if necessary, repaired).

All recorders, indicators or controls should be pneumatic, rather than the more sophisticated electronic equipment, which requires more skilled maintenance. To supply the air for pneumatic instruments, an oil-free air compressor should be used and the air should be dried (refrigerator/cooling). Both oil and water in the compressed air are the only threat to instrument reliability. Thus, compressed air direct from the plant air compressor cannot be used for pneumatic instruments.

The best solution is to have a separate instrument air compressor, in combination with a cooling water-separator. The size of the plant depends on the number of instruments installed. Boilers, centrifugals and turbo-generators are supplied complete with their own controls and instrumentation.

## REFERENCES

1. E. Hugot, *Handbook of Cane Sugar Engineering*, Elsevier, Amsterdam, 1960, p.386.
2. E. Hugot, *Handbook of Cane Sugar Engineering*, Elsevier, Amsterdam, 1960, p.517.

## CHAPTER 34

# LABORATORY

The task performed by the laboratory is really twofold.

(1) Record must be made of the following assets.

(a) The cane received and ground, and its quality, in order to determine the expenses involved in purchasing cane from independent growers.

(b) The sugar produced, its quanity and quality and its subdivision into export and local consumption.

(c) The molasses produced, its quantity and quality, the quantities of sugar and molasses sold and the available stock to hand.

(d) The consumption of chemicals, in stock and consumed, also sugarbags, etc.

(2) The laboratory is responsible for analysis, as a guideline for the process, to call the attention of responsible personnel should there be any abnormalities. Here the informational rapid analysis also appears. Further, periodic fabrication reports of results, lost time, sugar balances, to indicate the whereabouts and quantity of sugar lost, are made. An organized account and totalization of results and intermediate product quantities and "sugar in process" are maintained.

To ensure that the analyses are valid, they must originate from representative samples. A representative sample must be taken continuously, not instantaneously, to represent an average of all conditions under which the material is produced or received. If the sampling is defective, the analysis cannot improve on it and is worthless, regardless of how carefully it is done.

A well equipped and well-staffed laboratory is a lost investment if sampling devices are defective or absent; unfortunately, this is the case in many mills throughout the world. The equipment manufacturers are not at fault, since most sampling devices are home-made and in many cases home-invented.

Another generally overlooked convenience in the laboratory is a communication system "intercom", which should connect the laboratory primarily with the boiling house, mill house, boilers and office, and also with evaporators, material warehouse, sugar warehouse and workshop. An "intercom" system is better than a telephone, because of the high noise level in the mill: a loudspeaker can be heard better.

Information which can be conveyed to advantage is:

(1) rapid analysis made for the pan floor, before discharging strikes, the so-called cyclones

(2) advice to the laboratory of discharging strikes

(3) advice to the laboratory of breakdowns and mill stops (lost time records)

(4) advice to boilers on feed-water quality or abnormality or requesting a laboratory analysis

(5) advice to laboratory about sugar or molasses shipment (truck weighing in and out)

(6) advice to laboratory of cane ground in last 24 hours at the moment of closing the day.

These are only a few reasons for recommending installation of an "intercom". It is not a luxury, but a necessity. Other necessities are: (a) an electric typewriter for daily and bi-weekly* reports; three electronic calculators with print-out and memory; (b) a photo-copying machine to produce the required copies of daily and bi-weekly reports. This machine, although located in the air-conditioned laboratory, can be used for other general office work (accounting, purchasing, etc.). Such an arrangement has the advantage that a full-time operator can be employed just to handle the copying machine. Such a machine is an expensive item and it is recommended that there is a permanent operator; (d) an air-conditioner of adequate capacity to maintain a temperature of 70 °F (20 °C), the standard temperature for polarization.

*i.e. once every two weeks

## Sampling

The samples can be divided into two categories:

(a) the continuous samples and
(b) the intermittent or occasional samples.

The continuous samples are:

first expressed juice (primary juice)
diluted juice (mixed-raw)
limed juice
clarified juice (clear juice)
filter juice
syrup
A molasses
B molasses
final molasses

The occasional ones are:

massecuites
magma
commercial sugar (can also be continuous)
C sugar
boiler feed water
boiler water
mud
milk of lime
bagasse
last mill juice

The continuous samples are collected every hour and brought to the laboratory. The sample containers are replaced and provided with the correct amount of disinfectant to preserve the sample quality between the hourly collections.

According to Spencer/Meade[1], the best preservative is mercuric chloride 200 ppm of juice, or 0.5 ml of saturated alcoholic solution per liter of juice, which gives the required concentration. Another preservative is Horne's dry lead (lead subacetate) at 20 g/liter, which keeps juice good for several days.

The containers should be cleaned well, disinfected thoroughly (using steam) and completely dried before re-use. For juices there are many automatic devices of local construction available. In most, a sample is taken and transferred to the container, using the rotary movement of the rollers as a driving force.

The simplest is the Java sampler pictured here (Fig. 51). Movement is derived from an eccentric point of the mill roller by means of a nylon cord. The screen on the spoon is interchangeable and prevents bagacillo from entering with the juice. The arm of the spoon is a ¼" copper tube, through which the juice flows to the container. The trough from which the sample is taken leads the juice from the mill pan to the outside tank under the cush-cush (or before the pump).

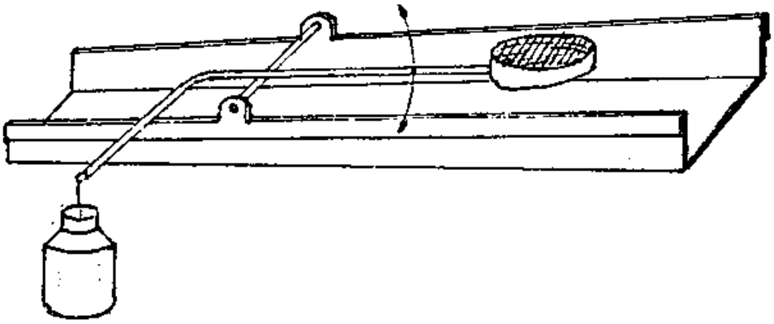


Fig. 51. The Java sampler for mill juice.

It is very important that the sample of diluted juice is representative, because it is on this juice that the accuracy of the accounting is based. Its weight multiplied by its polarization represents the sucrose entering the process. This sucrose assessment is used to make accurate payment for cane from independent growers, as well as to calculate the expected sugar output.

Many makes of juice scales carry their own sampling device, which collects a constant amount of sample from each weighing operation.

In other systems, the primary juice (first expressed juice) is used as the basis for cane payment and is also required where normal juice is calculated for laboratory control, applying the brix factor. Last mill juice (residual juice-last expressed) is a hand-taken specimen, sampled simultaneously with the bagasse specimen. The brix is too low for the sample to be conserved: this is because of the low density and a higher temperature, both ideal conditions for micro-organisms to develop and to multiply.

The sample must be taken over the entire width of the mill. This is quite a problem, because it is difficult to ensure that the collector really does sample it this way.

Samples of limed, clarified and filtered juice as well as syrup, A and B molasses, are easier to collect: a small nozzle and valve are mounted in the delivery line from the pump, and connected to piping returning to the tank in front of the pump. This piping can be ¼ ″ or ⅜″ (for higher-density liquid), for instance. From the outflow of the pipe, a copper wire guides a small drip into a container, which is suspended above the tank so that any overflow drips back into the tank (Fig. 52).

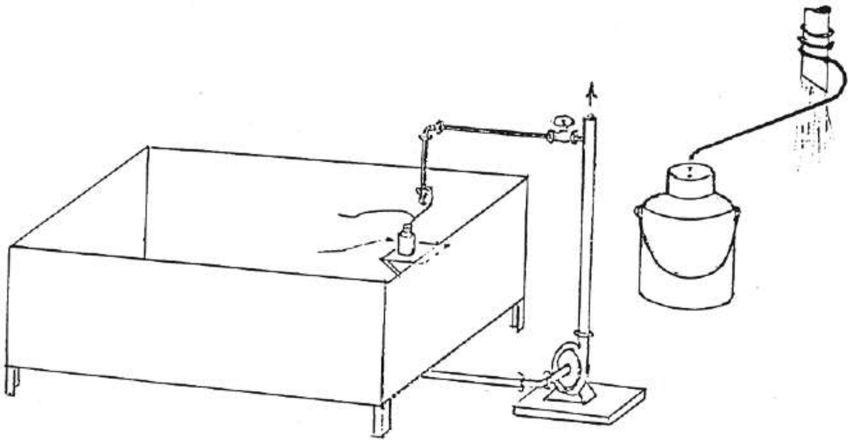


Fig. 52. Sampling from the pump delivery line.

The sampling of final molasses does not require a copper wire, since the sample line itself gives only a small amount of molasses because of the high viscosity. Not only must the sample be larger, but two samples are separated: one is just a sample similar to the other juices, taken hourly for 24 hours, and another accumulated for the bi-weekly special analysis. This aspect will be discussed later.

## The occasional samples

*Massecuite* is sampled individually each strike, as A, B and C massecuites. It is taken from the pan discharge after about half has flowed out, after opening the foot valve. This is done by the pan-floor assistant and announced by the pan foreman by intercom to the laboratory. More about these samples can be found in a later chapter under "Laboratory Reports and Bookkeeping" (see p.201).

*Magma* is taken once per shift, instantaneously.

*Sugar* can be sampled continuously but is usually a periodic sample, for instance a particular quantity for every ten bags. The problem with sampling raw sugar is that it sticks together and plugs up holes or fills the sample spoon, whatever the sampling device might be.

A rather satisfactory way of sampling is to make a tube-formed outlet in the middle of a conical side of the scale funnel, above the bag filler. Whatever continuous system is applied, it needs constant attention and cleaning to keep it functioning.

A C-sugar sample can be taken once per shift in batch form. Boiler feed water, which should be checked at least once per hour for sugar traces, is sampled intermittently. Boiler water is boiler feed water after chemicals have been added to control pH and hardness. This is the same as boiler-feed-water sampling.

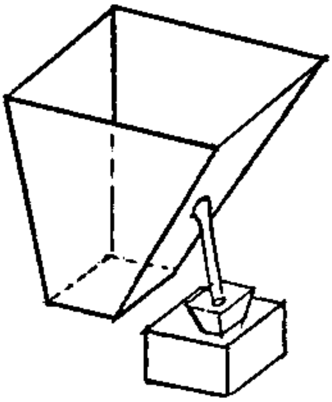


Fig. 53. Sugar sampler.

Mud from rotary vacuum filters should be sampled using a square of galvanized plate 6" × 6" with a 1" high border fitted on a file handle (see Fig. 54). The sample is checked for moisture by drying, and pol and weight per sq ft of mudcake are determined.

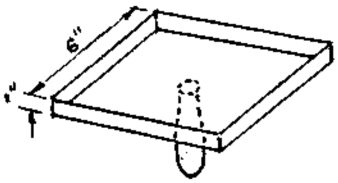


Fig. 54. Mud sampler.

Milk of lime samples are taken only occasionally when the density has to be checked.

The bagasse sample is one of the most unreliable samples in the sugar mill. As it can only be taken instantaneously, it is difficult to know if it is representative. It is analyzed on pol and moisture, and both depend on:
(a) imbibition water variations
(b) matt-thickness variations
(c) temperaure variations

Furthermore, it should be taken over the entire roll width, as extraction of moisture is not constant throughout. Wear of the roller reduces the diameter more in the middle than at the sides. In this respect, bagasse is drier at the extremes and wetter in the middle of the roller.

The sample falls in a wooden box as wide as the roller and must be enclosed to prevent evaporation during transporation to the laboratory (imbibition water is hot and evaporation is high). To secure a sample of the entire width, the chute discharging bagasse from the last mill onto the carrier should have an opening about 3″ wide covered by a 4″-wide hinged lid, kept closed by counter-weights and an arm at both sides (see Fig. 5). To take the sample, the counter-weight is lifted manually and a osed by counter-weights and an arm at both sides (see Fig. 55). To take the sample, the counter-weight is lifted manually and a curtain of bagasse falls out into the sample box. The lid is then placed on the box.

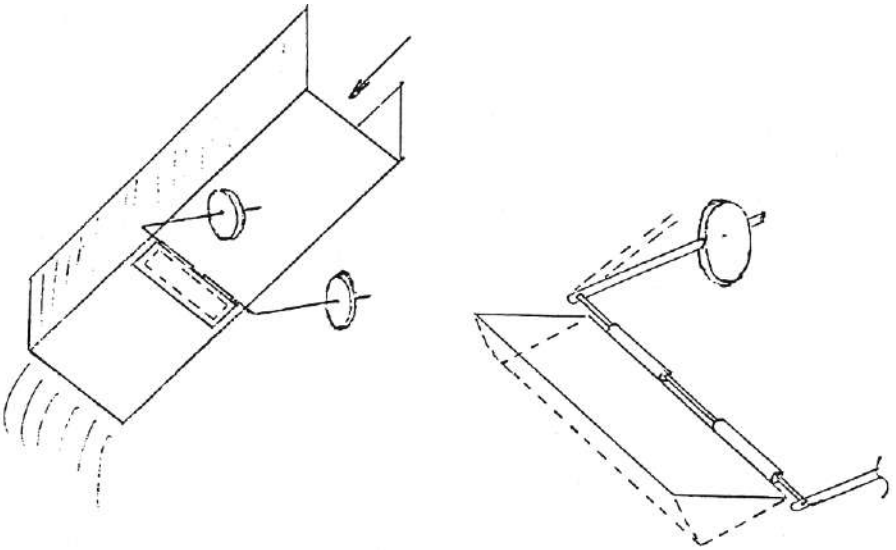


Fig. 55. Bagasse sampling device in bottom plate of last mill chute.

## Personnel required in a well equipped laboratory

There is one chief chemist responsible for all laboratory operations and accounting, who reports directly to the management on all accounting matters. As regards his laboratory guideline obligations, he informs the superintendent, fabrication chief or chief engineer of the results and any abnormalities. As regards cane analysis, he informs the canefield surveyor about results, abnormalities, cane weight and field productions.

The 24-hour day is normally divided into three shifts. In this case, there are also

3 shift chemists
3 helpers
3 sample boys
3 feed-water attendants.

In the day shift, there are, in addition:

1 office attendant (typing, photocopying)
1 messenger boy (distribution of reports, etc.)
1 chemist for special analysis.

The daily job of this chemist is to:

(a) determine glucose in juices, syrup and final molasses
(b) determine ash of final molasses and sugar
(c) do precision analysis of pol of sugar
(d) take readings and monitor charts of all instruments.

He also makes bi-weekly:

(e) complete analysis of accumulated molasses samples: brix, pol, clerget, glucose, solids, ash, and calculation of target purity (obtainable) against obtained purity, reporting the difference in loss of available sugar in money by incomplete exhaustion of final molasses.

(f) complete sugar analysis, as used by the laboratory of the country receiving the exported sugar, to allow calculation of the basic price plus premiums minus penalties.

## Preparation for analysis

The continuous samples are collected every hour and containers replaced. The samples brought to the laboratory are transferred to one-gallon bottles and the collective hour samples analyzed once per shift as an average 8-hour sample. These analyses should be made in the middle of the shift. Suppose one shift starts at 6 a.m. and finishes at 2 p.m., then the 8-hour samples are analyzed at 10 a.m. It is clear that the sample shift differs from the personnel shift (see Fig. 56).

The last shift of the day finishes by calculating the average for the day from the three analyses made, one per shift. This should be done before the chief chemist starts his daily report at close of day. After preparation of all samples for analysis in the middle of the shift (in this example at 10 a.m.), they are thoroughly stirred before removing any samples.

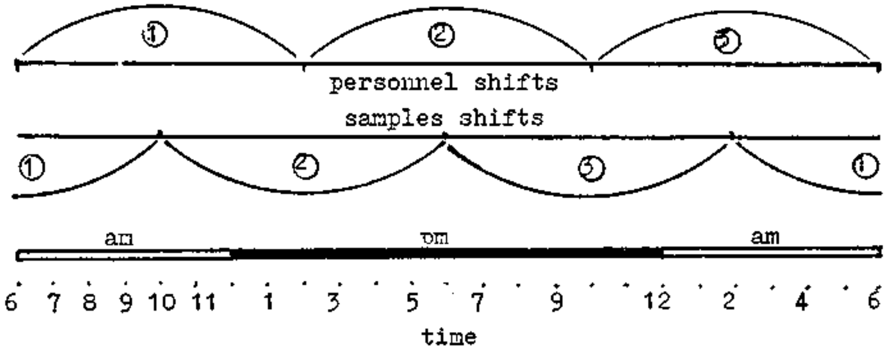


Fig. 56. Timing of analyses of cumulative samples and its relation to the time of the personnel shifts.

On one table, all brix cylinders are filled (and marked), on another all filtrations for polarization are prepared, in the same sequence as the brix cylinders. All analyses are made as prescribed in laboratory-procedures handbooks (e.g. Spencer/Meade), and do not require explanation here. Only sampling procedures that differ from routine sampling need further explanation.

## Final molasses bi-weekly sample

From the same hourly sample for shift average, a certain quantity (e.g. 100 ml) is transferred to a one-gallon bottle to form the bi-weekly accumulating sample used by the special-analysis chemist. The 100-ml sampler is left dripping for a reasonably long time above the container. The dripping time must be constant to ensure quantity uniformity for all sample components. Before analysis, the bi-weekly sample must be well mixed, as each new addition to it stays on top forming separate layers.

## Mud sample treatment

After the 6″ × 6″ cake sample has been taken once per shift, the whole sample is weighed. Its weight multiplied by four gives the weight per square foot of cake, and this multiplied by drum area gives the weight of cake per revolution. The total number of revolutions is known from the 24-hour reading of the counter, which each filter must have. From this, the total weight of filter cake in 24 hours is known.

After it has been weighed, the sample is used to determine the pol and the solids by drying a known quantity in an oven. If mud is transported in dump-trucks, each truck load could be weighed "in and out", but this is seldom done since it is too messy.

*Note.* Pol of mud is never corrected for bagacillo content. Last mill juice, also named residual juice or last expressed juice. As explained before, the density is too low to guarantee the preservability required for continuous sampling.

For this reason, in many mills occasional sampling is preferred. This is acceptable provided that the sample is collected from the complete width of the mill — for the same reason, the sampling of bagasse must also be done this way.

It must be remembered that the juice lost in bagasse actually is the last expressed juice, not last mill juice. The difference is that the latter is all the liquid from the three-roller mill, while "last expressed" means the liquid expressed by the top roller and the last (bagasse) roller. However, this juice is not physically separate and cannot be sampled individually, as will be seen in Fig. 57.

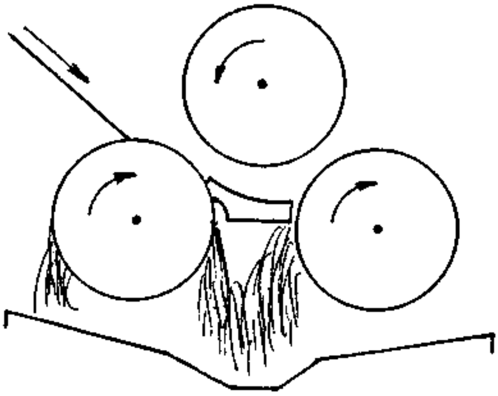


Fig. 57. Flow of juice from front and back roller of a three-roller mill.

## Milk of lime

In general practice, the density of the milk of lime is measured with a Beaume spindle. Although it is usually done this way, this method is not at all reliable, because it is possible to insert the spindle at any point, since it does not float freely. It is thus possible to take a reading of 10° or 15° Bé in the same sample.

The man in charge of preparation needs to have an easy control method that is fast, reasonably accurate, and free from complications. A better method is the following. Use a simple balance at the lime station, such as those found in grocery stores. Use a small sugar sample bottle. Fill it complete with water and determine the weight of the bottle and bottle plus water in the laboratory. Knowing the volume, calculate the weight of the bottle plus milk of lime at 10° Bé, and prepare a counter-weight for this weight.

This can be repeated for 5° and 15° Bé; there are three different resulting counter-weights for 5°, 10° and 15° Bé (or any other set of densities required). This is a crude type of picnometer but accurate enough for the purpose. The bottle can be filled using a piece of glass on the top and including its weight in the tare of the bottle.

## Massecuite and seed cyclones

The word "cyclon" in this sense is derived from the Spanish, and means a rapidly made purity determination, used as an operator guideline for composition of seed strikes and massecuites, information is needed instantaneously. The analysis is only approximate and is not intended to be exact. For instance, the pan operator mixes syrup and A molasses to obtain a mixture of 70 purity for crystallization for C massecuite. Before injecting the seed, he needs to know if the purity is correct. After seeding and completing the pan, he might have made purity corrections (feeding syrup or A molasses alone) and must know the end results. The preparation is as follows.

A small quantity of massecuite (or mixture) is mixed, without being weighed, with a quantity of water, also undetermined, to make a solution of about 10-25 brix. Brix and pol of this solution are determined as if it were a juice. While the results are awaited, the pan is stopped (steam closed).

The cyclone system is also important to the final purity of C massecuite. When the pan is 95% full, the cyclone is made and, according to the results, the last 5% can be applied correctively to reach a desired end purity. The addition could be B molasses, A molasses, or even syrup, if so indicated: B molasses is added in the case of too high a cyclone, and A molasses or syrup in the case of low results.

*Note.* As a rule, high-purity material should not be fed to the pan at the final stage. It counteracts optimum exhaustion. In the above case, only a small amount is needed to prevent extremely low end purities in C massecuite. A cyclone analysis in the laboratory should always have preference above routine work. The results should be conveyed by "intercom" to the pan-floor personnel.

## REFERENCES

1. Spencer-Meade, *Cane Sugar Handbook*, 9th edn., Wiley, New York, 1963, p.532.

1 of 3

Table 12 CALCULATING SHEET FOR DAILY REPORT

Mill ____________ Date ______ 19 __ No. ______

| | | | | |
|---|---|---|---|---|
| 1 | | cane ground | | |
| 2 | | hours grinding | : | |
| 3 | | tons cane ground per hour | | |
| 4 | | hours lost time | | |
| 5 | | total hours | : | |
| 6 | | lost time % total time | | |
| 7 | 61 | % fiber in cane × 100 | | |
| 8 | 1 | cane ground | × | |
| 9 | 52 | tons fiber in cane(tons fiber in bagasse) | | |
| 10 | 2 | hours grinding | : | |
| 11 | | tins fiber ground per hour | | |
| 12 | | reading imbibition flow × factor | | |
| 13 | | tons imbibition water | | |
| 14 | 1 | cane ground | | |
| 15 | 13 | tons imbibition water | : | |
| 16 | | imbibition % cane | | |
| 17 | | gal diluted juice × weight of 1 gal at brix ____ : 2205 | | |
| 18 | | tons diluted juice | | |
| 19 | | brix diluted juice : 100 | | |
| 20 | 18 | tons diluted juice | × | |
| 21 | | tons brix in diluted juice | | |
| 22 | | pol diluted juice : 100 | | |
| 23 | 18 | tons diluted juice | × | |
| 24 | | tons pol in diluted juice | | |
| 25 | | (1.4 40/pur) × pol = available sugar in juice : 100 | | |
| 26 | 18 | tons diluted juice | × | |
| 27 | | tons available sugar in diluted juice | | |
| 28 | 1 | tons cane ground | | |
| 29 | 13 | tons imbibition water | + | |
| 30 | | | | |
| 31 | 18 | tons diluted juice | − | |
| 32 | | tons bagasse | | |
| 33 | | pol bagasse × 100 | | |
| 34 | | purity last mill juice | : | |
| 35 | | brix bagasse | | |
| 36 | | moisture % bagasse | + | |
| 37 | | solubles % bagasse | | |
| 38 | | | | 100.00 |
| 39 | 37 | solubles % bagasse | − | |
| 40 | | fiber % bagasse | | |
| 41 | 35 | brix bagasse | | |
| 42 | 32 | tons bagasse : 100 | × | |
| 43 | | tons brix bagasse | | |
| 44 | 33 | pol bagasse | | |
| 45 | 32 | tons bagasse : 100 | × | |
| 46 | | tons pol in bagasse | | |
| 47 | 36 | moisture % bagasse | | |
| 48 | 32 | tons bagasse : 100 | × | |
| 49 | | tons moisture bagasse | | |
| 50 | 40 | fiber % bagasse | | |
| 51 | 32 | tons bagasse : 100 | × | |
| 52 | | tons fiber bagasse (or cane) | | |

2 of 3

Table 12 continued

| | | | | |
|---|---|---|---|---|
| 53 | 24 | tons pol in diluted juice | | |
| 54 | 46 | tons pol in bagasse | + | |
| 55 | | tons pol in cane | | |
| 56 | 55 | tons pol in cane × 100 | | |
| 57 | 1 | tons cane | : | |
| 58 | | pol % cane | | |
| 59 | 52 | tons fiber × 100 | | |
| 60 | 1 | tons cane | : | |
| 61 | | fiber % cane | | |
| 62 | 13 | tons imbibition water 100 | | |
| 63 | 52 | tons fiber | : | |
| 64 | | imbibition % fiber | | |
| 65 | 24 | tons pol in diluted juice | | |
| 66 | 55 | tons pol in cane | : | |
| 67 | | pol extracted % pol in cane | | |
| 68 | | | | 100.00 |
| 69 | 67 | pol extraction | − | |
| 70 | | "A" | | |
| 71 | | | | 100.00 |
| 72 | 61 | fiber % cane | − | |
| 73 | | "B" | | |
| 74 | 70 | "A" | | |
| 75 | 73 | "B" | × | |
| 76 | | | | |
| 77 | 61 | fiber % cane | : | |
| 78 | | absolute juice lost % fiber | | |
| 79 | | | | 100.00 |
| 80 | 78 | absolute juice lost % fiber : 7 | − | |
| 81 | | reduced extraction at 12.5% fiber | | |
| 82 | | | | |
| 83 | | | | |
| 84 | | brix primary juice | | |
| 85 | | brix factor | × | |
| 86 | | brix normal juice | | |
| 87 | | purity diluted juice : 100 | | |
| 88 | 86 | brix normal juice | × | |
| 89 | | pol normal juice | | |
| 90 | 21 | tons brix in diluted × 100 | | |
| 91 | 86 | brix normal juice | : | |
| 92 | | tons normal juice | | |
| 93 | 92 | tons normal juice × 100 | | |
| 94 | 1 | tons cane | : | |
| 95 | | normal juice extraction | | |
| 96 | 18 | tons diluted juice × 100 | | |
| 97 | 1 | tons cane | : | |
| 98 | | diluted juice extraction | | |
| 99 | 86 | brix normal juice | | |
| 100 | 19 | brix diluted juice | − | |
| 101 | | difference × 100 | | |
| 102 | 86 | brix normal juice | : | |
| 103 | | dilution % juice | | |

Table 12 continued

3 of 3

| | | | | |
|---|---|---|---|---|
| 104 | 103 | dilution % cane (No.103 : No.98) | | |
| 105 | 1 | tons cane | x | |
| 106 | | tons dilution (No.18 – No.92) | | |
| 107 | 58 | pol in cane x 100 | | |
| 108 | | pol in primary juice | : | |
| 109 | | Java ratio | | |
| 110 | 46 | tons pol bagasse x 100 | | |
| 111 | 52 | tons fiber | : | |
| 112 | | pol % fiber in bagasse (milling losses) | | |
| 113 | | filter revolutions/day area in sq ft | | |
| 114 | | weight of 1 sq ft mudcake in lb | x | |
| 115 | | lb mud in 24 hours | | |
| 116 | | : 2205 = tons mud/day | | |
| 117 | | pol mud | | |
| 118 | 116 | tons mud : 100 | x | |
| 119 | | tons pol in mud | | |
| 120 | | | | 100.00 |
| 121 | | % solids in mud | – | |
| 122 | | % moisture in mud | | |
| 123 | | gal.molasses produced at brix | | |
| 124 | | lb solids per gal at brix | x | |
| 125 | | lb solids in molasses | | |
| 126 | | lb solids at brix 80 (table) | : | 9.418 |
| 127 | | equivalent gal molasses of 80 brix | | |
| 128 | | pol sugar – 92 | | |
| 129 | | | x | 1.75 |
| 130 | | | | |
| 131 | | | + | 93.00 |
| 132 | | | | |
| 133 | | tons sugar produced : 100 | x | |
| 134 | | tons raw value (sugar of 96 pol) | | |
| 135 | 27 | tons available sugar | | |
| 136 | | tons equivalent 96° (Spencer table) | | |
| 137 | 134 | tons equivalent 96° made (raw value) | – | |
| 138 | | tons equivalent 96° estimated in process | | |
| 139 | | tons equivalent 96° M and E | | |
| 140 | | tons equivalent 96° recovered (table) | : | |
| 141 | | boiling house efficiency (bhe) | | |
| 142 | 139 | tons equivalent 96° M and E | | |
| 143 | 1 | tons cane | : | |
| 144 | | tons equivalent 96° M and E/ton of cane | | |
| 145 | | | x | 2205 |
| 146 | | lb equivalent 96° per ton of cane | | |
| 147 | 139 | tons equivalent 96° M and E | | |
| 148 | 1 | tons cane : 100 | : | |
| 149 | | yield 96° | | |
| 150 | | moisture of sugar | | |
| 151 | | 100 – pol of sugar | : | |
| 152 | | safety factor | | |

Table 13 DAILY FABRICATION REPORT

Mill ____________ Date ____________ 19__ No. ______

| milling data | today | to date |
|---|---|---|
| crop days | | |
| hours grinding | | |
| hours lost | | |
| lost time % total | | |
| cane | — | — |
| tons ground | | |
| tons burnt | | |
| tons ground/hour | | |
| % pol | | |
| % fiber | | |
| fiber ground/hour | | |
| imbibition % cane | | |
| dilution % cane | | |
| dilution % normal j. | | |
| extraction | — | — |
| diluted juice | | |
| normal juice | | |
| pol % pol in cane | | |
| reduced | | |
| java ratio | | |
| bagasse | — | — |
| % pol | | |
| % moisture | | |
| % fiber | | |
| pol % fiber | | |
| % cane | | |
| production data | | |
| sugar | — | — |
| made (M) | | |
| estimated in process (E) | | |
| introduced | | |
| shipped | | |
| in stock | | |
| pol | | |
| moisture | | |
| ash | | |
| safety factor | | |
| equivalent 96° M + E | | |
| lb 96°/ton cane | | |
| yield 96° | | |
| yield commercial | | |
| final molasses | — | — |
| gal made | | |
| gal shipped | | |
| gal in stock | | |
| observations : | | |

| analysis | brix | pol | pur | gluc | ratio |
|---|---|---|---|---|---|
| prim. juice | | | | | |
| normal juice | | | | | |
| diluted juice | | | | | |
| last mill " | | | | | |
| clarif. juice | | | | | |
| filter juice | | | | | |
| syrup | | | | | |
| A massecuite | | | | | |
| B massecuite | | | | | |
| C massecuite | | | | | |
| A molasses | | | | | |
| B molasses | | | | | |
| final " | | | | | |
| magma | | | | | |

final molasses

| brix | pol | purity | clerg | gluc | tot.sug | %cane |
|---|---|---|---|---|---|---|
| | | | | | | |

| miscellaneous | today | to date |
|---|---|---|
| mud moisture | | |
| mud pol | | |
| mud lb/ton cane | | |
| inj.water temp | | |
| return temp | | |
| lb lime/t cane | | |
| firewood used | | |
| fuel oil used | | |
| acidity prim.j. | | |
| pH clar.juice | | |
| pH syrup | | |
| pH fin molasses | | |
| pH boiler feed | | |
| inches rain | | |
| outside temp. | | |

lost time

| reason | from | to | hours |
|---|---|---|---|
| | | | |
| total today | — | — | |

Superintendent ____________ Chief Chemist ____________

Table 14. BI-WEEKLY FABRICATION REPORT

Mill __________ from ________ to ______ .19__ No. ______

| milling data | | run | to date |
|---|---|---|---|
| crop days | | | |
| hours grinding | | | |
| hours lost | | | |
| lost % total time | | | |
| cane ground | t | | |
| cane purchased | t | | |
| grinding rate/hour | t | | |
| grinding rate/crop day | t | | |
| extraction: diluted juice | | | |
| normal juice | | | |
| pol % pol in cane | | | |
| reduced 12.5 fiber | | | |
| imbibition % cane | | | |
| % fiber | | | |
| dilution % cane | | | |
| fiber ground/hour | t | | |
| Java ratio | | | |

| production data | run | to date |
|---|---|---|
| sugar made | | |
| sugar estimated in process | | |
| sugar M and E | | |
| sugar equivalent 96° | | |
| sugar lb 96°/t cane | | |
| sugar polarization | | |
| yield equiv. 96° % cane | | |
| yield commercial | | |
| pol % pol in cane | | |
| pol % pol in juice | | |
| final molasses gal. prod. | | |
| final molasses in process | | |
| final molasses M and E | | |
| final mol. equiv. 80 brix | | |
| final mol. gal 80 bx/t cane | | |
| boiling house efficiency | | |
| mud tons made | | |
| mud tons solids | | |

| sucrose balance | % pol extracted | | % of cane | |
|---|---|---|---|---|
| | run | to date | run | to date |
| lost in bagasse | | | | |
| lost in molasses | | | | |
| lost in mud | | | | |
| lost undetermined | | | | |
| total losses | | | | |
| recovered in sugar | | | | |
| pol in juice/cane | | | | |
| pol in cane | 100.0 | 100.0 | | |

| | bagasse | | | | | cane | |
|---|---|---|---|---|---|---|---|
| | pol | moist | fiber | %cane | %fiber | pol | fiber |
| run | | | | | | | |
| to date | | | | | | | |

| fuel | total | | per t of cane | |
|---|---|---|---|---|
| | run | to date | run | to date |
| | | | | |

| miscellaneous data | | | run | to date |
|---|---|---|---|---|
| shipped | molasses | gal | | |
| | sugar | | | |
| stock | molasses | gal | | |
| | sugar | | | |
| materials | lime | lb | | |
| | lime/t cane | lb | | |
| | mur. acid | | | |
| | acid/t cane | | | |
| | caustic soda | | | |
| | soda/t cane | | | |
| | soda ash | | | |
| | soda ash/t cane | | | |
| | | | | |
| | | | | |

analytical data

| analysis of | | brix | pol | purity | glucose | glucose ratio | pH | acidity | ash | moist | clerg | total sugar |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| primary juice | run | | | | | | | | | – | | – |
| | to date | | | | | | | | | – | | – |
| normal juice | run | | | | | | | | | – | | – |
| | to date | | | | | | | | | – | | – |
| diluted juice | run | | | | | | | | | – | | – |
| | to date | | | | | | | | | – | | – |
| residual juice | run | | | | | | | | | – | | – |
| | to date | | | | | | | | | – | | – |
| clarified juice | run | | | | | | | | | – | | – |
| | to date | | | | | | | | | – | | – |
| syrup | run | | | | | | | | | – | | – |
| | to date | | | | | | | | | – | cu ft/t cane | |
| A massecuite | run | | | | | – | | | | – | | – |
| | to date | | | | | – | | | | – | – | |
| B massecuite | run | | | | | – | | | | – | | – |
| | to date | | | | | – | | | | – | – | |
| C massecuite | run | | | | | – | | | | – | | – |
| | to date | | | | | – | | | | – | – | |
| A molasses | run | | | | | – | | | | – | total | |
| | to date | | | | | – | | | | – | – | |
| B molasses | run | | | | | – | | | | – | – | – |
| | to date | | | | | – | | solids | | – | – | – |
| final molasses | run | | | | | – | | | | | | |
| | to date | | | | | – | | | | | | |
| magma | run | | | | | – | – | – | – | – | – | – |
| | to date | | | | | – | – | – | – | – | – | – |
| mud | run | – | | – | – | – | – | | – | | – | – |
| | to date | – | | – | – | – | – | | – | | – | – |
| sugar | run | | | – | | – | | – | | | | |
| | to date | | | – | | – | | – | | | | |

| analysis of lost time | hours | | % total time | |
|---|---|---|---|---|
| | run | to date | run | to date |
| holidays | | | | |
| rain | | | | |
| no cane | | | | |
| general mechanical | | | | |
| chokes | | | | |
| cleaning | | | | |
| no steam/electr. | | | | |
| miscellaneous | | | | |
| | | | | |
| total | | | | |

actual size 11" X 18"

superintendent

chief chemist

## CHAPTER 35

# LABORATORY REPORTS AND BOOKKEEPING

The laboratory produces daily and bi-weekly reports. In some countries weekly reports are preferred. But if these are as detailed as they ought to be, the task of producing them every week will prove too arduous and the quality of reliability will suffer.

A daily report should give the following information:

(1) grinding and time data
(2) extraction data
(3) production data, including yield of sugar and molasses
(4) analysis
(5) fuel and material use
(6) lost-time account
(7) miscellaneous (pH, rain, temperature, etc.)

The bi-weekly report gives the same information, but in addition contains:

(a) a sucrose balance (losses and recovery)
(b) all analyses of "run" and "to date"
(c) an estimate of products in "process"

Daily and bi-weekly reports should be standard in form for all mills in the same country. This makes direct comparison of results easier and enables the reports to be understood more easily by everyone concerned. Uniformity of reporting should be the concern of the local sugar authorities of all countries.

Some years ago, in Java, the Experimental Station, P.O.J., was responsible for uniform reporting and issued standard report forms for all mills (about 160). The advantage is that nothing has to be "invented" again or re-investigated if reports are fully written up. In Central and South American countries and the Caribbean, each mill has its own type of report form, and even worse, the form is changed from year to year. Only Peru has a standard report form for all mills.

As part of this chapter, a daily and bi-weekly report form is shown. This might serve as a model suitable for adoption. The possible variation should be the local units in use in certain countries, such as pounds, kilograms, metric tons, short tons, quintals, etc. In short, there is uniformity in sugar analysis and calculations, but a state of chaos as regards report forms.

Of course, the laboratory maintains a bookkeeping in which all supporting data for its daily reports are collected. It consists of the following.

(1) The daily analysis sheet, on which all analyses are collected and averaged for the day.

(2) A lost-time book, in which not only is down-time recorded, including an account of the causes, but also equipment down-time, not responsible for stoppage of grinding. This accounting can prove valuable later when replacement of equipment is being considered (diagnositic information).

(3) A cane book, in which all weighings are reported and classified according to independent growers. Here analyses are added if required for financial liquidation.

(4) A massecuite accounting based on report tickets from the pan-floor. Each strike sample is accompanied by a ticket (three different colors for three different strike types). It contains cu ft (hl, $m^3$, etc.) of strike volume, consecutive number, date, time started and finished, number of crystallizer.

(5) A sugar-storage accounting in cooperation with the sugar warehouse supervisor.

(6) A sugar-in-procress accounting.

(7) Miscellaneous items, such as fuel-oil consumption and stock.

(8) Cumulative data from day to day, for calculating averages.

(9) A warehouse inventory of chemical products used in the process, such as lime, muriatic acid, caustic soda, soda ash, formaldehyde, etc.

(1) The daily analysis worksheet (Spanish ''hoja diaria'') contains all analysis results for each shift. The last shift of the day makes the additions and averages of each intermediate product. In Table 15, the daily worksheet is given on a reduced scale. In reality it is 22″ × 17″. Of course, it must be adapted for local conditions. If there are four boilers, for instance, it should have space for four boilers.

Also shown is a complete data-calculation sheet. This is particularly useful when the person employed to calculate the reports is absent, and someone else has to do this work, but does not have the routine. Again, it is necessary to add (or omit) local features, such as having a different system for juice weighing (or measuring), or the use of absolute instead of normal juice, etc.

(2) The lost-time account must be maintained by the fabrication supervisor and/or the technical supervisor of each shift. Each stop should be clearly logged and its causes indicated.

The purpose of this account is to show at the end of the season where equipment failed and where there are bottlenecks, so that the necessary action can be taken to avoid these problems.

The cane weight and analysis account of the cane should be subject to local requirements, as each country has its own government control on cane purchasing from independent growers. There are only a few mills where all the cane is owned by the factory. Whatever the requirements, it is always necessary to have a cane book, which lists date, car (truck) number, name of grower, quantity of cane and if analysis available, name of section of origin.

In Java, there was an alphabetical file with small outline maps of each field together with this cane account. The dates of planting were entered in red ink, e.g. 4/10-4/21, average date 4/15. The same information on harvesting was written in black ink. At one side of the file card, cane age, analysis, irrigation and fertilizer data, etc. were noted.

(4) Massecuite accounting gives important information, which should never be ignored. Even so, in perhaps 90% of all mills, it is omitted or at least very incomplete. The accounting of A and B massecuites is rather simple, while the C massecuite account should provide data before and after cooling, to control optimum exhaustion of the final molasses.

Table 15. Daily worksheet of analyses.

| primary juice | | | | | | | |
|---|---|---|---|---|---|---|---|
| hour | brix | pol | pur | gluc | ratio | acid | pH |
| | | | | | | | |
| ave | | | | | | | |
| diluted juice | | | | | | | |
| | | | | | | | |
| ave | | | | | | | |
| last mill juice | | | | | | | |
| | | | | | | | |
| ave | | | | | | | |
| clarified juice | | | | | | | |
| | | | | | | | |
| ave | | | | | | | |
| syrup | | | | | | | |
| | | | | | | | |
| ave | | | | | | | |

| massecuite A | | | | |
|---|---|---|---|---|
| hour | cu ft | brix | pol | pur |
| | | | | |
| ave | | | | |
| massecuite B | | | | |
| | | | | |
| ave | | | | |
| massecuite C | | | | |
| | | | | |

| bagasse | | |
|---|---|---|
| hour | mst | pol |
| | | |

| Boiler feed water | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| sugar | pH | hardness | alcalin. | hydr | chloride | phosph | sulfite | TDSppm |
| | | | | | | | | |
| boiler 1 | | | | | | | | |
| | | | | | | | | |
| boiler 2 | | | | | | | | |
| | | | | | | | | |

steam produced

mills lb/24h = lb/h
turbo-gen lb/24h = lb/h
make-up lb/24h lb/h
total lb/h

| heaters | | | | evaporators | | | | | vacuum pans | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | P | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 5 | 6 |
| | | | | | | | | | | | | | | |

| quantities | | | | | | | |
|---|---|---|---|---|---|---|---|
| juice | imbib | pneumerc. | lime | acid | c.soda | s.ash | separ. |
| | | | | | | | |

| A molasses | | | | B molasses | | | |
|---|---|---|---|---|---|---|---|
| shift | brix | pol | pur | shift | brix | pol | pur |
| | | | | | | | |
| ave | | | | ave | | | |

| magma | | | |
|---|---|---|---|
| shift | brix | pol | pur |
| | | | |
| ave | | | |

| final molasses | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| shift | brix | pol | pur | gluc. | clerg | tot sug | ash | solids | pH | real pur. | g/ash |
| | | | | | | | | | | | |

| sugar | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| hour | moist | pol | hour | moist | pol | hour | moist | pol |
| | | | | | | | | |
| | | | | | | ave | | |

| mud | | |
|---|---|---|
| lb | moist | pol |
| | | |
| ave | | |

| lost time | from | to | hours |
|---|---|---|---|
| | | | |
| total hours | | | |

cane weights
cane entered
cane in yard
total today
cane ground
left in yard

actual size: 22" x 17"

Control starts with blocknote-type tickets, filled out by the pan boilers, and delivered to the laboratory, together with the sample of each strike. Tickets should have a different color for each kind of strike, for instance white for A; yellow for B; orange for C. They should indicate date, strike number, strike volume (hl, cu ft, $m^3$, etc.), panman's name, hour started, hour discharged, number of crystallizer.

After analysis, the laboratory chemist write the brix, pol and purity on it and returns it to the pan floor, where it is kept in a file. For A and B massecuites the same data are transferred to the massecuite book in the laboratory. Strike volumes are totaled and analysis averaged for the next bi-weekly report. The C massecuite account should have the same information, but in addition it should show the crystal yield at the moment of pan discharge and also at the moment of crystallizer discharge (after the cooling period).

This is simple, provided that crystallizers are used in batch form, but in the case of continuous operation it is impossible to know exactly when purging of a certain strike begins or ends. The only guideline is the massecuite volume of the 24-hour day, compared with the total volume of the crystallizer system. For instance, if today's production was 4000 cu ft, and the system contains 10,000 cu ft, then the average retention is 2½ days or 60 hours. It can be assumed in this case that the strike remains in the system 60 hours, and that analysis made at crystallizer discharge occurs 60 hours after pan discharge.

For C massecuite, the left-hand side of the book is for pan discharge, and on the same line at the right-hand side the results after cooling are noted. In this way, each line gives results of one strike before and after cooling. In other words, it shows the efficiency of the crystallizer station.

To be able to calculate crystal yield, a laboratory centrifugal is required, to separate grain and molasses of the sample at pan discharge. Later, at crystallizer discharge, the results of the factory centrifugals are used.

Crystal yield in % of weight per 100 brix is:

$$\frac{\text{purity massecuite} - \text{purity molasses}}{\text{purity sugar} - \text{purity molasses}} \times \text{brix mc.}$$

For instance:

| | |
|---|---|
| C massecuite purity | = 58 |
| C sugar purity | = 90 |
| C molasses at discharge | = 45 |
| C molasses at purging | = 32 |
| brix massecuite | = 96 |

Yield at pan discharge (left-hand side of book)

$$\frac{58 - 45}{90 - 45} \times 96 = \quad 27.73\% \text{ (laboratory centrifugal)}$$

Yield at crystallizer discharge (right-hand side)

$$\frac{58 - 32}{90 - 32} \times 96 = \quad 45.03\% \quad \text{(factory centrifugal)}$$

The difference is 15.3%, which means that, during retention in the crystallizers, 15% of its total weight is extracted from the molasses and deposited as sugar on the existing crystals. If a crystallizer is defective (e.g. water leaking from the cooling elements into the massecuite), the yield increase is lower or can even be negative.

(5) Sugar storage accounting requires no explanation. Only average analysis should be calculated and added from day to day, according to the quantity produced.

(6) Sugar ''in process'' should be determined daily at the close. It is very important to know when ''sugar in process'' increases, since it could reach the point where it causes shutdown of the mill. Also, accounting mistakes will be revealed, such as juice-weighing error. Such an error might falsely indicate that more sugar entered the process than actually was the case. If this happens, ''sugar in process'' will appear to increase from day to day, although in fact it does not.

As estimating sugar ''in process'' is a daily routine, it sould be made as simple as possible. It is an estimate and need not be too meticulous, as the content of each tank or pan is also estimated by sight. The sugar estimated ''in process'' comes from the following:

(a) Equipment which in working condition always contains the same quantity of materials, such as clarifiers, juice heaters, evaporators, etc.

(b) Equipment working under variable conditions, and batches, such as vacuum pans, supply tanks, etc.

It is therefore logical to design a printed form for sugar ''in process''. However, some assumptions must be made. In the first place, analysis of all intermediate products can be averaged from actual data obtained. This is good enough because quantities are also only roughly estimated. An error in quantity has much more influence than an error in the averaged purity.

If the mill is grinding, all the fixed quantities mentioned under (a) can be added and the available sugar calculated, as a constant quantity. Crystallizers, pans, supply tanks, sugar on the floor, etc., should be estimated. For this purpose, all tanks and pans can have a scale calibrated directly in available sugar, by assuming averaged purities.

It is important that inventory checks should always be done by the same person, to ensure as far as possible a constant estimating error. In so doing, one can be quite sure that the variations from day to day are true. After all, it is not so much the quantity that matters, but rather the increase or decrease from day to day.

Making a daily inventory of sugar ''in process'' is a ''watchdog'' operation, to prevent accumulation of daily errors, which might add up to an appreciable deficit at the end of the crop (see Table 16).

(8) Cumulative data for the bi-weekly report is best maintained in totals of weight: weight material, weight of solids (brix), weight of pol. It is best recorded in a book, each page for a bi-weekly period with totals carried over.

Table 16. ESTIMATED SUGAR IN PROCESS

#___ Mill ________________ Date ________ 19 __

bhe = %

| | lb when full | lb % full | Available sugar when full | Available sugar estimated |
|---|---|---|---|---|
| FIXED | | | | |
| Liming tank raw juice | | | | |
| Limed juice tank | | | | |
| Scale raw juice | | | | |
| Juice heaters, raw juice | | | | |
| Clarifier raw juice | | | | |
| Filter | | | | |
| Clarified juice tank | | | | |
| Pre - heater | | | | |
| Evaporators | | | | |
| | | | | |
| VARIABLE | | | | |
| Syrup tanks | | | | |
| A molasses tanks | | | | |
| B molasses tanks | | | | |
| A pans (+magma) | | | | |
| B pans (+grain) | | | | |
| C pans | | | | |
| A crystallizers+magma | | | | |
| B crystallizers+grain | | | | |
| C crystallizers | | | | |
| A mixer | | | | |
| B mixer | | | | |
| C mixer | | | | |
| A centrifugals | | | | |
| B centrifugals | | | | |
| C centrifugals | | | | |
| Sugar on floor | | | | |
| Sugar in bin | | | | |
| Avail. sugar in process today | | | | |
| Avail. sugar in process yesterday | | | | |
| DIFFERENCE ( + or - ) | | | | |

CHAPTER 36

# THE PURCHASE OF CANE

There are no set rules for cane purchasing, because each country has its own standards and governmental regulations. It is clear of course that price determination on weight alone, with no compensation for quality, cannot be correct. Even so, in many countries cane is purchased this way. It is also usually purchased "as is" with no discount for foreign matter, such as stones, trash, etc. Undoubtedly, the legal protection of a cane grower is much more developed than the legal position of the mill owner. It is probably a matter of numbers: there are many more growers than mill owners. It is not exceptional that one sugar mill should be served with cane from 100-800 growers, especially in countries of heavily developed "small farm owners", such as Haiti, Jamaica, Barbados and even Mexico.

If any quality factors are to be applied in the purchasing of cane, it is obvious that reliable samples must be taken and analyses made. In many countries (e.g. the U.S.A.), the frequency of sampling and the system is controled by the Department of Agriculture and is subject to rigid rules. This is also the case with the weight determination.

If all these factors are under strict control, there is no problem in applying a weight correction for trash, as long as it falls under the same honest rules.

It is no myth that cane growers put stones under the cane load to increase weight, but then, on the other hand, some cheating occurs in cane weighing from the buyer's side. For this reason, discount for trash is very unpopular. In the U.S.A. it is applied, and both gross cane and net cane are reported.

There is a great advantage in buying cane on a quality basis; the cane grower is made aware of the sales value of good cane as opposed to poor cane. This incentive does not exist when weight is the only criterion. The grower is also prompted not to leave cut cane stockpiled in the field, as heavy losses occur rather soon after cutting.

The biggest problem is the sampling of the cane. If done by hand, there is a possibility of bias or even fraud. Recently, most sampling has been done by core drilling in the middle of a cane load.

In cases where factories buy cane from a few growers owning large cane fields, sampling is much simpler than for mills serving hundreds of small growers. In the first case, one or two samples per day are adequate for one grower, but in the latter case, each small load must be sampled and analyzed.

The buyer should always have the right to reject cane because of unacceptable quality, such as frozen cane, burned cane, excessive trash, stones, tops, etc., excessive time lapse between cutting and delivery (acidity test).

The following are some of the rules set by the U.S. Department of Agriculture for cane purchase in Florida[1]:

(a) The scale should be checked periodically, but at least once by the Department of Agriculture and then regularly by an authorized testing crew. It must be rechecked at the beginning and once during the season. There must be a test wagon, approximately the weight of a truck.

(b) Side-dump cars can be tared once a week, but if cane is delivered by semi-trailer it should be weighed in and out.

(c) Samples of first expressed juice must be analyzed every hour.

(d) The sample mill factor is brix sample mill divided by brix undiluted juice.* All brixes to two decimal places.

(e) Samples must consist of ten stalks for each normal juice sample.

(f) Tests must be related to every 60 tons of cane.

(g) Acidity and turbidity must be determined once daily.

*undiluted juice is normal juice.

These are just some requirements illustrating the extent of government involvement.

## Trash in cane, and its consequences

It can be safely assumed that reasonably clean cane contains about 3% trash. If the trash content increases, losses also increase, because the extraneous matter retains sugar, as do bagasse and mud. By retention of sugar in extraneous matter, the purity of the juice decreases, because the sugar retained comes from the sugar in juice. Tests published in the I.S.J.[2] of July 1966 show a range of juice purities (see Table 17). The table shows that discount for trash is a very reasonable measure.

Table 17. Influence of trash on sugar losses

| Basic purity | % Extraneous matter | Purity drop | Purity | Yield 96 pol | Tons sugar 96 pol in 100,000 t cane |
|---|---|---|---|---|---|
| 81.00 | 3 | 0.78 | 80.2 | 11.48* | 11480 |
| 81.00 | 5 | 1.30 | 79.7 | 11.29 | 11290 |
| 81.00 | 7 | 1.83 | 79.2 | 11.08 | 11080 |
| 81.00 | 9 | 2.34 | 78.7 | 10.87 | 10870 |
| 81.00 | 11 | 2.85 | 78.2 | 10.65 | 10650 |
| 81.00 | 13 | 3.37 | 77.6 | 10.42 | 10420 |
| 81.00 | 15 | 3.89 | 77.1 | 10.05 | 10050 |
| 81.00 | 17 | 4.41 | 76.6 | 9.65 | 9650 |

*assumed yield

In countries where cane is purchased by weight alone, it is quite understandable that both buyers and growers are trying to develop a system that takes cane quality into account, in addition to a basic cane-weight price. It is only logical that such a system should work in both directions: an increase in price for better than normal quality and a penalty for sub-normal quality.

About ten years ago, such a simple system was designed for use in Costa Rica, where no quality compensation had been known. In that country there are three cane regions of distinctly different production levels. The average yield for each region was calculated, together with average brix and purity of the juice. Tables were prepared with higher and lower available sugar figures, expressed as a correction factor: higher than 1 for premiums, and lower than 1 for penalties. One table was for pol, another one for purity. Of course, it was not intended to be a foolproof system, just a prototype to try to improve the purchasing system. After an introductory period, it was open to improvement. In Australia, the country where the most sophisticated systems were developed, a start was made in a simple way and improvements were gradually introduced.

The most sensitive point is the method of cane sampling. The latest improvement in this respect is the core drill, where biased selection of stalks is completely eliminated. In Tables 18 and 19, which relate to Costa Rica, there is a factor for purity, which has to be multiplied by the factor for pol.

Average purity for the zone is 85 and the pol is 13.8. Suppose a sample has purity 86.3 and pol 14.2. Then the correction factor is: $1.013 \times 1.040 = 1.053$. If weight of truck-load is 12.510 tons, premium-corrected weight $= 12.510 \times 1.053 = 13.173$ tons, which is the theoretical weight for payment of this cane truck-load. The advantage of the system is that it is an incentive for the grower to improve quality, which means using fertilizer, irrigation and careful handling as regards time delays in harvesting.

## Yield calculations

There are different formulae and ways of calculating yields expected from a sample of cane. One of the simplest formulae is the Puerto Rico formula devised by Valle, which is now also used in Louisiana and Florida, because of its simplicity.

$$\text{Yield} = \text{factor}\ (\text{pol} - 0.3\ \text{brix})$$

where pol = pol primary juice
brix = brix primary juice.

### Determination of factor

Pol and brix of primary juice are taken from the previous year's report, being the year's average. The production of sugar is also known, as well as tons of cane ground. If sugar has average pol, the yield is commercial yield and if sugar is "sugar 96°" it is equivalent 96° yield. By taking the previous year's yield obtained, pol and brix of primary juice, the factor can be calculated and applied for future yield calculations.

If a sample mill is used, then the brix and pol factors of this mill must be applied to convert the results to the expected results of the mill's tandem itself. If the Valle formula is used for a new mill, which has no precedents, then the factor is temporarily taken as unity, until results can be used for later correction.

## Fresh cane versus stale cane

Although already mentioned in Chapter 1, it must be emphasized again that the largest losses that can occur in a sugar industry are those due to leaving cane for an extended period of time after cutting, before grinding. Graphs show that leaving the cane in the open exposed to sun guarantees rapid deterioration. In the shade, the loss is only slightly less. This is not surprising, since in the hot sun (tropical countries), the juice evaporates fast and the increased temperatures accelerates inversion of sucrose. In the shade and under moist conditions, molds are easily formed and acid formation increases (smell of vinegar). If the cane remains exposed to heat and sun for a considerable time, the loss of juice is so high that the stalk dehydrates and forms a tube; i.e. a hollow center and a wooden appearance. Weight loss is very high, purity is low and juice content is virtually nil.

The deterioration is accelerated still more if the cane was burnt before harvesting. Damage by burning is very slight provided that the cane is ground within a safe time-limit, but after that losses increase rapidly.

From the point of view of the cane grower, there is a tendency to include tops and water sprouts with the cane, as they represent weight. This is another good reason for incorporating a quality correction to the cane value, as the sugar content and purity of tops and sprouts ruin the quality premium and increase penalties. Yields of sprouts and tops are never more than 6% and most often around 3%. Purity is never above 60.

As a rule, all juices with purities lower than the purity of the last expressed juice should be rejected and the cane should not be accepted even after grinding it. After all, who wants to buy impurities?

## REFERENCES

1. Department of Agriculture, Florida, Personal communication, 1962.
2. *International Sugar Journal,* London, July 1966.

Table 18. COSTA RICA CANE QUALITY.
Low Atlantic coast slope, average production 160 lb/t cane.
Table of compensation factors of primary juice pol.

Decimals of pol

| % pol | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 0.430 | 0.445 | 0.460 | 0.475 | 0.490 | 0.505 | 0.520 | 0.535 | 0.550 | 0.565 |
| 11 | 0.580 | 0.595 | 0.610 | 0.625 | 0.640 | 0.655 | 0.670 | 0.686 | 0.700 | 0.715 |
| 12 | 0.730 | 0.745 | 0.760 | 0.775 | 0.790 | 0.805 | 0.820 | 0.835 | 0.850 | 0.865 |
| 13 | 0.880 | 0.895 | 0.910 | 0.925 | 0/940 | 0.955 | 0.970 | 0.985 | 1.000 | 1.010 |
| 14 | 1.020 | 1.030 | 1.040 | 1.050 | 1.060 | 1.070 | 1.080 | 1.090 | 1.100 | 1.110 |
| 15 | 1.120 | 1.130 | 1.140 | 1.150 | 1.160 | 1.170 | 1.180 | 1.190 | 1.200 | 1.210 |
| 16 | 1.220 | 1.230 | 1.240 | 1.250 | 1.260 | 1.270 | 1.280 | 1.290 | 1.300 | 1.310 |
| 17 | 1.320 | 1.330 | 1.340 | 1.350 | 1.360 | 1.370 | 1.380 | 1.390 | 1.400 | 1.410 |
| 18 | 1.420 | 1.430 | 1.440 | 1.450 | 1.460 | 1.470 | 1.480 | 1.490 | 1.500 | 1.510 |
| 19 | 1.520 | 1.530 | 1.540 | 1.550 | 1.560 | 1.570 | 1.580 | 1.590 | 1.600 | 1.610 |
| 20 | 1.620 | 1.630 | 1.640 | 1.650 | 1.660 | 1.670 | 1.680 | 1.690 | 1.700 | 1.710 |

Table 19. COSTA RICA CANE QUALITY.

Low Atlantic coast slope, average production 160 lb/t cane.

Table of compensation factors of primary juice purity.

Decimals of purity.

| juice purity | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 75 | 0.825 | 0.827 | 0.829 | 0.831 | 0.833 | 0.835 | 0.837 | 0.839 | 0.841 | 0.843 |
| 76 | 0.845 | 0.847 | 0.849 | 0.851 | 0.853 | 0.855 | 0.857 | 0.859 | 0.861 | 0.863 |
| 77 | 0.865 | 0.867 | 0.869 | 0.871 | 0.873 | 0.875 | 0.877 | 0.879 | 0.881 | 0.883 |
| 78 | 0.885 | 0.887 | 0.889 | 0.891 | 0.893 | 0.895 | 0.897 | 0.899 | 0.901 | 0.903 |
| 79 | 0.905 | 0.907 | 0.909 | 0.911 | 0.913 | 0.915 | 0.917 | 0.919 | 0.921 | 0.923 |
| 80 | 0.925 | 0.926 | 0.927 | 0.928 | 0.930 | 0.932 | 0.934 | 0.935 | 0.937 | 0.938 |
| 81 | 0.940 | 0.941 | 0.942 | 0.943 | 0.945 | 0.947 | 0.949 | 0.950 | 0.952 | 0.953 |
| 82 | 0.955 | 0.956 | 0.957 | 0.958 | 0.960 | 0.962 | 0.964 | 0.965 | 0.967 | 0.968 |
| 83 | 0.970 | 0.971 | 0.972 | 0.973 | 0.975 | 0.977 | 0.979 | 0.980 | 0.982 | 0.983 |
| 84 | 0.985 | 0.986 | 0.987 | 0.988 | 0.990 | 0.992 | 0.994 | 0.995 | 0.997 | 0.998 |
| 85 | 1.000 | 1.001 | 1.002 | 1.003 | 1.004 | 1.005 | 1.006 | 1.007 | 1.008 | 1.009 |
| 86 | 1.010 | 1.011 | 1.012 | 1.013 | 1.014 | 1.015 | 1.026 | 1.017 | 1.018 | 1.019 |
| 87 | 1.020 | 1.021 | 1.022 | 1.023 | 1.024 | 1,025 | 1.026 | 1.027 | 1.028 | 1.029 |
| 88 | 1.030 | 1.031 | 1.032 | 1.033 | 1.034 | 1.035 | 1.036 | 1.037 | 1.038 | 1.039 |
| 89 | 1.040 | 1.041 | 1.042 | 1.043 | 1.044 | 1.045 | 1.046 | 1.047 | 1.048 | 1.049 |
| 90 | 1.050 | 1.051 | 1.052 | 1.053 | 1.054 | 1.055 | 1.056 | 1.057 | 1.058 | 1.059 |
| 91 | 1.060 | 1.061 | 1.062 | 1.063 | 1.064 | 1.065 | 1.066 | 1.067 | 1.068 | 1.069 |
| 92 | 1.070 | 1.071 | 1.072 | 1.073 | 1.074 | 1.075 | 1.076 | 1.077 | 1.078 | 1.079 |
| 93 | 1.080 | 1.081 | 1.082 | 1.083 | 1.084 | 1.085 | 1.086 | 1.087 | 1.088 | 1.089 |
| 94 | 1.090 | 1.091 | 1.092 | 1.093 | 1.094 | 1.095 | 1.096 | 1.097 | 1.098 | 1.099 |
| 95 | 1.100 | 1.101 | 1.102 | 1.103 | 1.104 | 1.105 | 1.106 | 1.107 | 1.108 | 1.109 |

## CHAPTER 37

# PAINT AND COLOR SPECIFICATIONS

Surfaces of galvanized metal, stainless steel, non-ferrous surfaces, insulated piping and vessels are not normally painted. New equipment that leaves the manufacturer's workshop is normally painted with primer. In case of damage to the primer coat it should be touched up, prior to the finishing coat. Structural steel has only a primer and is not given a second or finishing coat. Unpainted structural steel must be cleaned of grease and dirt before primer painting.

The primer coat is an anti-corrosive paint, usually red oxide zinc chromate. It should comply with Federal (or local) specifications. A finishing coat could be any paint of a well known manufacturer, such as Sherwin Williams, Dupont, Carter, etc. After application, the primer coat should be left to harden for at least the time recommended by the manufacturer, before applying the finishing coat.

Surfaces of steel which are in contact with concrete should be painted with bituminous paint. Zinc-chromate primer is used between contacting steel surfaces. Uninsulated pipe lines are painted after removing grease and dust, with a primer and a finishing coat. The primer is anti-corrosive (red oxide zinc chromate) coat and the finishing a commercial gloss finish (Alkyd base enamel). Hot surfaces, such as smokestacks, reaching 700°F, should be painted with an aluminum paint of the Hi-Heat silicone alkyd type (Sherwin Williams).

The official color-coding schedule for pipes and tanks in a sugar mill is, in our opinion, too complicated, because it is based on one color with bands of a different color. Neither color is related to the material flowing through it, and therefore the code is not easily memorized.

The code is shown as follows:

| | |
|---|---|
| Juice | brown |
| Clarified juice | brown |
| Clarified muddy juice | green with white |
| Filtered juice | brown with green bands |
| Syrup | yellow |
| Massecuite, magma | brown with white bands |
| A molasses | brown with blue bands |
| B molasses | brown with blue bands |
| C molasses | brown with blue bands |
| Caustic soda | white with orange bands |
| Milk of lime | white with red bands |
| H.P. steam | red |
| Blow down | red |
| Boiler feed | red |
| L.P. steam | green with red bands |

| | |
|---|---|
| Vapor | gray |
| Condensate | dark blue |
| Hot water | light blue |
| Plant air | red with blue bands |
| Cold water | white |
| Injection water | black with white bands |
| Instrument air | blue with white bands |

The author believes that the color of the paint should imitate as far as possible the color of the material that is handled or be linked with the name of the material. For instance: H.P. steam is white; exhaust steam is gray.

Here follow the author's recommendations, as used in some mills in Cuba, Peru and Florida.

| | |
|---|---|
| Raw juice | very light green |
| Clarified juice | yellow |
| Clarified muddy juice | gray |
| Filtered juice | light green/gray bands |
| Syrup | light brown |
| A massecuite, magma | light brown |
| B massecuite | somewhat darker brown |
| C massecuite | dark brown |
| A molasses | light green |
| B molasses | darker green |
| C molasses | black |
| Caustic soda | orange (caution) |
| Milk of lime | white |
| Live steam | white |
| Exhaust steam | light gray |
| Vapor | darker gray |
| Hot water (also condensates) | light blue |
| Cold water | darker blue |
| River water (crude) | darker blue/white bands |
| Air | aluminum |
| Instrument panels and valves | light green |
| Steam valves | hi-heat aluminum |
| Electrical equipment (all devices) 110/220 V | light blue |
| Electrical equipment (all devices) 440 V or more | dark blue |
| All machinery (not hi-heat) | light gray |
| Insulated pans and vessels | not painted |
| **Danger:** all top rungs of handrails | yellow (unless made of brass) |

| | |
|---|---|
| Rotating devices or shaft ends | orange |
| Fire equipment and piping | red (signal red) |
| Beams and columns | gray (lower 4 ft of column black) |
| Cement (if required) | brick color |
| White sugar contact areas | white epoxy |
| Inside tanks | aluminum (or primer) |

It is recommended to paint undersides of floors, tanks, etc., where they form a ceiling for the lower floors, a white or cream color to reflect light and improve the over-all light effect. If steel floor plates are used, they can be painted either a light gray or green. Painting floor plates provides worthwhile protection of the metal and it improves over-all cleanliness of the factory. It also stimulates factory cleaning!

Each floor should have at least two aluminum-painted garbage cans (oil drums), as many ash containers as necessary, and sanitary facilities on all floors. In a sugar factory, an edible product is processed, and therefore over-all cleanliness is mandatory. Cigarette-butts belong in an ashtray, not in crystallizers or centrifugal mixers! Also, massecuite does not mix well with orange peels; these should go into the garbage cans instead!

Leaking material from pipes and any sort of dirt is usually more visible on clean floors, whether concrete or steel plates. In particular, around the mill tandem, dirty floors can even be the cause of infection and can also cause sugar losses. It should be remembered that sugar and concrete are enemies. Concrete mix contaminated with even a small amount of sugar-containing liquid, does not set or cure, but stays soft and moist. Through lack of cleanliness around the mills, sugar-containing liquid can even "corrode" old concrete. For this reason, most floors in the mill-houses in Java were covered with tiles.

## CHAPTER 38

# OFF-SEASON WORK FOR REGULAR STAFF PERSONNEL

There are certain jobs to be done in the off-season. For fabrication personnel, the most important are:
(1) shipping of sugar from warehouse
(2) cleaning and adjusting of instruments and gauges
(3) inventory of chemicals and spare parts in warehouse
(4) preparation of orders for chemcials, etc.
For (1), control of weight, sampling and analyzing are the requirements. For (2), cleaning and calibration of gauges (pressure, vacuum, temperature) are important, as the price of this kind of instrumentation increases constantly. It requires a minimum of tools and testing equipment.

In some countries, the off-season is longer than the grinding season and there is more time than necessary available for above jobs.

We always liked the system followed in Java for keeping the junior fabrication staff busy in the off-season period. In the first year, they were delegated to the general warehouse for a period of 2-3 months. This work gained them a knowledge of spare parts, tools and their names. They were also put in charge of the tool-house, issuing and collecting borrowed tools.

The next year, they spent some time in bookkeeping and general accounting, just to become acquainted with these departments.

In the third year, they worked in the field doing maintenance and tending the test fields, where all kind of testing was done, such as: optimum fertilizer tests; variety tests; plant systems; irrigation systems, etc. All this work was done under the supervision of the general field manager. In Java each mill grows, plants and harvests its own cane; only the land is rented.

All these auxiliary off-season jobs were not intended to make new accountants, field surveyors or warehouse managers of the junior fabrication staff, but just to give them some understanding of the problems in the other departments, and to increase their general over-all sugar mill knowledge and experience.

For instance, a thorough overhaul and repair is required of the filter station. The technical maintenance staff has no time to devote to this extra job. Therefore one or two of the regular fabrication staff are assigned to full-time supervision of this job instead, under the direct supervision of the chief engineer. In this way, one station can be given special attention each year.

## CHAPTER 39

# INTERPRETATION OF INFORMATION CONTAINED IN THE LABORATORY REPORTS

The daily and bi-weekly laboratory reports have to provide data, not only to the technical departments, but also to the general mill management, the company's main office or the owner(s) of the factory. In order to be able to judge the results, management and officers should be able to distinguish between good and bad results in any set of figures presented in a report.

In most mills, the general manager usually has an agricultural background and possibly some education in accounting or business administration, but he is seldom an engineer. It is obviously necessary to provide the management with certain pertinent daily data. It is therefore customary to send a message, before the daily report is completed, to enable the manager to inform his main office (or owner) of the most important data.

This message is called the ''Advance daily report'', and should contain information such as:

cane ground
cane in yard
sugar produced (made)
sugar in process (estimated)
pol in cane
pol of sugar
molasses produced
molasses shipped
molasses in stock (in tanks)
sugar shipped
sugar in warehouse
purities of mixed juice, final molasses
lost time and causes

and any further information that the management might require.

In many mills, the ''advance'' contains all the information the management ever requests, because in most cases the other information contained in the report is only of marginal interest to them. The purpose of this section is to explain simply the meaning and values of the figures for management and main office staff, so that they can interpret the results with more authority and confidence. To do this, let us consider a sample report such as the one shown in Table 13 (p.198).

## Milling data

"**Crop days**" are all days of 24 hours, between the time the grinding starts and finishes. If the day is from 6 a.m. to 6 a.m., and the grinding started at 2 p.m., then the first crop day is only 0.67 day long.

"**Hours grinding**" is what is left of 24 hours after discounting lost time.

"**Hours lost**" are all hours when mill operation is discontinued.

"**Total time**" is hours grinding plus hours lost. Divided by 24, it must equal "Crop days".

## Cane

"**t cane ground**" are the tons cane received "as is". If trash is discounted, t net cane should also figure.

"**t burnt**" is included to explain an abnormal juice purity. If, for instance, burnt cane lasts about one week at the end of the week during which this cane was processed, juice purity is bound to decrease.

"**t ground/h**" is grinding rate, i.e. cane ground divided by hours grinding (effective hourly rate).

"**% pol**" in cane is weight of pol in juice plus weight of pol in bagasse, divided by weight of cane × 100. The higher this figure, the better the cane quality. Factors that influence this figure are the juice purity and its brix; higher proportions of solids in juice also mean higher pol; and higher purity means that a larger portion of the solids (brix) is made up of sucrose.

"**% fiber**" in cane contains the same weight of fiber present in the bagasse. Cane and juice weight are known as is imbibition water weight (all on scales). The basic formula is: weight cane + weight water = weight juice + weight bagasse. Weight bagasse forms the difference.

% pol in juice and % pol in bagasse are laboratory results and multiplied by the weight. Weight pol in juice plus weight pol in bagasse give weight pol in cane (above). % fiber in bagasse is a laboratory calculation from % pol, % water and % brix. Now, weight of fiber in bagasse is known and this same weight of fiber in bagasse is also weight fiber in cane, therefore % fiber in cane is known:

$$\frac{\text{weight fiber in bagasse}}{\text{weight of cane}} \times 100 = \%\text{ fiber in cane}$$

What does % fiber in cane tell us? Fiber in cane is the main source of fuel for the boilers, to produce steam. A low-% fiber produces less steam than a high-% fiber. The standard fiber content of cane is taken as 12.5%. A fiber content of below 12.5% is low; one above that percentage is considered high. It can be so high that there is a large excess not required by the boilers for producing steam. This excess has to be stored for times of low production, such as prolonged mill stops. In these cases, it is reclaimed from storage and taken to the boilers. On the other hand, it can be so low that it cannot produce the steam requirement. In this case, additional fuel such as fuel oil, firewood or natural gas must be used. In the latter case, all ways of improving steam economy should be considered, while in the case of high fiber content it is often easier to deal with an excess of steam rather than an excess of bagasse. Steam excess can be blown off, but bagasse requires bulldozers, manpower or both.

In Louisiana, a cane area of high fiber, some mills have extra boiler capacity installed to deal with a large amount of excess bagasse. All mills use triple-effect evaporation instead of quadruple-effect, because they can afford to be less economical in steam consumption.

There is a second detail to consider regarding low or high fiber. A mill tandem grinds cane to separate juice from it, leaving bagasse (fiber). The mill rollers deal mainly with fiber and fiber loads. Therefore, if fiber is high, less cane can be passed through a mill. The mill setting (adjustment of roll openings) is done for a specified local fiber content and grinding rate. If fiber is higher than that for which the mill is set, the grinding will be slower than the required rate. Therefore, we now require "fiber ground/h", which is a better figure on which to judge mill performance than "cane ground/h".

"**imbibition % cane.** For the reason mentioned above, this figure is less accurate than imbibition % fiber. Imbibition has the purpose of diluting the juice left in bagasse before the last mill. The more water used for imbibition, the more sugar is leached out of the bagasse. But there is an economical limit. Even more water eliminates a very small amount of sugar, which has less value than the cost of later evaporation of the extra water added. This is where the role of the fiber comes in. The practical limit of imbibition is 180-200% imbibition % fiber. This figure cannot be made use of if fiber ground/h or % fiber in cane are not reported.

$$\text{imbibition \% fiber} = \frac{\text{imbibition \% cane}}{\text{fiber \% cane}} \times 100$$

Imbibition % cane is an essential figure, because it forms part of the basic weight formula mentioned before. The above explanation of imbibition % fiber implies that, if the figure is 200% or more, then this is the limit as regards imbibition.

Further explanation is required: if on a particular day imbibition % cane is 25%, this figure is only the average for that day. Grinding cane shows many fluctuations resulting from short stops, different varieties of cane, variation in resistance and hardness of cane, irregular feeding of cane to the carrier, etc.; all of which cause fluctuation. In other words, if a mill grinds 3000 tc today, it might momentarily have a rate of 4000 and at other times 2000, but the average is 3000. The 25% of water on the weight of cane inevitably cannot always be 25% and could fluctuate say from 10 to 50%. At moments of 10%, the quantity of water is inadequate, while at 50% it might leak through the bagasse layer without effect. Of course, this condition is well known, but it is not easy to remedy.

The best approach is to measure the density (brix) of the last mill juice and let the control valve regulate the flow of water (by throttling). Last mill juice has a brix of 4-6 and a rather ideal temperature for the cultivation of micro-organisms. Because of the low brix, it is not very stable, which is why a sample cannot be maintained.

"imbibition % cane" should correlate with imbibition % fiber, which is 180-200%. It should therefore be 20-35%, depending on fiber % cane (more if fiber is higher). Imbibition should be reduced if evaporators are scaled: it can no longer cope with large quantities of water and steam consumption becomes prohibitive.

"**dilution % cane**" is that part of the imbibition % cane that goes to the juice. The remainder stays in the bagasse. It is therefore smaller than imbibition. The nearer it approaches imbibition, the better is the juice extraction of the mill.

## Extraction

"**Diluted juice extraction**" (same as mixed, raw juice). It is also called diluted juice % cane. It fluctuates in accordance with the dilution % cane, or the amount of water from imbibition mixed with it. Juice weight is determined by the scale. Extraction can exceed 100%. For instance:

cane + water = juice + bagasse.

Assume:

cane = 100
bagasse = 30

then juice is proportional to water

$$100 + 60 = 130 + 30 \text{ or}$$
$$100 + 20 = 90 + 30$$

in which the examples 130 and 90 are percentages of "diluted juice extraction". The average value for "diluted juice extraction" is 90-105%.

"**normal juice extraction**". Normal juice is juice in the cane, assuming the mill is operated without imbibition water. It is also called undiluted juice. Normal juice extraction = diluted juice extraction minus dilution % cane. Normal juice (undiluted juice) is no longer used, with the exception of mills in Louisiana and Florida, because the Department of Agriculture still uses it. In its place, absolute juice is used. However, normal juice has the advantage of being easy to calculate.

Brix normal juice = brix first expressed juice × milling factor (normally about 0.97). Its purity is the purity of diluted juice, because adding water to juice does not change its purity.

Absolute juice = cane − fiber. The difference is that cane contains both juice and water.

Although the quantity of absolute juice is simple to find, calculation of brix and pol is a little more complex. If juice quantities are known, dilution can be calculated from brix differences.

"**Pol extracted % pol in cane**", or "**pol extraction**" for short, is the pol in mixed juice % pol in cane, after pol in bagasse is lost.

Weight pol in mixed juice + weight pol in bagasse = weight pol in cane.
It depends mainly on the mechanical condition of the mill tandem and the composition of the mills. A tandem of 5 mills gives a higher pol extraction than one of 4 mills, etc. A tandem with worn-out rollers gives a lower pol extraction than one with newer rollers. Higher hydraulic pressure on top rolls means higher extraction. Good mill conditions, correct settings and optimum imbibition together secure a good extraction. Because of these conditions there is no definite figure for extraction. A good average extraction, for instance is from 94% upwards; over 95% is excellent; above 96% is outstanding.

"**Reduced pol extraction**" is a figure which allows comparison between mills of different fiber % cane. The extraction results of a mill A having 17.5% fiber is not comparable with mill B having only 11%. Therefore, the "reduced pol extraction" is calculated on a theoretical fiber % cane of 12.5%.

*Example:*
Mill A has 17% fiber and pol extraction 92%
Mill B has 11% fiber and pol extraction 94%
What is the reduced extraction in both cases?

Calculation for 17% fiber:
100 − extraction = 100 − 92 = 8 (a)
100 − % fiber = 100 − 17 = 83 b)
(a) × (b) = 8 × 23 = 664
665 divided by % fiber 664/17 = 39.06
reduced extraction = 100 × $\frac{39.06}{7}$ = 94.42%

Calculation for 11% fiber:
100 − extraction = 100 94 = 6 (a)
100 − % fiber = 100 − 11 = 89 b)
(a) × (b) = 6 × 89 = 534
534/% fiber = 534/11 = 48.55

$$\text{reduced extraction} = 100 \times \frac{49.55}{7} = 93.06\%$$

**"Java ratio"**. This is pol in cane divided by pol in first expressed juice, multiplied by 100. It is understood that its value is usually around 80%. This is not quite true. If the mill extracts very well, pol in first expressed juice should increase and the "Java ratio" should decrease, as pol in cane is a constant. Its value can only be quoted for a given mill. If the Java ratio is always 80 and new rollers are installed, it should decrease to about 78.

## Bagasse

**"% pol"**. This figure is derived directly from analysis. Obviously, the lower the better, because pol in bagasse is a direct loss. However, as explained earlier, there is an economical limit to the amount of imbibition water that should be added before the last mill to reduce pol in bagasse. Again, the value of pol in bagasse depends mainly on number of mills in the tandem, mill setting, top roller pressure, available driving power, etc. Therefore, instead of giving an acceptable value of pol, it is better to use pol lost in bagasse % of cane. A figure of 0.8 for this loss indicates good grinding conditions. If it exceeds 1.0, it is less efficient and less acceptable.

**"% moisture"** is also a direct-analysis figure. It is related to good pressures in the mill, although in some countries it is higher than in others. This might be due to soil type, as for example in Florida, where % moisture in bagasse never falls below 52-54% without application of special treatment (presses). In other countries, a normal figure is 47-50%. These two data, % pol and % moisture, are required for calculating % fiber in bagasse, which has the same weight as the fiber in cane.

Bagasse has the composition of moisture, soluble solids (including sugar) and fiber. The soluble solids are assumed to have the same composition as those in the juice left in the bagasse. Therefore the purity is assumed to be that of the last mill juice. It should actually be the last expressed juice, which is the juice coming from the last two rollers of the mill, but it is not possible to sample it. Therefore it is replaced by last mill juice. Dividing % pol by last mill purity gives % soluble solids. The meaning of purity is explained in the section on analysis (see below).
% fiber = 100 − (% moisture + % soluble solids).

**Sample calculation**

Assume % pol = 2.8 % moisture = 48.2

purity last mill juice = 70

$$\% \text{ soluble solids} = \frac{2.8}{70} \times 100 = 4.0$$

$$\% \text{ fiber} = 100 - (48.2 + 4) = 47.8\%$$

The quantity of bagasse is known from

cane + imbibition water = juice + bagasse

Then

$$\text{weight bagasse} \times \frac{47.8}{100} = \text{weight fiber (also in cane)}$$

$$\frac{\text{weight fiber}}{\text{weight cane}} \; 100 = \% \text{ fiber in cane.}$$

This explanation is treated in detail because it leads to % fiber in cane, which is a very important figure for judging variations in grinding rate, availability of fuel and consumption of fuel oil, imbibition water requirements, etc.

## Analysis

The routine figures produced by the laboratory are brix, pol, purity. As these names are common notations, it is logical that they are well understood.

''**Brix**'' is one of the many indications of soluble solids present in a juice (or liquid). It is actually the name of the person who determined soluble solids in a sugar solution by a simple method. A spindle hydrometer is used, which floats partly in the solution. It measure from 0-100 brix, subdivided in hydrometers, each for a step of about 10° brix. The degrees are based on pure sugar solutions at a standard temperature (recently 20 °C has been used).

Liquids in the sugar mill are not pure but contain impurities. Therefore, the degrees brix measured do not indicate the real soluble solids in the impure solutions. Provided that the concentration of impurities forms a small part of the sugar concentration, the error is small. The concentration of impurities becomes higher as the process of fabrication advances, and is highest in final molasses, where they are eliminated from the process. It shows that the error in juices is very small.

One may ask ''Why are brix spindles used if they incorporate errors?'' The answer is ''They are so simple to use and using them is so quick. Besides, the errors are always in the same direction, thus making the results comparable. In other words: a brix of 20 today exceeds the brix of 19 yesterday by one, for the same solutions, regardless of errors''.

We must not forget that a process laboratory is not a place for research, although part may be used as such. It has to function at the same speed as the process itself and cannot afford to lag behind, as it has to supply the results and process information when needed.

Of course, there are other systems for determining soluble solids more precisely then the brix spindle (hydrometer). Many are used when process velocity allows more time, and when greater accuracy is required. One such is the refractometer. The problem is that if one mill uses it, and others do not, then results are no longer comparable. Therefore, all mills which use a refractometer for measuring soluble solids are required to report the brix as "refr. brix".

Why do so few mills use refractometers? There are two reasons. Firstly, the refractometer is a rather expensive and delicate optical instrument, and it is hard to arrange for maintenance locally. Moreover, although it is rather simple to use, it takes longer than the hydrometer brix spindle. A decision to switch over to refractometer use should be taken jointly by a group of mills to maintain comparative reporting.

True solids are determined by drying a sample of determined weight, and reweighing the remainder. True solids are also called "dry matter". It is obvious that this system cannot be applied in an industrial laboratory. It requires a dry container, weighing the sample, drying it in an oven, cooling, re-weighing and calculating the percentage. It can only be done on final molasses (largest error) bi-weekly by a special-analysis chemist, who specializes in this sort of precise investigation.

"**pol**" is the determination of sucrose in a solution, determined in a polarimeter. If 26 grams of pure sucrose are dissolved in distilled water at 20 °C and made up to 100 ml, then its pol equals 100 °S (International Sugar Scale). Before 1920, the standard was 26.048 g of sucrose dissolved in distilled water at 17.5 °C and made up to 100 cc, which gave a pol of 100 °V (Ventzke).

Again, this is an easy short-cut, because polarization is a rotation of an optical field, caused by many carbohydrates, not only sucrose, but also dextrose, levulose, etc., the components of the so-called R.S. (reducing sugars). Rotation of sucrose is to the right (positive), as is dextrose, but levulose rotates to the left (negative). As long as the R.S. is very low, the error is small, but towards the end of the process, the error increases.

Final molasses of cane sugar has about 28% sucrose and 15-22% R.S., so the "pol" here does not mean a great deal. The same considerations hold as those on brix. It is simple, and the error is approximately constant. It is a good comparison basis for daily reports.

For the true sucrose, a double polarization has to be made, as first applied by Clerget. It is a regular "pol", followed by a complete inversion of all sucrose into R.S. From the two results and the Clerget constant, the true pol (sucrose) can be calculated. The Clerget constant is a factor found by the double pol of pure sucrose (in the absence of original R.S.). Again, this Clerget method can only be done for final molasses bi-weekly by the special-analysis chemist.

**"purity"** is the pol divided by the brix multiplied by 100. It indicates which part of the solids is composed of sugar. From the above descriptions of brix and pol, it is clear that there are many variations of the various brixes and pols used. In the daily and bi-weekly reports, when purity is mentioned, "apparent purity" is implied. It is derived from brix measure by hydrometer spindle and pol as a single polarization. Therefore:

$$\text{apparent purity} = \frac{\text{pol}}{\text{brix}} \times 100$$

It is clear that the difference between brix and pol is equal to "non-sugars" (impurities).

$$\text{non-sugars} = \text{brix} - \text{pol}$$

$$\frac{\text{pol}}{\text{refr. brix}} \times 100 = \text{refr. purity}$$

$$\frac{\text{clerget}}{\text{true solids}} \times 100 = \text{true purity}$$

## Glucose (R.S., invert)

In the reports, the glucose of a few juices are mentioned. These analyses are made by the special-analysis chemist, as they required skill and time. They cannot be incorporated in the daily routine of the processing information the laboratory provides.

Glucose is determined from primary juice, diluted juice, clarified juice and syrup. In the primary juice, it indicates whether or not the cane is approximately at optimum maturity or stale, resulting from a long delay after being cut when inversion can occur. If this is the case, glucose is relatively high and, together with acidity determination, it can indicate staleness of the cane.

The reason why glucose is determined in the other juices mentioned is for calculating the glucose ratio or R.S. ratio of these juices. The ratio indicates whether or not inversion of sucrose has occurred during the process.

$$\text{The R.S. ratio is: } \frac{\%\ \text{R.S.}}{\text{pol}} \times 100$$

This ratio should remain more or less constant from diluted juice up to syrup. If it increases, then inversion has taken place, and if it decreases, then decomposition of R.S. has occurred. The latter can be caused by high alkalinity in the juice. The glucose forms organic acids, and the acids attack the steel of tanks and pipelines, and dark iron salts are formed. R.S. of clarified juice should be 0.80-1.10, with a ratio of about 7.00. This ratio should be maintained in syrup. Therefore the determination of the R.S. ratio is justified. It is good practice and provides positive information.

Another figure found in the "Analysis" section of the reports is the so-called "purity drop" of massecuites. This is the difference in purity between the massecuites and its molasses. It is a positive indication of massecuite quality as produced in the boiling house. If it is too low, this can be due to a low massecuite brix (low massecuite brix indicates low supersaturation and poor grain formation). Normal ranges of purity drops are, for instance:

| | |
|---|---|
| A massecuite to A molasses | 17-20 |
| B massecuite to B molasses | 20-23 |
| C massecuite to final molasses | 25-30 |

For A and B massecuite, there are three main reasons for inadequate purity drop:

(1) low final brix of massecuite on leaving the pan,
(2) insufficient grain in massecuite
(3) purging too hot; not enough cooling between leaving the pan and purging.

For C massecuite, it is more complicated, since for this massecuite seed is crystallized, while for A and B, magma is used as seed.

Here are the reasons:

(1) not enough grain formed
(2) crystallizer capacity too low
(3) final brix too low
(4) holes in centrifugal screens
(5) massecuite purity too high.

Final molasses data should include the special analysis made by the chemist, such as: Clerget, R.S., total sugars, ash.

These data make it possible to calculate the exhaustion obtained and theoretically obtainable, or "the target purity". A low final-molasses purity is, for instance, 28, but to guarantee it the ratio R.S./ash should be high, say 2-2.5. If it is less, the purity is bound to be higher. To obtain 2-2.5, R.S. should be 20-25 and ash about 10. In factories where R.S. is 15 and ash, say, 12 (a ratio of 1.25), the purity obtainable is much higher than 28, probably nearer 35-36. For more information on this, see Chapter 23, Final Molasses Exhaustion.

## Production data

Besides the normal data, such as sugar made, shipped, in warehouse, etc., an important factor is sugar equivalent 96°M and E (made and estimated). "Estimated" is the amount of sugar one can expect to be produced from the materials in stock, if grinding were discontinued from this instant. It is expressed in equivalent 96° pol, because its future pol is not as yet known. Equivalent 96° pol (also raw value) is used, because it is on this basis that the raw sugar is sold in the export market. Analytically, the information on sugar is:

(a) pol
(b) moisture

(c) ash
(d) safety factor
(e) sometimes color and crystal size.

The safety factor shows whether or not sugar can be expected to stay good in storage. It should be below 0.250:

$$\text{safety factor} = \frac{\text{moisture}}{100 - \text{pol}} < 0.250.$$

This shows that if the pol is high, 100 − pol is small and moisture should be reduced. It may be necessary to pass the sugar through a dryer. If the safety factor exceeds 0.250, then it is likely that micro-organisms will develop, reducing the keeping qualities during storage.

As we have to deal here with small quantities of moisture and 100 − pol, accuracy in the determination of pol and sugar moisture are essential. The pol should be determined daily by the special chemist from the accumulative sample, while for sugar moisture an accurate instrument is required. Of late, moisture balances have tended to be of the Ohaus type, which are very accurate, rather robust and easy to operate.

Modern centrifugals are capable of producing a sugar of about 0.3% moisture (it also depends on the sugar purity). All sugar contracts have a basic raw-value price, corrected by premiums and penalties for quality in excess of or below the accepted norm. This is logical, because if the pol is 98 instead of 96, say, then it means the buyer receives more sucrose and fewer impurities (non-sugars). Because of exclusion of impurities the weight is less, i.e. the 98 pol requires more sugar to complete the contract, and therefore a premium is a must. If there were no premiums, nobody would bother to improve the sugar quality above 96 pol.

It is acceptable to determine % ash in sugar bi-weekly and keep that figure for 14 days. It is important, because a high ash is the cause of high carbon consumption later in the refinery. For this reason, penalties for high ash are high.

## Molasses storage

To measure stock of molasses in tanks, it is not correct to use floats which an outside indicator. They cannot be relied upon because of foam in tanks. The only correct way is by using a so-called pneumercator. This is an external mercury level, indicating the equivalent height in mercury of the tank height in molasses. Tank volume is important, because a small error in height represents many gallons, as the tank diameter is often 40 or 60 ft.

## Miscellaneous data

*"Moisture and pol"* of mud (filter-cake). Here the pol is important, because it is a definite loss. Pol of mud of rotary vacuum filters (such as Dorr Oliver or Eimco) should be below 1%. If it is higher, then:

(1) filter capacity installed is for lower capacity

(2) water sprays used to sweeten off mud cake on the drum are not atomizing correctly, or water pressure is not correct (it should be 30-40 psi).

A filter of 8′ × 16′ (400 sq ft area) is normally used for mills up to 2800-3000 tcd.

The bi-weekly report contains basically the same information as a daily report, with the exception of the "sucrose balance", also known as the "pol balance". It gives all sucrose (pol) lost in bagasse, final molasses, mud, and undetermined. Together with the pol recovered in sugar, it should add up to the pol in cane. The balance gives these losses in two ways: % of cane and % of pol extracted.

As an illustration of what the figures should be, a few actual mill results (Table 20) will serve better than an explanation.

TABLE 20.
POL BALANCE*

| Mill A (Cuba 1958) | EXCELLENT | | | |
|---|---|---|---|---|
| | % pol extracted | | % of cane | |
| Pol balance | run | to date | run | to date |
| lost in bagasse | | | | 0.612 |
| lost in final molasses | | 5.673 | | 0.762 |
| lost in mud | | 0.189 | | 0.025 |
| lost (undetermined) | | 1.433 | | 0.193 |
| total losses | | 7.295 | | 1.592 |
| recovered in sugar | | 92.705 | | 12.458 |
| pol in juice/cane | | 100.00 | | 14.050 |

*The "run" column is not used, it shows the way the form is printed.

Mill B (Peru 1960) GOOD

| Pol balance | % pol extracted | | % of cane | |
|---|---|---|---|---|
| | run | to date | run | to date |
| lost in bagasse | | | | 0.952 |
| lost in final molasses | | 9.357 | | 1.299 |
| lost in mud | | 0.462 | | 0.061 |
| lost (undetermined) | | 0.686 | | 0.090 |
| total losses | | 10.505 | | 2.332 |
| recovered in sugar | | 89.495 | | 11.755 |
| pol in juice/cane | | 100.000 | | 14.087 |

Mill C (Guatemala 1977) MEDIOCRE

| Pol balance | % pol extracted | | % of cane | |
|---|---|---|---|---|
| | run | to date | run | to date |
| lost in bagasse | | | | 1.076 |
| lost in final molasses | | 16.113 | | 1.641 |
| lost in mud | | 0.287 | | 0.029 |
| lost (undetermined) | | 3.504 | | 0.356 |
| total losses | | 19.904 | | 3.102 |
| recovered in sugar | | 80.096 | | 8.156 |
| pol in juice/cane | | 100.000 | | 11.258 |

Mill D (Nicaragua 1977) MEDIOCRE

| Pol balance | % pol extracted | | % of cane | |
|---|---|---|---|---|
| | run | to date | run | to date |
| lost in bagasse | | | | 0.817 |
| lost in final molasses | | 13.625 | | 1.842 |
| lost in mud | | 0.558 | | 0.075 |
| lost (undetermined) | | 10.741 | | 1.452 |
| total losses | | 24.924 | | 4.186 |
| recovered in sugar | | 75.076 | | 10.148 |
| pol in juice/cane | | 100.000 | | 14.334 |

Mill E (Venezuela 1971) GOOD

| Pol balance | % pol extracted | | % of cane | |
|---|---|---|---|---|
| | run | to date | run | to date |
| lost in bagasse | | | | 0.538 |
| lost in final molasses | | 12.096 | | 1.282 |
| lost in mud | | 0.692 | | 0.073 |
| lost (undetermined) | | 3.501 | | 0.372 |
| total losses | | 16.289 | | 2.265 |
| recovered in sugar | | 83.711 | | 8.874 |
| pol in juice/cane | | 100.000 | | 11.139 |

Mill F (Florida 1975) GOOD

| Pol balance | % pol extracted | | % of cane | |
|---|---|---|---|---|
| | run | to date | run | to date |
| lost in bagasse | | | | 0.847 |
| lost in final molasses | | 11.715 | | 1.170 |
| lost in mud | | 2.364 | | 0.236 |
| lost (undetermined) | | 1.643 | | 0.164 |
| total losses | | 15.722 | | 2.417 |
| recovered in sugar | | 85.278 | | 8.418 |
| pol in juice/cane | | 100.000 | | 10.835 |

*Note:* Undetermined losses are found by difference. Weight of pol in cane is known, as well as weight recovered in sugar:

wt. pol in cane − wt. recovered in sugar = wt. total losses.

Individual losses are also known: in bagasse, final molasses, in mud.

wt. total losses − wt. losses (bagasse + final molasses + mud) = wt. undetermined losses.

If errors are made in losses in bagasse, final molasses or mud, the undetermined losses are incorrect. Errors can be made in either weight or analysis. Undetermined losses should not be higher than those in mill B, say, a maximum of 0.100% pol in cane. In mill D, for instance, pol bagasse was probably higher, in which case the undetermined amount would decrease.

The pol balance shows how important it is to be sure that all losses are as accurate as possible, because only then are undetermined losses really what they are supposed to be, namely, an indication of entrainment in evaporators or pans, leaking tanks or valves, or even fraudulence.

Often the reliability of quantities suffers because a cause of error is simply overlooked — for example, the weight of the sugar scale can be off, or the level of the molasses in the tank is wrong. Before seeking undetermined losses, one must be sure of the authenticity of the determined losses.

Frequently, there are queries about the sugar production equivalent of, for instance, 1% more pol extraction in the mill tandem. Let us assume the following mill conditions:

| | | | | |
|---|---|---|---|---|
| daily grinding capacity | | | 3000 | tcd |
| % pol in cane | | | 13% | |
| daily weight of pol in cane | 3000 × 0.13 | = | 390 | td |
| pol extraction | 92% | = | 358.8 | td |
| pol extraction (1% more) | 93% | = | 362.7 | td |
| 1% more extraction | | = | 3.9 | td |

This quantity has to go through the process and is not the final quantity in the sugar warehouse. First, the theoretical retention has to be calculated, because the normal losses have to be discounted from the 3.9 td. Once this is known, the boiling-house efficiency (BHE) takes care of further discount.

Assume juice purity 84.00
bhe 0.97

According to the formula of Winter and Carp, the available sugar from juice of 84 purity is

$$1.4 - 40/\text{purity} = 92.38 \text{ and}$$

$$92.38 \times 0.97 = 89.61\%$$

Sugar available from 3.9 td (1% more extraction):

$$3.9 \times 0.8961 = 3.495 \text{ td} = 7706 \text{ lb/day.}$$

*Raw value* sugar equivalent. Raw value is important because it is the form on which the price is based for the U.S. sugar quota. It is not calculated exactly as most mills calculate "equivalent 96° pol", by simply multiplying sugar weight by its pol and dividing by 96. The U.S. Treasurey Department states: "All taxes shall be imposed and all quotas established in terms of raw values, and for the purposes of quota and tax measurements all sugars shall be translated into terms of raw value." The definition is as follows. It is based on the fact that 107 lb of 96° pol raw sugar are required to yield 100 lb refined sugar. This means that of the 7 lb extra of 96° sugar required to produce 100° pol sugar, each degree of pol over 96° represents 7/4 = 1.75 lb less, required to produce 100° pol sugar.

Raw value = [(pol − 92) 1.75 + 93] lb physical raw sugar.

*Examples:*

(1) Let us assume that the contract is 1000 t.

(2) Sugar produced has pol = 98.2

$$\text{Raw value } \frac{[(98.2 - 92)\ 1.75 + 93].\ 1000}{100} = 1038.500 \text{ t.}$$

If it were calculated as follows:

$$\frac{1000 \times 98.2}{96} = 1022.917 \text{ t}$$

a difference of about 16 t less sugar would result.

(2) Same contract (1000 t), but pol 95.6.

$$\text{Raw value } \frac{[(95.6 - 92) \, 1.75 + 93]}{100} \times 1000 = 993 \text{ t.}$$

The interpretation is as follows. If 1000 t of sugar of 98.2 pol is shipped, the liquidation of the contract will be for 1038.5 t. So if 1000 t of pol 95.6 sugar is shipped, it has a shortage of 7 t.

*Note:* This is a correction for pol only, and has nothing to do with correction for weight.

*BHE.* The boiling-house efficiency is a number indicating the percentage of theoretically available sugar that the factory produces. In other words, according to the weight of pol present in the juice entering the factory, a certain amount ends up in the product, and another amount represents the losses. If the plant produces this calculated amount of pol as going to the product, then the BHE = 100%. If it produces less, the BHE is under 100%, and if more goes into the bags, the BHE exceeds 100%. This latter case can also occur, for example, if the losses really produced are less than those calculated.

*Final molasses.* Equivalent 80 brix (or 88 brix). Each factory produces final molasses of different brix. Many factories also report "gal molasses produced per t of cane". This figure is not comparable with a similar figure from another factory, because the brixes are not the same and therefore the weight per gallon is different. For purposes of comparison, not only between different mills, but also between different run reports of the same mill, the quantity should be corrected to a standard brix. This density is 80 in some countries and in others 88 or 85 brix. It does not matter, provided that it is always the same density for the mill and same country.

*Example:*

Assume that 820325 gal molasses are produced at 91.27 brix. What are the equivalent gallons produced at 88 brix?

Solids in 1 gal of 91.27 brix = 11.3505 lb.
820325 × 11.3505 = 9,311,086 lb solids.
Solids in 1 gal of 88 brix = 10.759 lb.
9311086 : 10.759 = 865423 gal of 88 brix equivalent.
Solids in 1 gal of 80 brix = 9.418 lb.
9311086 : 9.418 = 988648 gal of 80 brix equivalent.
Suppose cane ground was 162000 t (to date), then
gal molasses equivalent 88 brix per t cane = 5.34 gal/t.
gal molasses equivalent 80 brix per t cane = 6.10 gal/t.
gal physical molasses 91.27 brix per t cane = 5.06 gal/t.

This last number indicates only the storage capacity required.

## Miscellaneous

Under the miscellaneous data in the bi-weekly report, the figures indicating chemicals used per t of cane are required for future purchase orders. The products involved are those for which the quantities are rather large, such as lime, muriatic acid, caustic soda. They can be extended at will with soda ash, Separan, Busan, etc.

To prevent errors, lime in this column is lime as ordered, quick lime or hydrated lime, but must be specified in the report. If not specified, it should be reported as CaO. For the purpose of ordering the necessary quantities: quick lime contains 95% CaO and hydrated lime contains 70% CaO.

## CHAPTER 40

# SOLIDS BALANCE

This is also called material balance. It is important to keep track of the flow of the solids as they enter the factory, and their routes through the different stages of the process. In existing sugar mills, such a balance gives information on the losses of sucrose (inversion, etc.), destruction of R.S. or disappearance of solids through leaks or for other reasons. In a newly-designed mill, a solid balance is required to facilitate sizing of equipment by showing the quantities it must handle. During all manipulations in the process, water is usually either added or removed, but the solids should show a virtually constant quantity after accounting for the losses in by-products and the recovery in the sugar, with the exception of the above-mentioned reasons.

For control purposes, in an existing factory a solid balance can be based on actual analytical data, as provided by the laboratory, and then the results can be compared with theoretical ones based on solids entering the process and the juice quality, together with other data (such as molasses and sugar purity, massecuite analysis, etc.).

In the boiling house, all solids enter in the syrup, and end up in sugar and molasses. Two examples have been evaluated. One is a theoretical solid balance of a 2300 tcd factory using the two-boiling system (product exclusively A sugar). The balance is presented as a type of flow diagram. (Fig. 58) as well as in table form (Table 21). It originated from an existing mill, which provided insufficient data. In most cases, likely averages obtainable in this plant had to be assumed.

The second example (Table 22) is of a 2664 tcd normal raw-sugar mill, which uses the three-boiling system. Here C magma is used as seed for both A and B massecuite. The product is a combination of A and B sugar. In this case the laboratory data were quite complete.

The theoretical balance, as shown here, served as a control on the actual balance. It was obtained by using all laboratory data, such as quantities of massecuites produced, etc.

For the calculations of boiling-house solids, the required laboratory data are given in table form at the very beginning of the calculations. They are followed by the calculations of solids that go to the sugar and to the final molasses, with respect to the solids in syrup. Then all components of the three types of massecuites are calculated, also in relation to the basic solids in syrup entering the boiling house. Finally, the physical quantities of the components are calculated from the brixes as supplied by the laboratory. The steam required to evaporate is also mentioned.

These calculations are followed by a solid balance in table form. For the purpose of sizing new equipment or checking capacities of existing equipment, all quantities are also given in cu ft per hour (cfh) and gal/min (for pumping).

In the case of a new design of a mill, enough margin should be taken for data, such as imbibition % cane, to allow increase in the percentage of diluted-juice extraction, because

cane + imbibition water = juice + bagasse

This in turn increases the pump size of diluted juice. Also, the syrup pumps might sometimes be required to displace a syrup of a lower density (more diluted) than the one for which it is calculated. The theoretical solids balance therefore indicates the minimum safety level.

This is especially important when rather small quantities have to be pumped, such as milk of lime, A and B molasses, magma. Milk of lime is overdosed to maintain re-circulation. A and B molasses have peaks at the beginning of the centrifugal cycle, which can be as high as 200% of the average capacity. Magma pumps have a low efficiency, being of the vane type, etc.

As far as a newly designed mill is concerned, the data normally available are those of cane from the immediate neighborhood. But often even these are not available, if the cane-sugar industry is completely new to a given territory.

In such cases, a test planting has to be made of a few cane varieties, to obtain at least an indication of cane per acre (ha), sugar yield, fiber contents, juice purity, etc. In many cases, such test results are already available, if they have formed part of a feasibility study.

It should be remembered that a solids balance composed of laboratory data will never balance exactly. The reasons are:

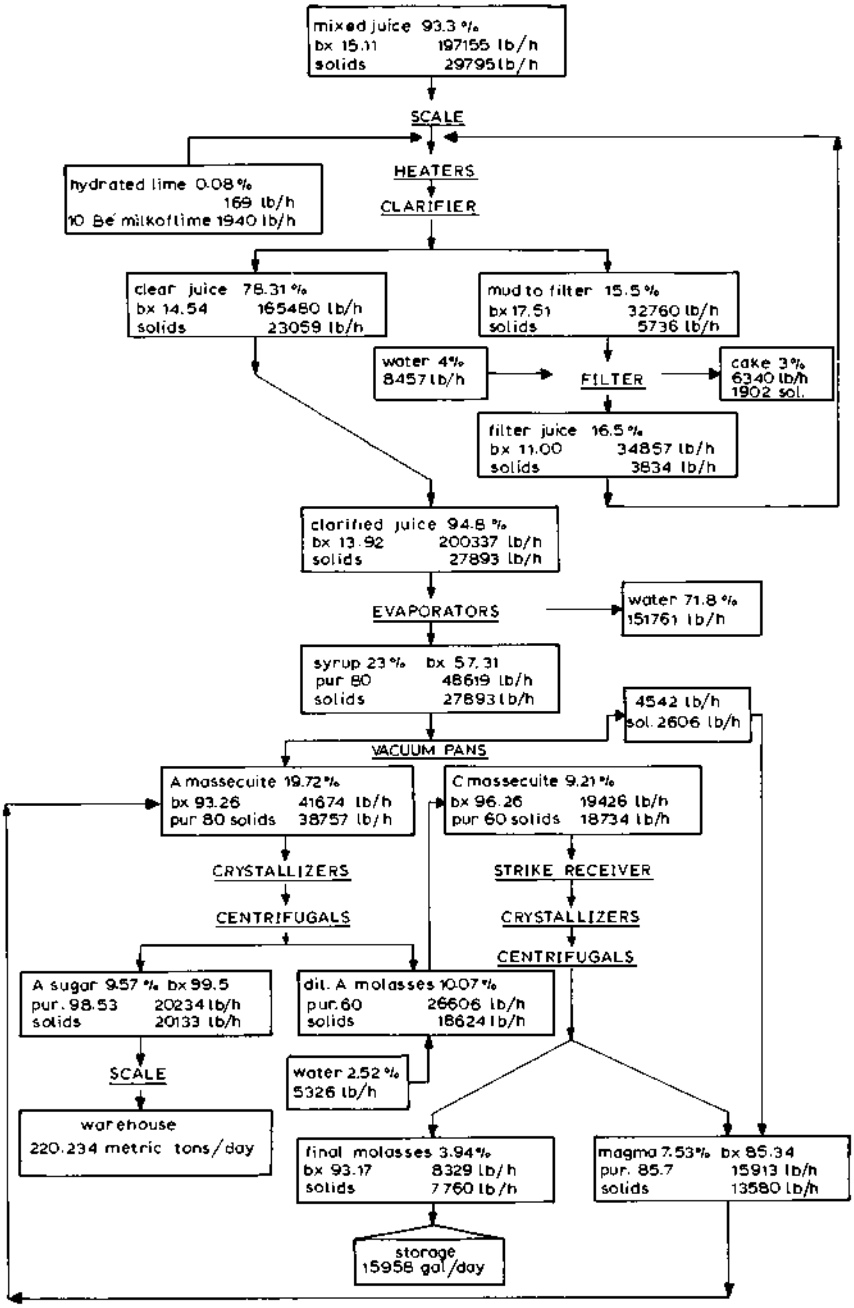
(a) The sampling is not fully representative.

(b) The brixes (solids) used are not true dry matter figures: the error increases when the impurities increase.

(c) In all mills, there are always mechanically lost solids, (through leaks or otherwise) even though they may be small.

(d) Massecuite quantities are only approximate: the pan level differs when read under vacuum and atmospheric pressure.

Once the theoretical balance is made and compared with the practical, the errors can be corrected as far as possible. For instance, if the quantities of massecuites are consistently higher than the calculated figures, a certain correction factor can be applied, to represent the real case more accurately.



| | | |
|---|---|---|
| Entering in A massecuite 15913 + 44077 = | 59990 lb/h | C massecuite 26606 lb/h |
| leaving | 41674 lb/h | 19514 lb/h |
| evaporation | 18316 lb/h | 7092 lb/h |
| steam required (about 125%) | 23000 lb/h | 9000 lb/h |

commercial yield = 220.234 / 2300 = 9.575 %

Table 21. Material balance of a raw sugar mill of 2300 tcd. 2-boiling system

| Materials | % cane | lb/ft$^3$ | per hour |  | gal/min | solids | analysis |  |  |
|---|---|---|---|---|---|---|---|---|---|
|  |  |  | lb | cu ft |  | lb/h | brix | pol | purity |
| Cane | 100 | 25 | 211312 | 8452 |  |  |  | 11.686 |  |
| Bagasse | 31.70 | 5 | 66986 | 13397 |  |  |  | 3.40 |  |
| Imbibition water | 25 | 62 | 52828 | 852 | 106 |  |  |  |  |
| Diluted juice | 93.30 | 66.08 | 197155 | 2984 | 372 | 29795 | 15.11 | 11.37 | 75.24 |
| Milk of lime | 0.92 | 67.10 | 1940 | 29 | 4 | 169 |  |  |  |
| Limed juice | 94.22 | 66.06 | 199095 | 3014 | 376 | 29964 | 15.05 | 11.26 | 74.81 |
| Mud to filter | 15.50 | 66.73 | 32760 | 491 | 61 | 5736 | 17.51 |  |  |
| Filter cake | 3 | 35 | 6340 | 181 | 23 | 1902 | 30 | 1.48 |  |
| Filter wash water | 4 | 62 | 8457 | 136 | 17 |  |  |  |  |
| Filter juice | 16.50 | 65 | 34857 | 536 | 67 | 3834 | 11.00 |  |  |
| Clarified juice | 78.31 | 65.91 | 165480 | 2511 | 313 | 24059 | 14.54 | 11.09 | 76.27 |
| Evaporator juice | 94.81 | 65.75 | 200337 | 3047 | 380 | 27893 | 13.92 | 11.14 | 80 |
| Syrup | 23 | 79.25 | 48619 | 613 | 76 | 27893 | 57.37 | 45.90 | 80 |
| Evaporation | 71.80 | 62 | 151718 | 2442 | 304 |  |  |  |  |
| A massecuite | 19.72 | 93.77 | 41674 | 10667 cfd |  | 38867 | 93.26 | 74.61 | 80 |
| A sugar | 9.57 | 53 | 20234 | 382 |  | 20133 | 99.50 | 98.03 | 98.53 |
| A molasses | 10.07 | 91.25 | 21280 | 233 | 29 | 18624 | 87.52 | 52.51 | 60 |
| A molasses diluted | 12.59 | 84.04 | 26606 | 317 | 40 | 18624 | 70 | 42 | 60 |
| B masssecuite |  |  |  |  |  |  |  |  |  |
| B sugar |  |  |  |  |  |  |  |  |  |
| B molasses |  |  |  |  |  |  |  |  |  |
| B molasses diluted |  |  |  |  |  |  |  |  |  |
| C massecuite | 9.21 | 95.12 | 19462 | 4915 cfd |  | 18734 | 96.26 | 57.75 | 60 |
| C sugar | 5.27 | 55 | 11141 | 203 |  | 10974 | 98.50 | 85.70 | 87 |
| Final molasses | 3.94 | 93.70 | 8329 | 89 | 15958 gpd | 7760 | 93.17 | 29.81 | 32 |
| C magma | 7.53 | 90.31 | 159132 | 176 | 22 | 13580 | 85.34 | 73.14 | 85.70 |
| Syrup to magma | 2.15 | 79.25 | 4542 | 57 | 7 | 2606 | 57.37 | 45.90 | 80 |

## TABLE 22
## PRODUCTION OF SUGAR, MOLASSES AND MASSECUITES

| Laboratory data | Quantity lb/h | Solids lb/h | Brix | Purity |
|---|---|---|---|---|
| cane | 244755 | | | |
| syrup | 63902 | 38993 | 61.02 | 84.48 |
| A massecuite | | | 92.24 | 84.20 |
| A molasses, diluted | | | 71.31 | 63.20 |
| B massecuite | | | 94.16 | 73.48 |
| B molasses, diluted | | | 71.04 | 49.55 |
| C massecuite | | | 96.46 | 58.73 |
| final molasses | | | 90.87 | 30.55 |
| C footing (A molasses + syrup) | | | 89.28 | 72.00 |
| C sugar | | | 99 | |
| commercial sugar | | | 99.37 | 97.28 |

solids in sugar % sol. in syrup = $\frac{84.48 - 30.55}{97.28 - 30.55} \times 100$ =80.82%

solids in final molasses % sol in syrup = 100 − 80.82 = 19.18%

solids in sugar = 0.8082 × 38993 = 31514 lb/h

sugar = 31514/0.9937 = 31714 lb/h

solids in final molasses = 0.1918 × 38993 = 7479 lb/h

final molasses = 7479/0.9087 = 8230 lb/h

weight/gal molasses 90.87 brix = 12.396 lb

molasses in gal per day = 8230 × 24/12.396 = 15934 gal/day
5.11 gal/t cane

commercial yield = $\frac{31714}{244755} \times 100$ = 12.975 %

| | | % solids in syrup | solids lb/h |
|---|---|---|---|
| **C massecuite** | $19.18 \dfrac{84.48 - 30.55}{84.48 - 58.73}$ | 40.170 | 15663 |
| in footing | $40.17 \dfrac{58.73 - 49.55}{72.00 - 49.55}$ | 16.426 | 6405 |
| in B molasses | 40.17 − 16.426 | 23.744 | 9258 |
| in A molasses of footing | $16.426 \dfrac{84.48 - 72.00}{84.48 - 63.20}$ | 9.633 | 3756 |
| in syrup of footing | 16.426 − 9.633 | 6.793 | 2649 |
| in C sugar | 40.170 − 19.180 | 20.990 | 8185 |
| syrup to magma (25% on C sugar) | | 5.250 | 2047 |
| magma | 20.990 + 5.250 | 26.240 | 10232 |
| in final molasses | | 19.180 | 7479 |
| **B massecuite** | $23.744 \dfrac{97.28 - 49.55}{97.28 - 73.48}$ | 47.618 | 18568 |
| in B sugar | 47.618 − 23.744 | 23.874 | 9309 |
| in footing | $47.618 \dfrac{73.48 - 63.20}{84.48 - 63.20}$ | 23,003 | 8970 |
| in A molasses | 47.618 − 23.003 | 24.615 | 9598 |
| **A massecuite** | $(9.633 + 24.615) \dfrac{97.28 - 63.20}{97.28 - 84.20}$ | 89.233 | 34795 |
| in A sugar | 89.233 − (9.633 + 24.615) | 54.985 | 21440 |
| in A molasses | 89.233 − 54.985 | 34.248 | 13355 |

| | solids lb/h / brix | quantity lb/h | cu ft/day |
|---|---|---|---|
| **C massecuite** | 15663/0.9646 | 16238 | 4093 |
| diluted B molasses | 9258/0.7104 | 13032 | |
| diluted A molasses in footing | 3736/0.7131 | 5267 | |
| syrup in footing | 2649/0.6102 | 4341 | |
| C sugar | 8185/0.99 | 8268 | |
| final molasses | 7479/0.9087 | 8230 | 15934 gal/day |
| syrup to prepare magma | 2047/0.6102 | 3355 | |
| input : 13032 + 5267 + 4341 | | 22640 | |
| output : | | 16238 | |
| evaporation | | 6402 | |
| steam required (125% of evaporation) | | 8000 | |
| | | | |
| **B massecuite** | 18568/0.9416 | 19720 | 5026 |
| diluted A molasses | 9598/0.7131 | 13460 | |
| footing | 8970/0.8928 | 10047 | |
| B sugar | 9309/0.9937 | 9368 | |
| B molasses | 9258/0.7104 | 13032 | |
| input : 13460 + 10047 | | 23507 | |
| ouput: | | 19720 | |
| evaporation | | 3787 | |
| steam required | | 5000 | |
| syrup: for C footing 2649 lb/h solids | | | |
| for C magma 2047 lb/h solids | | | |
| for B footing 8970 lb/h solids | | | |
| 13666 lb/h solids | | | |
| to A massecuite 25327 lb/h solids | | | |
| in syrup 38993 lb/h solids | | | |
| **A massecuite** | 34795/0.9224 | 37722 | 9702 |
| A sugar | 21440/0.9937 | 21576 | |
| A molasses 9598 + 3756 | 13355/0.7131 | 18728 | |
| syrup | 25327/0.6012 | 42127 | |
| used magma 34795 − 25327 | 9468/0.8928 | 10605 | |
| remelted magma 10232 − 9468 | 764/0.8928 | 856 | |
| input : (syrup + magma) | | 53588 | |
| (A massecuite) | | 37722 | |
| evaporation | | 15866 | |
| steam required | | 20000 | |

## STEAM CONSUMED IN VACUUM PANS

| | | |
|---|---|---|
| For:A massecuite | 20,000 lb/h | |
| B massecuite | 5,000 lb/h | |
| C massecuite | 8,000 lb/h | |
| total | | 35,000 lb/h |

Check on steam consumption:
steam consumed by vacuum pans = 1.5 × water in syrup (lb/h)
water in syrup = 63902 − 38993 = 24909 lb/h
steam consumption = 24909 × 1.5 = 37,363 lb/h

A massecuite = 9701 cu ft/day = 3.64 cu ft/t cane per day*
B massecuite = 5026 cu ft/day = 1.89 cu ft/t cane per day
C massecuite = 4093 cu ft/day = 1.54 cu ft/t cane per day
total massecuite 7.07 cu ft/t cane per day

*cane = 2664 tcd.

Table 23. Material balance of mill E.P. in 1959, 2664 tcd. 3-boiling system.

| Materials | % cane | lb/ft³ | per hour | | gal/min | solids | analysis | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | lb | cu ft | | lb/h | brix | pol | purity |
| Cane | 100 | 25 | 244755 | 9790 | | | | 14.112 | |
| Bagasse | 23.96 | 5 | 58643 | 11729 | | | | 2.60 | |
| Imbibition water | 21.67 | 62 | 53038 | 855 | 107 | | | | |
| Diluted juice | 67.71 | 66.53 | 239150 | 3595 | 448 | 40047 | 16.74 | 13.805 | 82.51 |
| Milk of lime | 0.60 | 67.10 | 1469 | | 3 | 175 | | | |
| Limed juice | 98.31 | 66.48 | 240619 | 3619 | 451 | 39872 | 16.59 | 13.70 | 82.68 |
| Mud to filter | 15.50 | 67.41 | 37937 | 563 | 70 | 7573 | 19.96 | 14.08 | 70.55 |
| Filter cake | 2.50 | 35 | 6119 | 175 | | 1224 | | 1.20 | |
| Wash water to filter | 3.73 | 62 | 9133 | 309 | 38 | | | | |
| Filter juice | 16.73 | 66.19 | 40951 | 619 | 77 | 6349 | 15.50 | 12.87 | 83.00 |
| Clarified juice | 82.84 | 66.35 | 202755 | 3256 | 381 | 32644 | 16.10 | 13.52 | 84.77 |
| Evaporator juice | 99.57 | 66.32 | 243706 | 3675 | 458 | 38993 | 16.00 | 13.52 | 84.48 |
| Syrup | 26.11 | 80.32 | 63902 | 796 | 99 | 38993 | 60.12 | 51.55 | 84.48 |
| Evaporation | 73.46 | 62 | 179804 | 2900 | 362 | | | | |
| A massecuite | 15.41 | 93.32 | 37722 | 9702 cfd | | 34795 | 92.24 | 77.67 | 94.20 |
| A sugar | 8.82 | 53 | 21576 | 407 | | 21440 | 99.37 | 96.67 | 97.28 |
| A molasses | 6.60 | 89.19 | 16146 | 181 | 23 | 13355 | 82.71 | 52.27 | 63.20 |
| A molasses diluted | 7.66 | 84.55 | 18728 | 222 | 28 | 13355 | 71.31 | 45.07 | 63.20 |
| B massecuite | 8.06 | 94.17 | 19720 | 5026 cfd | | 18568 | 94.16 | 69.19 | 73.48 |
| B sugar | 3.83 | 53 | 9368 | 177 | | 9309 | 99.37 | 96.67 | 97.28 |
| B molasses | 4.23 | 92.07 | 10352 | 112 | 14 | 9258 | 89.43 | 44.31 | 49.55 |
| B molasses diluted | 5.32 | 84.43 | 13032 | 154 | 19 | 9258 | 71.04 | 35.20 | 49.55 |
| C massecuite | 6.63 | 95.20 | 16238 | 4093 cfd | | 15663 | 96.46 | 56.65 | 58.73 |
| C sugar | 3.36 | 55 | 8218 | 149 | | 8185 | 99.60 | 87.65 | 88.00 |
| Final molasses | 3.36 | 92.72 | 8230 | 89 | 11 | 7479 | 90.87 | 27.76 | 30.55 |
| C magma | 4.75 | 91.46 | 11623 | 127 | 16 | 10232 | 88.03 | 76.55 | 86.96 |
| Syrup to magma | 1.39 | 80.32 | 3405 | 42 | 5 | 2047 | 60.12 | 50.79 | 84.48 |

# SUBJECT INDEX