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Cane Sugar Handbook

a manual for cane sugar manufacturers and their chemists

by

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TWELFTH EDITION

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PART FOUR
Analytical Procedures

The earliest mills were probably mortar and pestle arrangements[5] similar to those still used to crush *S. barberi* near the Caspian Sea. The early mills were first powered by man, than by animal or water power. Screw and levered presses were widely used to extract juice until they were superseded by the roller mill, invented by a cane grower in Sicily in 1449. Wooden mill rolls were not clad with iron until the mid-1600's. Animals and waterwheels and windmills developed in the East were widely used to power mills. Steam drive was first used in sugarcane milling in Jamaica in 1768. Evaporation of juices began in thin clay pans, and was done in metal pans, singly or in trains, for decades with little change. The evolution of steam evaporators, vacuum pans, double-effect evaporators, and so on, is described in detail by Deerr.[5]

1.2   The Sugarcane Plant.   Sugarcane is a tropical grass belonging to the same tribe (Andropogoneae) as sorghum, johnsongrass, and corn (maize). Modern sugarcane is a complex hybrid of two or more of the five species of the genus *Saccharum*: *S. barberi* Jeswiet, *S. officinarum* L., *S. robustum* Brandes & Jesw. ex Grassl, *S. sinense* Roxb., and *S. spontaneum* L. Many forms of these species interbreed, making a highly diverse genus. *Saccharum* is thought[6,7] to have evolved in the Burma–China–India area of southern Asia. Typical of southern Asia are *S. spontaneum*, *S. sinense*, and *S. barberi*; relatively juicy forms of the latter two were used at the beginning of sugarcane cultivation and processing in India and China. As the cane spread to other areas, *S. robustum* developed in the islands of southeast Indonesia, possibly interbreeding with *Miscanthus*, and evolving into *S. officinarum* in the New Guinea area. The accepted view[8] is that *S. officinarum* was developed through selection by the aboriginal headhunters; the high-fiber forms (*S. robustum*) were used for construction, and the sweet, soft, and juicy forms (*S. officinarum*) were propagated for chewing.

1.3   Varieties.   The forms of sugarcane distributed from the Indian subcontinent to the West by Arabs and Columbus were different from those distributed by Polynesians and western sea captains (Bougainville, Cossigny, Cook, and Bligh). The Indian variety that became the basis for the expanding sugarcane industry in the Western Hemisphere was probably the one described by Linnaeus in 1753 as *Saccharum officinarum*. Fifteen years later Bougainville delivered the variety Otaheite from Tahiti to Mauritius, and Bligh delivered several East Indian varieties to the West Indies in 1793. The new varieties were rapidly disseminated through the Caribbean and reached North and South America before the end of the century. The variety Otaheite caused a revolution in sugar agriculture. It and the other "noble" varieties were so superior to the original, now called Creole, that sugar production became the driving force in the tropical Americas. So popular were the noble varieties that Creole had been supplanted by Otaheite in Puerto Rico by the early 1800's[9] and had virtually disappeared in Louisiana by 1848.[10] Almost a century after its replacement in Puerto Rico, Earle[9] collected a variety called Criolla there and assumed it to be the original. Other candidates (Creoula, Puri) differ from Criolla and from each other; our best illustration of Creole may remain the engraving of Fleischmann.[10]

Otaheite began to fail in the mid-1800's and was replaced by Black, Striped, and White Cheribon. These color variants of the cane variety have many synonyms including Loui-

6. Grassl, *ISSCT Breeders Newsl.*, 1974 **34**, pp. 10–18.

7. Daniels, *ISSCT Breeders Newsl.*, 1974 **34**, pp. 21–26.

8. Artschwager and Brandes, *Sugarcane*, USDA Agri. Handbook 122, Washington, DC, 1958, 307 pp.

9. Earle, *J. Dep. Agric. Puerto Rico*, 1921 5(3), p. 48.

10. Fleischmann, Ex. Doc. No. 59, U.S. Patent Office, 1848, pp. 278–388, 29 figs.

(A)   (B)
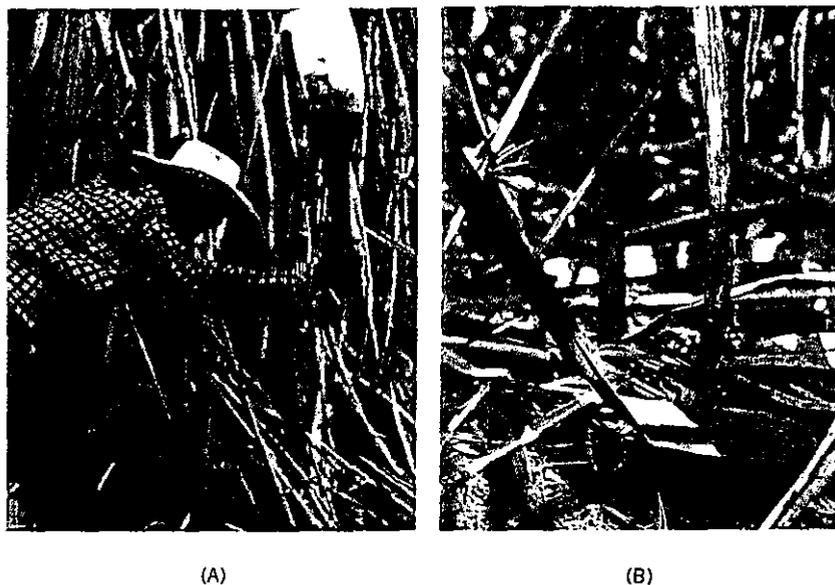
Figure 1.1. Cutting sugarcane with Australian 135° knife. (Courtesy of H. D. Tendero) (A) in Central America. (B) The angle of knife helps leveling closer to ground—increasing tonnage.

ratoon crops. These factors, and the effects of disease and mechanical harvesters, tend to limit the number of ratoons that can be harvested. Only the plant cane crop is harvested in a few areas, but it is not unusual to find fields of tenth or older ratoon crops in the Caribbean. Where mechanized harvesting is practiced, or where winters are severe, the plant cane and two or three ratoon crops are followed by reconditioning of fields and a new planting.

1.6   Harvesting.   The goal of the harvest is to deliver sugarcane stalks of good quality to the mill. Quality, measured by sucrose and trash content, is reduced by damaging cane, increasing trash in delivered cane, and delaying cane delivery. Payment based on quality as well as tonnage increases the incentive for improving quality.

The removal of cane tops is highly desirable in the harvesting operation. Cane tops and leaves have little sucrose but are high in starch and reducing sugars. These tops and leaves lower sugar yields in the boiling house. The residue from the tops absorbs sucrose and exits from the mill train with more sucrose than the tops had on entering. Cane leaves have a high silica content which contributes to mill roll wear. The top is most effectively removed by hand cutting, the harvesting method of choice in most of the sugarcane world (Fig. 1.1). Hand stripping cane stalks further reduces the trash content to 2-3%. Deerr[11] states that "expert cutters can cut, top, and throw 1000 lb of cane per hour." To this rate of 2 h/t of cane harvested must be added $\frac{1}{2}$ h for cleaning burned cane or 1 h for green cane.[16] The many hand tools used to cut and clean sugarcane include the ancient sickle of the Indian subcontinent, the adze in Morocco, the machete in Latin America, the short-handled cane knives in South Africa (Fig. 1.2), the modern Australian 135° knife (Fig. 1.3), and the

16. Chen, 1985, p. 7.

Figure 1.4. New "Allrounder" cane knife (foreground). (South Africa)

new South African "Allrounder" knife (Fig. 1.4), showing the cutting length of the blade (foreground) with that of the normal long-handled knife.[17]

In order to reduce leg injuries, the new CALSAF shin protectors (Fig. 1.5)[18] are a practical innovation. Mechanical harvesting was at one time a "fashion" of modernization in the sugar world, but for practical reasons and unexpected problems encountered, many sugar factories are back to hand-cut operations.

Because of a shortage of labor, the entire crop in Louisiana and Hawaii has been mechanically harvested for several decades, and the oldest system of mechanical harvesting still used is the soldier system of Louisiana. The soldier harvesters (Fig. 1.6) can harvest one or two raised rows at a time and are adapted to erect crops with yields up to 100 t/ha. The soldier harvester operates in green cane, and topping is effective in erect or semilodged fields. Gathering arms and chains lift lodged cane, an adjustable base cutter cuts the bottom of the stalk, and an adjustable topper removes the tops. The whole stalks are carried erect for the length of the machine by the sticker chains and an adjustable gate delivers the stalks to the heap raw. Two to six cane rows are placed on a heap row with stalks placed across the raised rows. Heap rows are fired to remove leafy trash, and grab loaders place the cane in wagons for transport to transloading stations or directly to the mill. The newer one-row soldier harvesters can average 50 tons of cane per hour (tch) and reach 100 tch in erect cane and dry fields. The two-row soldier harvester can average 100 tch and reach 200 tch for a day's production. Cutting rates for either machine are severely reduced by operation in lodged cane or in wet, muddy fields. A grab loader can load 60 tch; its efficiency depends on the number of cane rows per heap row. The operation of a two-row harvester is shown in Fig. 1.7.

17. SASJ, May 1991, p. 124.
18. *Ibid.*, p. 143.
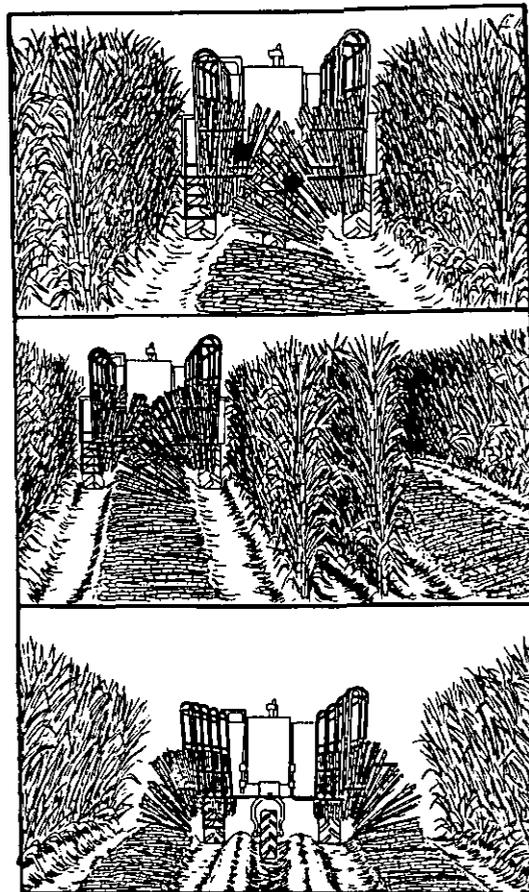
(1) The two-row harvester opens a field by cutting two rows and piling the cane in a common heap behind the harvester.

(2) Skipping two rows, another two rows of cane are cut and piled into one heap behind the harvester.

(3) The harvester cuts the standing rows two at a time, conveying the cane onto earlier piles to provide four rows of cane in each heap.

Figure 1.7. Operation of a two-row harvester.

The longer the growing season, the more likely the crop will lodge and become tangled and matted. Because it erects the cane before it cuts, the soldier harvester has not been used for tangled, long-season cane. Mechanical harvesting as developed over several decades in Hawaii evolved from grab loading (*Cane Sugar Handbook*, 8th ed.) to push rake (*Cane Sugar Handbook*, 9th ed.) to the V-cutter (*Cane Sugar Handbook*, 10th ed.). All three systems are still in use in Hawaii, but none has become widely adapted elsewhere. Of all harvesters in commercial use, the V-cutter harvests at the lowest cost per ton of cane. It cuts the stalks at the bottom but not at the top, piles the cane into windrows, and harvests 100 tch in high-yielding, matted fields. Loading is done mechanically with machines of several designs, varying from grab loaders to continuous loaders (see Figs. 1.10 and 1.11).

The soldier harvester evolved in an area with light tonnage and an erect crop and the V-cutter in an area with high tonnage and a matted crop. But harvesting conditions in many areas are between these extremes. A third system was developed in Australia to harvest under intermediate conditions. The Australian cane combine has been used and modified in other areas and currently may be the most talked-about mechanical harvesting system. The
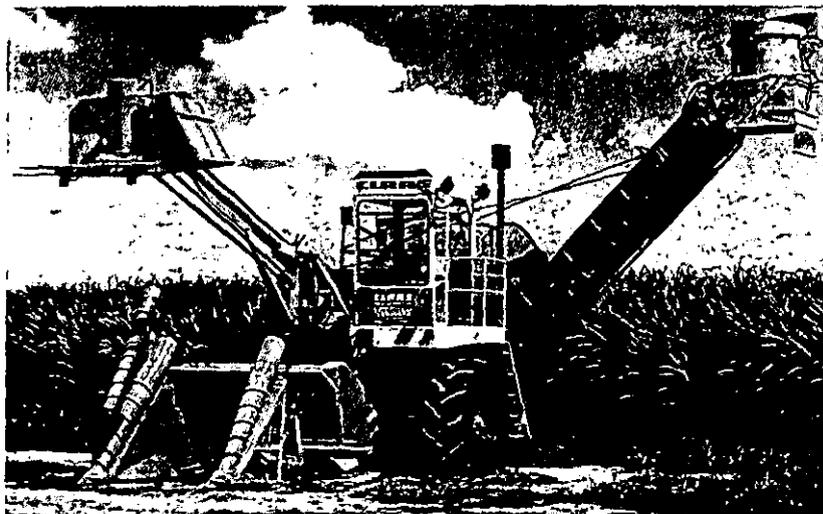
Figure 1.8. Claas Combine. (Inter-American Transport Equipment Co.)

combine harvester pushes the stalks over, cuts or breaks them at the base, and draws the stalk into the machine, butt first. The stalks are then cut into billets and these are elevated on a carrier past one or two blowers or extractor fans for trash removal. The partially cleaned, chopped cane is then dropped into a tractor-drawn bin traveling at the side of the combine. Combines operate more efficiently in burned fields; under good conditions the system delivers 30 tch. Figure 1.8 shows a Class Combine and Fig. 1.9 shows a CAMECO Combine.

The combine harvester captured the interest of processors because of the possibility of reduced leafy trash and field soil. However, if the topping mechanism is not able to function, the leaf roll at the top of the stalk behaves like a cane billet and goes into the bin and onto the mill. This has reduced sugar recovery in some areas that use combines. Because of the extensive damage to the stalk caused by the combine system, deterioration becomes a problem in cane that is not rapidly processed.

So far, the combine machine is only efficient for standing straight cane. Some factories in the Western Hemisphere adopted the combine operation but failed to achieve expected results. Instead of reducing leafy trash, it collected more cane tops and leaves.

Before considering the adoption of mechanical harvesting, especially a combine system, it is essential to examine cost-benefit ratios carefully, such as high capital investment, effective maintenance programs, cane quality (physical), type of soil, etc. Burleigh[19] showed that the costs of harvesting, transporting, and processing were 44% higher when the combine system was compared to hand harvesting in the Sudan.

1.7 Cane Handling and Transport.   The bulk of the world's sugarcane is harvested and loaded by hand and some is still transported by animals. However, the first moves toward mechanization are usually in loading and hauling. The use of grab loaders (Fig. 1.10) is widespread, and these devices are relatively simple and inexpensive. Continuous loaders (Fig. 1.11) are more costly, but since cane is lifted without pushing (as with

19. Burleigh, *Sugar J.*, 1978 41(5), p. 10.
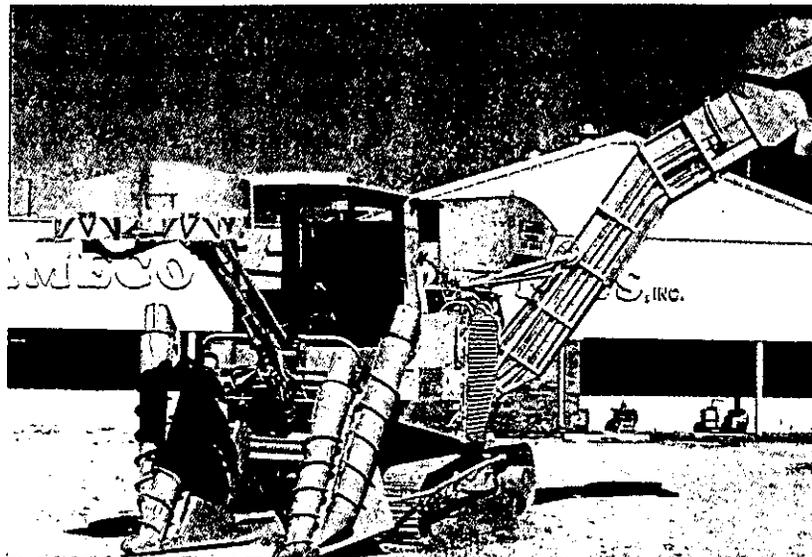
Figure 1.9. CAMECO combine harvester.
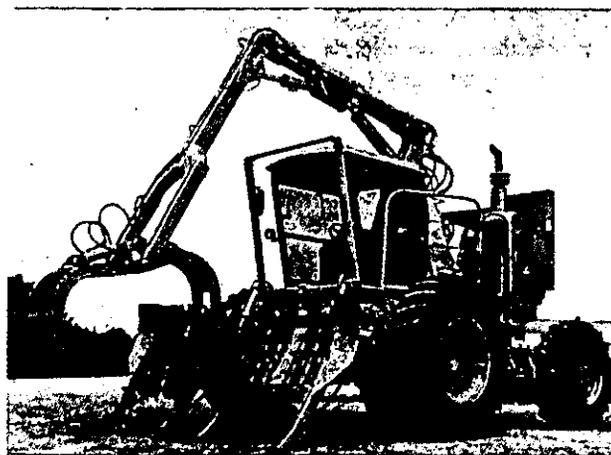
Figure 1.10. Grab loader. (CAMECO SP2254)

the grab loader) the soil content in delivered cane is reduced. Both are designed to keep the field trash in the cane to a minimum. Some models of the continuous machine are fitted with extractor fans to remove leafy trash.

Infield transport depends on the design of the transport system. Capacity of vehicles may vary from 3-20 tons. Tractor-drawn wagons may go to a transloading station or directly to the mill. Some harvesters and loaders deliver directly to trucks. Narrow gauge railroads or
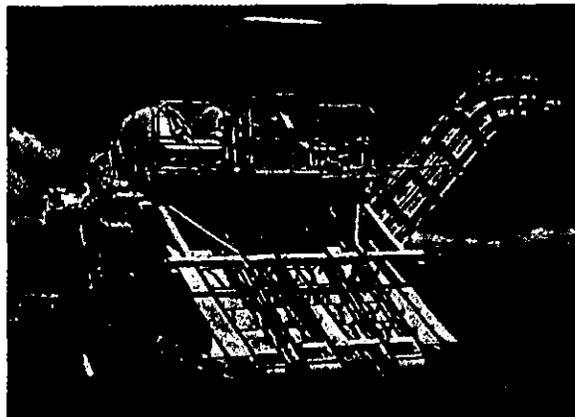
Figure 1.11. Continuous loader. (CAMECO R-6)

barges are still used to haul cane to the mill, although these transport systems are gradually being replaced as highway transport improves.

The economics of cane transport determines whether infield units should haul to the mill or cane should be transloaded to larger vehicles. Economic considerations also determine whether the system used should be chain net (Fig. 1.12), side-dump (Fig. 1.13), or container (Fig. 1.14). Burleigh[20] determined that the efficiency of a transport system is directly related to mill yard handling. For handling chopped cane, a container system with bulk storage has the lowest total cost. Using containers for mill yard storage greatly increases costs, as does the use of small (4-ton) side-dump units. Cost factors for harvesting and handling systems vary widely. Choices of the most economical system depend on the current needs and future plans of the specific enterprise.

The following equation was used by Gentil et al.[21] to calculate the maximum economical distance to transport sugarcane between field and factory in Brazil

$$MD = \frac{(PT - CT)TV}{2\left(\dfrac{CF}{X} + CVK\right)}$$

where PT = gross price/harvested t field cane.
CT = cost of producing one t of cane
TR = net t/trip
CF = fixed cost
CVK = variable cost/km
X = number of km

The equation applies to a simple, specific example and does not account for variables in transport type or transloading.

1.8 Deterioration. The quality of standing sugarcane tends to improve with age,

20. Burleigh, Personal communications.
21. *ISJ*, 1978, pp. 202–204.

Figure 1.14. Cane containers. (Courtesy of Cowley Sugar House, Texas)

reach a maximum, and then decline. Whatever the quality at time of harvest, rapid deterioration begins from the moment the cane is cut. Stale cane is an anathema to the whole industry: growers lose tonnage and processors lose sugar.

Before harvest, deterioration may occur from disease, pest, or weather damage. After cutting, sugarcane loses water (1–2% daily for the first week). Where cane is burned before cutting, water losses are minimal, especially if cane is crushed within one day of burning. Water loss creates an apparent increase in sugar content.

Traditionally, deterioration proceeds by enzymic, chemical, and microbial processes.[22-24] The enzyme invertase, which occurs naturally in cane, converts sucrose to invert sugars (glucose and fructose), thus lowering purity. The rate of inversion, which is a genetic trait that can be minimized by variety selection, varies with temperature and moisture, and is most rapid in hot, dry periods.

Chemical deterioration includes inversion caused both by acid conditions, which increase as cane becomes staler, and as a side effect of some microbial growth. The products of inversion change further with time to form acids and colored compounds.

Microbial deterioration is primarily caused by a *Leuconostoc* bacterium, although many other types of bacteria can invade cut cane.[24] *Leuconostoc*, which is in most soils, invades exposed internal stalk tissue, whatever the cause. Fire, cutting, mechanical damage, stalk damage by disease or insects, damage by wind or freezing may all lead to stalk wounds that allow entry of *Leuconostoc* and encourage dextran formation. The interval between cutting and grinding is the period when dextran levels build up most severely.[24] Foster has found dextran levels on chopper-harvested cane to increase to 7000 ppm in two days. Re-

22. Clarke et al., ISSCT, 1980, pp. 2192–2203.
23. Foster, ISSCT, 1969, pp. 22–23.
24. Foster et al., ISSCT, 1980, pp. 2204–2220.

duction of cut-to-crush time to a minimum is the most effective and practical control measure for dextran formation. Dextran is discussed further in Chapter 26.

Burning, which improves quality by removing trash, also removes wax and cooks the peripheral storage tissue of the stalk: the more intense the burning, the greater the damage. Florida studies[25] have shown that sucrose yields on cane can be up to 5% greater in cool burnt cane than in hot. This observation agrees with the recurrent interest in harvesting green cane (that is, unburnt cane) either by chopper harvester in Queensland or in mechanical whole-stalk harvester tests in South Africa.[24,26,27] Foster[24,26] reports that sound, long billets of green cane yield up to 1.5% higher C.C.S. (commercial cane sugar) and lower dextran levels than does burnt cane with a similar cut-to-crush period. Alcohol formation, owing to yeast infection, and adding to BOD of effluent water, is also decreased with green cane.

Freezes cause deterioration in marginal climate areas. In addition to the United States, Argentina, Iran, India, and Pakistan, the places affected includes parts of Brazil, South Africa, Zimbabwe, Australia, Spain, and Morocco.

Susceptibility to freeze damage is affected by variety, disease, canopy, nutrition, soil moisture, and duration of cold. In general, temperatures of 25–26 F (−3.3 to −3.9 C) kill leaves and terminal buds, and sugar production stops. If there is no stalk damage, cane so affected may keep for up to three months. Temperatures of 23–24 F (−4.5 to −5.0 C) will kill most of the lateral buds and the top half of the internal stem tissue in erect cane. The frozen top will sour and dextran will form, requiring low topping by the harvesters. This cane may be milled up to six weeks after damage if topping removes the soured tissue. Temperature of 22 F (−5.6 C) and below will freeze entire stalks, and 20 F (−6.7 C) will split stalks. Depending on postfreeze temperatures, completely frozen cane may keep for a week or two.

Mechanical damage and localized cell death occur whenever there is a cut, bruise, or puncture caused by knives, gathering chains, sticker chains, tires, tracks, slings, etc. Because the formation of dextran by *Leuconostoc* is closely associated with the damaged area, there is a direct relation between cane quality and the amount of mechanical damage. There have been several studies on the cane quality; these are listed in the Bibliography on the Quality of Sugarcane.[28]

A miscellaneous array of pests may indirectly lower quality. Borer channels and wounds by cane-chewing mammals such as bears and wild pigs permit the entry of stalk-rotting fungi, which debase quality by lowering the sucrose content. Dextran is probably not associated with fungal deterioration.

1.9 Harvest and Processing Season. Unlike sugar beets, sugarcane cannot be stored for processing without excessive inversion and deterioration; thus, harvesting and processing to raw sugar are concurrent. In general, sugarcane is harvested during the cooler, drier months in each hemisphere. Sugar content and recoveries are usually lower at the beginning and end of the harvest period. Some irrigated areas may harvest year-round, regulating maturity by fertilizer and irrigation management or by chemical ripeners.

The grinding season of cane sugar producing countries is shown in Table 1.2.[29]

25. Holder and DeStefano, ASSCT (US), 1977, pp. 58–60.
26. Foster, ASSCT (QL), 1979, pp. 11–19.
27. DeBeer, ISSCT, 1983.
28. ISSCT Bibliography on the Quality of Sugarcane, SASA Expt. Stat., Mt. Edgecombe 4300, S. Africa, 1982.
29. Chen, 1985, p. 17.

Outline of Raw Sugar Process and Extraction of Juice*

PART (A) OUTLINE OF PROCESS

4.1 Introduction. This outline defining technical terms and providing a condensed description of raw sugar manufacture will prove useful for those who may not care to study the detailed processes given in separate chapters devoted to the various stations in the raw sugar factory. A flow diagram (Fig. 4.1) representing the standard process includes only general practice without the refinements and variations that are in use in many parts of the world. No attempt has been made to indicate the number of units of each type of apparatus of the relative sizes of equipment.

4.2 Extraction of Juice. The cane is first prepared for grinding by revolving knives that cut the stalks into chips, by hammer-mill shredders that shred the cane but extract no juice, by heavily grooved crusher rolls that break the cane and express a large part of the juice, or, more generally, by a combination of two or three of these methods. Mills consist of multiple units of three-roller combinations through which the crushed cane or bagasse successively passes. To aid in the extraction of the juice, sprays of water or thin juice directed on the blanket of bagasse as it emerges from each mill unit help to leach out the sugar. The process termed *imbibition* (or, less frequently, *saturation* or *maceration*) has many modifications. In best milling practice, more than 95% of the sugar in the cane goes into the juice; this percentage is called the sucrose extraction (or Pol extraction) or, more simply, the extraction.

Commercial units of cane diffusion have been adopted in several sugar-producing countries since the early 1960's.

The final bagasse (or megass) from the last mill contains the unextracted sugar, the woody fiber, and 45–55% water. This material usually goes to the boilers as fuel, but many factories purchase fuel and use the bagasse for wallboard or paper manufacture, cattle bedding, or other commercial byproduct utilization (see Chapter 10). The flow diagram shows a milling tandem, with two sets of revolving cane knives, a 2-roll crusher, and four 3-roll mills.

4.3 Purification of Juice: Clarification. The dark-green juice from the mills is acid and turbid. The clarification process, designed to remove both soluble and insoluble impurities, universally employs lime and heat as the clarifying agents. Milk of lime, about 1 lb (0.5 kg) CaO per ton of cane, neutralizes the natural acidity of the juice, forming

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*by J. C. P. Chen
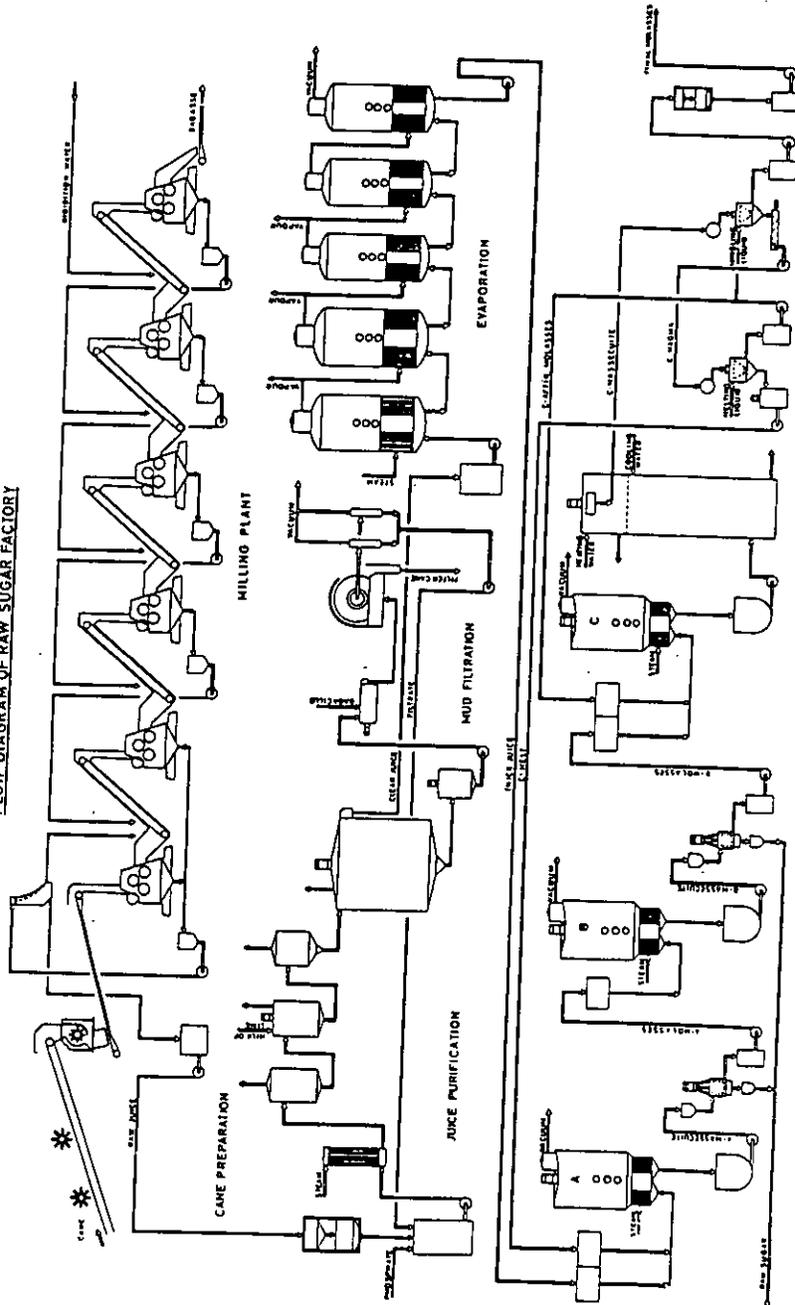
FLOW DIAGRAM OF RAW SUGAR FACTORY

Figure 4.1. Flow diagram of raw sugar factory. (Courtesy of Dietrich Bosse, BMA)

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insoluble lime salts, mostly calcium phosphate. Heating the limed juice to boiling or slightly above coagulates the albumin and some of the fats, waxes, and gums, and the precipitate thus formed entraps suspended solids as well as finer particles. The muds separate from the clear juice by sedimentation. The muds are filtered on rotary drum vacuum filters. The filtered juice returns to the process or goes directly to clarified juice, and the press cake (*cachaza* in Latin America) is discarded or returned to the fields for fertilizer. The clear brownish clarified juice goes to the evaporators without further treatment. A wide variety of modifications of the heat and lime treatment has developed, as described in Chapter 5. The flow diagram (Fig. 4.1) shows continuous clarification in a clarifier with vacuum-filtered mud waters.

4.4 Evaporation. The clarified juice, having much the same composition as the raw extracted juice except for the precipitated impurities removed by the lime treatment, contains about 85% water. Two-thirds of this water is evaporated in vacuum multiple effects consisting of a succession (four or five) of vacuum-boiling cells or "bodies" arranged in series so that each succeeding body has a higher vacuum, and therefore boils at a lower temperature. The vapors from one body can thus boil the juice in the next one. By this system the steam introduced into the first body does multiple-effect evaporation. The vapor from the final body goes into a condenser. Figure 4.1 shows a quadruple effect in which steam evaporates four times its weight of water. The syrup (*meladura* in Latin America) leaves the last body continuously with about 65% solids and 35% water (see Chapter 6).

4.5 Clarification of Raw Syrup. The process is similar to the phosphatation of remelt in a sugar refinery. Here lime and phosphoric acid are added to the syrup, and the syrup is aerated with the addition of a polymer flocculant. The flocculated syrup is then passed directly to a clarifier, such as the Jacob type or the Talo Clarifier (see Chapter 5).

4.6 Crystallization. Crystallization takes place in single-effect vacuum pans, where the syrup is evaporated until saturated with sugar. At this point seed grain is added to serve as nuclei for the sugar crystals, and more syrup is added as the water evaporates. The growth of the crystals continues until the pan is full. Given a skilled sugar boiler (or adequate instrumentation) the original crystals can be grown without the formation of additional crystals, so that when the pan is just full, the crystals are all of the desired size, and the crystals and syrup form a dense mass known as *massecuite* (also called *fillmass* in some branches of the industry). The *strike* (or contents of the pan) is then discharged through a foot valve into a mixer or crystallizer.

The boiling of massecuites and the reboiling of the molasses are carried out by boiling systems chosen to suit many conditions (see Chapter 7).

4.7 Centrifuging or Purging; Reboiling Molasses. The massecuite from mixer or crystallizer is drawn into revolving machines called centrifugals. The cylindrical basket suspended on a spindle has perforated sides lined with wire cloth, inside of which are metal sheets containing 400–600 perforations per square inch. The basket revolves at speeds from 1000–1800 rpm. The perforated lining retains the sugar crystals, which may be washed with water if desired. The mother liquor, molasses, passes through the lining because of the centrifugal force exerted (from 500 up to 1800 × gravity), and after the sugar is *purged* it is *cut down*, leaving the centrifugal ready for another charge of massecuite. Modern installations are exclusively of the high-speed (or high-gravity) type with automatic control of the whole cycle. Low grades may be purged by continuous centrifuges.

In the three-boiling system shown in Fig. 4.1 the first boiling of raw syrup yields raw sugar and *A* molasses, which is returned to the vacuum pan to be reboiled on a *footing* of magma to a second massecuite, *B*, that in turn yields a second crop of crystals. The *B* sugar is mixed with the *A* sugar to form the commercial output of the factory. The second or *B*

molasses is of much lower purity and in turn is reboiled on a seed footing to form low-grade or *C* massecuite. These low-grade massecuites remain in crystallizers for more than one day, where they cool while being kept in motion with stirring arms (see Chapter 7). The *C* sugar is mingled with syrup and used for *A* and *B* massecuite seed. The final molasses, or *blackstrap*, a heavy, viscous material containing approximately one-third sucrose, one-fifth reducing sugars, and the remainder ash, organic nonsugars, and water, serves as a base for cattle feed, in the manufacture of industrial alcohol, in yeast production, and so on (see Chapter 10).

4.8 History of Machinery, Apparatus, and Processes. Sugar manufacture and refining have a proud history of pioneering in food processing and the chemical industries. Most of the basic apparatus was developed specifically for sugar work and later adapted for general usage. Sugar was the earliest food process to employ chemists and anticipated by many years the modern ideas of technical and chemical control now common to most large manufactories (see Sec. 2.8, 11th edition of this Handbook for details).

4.9 Capacity of Equipment. Since many factors influence the selection of adequate equipment in the cane factory, average figures may be quite misleading. Local conditions, the character and richness of the cane, the type of process, the desired quality of output, and many other considerations affect the size and capacity of the machinery and equipment at the various stations.

Detailed calculations on capacities can be found in such reference works as Hugot and Tromp. The latest compilation of formula appears in a booklet by Eisner.[1]

4.10 New Processes for Small-Scale Operation. The latest process developed is the Tilby Separator[2] (Fig. 4.2). The cane is split longitudinally into two halves. Each half passes through its own separator so that the pith is removed from the inside of the rind. Then the rind can be further scraped to remove its outside layer of wax coating. The layers are generally termed *Comfith* for the pith portion, *Comrind* for the fiber layer, and *Dermax* for the wax coating.[3,4]

Test runs have been conducted in Barbados and Florida. The analysis of Comfith for sugar production (Table 4.1),[3] and the rind for composite panel production (Figs. 4.3 and 4.4)[5] are given.

There are organizations doing research and development on small-scale sugar processing. The Intermediate Technology Development Group Ltd.,[6] is trying to improve the so-called open pan sulfitation (OPS) units by replacing the two-mill unit with a screw press, or with a small five-roller crusher mill. It is then followed by carbonation for purification and a three-stage gas/vapor system for evaporation. As for crystallization, investigation is being carried out on vertical crystallizers and continuous centrifugals.

Hagelberg[7] proposes a process for 20–300 t of cane per day. The raw juice is clarified by lime and phosphate, scum is removed by flotation, and the juice is evaporated in three stages (first, by short tube, vertical calandria evaporator to 35 Brix; then, by open evaporator, using flue gases at 300 C to 80 Brix; and finally by a thin-film evaporator to 95 Brix) before being cooled in an air-cooled crystallizer, and poured into molds. For direct-con-

1. Eisner, *Basic Calculations for the Cane Sugar Factory*, Fletcher and Stewart Ltd., England, 1988.
2. Anderson, ASSCT (US), 1978, pp. 100–103.
3. Hansen et al., *ISJ*, 1981, pp. 327–329.
4. Moeltner, ISSCT, 1980, pp. 2764–2786.
5. Nyberg, *ISJ*, 1981, pp. 296–300.
6. *ISJ*, 1978, pp. 357–358.
7. Hagelberg, *Zuckerind*, 1978, pp. 757–761.

Purification of the Juice*

PART (A) CLARIFICATION REACTION AND CONTROL

5.1 Preliminary Treatment. The juice to process from the mills is subjected to a coarse straining and further removal of suspended solids, after which the juice is weighed. Where part of the juices or mud waters are recirculated to the mills, the weighing should be done after clarification is completed.

In Hawaii, even after cane-cleaning operations, juices may average 2–4% insoluble solids, and in wet weather 6–7% is not uncommon. The material is mostly soil, sand, and ground rock that is not removed by preliminary screening. Continuous-type settling devices in use in several Hawaiian factories are effective in removing coarser particles, but not clay and fine soil. The cyclone appears to offer good promise. A rubber-lined Dorrclone system has a capacity up to 280 gal of mixed juice per minute (gpm), removing from 1–10 t of fine material in 24 h.[1]

Another type of hydrocyclone, the Bauer 600 EX, widely applied in paper and pulp mills, is reported by Chiang[2] for the removal of suspended matters, including bagacillo.

DSM Screens for Fiber Particles. The DSM screen, developed by Dorr-Oliver, consists of a feedbox, a feed spout distributor, and a screen deck of wedge-shaped bars at right angles to the juice flow (Fig. 5.1). The size separation depends on the opening between the bars. The mixed juice going to the clarifiers flows down the concave surface tangentially, passing through the 1.0 mm opening between the bars, the fiber particles are forced down the screen surface by the juice flow and discharge at the overflow spout. The removal of the additional fiber improves clarifier capacity and gives better juice clarity and a denser mud. A capacity of 120 gpm/ft [24.84 l/(sec)(m)] width of screen is conservative; no blinding occurs, and washing with hot water or steam once a shift keeps screens clean. Some factories use 45° DSM screen (Fig. 5.2) in place of the conventional cush-cush conveyor.

This screen is also employed in a two-stage operation, with 1.0 and 0.5 mm openings for first and second screens, respectively. A purity rise of 0.96 from mixed juice to clarified juice is reported by Suzor.[3] It is also commonly adopted as juice strainer in cane diffusion systems.

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*by J. C. P. Chen

1. Chen, 1985, p. 127.
2. *ISJ*, 1986, **88**, pp. 133–138.
3. Suzor, Rep. Hawaii Sugar Technol., 1976, pp. 17–24.
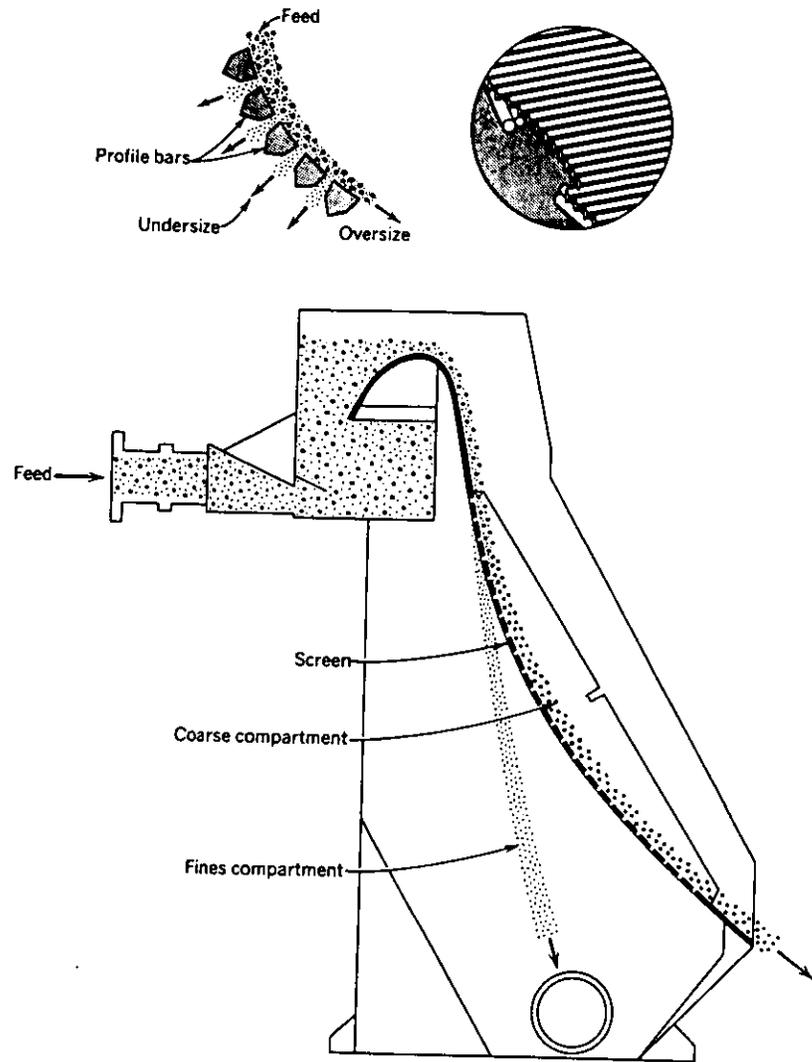
Figure 5.1. 45° DSM juice screen. (Dorr-Oliver)

The rotary screen being used in Australia has a rotational speed of the mesh drum from 3–12 rpm, thus enabling the desired mat thickness to be achieved (Fig. 5.3). Different parabolic-type screens with apertures 1.4 mm, 1.6 mm, and 2.0 mm have been compared.[4] The woven wire mesh, 1.0 mm aperture, 0.6 mm wire thickness has achieved impressive results. The capacity rating is estimated at 75 l/m^2 (1.84 gal/sq ft) screen area.

4. Allen et al., ASSCT (QL), 1979, pp. 157–159.
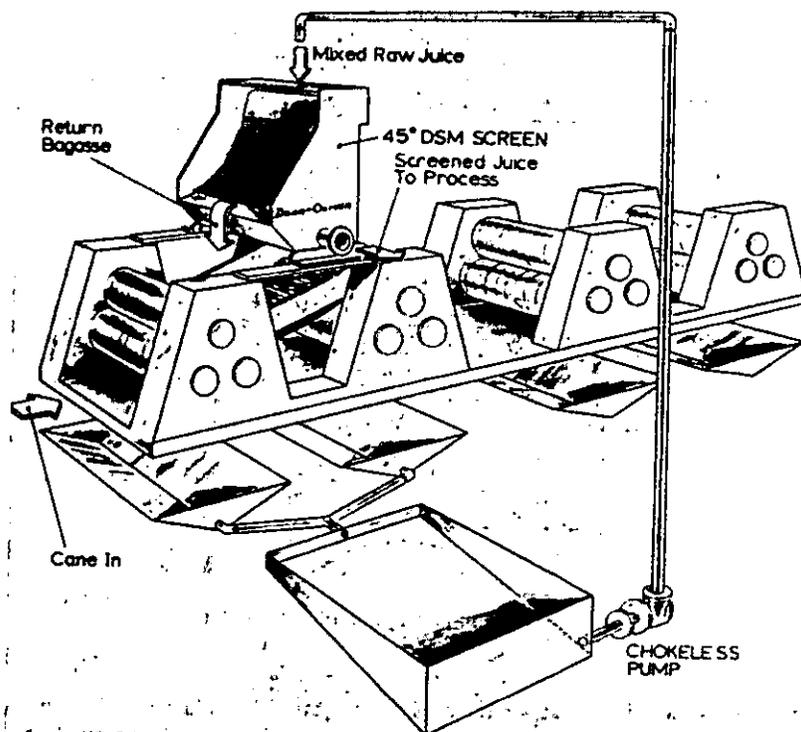
Figure 5.2. 45° DSM screen for cush-cush removal.

Brotherton et al.[5] compare screening equipment: DSM, rotary, and Contra Shear (Fig. 5.4), with different screen apertures. They show the improvement in fiber removal efficiency achieved as screen aperture is reduced (Fig. 5.5), and the fiber content of screened juice is a function of the quantity of fine material in the feed and thus is dependent on both the total fiber content and the fiber size distribution. They conclude that in order to achieve screened juice with a fiber content of less than 0.2% by weight, the aperture should not be larger than 0.8 mm, especially in mills with high level of cane preparature.

The unusually high level of bagacillo deluge can be the result of poor performance of the rotary juice separation unit which used punched stainless steel screens of 1.2 mm. By replacing with welded wedge bar screens of 0.5 mm aperture, good drainage properties and high throughput have been achieved.[6] The use of rotary screen with wedge bars of 0.5 mm aperture has reduced the fiber content of screened juice to a safe operating level of about 0.2%.[7]

5. ASSCT (QL), 1981, pp. 117–124.
6. Bickle and Webster, ASSCT (QL), 1982, pp. 249–253.
7. Brotherton and Noble, SASTA, 1982, pp. 243–248.
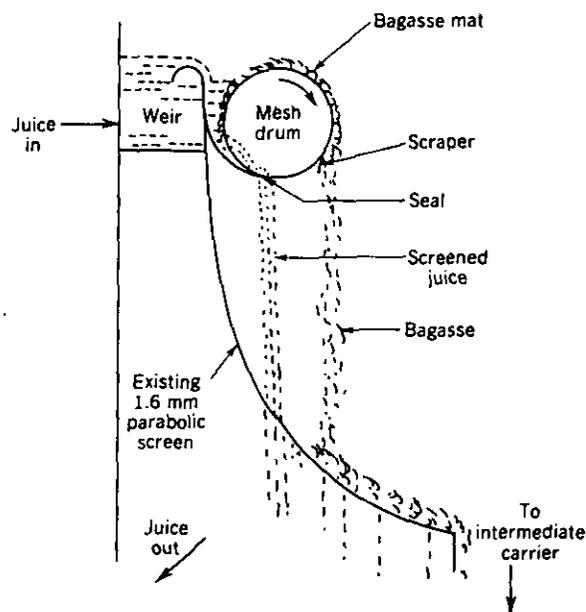
Figure 5.3. Schematic diagram of rotary screen.

A modified system is to pass the mixed juice first through a strainer (B₂) as shown in Fig. 5.6. The strainer is equipped with a wedge wire grid mesh of 0.5 mm aperture. The juice is collected in a reduced tank (C) before pumping to the vibratory spreaders. The removal of bagacillo, mud, and sand is 60-80%.[8]

A newcomer is the Delkor Linear Belt Filter reported by Gierke[9] to be more advantageous than the DSM screen. To handle 200 t juice/h, a 9 m² LBF unit costs a little more than four 2 m² DSM screens for same capacity, however, the LBF uses less power, less maintenance (no vibration), lower noise, less space needed, and with screening efficiency of 92% bagacillo removal. A simple weave mono-filament polypropylene cloth of 400 μm is used as the filtering medium (Fig. 5.7).

5.2 Object of Clarification. In raw sugar manufacture, lime and heat are the agents almost exclusively used, although a small amount of soluble phosphate may be added. The primary object of the clarification is to remove from the juice the maximum quantity of impurities, more specifically particles, at the earliest possible stage. Carpenter[10] relates that juice clarification is actually juice "departiculation." It does not decolorize but rather that the particles that are being removed are colored. Also turbidity indicates the presence of refractive index gradients, but not particles.

Shterman et al.[11] investigate and observe that the increase of 1% in dry solid nonsugars causes an equivalent of 0.6-0.7% increase of viscosity caused by increased sugar.

8. Prada, Sugar, February 1983, pp. 178-179.
9. SASTA, 1989, pp. 33-35.
10. Sugar J., January 1986, p. 10.
11. ISJ, 1985, 87, p. 118A.
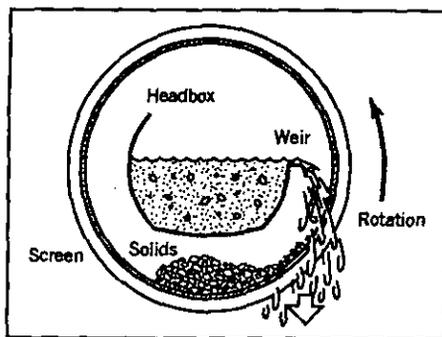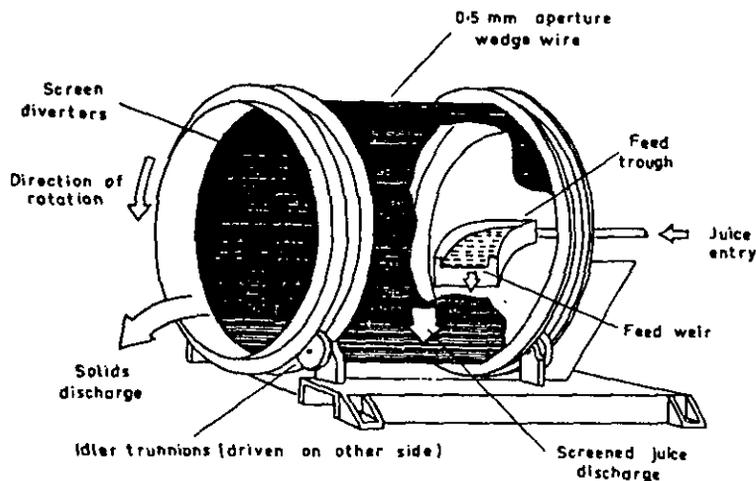
Figure 5.4. Contra-Shear flow pattern.

5.3 Defecation Process. Clarification by heat and lime, known as the simple defecation process, is the oldest and in many ways still the most effective means of purifying the juice. In general, sufficient time is added to neutralize the organic acids present in the juice, after which the temperature is raised to 95 C (200 F) or more. This lime and heat treatment forms a heavy precipitate of complex composition, part lighter and part heavier than the juice, which contains insoluble lime salts, coagulated albumin, and varying proportions of the fats, waxes, and gums. The flocculant precipitate carries with it most of the finely suspended material of the juice that has escaped mechanical screening. The separation of this precipitate from the juice is done by a juice clarifier. The different forms of clarifier are designed to carry out this separation as completely and rapidly as possible.

The degree of clarification has great bearing on the boiling house operations, the yield of raw sugar, and the refining quality of raw sugar.

5.4 Systems of Clarification. There are variations in the clarification system, other than the simple liming and heating. Because of the difficulty clarifying certain juices,
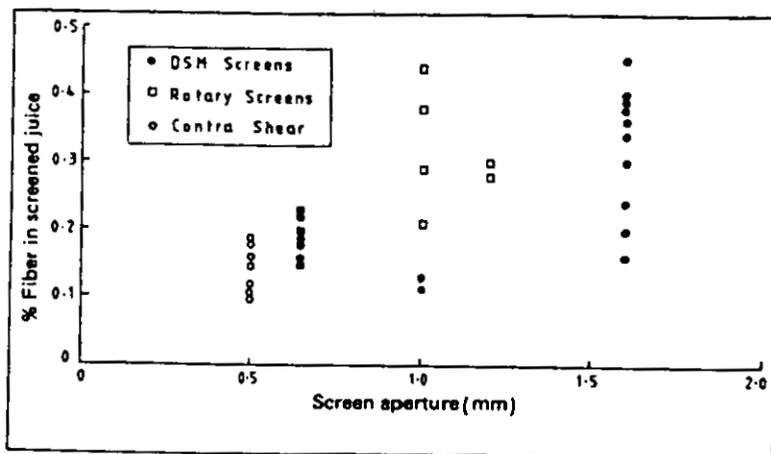
Figure 5.5. The influence of screen aperture on the fiber content of screened juice.
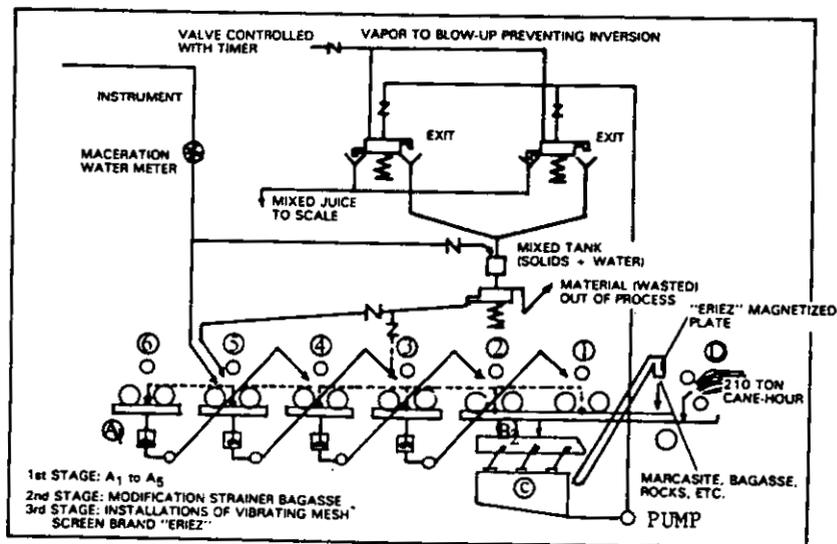
Figure 5.6. Straining of mixed juice.

many modifications have been devised, and equipment developed to overcome this problem.

The steps and the modifications are as follows:

1. Method of adding the lime: as milk, in batches or continuously, as saccharate.
2. Regulating quantity of lime: periodic tests, continuous recording of pH, automatic addition through pH control.
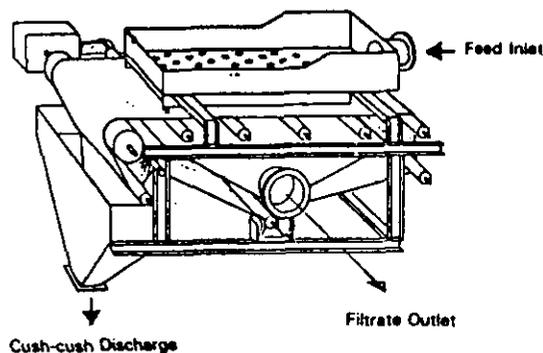
(A)
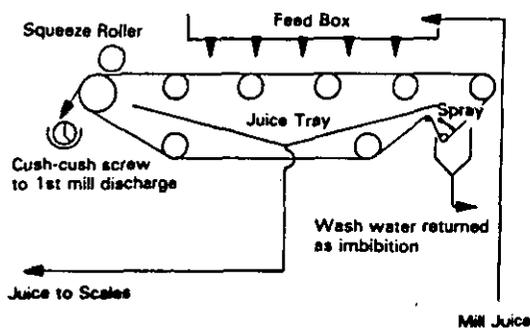
(B)

Figure 5.7. Linear belt filter. (A) General view. (B) Flow diagram.

3. Time of adding lime: before heating, "delayed liming" (increased reaction time before heating), after heating, fractionally before and after heating.
4. Temperatures: boiling, superheating, heating in two stages.
5. Treating juices from different mills, single clarification, compound and separate clarification.
6. Treatment of scums: single filtration, double filtration, returning to mills, redefecation separately or with thin juices, as in compound clarification.

It is evident that combinations of the modifications of these different steps make possible a vast number of procedures. The rather general practice of adding some form of soluble phosphate and some polyelectrolytes as flocculating agents have further complicated defecation processes. Sulfitation employed to some extent in the manufacture of raw sugars is in more general use as a plantation white sugar process.

5.5 Circulation of Lime. The lime circulatory system consists generally of two lime-mixing tanks with stirrers, in which the lime may be mixed with water to the desired density—usually 15 Baumé (148 g CaO/liter density, 1.116 g/ml). Frequently the lime content is lower, especially when automatic liming is employed. The milk of lime so prepared (done once per shift), is pumped to points in the factory where it may be needed. To slake one part of lime with three parts of water is considered as optimum. Condensate from the third and fourth evaporators should be used for slaking and diluting.

5.6 Addition of Lime as Saccharate. Handling the milk of lime slurry in pumps, pipes, tanks, and valves requires frequent cleaning and constant maintenance. Lime will dissolve in sucrose solution forming calcium saccharate, a true solution, which can be handled with none of the problems of handling a slurry. The probable cold saccharate formation is shown (Hartmann, STR, 1974):

$$C_{12}H_{22}O_{11} + Ca\ salt$$

$$\uparrow + acid\ (2e)$$

$$C_{12}H_{22}O_{11} + Ca(OH)_2 \rightarrow C_{12}H_{20}O_{11}Ca + 2H_2O$$
$$+ Ca(OH)_2$$
$$or + CaO + H_2O$$

$$C_{12}H_{22}O_{11} \cdot 2CaO$$

$$58°\text{-}85° \quad < 58°\ or\ with\ excess\ C_{12}H_{22}O_{11}$$

$$1/3\,C_{12}H_{22}O_{11} + 2/3\,C_{12}H_{22}O_{11} \cdot 3CaO \downarrow$$

$$+ 2/3\,H_2O \quad > 90°C.\ or\ with\ excess\ solid\ Ca(OH)_2$$

$$2/3\,C_{12}H_{20}O_{11}Ca + 4/3\,Ca(OH)_2$$
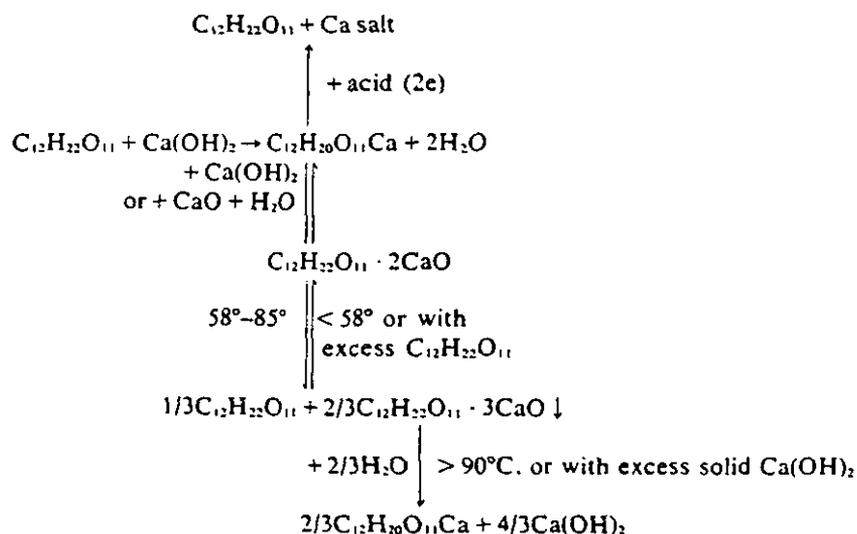
To apply saccharate liming in mixed juice, a practical development of the saccharate liming system is compared with the conventional hot liming method.[12] Instead of using mixed juice, raw syrup of 68 Brix is used to mix with 15 Bé lime milk at 7:1 ratio, for a retention time of 5 min. The resulting saccharate solution has a pH of 11.0–11.5 (Fig. 5.8). The saccharate is then dosed into the mixed juice at a point prior to the intermediate pump after the primary heating stage. The results from the comparison show that the saccharate liming process gives a clear juice with a far superior clarity and improves the purity drop across the clarification station. Moreover, saccharate solutions can be much more easily handled than the lime-milk suspension, thus improving the pH control of limed juice.

Because of syrup being exposed to high pH during the preparation of lime saccharate, some destruction of reducing sugar will increase organic acid, which will form calcium salts and slightly lower the pH. The magnitude of these changes is studied by Stringer et al.[13]

12. North-Coombes, SASTA, 1981, pp. 71-74.
13. ASSCT (QL), 1989, pp. 207-214.

compressed air for agitation has been recognized as uneconomical, and it is now known to be actually detrimental.

5.17 Reaction Time. General recognition that the time element plays an important part in the reaction of the lime has resulted in so-called delay liming, in which 10 or 15 min elapses between the time of adding the lime and the subsequent heating. In a common method of effecting the delay, the juice in an extra tank, fitted with stirrers, is maintained at constant level by an overflow or float valve. Prolonged stirring after liming permits improved floc formation, better settling rate, increased rise in gravity purity, lower turbidity, less increase in residual calcium, and lower final mud volume.

5.18 Nature of Precipitate. The precipitate that forms in cane juice with the combined action of lime and heat was formerly presumed to be tricalcium phosphate, but it is now found to be an amorphous calcium phosphate,[23] which within a few minutes begins to crystallize in two interlayered forms: octacalcium phosphate and hydroxyapatite. The two-stage precipitation first causes small particles to form, which grow and rearrange into a very intricate floc that entraps and adsorbs other nonsugars that are precipitated by the reaction change, by the heat, by the calcium, and by the increase in pH. The precipitate so formed depends on many variables, such as the variety, the maturity, and the freshness of cane, the clarification procedure, and pH.

Deben[24] makes an extensive study on the chemistry of calcium phosphate precipitation in cane juice clarification, and reviews the reports from previous investigators. He applies the classical laws and principles of chemical reactions and equilibria to describe the peculiarities of the $CaO-P_2O_5-H_2O$ system as manifested in highly simplified synthetic juice.

Fajardo and Bobrovnik[25] use x-ray diffraction and photomicrograph examination showing the precipitates to be formed from $CaHPO_4$ and $CaHPO_4 \cdot 2H_2O$.

5.19 Role of Phosphate. The accumulating evidence indicates that the phosphate content of the juice is the most important factor in efficient clarification. In sugarcane, the phosphates are inorganic as well as organic. The inorganic phosphates exist as free phosphate ions, whereas the organics exist in the form of phospholipids, phosphoproteins, nucleotide phosphates, and hexose phosphates.[26]

It is understandable that only the free phosphate ions take part in juice clarification. Therefore, juices with adequate quantity of inorganic phosphate are most desirable.

Sharma et al.[26] further confirm the need for application of balanced fertilizer quantities to cane crop, and observe a significant increase in total phosphate level during the peak of maturity and pronounced accumulation of inorganic phosphate in the juice. If fertilizers are not properly applied, there may be more organic phosphate in the juice than inorganic phosphate. The juice may not respond well to clarification (Table 5.3).

It is well documented that if the inorganic phosphate level in raw juice is less than 300 ppm w/v, the juice cannot be properly clarified, and addition of phosphate may be required (Sec. 5.30).

Honig[27] suggests that the amount of inorganic phosphate left in the clarified juice should not be less than 10 ppm, otherwise there exists a considerable danger that the juice has been

23. Carpenter et al., CSSRP, 1966, p. 134.
24. ISJ, 1976, pp. 3-7, 35-39, 73-75.
25. Centro Azucar, 1978, 5(1), pp. 55-67.
26. Sharma et al., ISJ, 1981, pp. 3-5.
27. Honig I, 1953, p. 498.
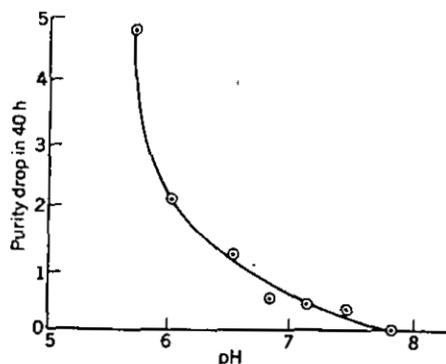
Figure 5.12. Relationship between final pH and purity drop (during shutdown).

It is necessary to adjust the temperature before shutdown, so that by the time the mill starts again, the temperature of the clarified juice will not have fallen below 160 F (71 C). Results generally obtained show that less deterioration occurs when the temperature of storage is lowered and initial pH raised.

Ravno[43] suggests for shutdown practice, either to maintain at 75 C with addition of lime immediately before shutdown, or to allow the temperature to drop below 75 C to avoid chemical reaction, but to add formalin during the last 2–3 h of milling, without adding any lime. However, bacterial loss can be high if there are large mud remains in the tanks and recirculating system.

ADDITIVES TO AID CLARIFICATION

5.30 Soluble Phosphates.   The role of P_2O_5 in clarification has been so generally recognized that the addition of a soluble phosphate to the mixed juice to bring the percentage to the minimum 0.03 % (300 ppm) is a common practice. Triple superphosphate (48 % P_2O_5) is generally used.

The advantages from adding phosphate are clearer juice, greater colloid elimination, fewer lime salts in clarified juice, more rapid settling, faster mud filtration, better sugars, and better working quality of low-grade materials in the factory. The disadvantages are increased mud volume, higher lime consumption, and greater expense. Most users are convinced that increased yields more than offset the extra cost.

Besides the triple superphosphate, other soluble phosphates can also be used, such as ordinary superphosphate, dicalcium phosphate, di- and monoammonium phosphates, and clear phosphoric acid. Cost is the controlling factor in the selection.

Bennett[44] shows the mechanism of bridging by calcium-phosphate precipitation (Fig. 5.13), which is the primary flocculation by which the impurities are bound.

5.31 Polymer Flocculants.   A number of synthetic water-soluble polymers bearing various trade names have come into general factory use. The action of these polyelectrolytes is to produce the secondary flocculation. Generally, a good flocculant improves

43. SMRI, 1979, pp. 28–32.
44. SIT, 1975.
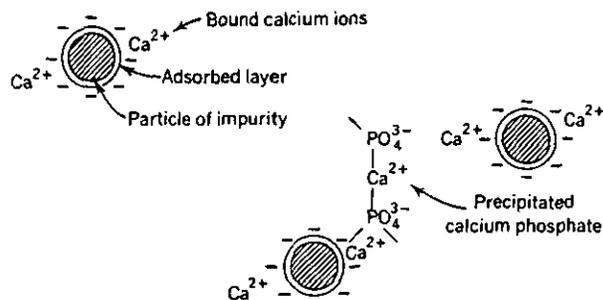
Figure 5.13. Calcium ions and calcium phosphate.

flocculation, increases settling rate, reduces mud volume, decreases Pol in cake, and most important, increases the clarity of the clarified juice.

Factors that affect the performance of polymers in juice clarification are: time of agitation of stock solution, solvent ionic strength, polymer solution concentration and solution pH, influence of P_2O_5 precipitate, and concentration of calcium in clear juice.[45]

The most successful flocculating materials for the raw sugar industry are the partially hydrolyzed polyacrylamides.

$$CH_2=CH-\underset{\underset{O}{\parallel}}{C}\cdots NH_2 \qquad CH_2=CH\cdots\underset{\underset{O}{\parallel}}{C}-O^-Na^+$$

Acrylamide   Sodium acrylate

$$\left[\begin{array}{c}CH_2-CH-\\|\\CONH_2\end{array}\right]_X \left[\begin{array}{c}CH_2-CH-\\|\\COO^-Na^+\end{array}\right]_Y$$

polyacrylamide chain
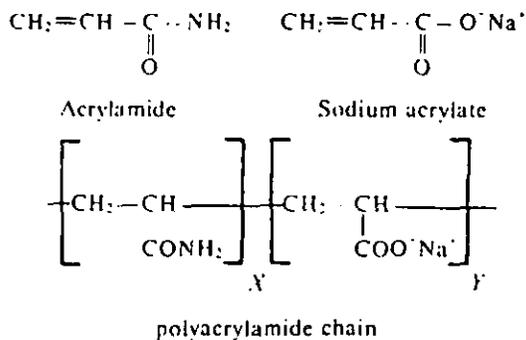
$$\text{degree of hydrolysis} = \frac{100\ Y}{(X+Y)}\%$$

Ruehrwein and Ward[46] propose the bridging theory of flocculation, and La Mer[47] suggests that the chain molecules form interparticle bridges and bind the particles together. Whayman and Crees[48] show the difference between the phenomena of coagulation and flocculation (Figs. 5.14 and 5.15).

The Polymers adopted for juice clarification are mainly anionics, which carry the same

45. Shephard, SASTA, 1978, pp. 106–112.
46. Soil Sci., 1952, 73, p. 485.
47. J. Colloid Sci., 1964, 19, p. 291.
48. ISSCT, 1974, p. 1176.

polymerization of 1–7. However, the use of yeast amylase at 50–55 C, was formed mainly of maltose and a small quantity of glucose and maltotriose.

5.37 Other Additives. In Central America, some small factories are using extract of tree barks as flocculating agents for cane juice clarification. It is generally called *mozote*. According to Samuels,[94] the tree bark used for clarification known in Costa Rica as *Guazuma hembra* is *Guazuma ulmifolia*, Lan. of the family Sterculiaceae. Mozote is related somewhat to *Triunfetta Lappula*, L., having an astringent mucilage in the bark used in clarifying sugar solutions and also as a cold remedy in Costa Rica. The bark is soaked in water, and the mucilage extracted out from the bark is applied to the limed juice, and the juice is then heated to boiling. The mucilage has to be used fresh. Its flocculating property is lost if the mucilage is left in contact with air too long.

In India, the use of *A. vera* (the common aloe) extracted as flocculant to juice clarification is common. The dosage of 3 ppm is optimum, which functions better than Magnafloc LT 27 at 1 ppm.[95]

PART (B) JUICE CLARIFIERS AND MUD FILTRATION

5.38 Function of a Clarifier. The function of a clarifier is to separate the insoluble particles from the limed juice. The effectiveness of such removal is very often termed "turbidity reduction" which, according to Carpenter,[96] is a misconception. He emphasized that the relation between particles and turbidity is false. The absence of turbidity only means the absence of refractive index gradients, but not particles. Neither can we expect a clarifier to decolorize. If there is any reduction in color, it is because the particles that are being removed are colored (see Sec. 5.32).

A good clarifier should not only produce good juice clarity, but also should have short retention time and more efficient mud removal, in order to reduce inversion losses due to mud accumulation. Any accumulation of mud that is not definitely scraped away will crust over rapidly and cool to a temperature that permits bacterial action and souring, resulting in undetermined losses of varying extent.

Ravno[97] discusses the mechanics of juice settling in a clarifier, and points out that the solids concentration has a distinct effect on settling rate. The other factors are the retention time of juice and mud. Retention of juice at an elevated temperature leads to inversion and reducing sugar degradation to form organic acids, resulting in purity and pH drop. On the other hand, if temperature drops below 75 C, there is a chance of loss due to microactivity. For good control, the difference in pH between mud and clarified juice should not be more than 0.2 unit (see Table 5.10). Crees et al.[98] relate Kych's theory to the effect of mud solids loading on clarifier capacity, demonstrating the significant advantages to be gained from a consistently clean cane supply in terms of ease of operation, flocculant economy, and sugar quality.

The clarified juice, which comprises 80–90% of the original juice, almost invariably goes to the evaporators without further treatment. The combined scums and settling muds are filtered.

94. Personal correspondence, Feb. 1969.
95. *ISJ*, 1987, **89**, p. 12A.
96. *Sugar J.*, January 1986, p. 10.
97. SMRI, 1979, pp. 28–32.
98. QSSCT, 1978, pp. 191–194.
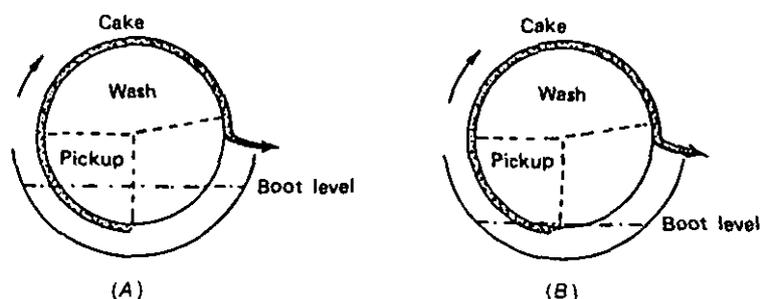
Figure 5.32. Cake pick-up on filter drum. (A) Normal pick-up; (B) tangential pick-up.

Basing on these conditions, results obtained are:

Specific cake resistance (α)	0.4×10^{11} mkg^{-1}
Filtration efficiency (e)	90
Suspended solids % filtrate	$<0.5\%$

5.49 Fly Ash for Filter Feed. Marie-Jeanne[122] conducts tests on replacement of bagacillo with a corresponding quantity of fly ash slurry (80% moisture) for cane mud filtration and finds that the fly ash improves filtercake porosity and does not affect juice quality, while eliminating atmospheric pollution caused by the dry ash.

5.50 Pumping of Mud. The pumping systems of cane mud on the filtration characteristics showed that higher mud solids output is achieved with a centrifugal pump than with an air blowcase system. But the Mono CD910 unit is proved even more effective than the centrifugal pump.[123]

5.51 Washing of Cake. The buildup on the screen occurs almost instantaneously when the flow through the cake is zero (Fig. 5.32).[124] Besides quantity of water, good washing of cake depends on the distribution of water and the correct location of spraying nozzles. The high- and low-vacuum zones and the general location of nozzles are indicated in Fig. 5.33.

To wash the cake efficiently reduces the Pol losses in cake without excessive consumption of water. With high drum speed (16–18 rph), thin cake (0.75–1 lb/sq ft, 3.6–4.9 kg/cm^2), medium pickup vacuum (5–10 in. Hg), high drying vacuum (20 in. Hg), and good distribution of water at 8–9% on cane, the cake Pol can be obtained at as low as 0.5–1.5%.[125]

The relation of wash water to cake Pol is plotted in Fig. 5.34.[125] This shows that increasing washing water in excess of 150% has little effect in the reduction of cake Pol. Chen[126] has experienced the necessity of timely adjustment under operational conditions, for effective reduction of Pol in cake, which confirms closely the results obtained by McGrath.[125]

Baikow[127] states that a well-washed cake should contain about 1.5–2.0% sugar and that

122. ARTAS (Reunion), *ISJ*, 1979, p. 155.
123. Noble and Brotherton, QSSCT, 1978, pp. 195–202.
124. Hale et al., QSSCT, 1974, pp. 269–278.
125. QSSCT, 1971, pp. 261–268.
126. Chen, personal test data, 1973, 1974.
127. Baikow, 1967, p. 119.

polymer flocculant, followed by a belt-filterpress to dewater the cake to reduce sugar loss in cake by 50%.[129]

5.52 Quantity of Filtercake. The amount of filtercake, no matter what system of mud removal is employed, varies greatly with locality and many other factors. The efficiency of milling and of straining of juices and the quantity of lime and special additives used in clarification, all affect the final weight of mud removed. In general, the amount of cake per ton of cane increases as the season progresses. Mechanical harvesting, because of the introduction of field trash and dirt, is an obvious cause of increased muds.

With such a set of variables, weights of filtercake, particularly wet filtercake, are of doubtful value. The data given here must be considered as broad guides and not as accurate or criterion figures. With filter presses, weighing of the cake can be done with reliable figures obtained. In Cuba, filter-press cake averaged 30–40 lb (14–18 kg) per ton of cane with moisture from 55–65%; similar figures were reported from Java and Puerto Rico. For rotary vacuum filters, the range is from 60–140 lb (27–64 kg) per ton of cane with moisture content of 65–80%, depending on the extent of field mechanization, effectiveness of cane washing, and the characteristics of field earth.

Cake may be measured by collecting and weighing a known area of cake, converting this area to the peripheral area of the filter, then multiplying by the numbers of revolution of this filter during a given period of time. Some factories actually weigh truckloads of cake before disposition for landfill and field utilization or for industrial purposes (see Sec. 10.24).

5.53 Other Methods of Mud Handling. Mud can be filtered under pressure. Some factories have experienced the use of Fas-Flo filters, but pressure filtration of raw house mud is not generally adopted. Details of the Fas-Flo filter is given in the 11th edition of this Handbook, Sec. 7.16, Figs. 7.6, 7.7, and 7.8.

Mud can also be centrifuged with a solid bowl centrifuge. Information from Australia and South Africa can be found in the 11th edition of this Handbook, Sec. 7.18.

5.54 Disposal of Filtrates. Two practical methods of handling the filtrates are: (1) sending the filtrate directly to the evaporators with the clarified juice, and (2) returning the filtrate for reclarification. The first method requires that the reactions of the filtrate and clarified juice be the same, to avoid further precipitation with excess lime. The second method, because of poor clarity of filtrate, puts an extra load on the clarifiers.

Munsamy[130] relates that the most important factor affecting the purity of the filtrate are the retention time of clarified mud and filtrate. It is not necessary to add the filtrate into the mixed juice tank but rather to introduce it at any point before the liming of mixed juice.

To avoid the recirculation of the filtrate of rotary vacuum filters, new systems have been developed to provide clear filtrate to be sent directly to the evaporators. When properly operated, the recirculation can be avoided and that filtrate is of high enough quality to permit mixing directly with clarified juice for evaporator feed.

Filtrate from a vacuum filter can be reclarified with the air flotation process by adding phosphoric acid (5 ppm on cane), neutralizing with milk of lime, and dosing with 1–1.5 ppm polymer flocculant to the aerated filtrate before entering a clarifier—similar to the process of raw syrup clarification.

Filtrate of a vacuum filter can also be refiltered with a pressure filter such as the Fas-Flo filter, but whether to reclarify or to refilter, rests on the overall economy.

129. *Sugar*, June 1985, pp. 43, 46–47.
130. SASTA, 1985, pp. 68–72.

The method is comparatively troublefree and adapts itself readily to automatic pH control. A large reduction in sulfur consumption results; freedom from sulfuric acid, precise control of SO_2 addition, and elimination of sulfur-burning equipment are other advantages.

5.67 Hydrogen Peroxide. Jahhar et al.[138] added hydrogen peroxide to replace sulfitation, and reduced white sugar color by 46% and ash by 20%. Hydrogen peroxide has also been tried in sugar refining.

CARBONATION PROCESSES

5.68 de Haan Process. de Haan formulated the conditions for the carbonation of raw cane juice as follows.

First, the carbonation of cane juice, consisting of the addition of milk of lime and carbonating the excess of lime, should be held to a temperature of 55 C (131 F). At higher temperatures reducing sugars are decomposed, dark reaction products are formed, and a sugar of poor color is obtained.

Second, for a good filtration, the milk of lime must be added at just such a speed that the alkalinity never exceeds 800 mg of CaO per liter. To accomplish this, the speed of addition of milk of lime has to be regulated by a continuous control on the alkalinity according to the lime precipitated by the carbonic acid.

For many years this was the standard practice. The amount of lime used per ton of cane was reduced considerably, the purity of the thin juice was increased, and the quality of the manufactured white sugar was improved (Fig. 5.37).

Carbonation of juice has been a batch operation. Sang et al.[139] developed a continuous system with fractional liming and multiple saturation (Fig. 5.38) that has proved to be more stable and simple in operation, requiring less skilled labor. The color and filterability of treated juice, as well as the color of product sugar, are all comparable to those of a batch
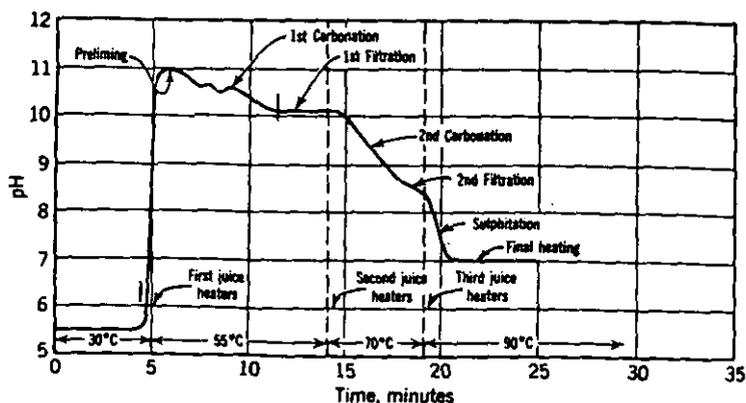
Figure 5.37. Standard practice of carbonation process.

138. *ISJ*, 1989, **91**, p. 80A.
139. *Taiwan Sugar*, 1976, **23**(1), pp. 7–12.
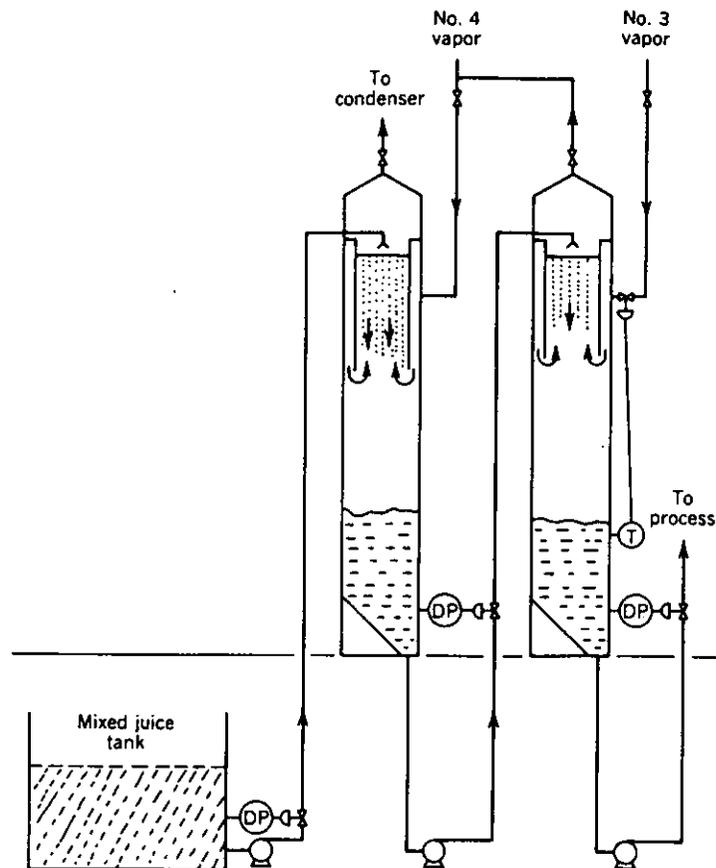
Figure 6.3. Dual contactors for full primary heating.

time and velocity. It is observed that under mild scaling conditions, the fouling rate factor for juice heaters is 0.0035, but where low juice solids content is encountered, the factor can be five times larger.

In order to reduce scale formation, thus to prolong operation time, the heaters should be operated with as large a velocity as possible through the tubes. The juice velocities in practice are 1.5–2.2 m/s. If the velocity is raised from 2–3 m/s, the initial heat transfer coefficient has an increase of 14%, with the period of operation extended by 116%, but at the expense of 200% increase of pressure drop.

PART (B) EVAPORATION

6.6 Evaporation. The evaporation is done in two stages; first in an evaporator station to concentrate the solution, and second in a vacuum pan to crystallize the sugar from solution. The first step is generally done in multiple-effect evaporators for improved thermal economy, and the second is performed in single-effect vessels, e.g., vacuum pans, to permit
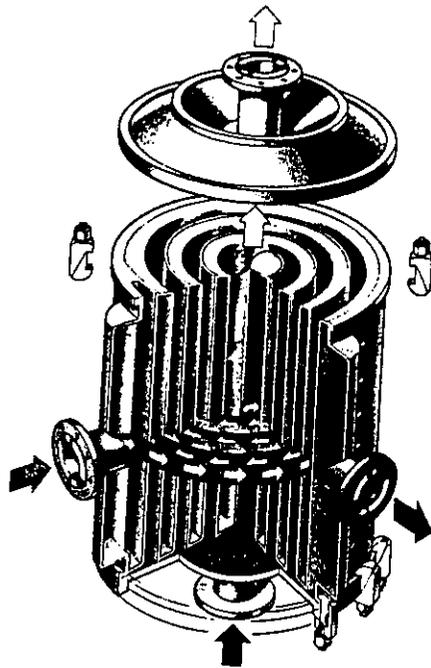
Figure 6.4. Spiral heat exchanger. (Alfa-Laval)

control of the batch crystallization's varying conditions of temperature, absolute pressure, and supersaturation.

The importance of the evaporator station in raw sugar manufacturing and refining processes is evidenced by the following tabulation of evaporator station performance:[16]

	Manufacturing	Refining
Approximate range (% of total process evaporation)	85–90	20–30
Approximate range (% of total process steam)	40–60	5–10

The evaporator station in raw sugar manufacture typically removes about 90% of the water from the clarified juice, increasing the juice solids from about 15 Brix to about 65–70 Brix.

In the refining of raw sugar, two evaporator stations are frequently employed. The first concentrates high quality liquors before crystallization in vacuum pans. In this service the liquor Brix is typically increased from 60–65 to 65–72. The second evaporator station concentrates sweetwater, a low Brix mixture of waters collected primarily from sweetening-off operations throughout the refinery for return to the process. Refinery sweetwater evaporation is analogous to raw factory juice evaporation in that a dilute solution (10–30 Brix) is concentrated to more useful density (45–65 Brix).

During the past decade the cost of energy has risen dramatically—200–500% of the 1973 base price of oil for various parts of the world. These cost increases have placed a high priority on improved efficiency of the sugar industries' most energy-intensive phases, evaporation and crystallization.

16. Chen, 1985, p. 213.

6.7 Single and Multiple Effect. A single-effect evaporator, in its simplest form, would be a closed pressure vessel divided into two sections by a pressure-tight divider. One section is connected to a steam source and the other is partially filled with water (juice). If the steam is at a temperature higher than the boiling point of the water (juice) in the other section, two things will occur:

1. The steam will condense and will transfer heat to the water (juice).
2. The water (juice) will boil and will drive off water vapor.

The multiple effect is usually three, four, and more effects. The basic requirement to ensure operation is that the boiling temperature of the liquid in each succeeding effect be lower than the temperature of steam entering the effect. This temperature difference provides the driving force for heat transfer from steam to liquid and in turn is provided by having the liquid-side vapor pressure lower than the steam-side pressure.

Goodall's *The Efficient Use of Steam* presents an excellent discussion of single- and multiple-effect evaporation with emphasis on the basic mathematics and parameter relationships.[17]

6.8 Rillieux' Principles. The phenomenon of multiple-effect evaporation was discovered by Rillieux in Louisiana and was patented in the 1840's. From his investigations and applications in the cane sugar industry, he developed three generalized rules or principles that are useful today as estimating guides for evaporator design and performance:

1. In a multiple-effect evaporator, one pound of steam will evaporate as many pounds of water as there are effects. Thus, a double-effect evaporator will evaporate two pounds of water, a triple effect, three pounds, and so on. (This principle has the basic assumption and limitation that the water entering each effect is at or near its boiling point.)
2. If vapors are withdrawn from a given effect of the multiple-effect evaporator and used *outside* the evaporator system in place of steam, the steam saving will be

$$\frac{\text{(number of withdrawal effect)} \times \text{(pounds of vapor withdrawal)}}{\text{total number of effects}}$$

Thus, one pound of vapor withdrawn from the second effect of a four effect evaporator would save

$$\tfrac{2}{4} \times 1 = 0.5 \text{ lb of steam}$$

Similarly, one pound of vapor withdrawn from the third effect of the same evaporator would save

$$\tfrac{3}{4} \times 1 = 0.75 \text{ lb of steam}$$

3. Wherever steam or vapor is condensed, provision must be made to continuously withdraw noncondensable gases.

17. IPC Science and Technology Press Limited, 1980, pp. 335–358.

Despite Rillieux' early recognition of this need, noncondensable gas accumulation has continued to plague designers and operators of evaporators and heaters and is a significant factor in equipment performance.

6.9 Evaporator Types. A variety of multiple-effect evaporator types are used in raw sugar manufacture and refining. Calandria vessels are used in raw sugar manufacture for clarified juice evaporation and in refining for sweetwater evaporation. Long tube, vertical rising film (LTVRF or Kestner) units are used for clarified juice evaporation in raw sugar manufacture. Falling film evaporators are used for liquor concentration and sweetwater evaporation in the refining process. These falling film units range from the venerable Lillie horizontal tube evaporators with internal vapor separation to the most modern long tube vertical falling film (LTVFF) units with external vapor separation. The typical calandria multiple-effect evaporator is discussed in the 11th edition of this Handbook (Sec. 9.8).

A new design, such as the one built in Australia (Fig. 6.5), has been proved to be a most satisfactory process unit, as reported by Quinan et al.[18] and Watson.[19] Because of the very large diameter of the vessel, one single center downcomer (downtake) would do little to reduce the liquid level at the sides of the vessel. Instead, there are forty-four downcomers positioned in the calandria. Such installation of multiple downtakes is observed to be a worthwhile modification, and experiences a 50% reduction in boiling juice height above the calandria, enhancing a smooth juice circulation pattern. The maximum heat transfer coefficient is thus increased by 7.5%. Results obtained suggest that any future vessel should include distributed downtakes in their design—offering an increase in performance at relatively little cost.

A milling tandem is more flexible to increase capacity than the evaporator station. In order to meet immediate needs for a small increment, Wright[20] applies a modular concept to propose a modification to increase existing evaporator capacity. The concept starts with the splitting of the existing vessel [Fig. 6.6(a)] with proposed modification [Fig. 6.6(b)] to become Fig. 6.6(c) and then [Fig. 6.6(d)]. It may end up with a new multiple-effect as each becomes three times its original size, and may further be expanded as the need arises.

LTVRF evaporators employ long (18–32 ft; 5.4–9.6 m), approximately small-diameter (1.5 in; 3.8 cm) tubes in a vertical tube bundle between horizontal sheets (Fig. 6.7). The juice or liquor enters below the bottom tube sheet and passes at high velocity up the inside of the tubes, discharging above the upper tube sheet without recirculation. The juice and vapor are usually discharged from the tubes against a splash umbrella mounted in an enlarged diameter vapor dome above the tube bundle. There is no center well, and the upper tube sheet extends into the vapor dome, creating an annular liquid collecting ring outlet. The vapor passes out through an entrainment separator, mounted in the vapor dome or placed external to the body.

The principal advantage of this evaporator is the short liquid residence time due to high velocity and favorable heat transfer in the tubes. This high velocity is very advantageous, and can be attained quickly only if liquid heating (temperature increase of the liquid) in the vessels is minimal. Ideally, the temperature of liquid entering should be sufficiently high to permit flashing upon entrance. For this reason, steam and liquid flows are generally in parallel through an LTVRF multiple-effect evaporator.

LTVRF evaporators are preferred for low Brix service—for example, as preevaporators

18. ASSCT (QL), 1985, pp. 241–246.
19. ASSCT (QL), 1986, pp. 223–230.
20. ASSCT (QL), 1985, pp. 247–251.

NON-CONDENSABLE
GASSES PIPE

STEAM SLOT
AND BAFFLE

STEAM SLOT
AND DEFLECTOR

STEAM INLET

DOWNCOMER

MANHOLE

CONDENSATE
DRAIN

(A)
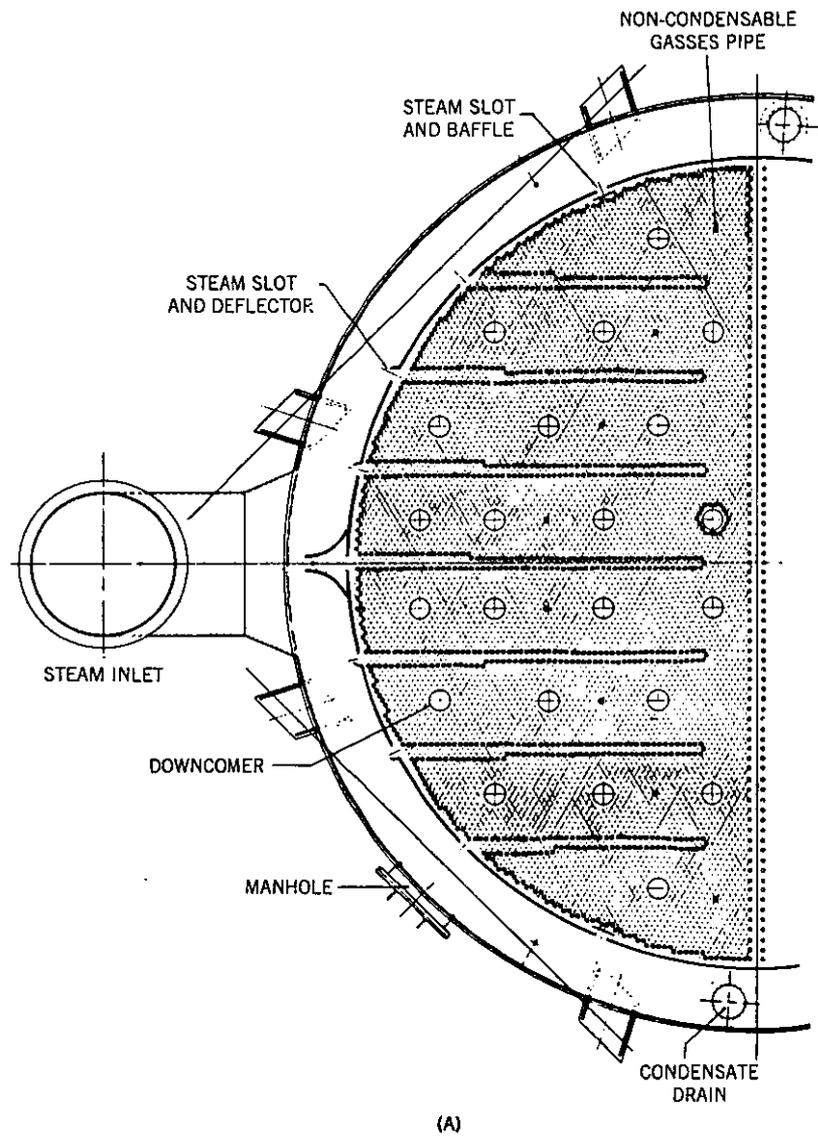
Figure 6.5. A 5100 m^2 evaporator. (Australia) (A) Half calandria. (B) General arrangement.

on cane juice using live steam and sending vapors to the exhaust steam system. However, they have been used in the beet sugar industry to concentrate thin juice from 10–15 Brix to more than 60 Brix.[21]

LTVFF evaporators (Fig. 6.8) consist of a vertical tube bundle, with a juice distributor at the top and a juice separator to eliminate the entrained juice particles from the vapor.

Falling-film evaporators were formerly used mainly in raw sugar refining, and are now

21. McGinnis, 1982, p. 365.

① DOWNCOMER
② STEAM SLOTS
③ CONDENSATE DRAIN
④ 'NON-CONDENSABLE GASSES'
⑤ LOUVER BAFFLE ARRESTOR
⑥ LIQUID LEVEL INDICATOR
⑦ FEED RING
⑧ SIGHT GLASS
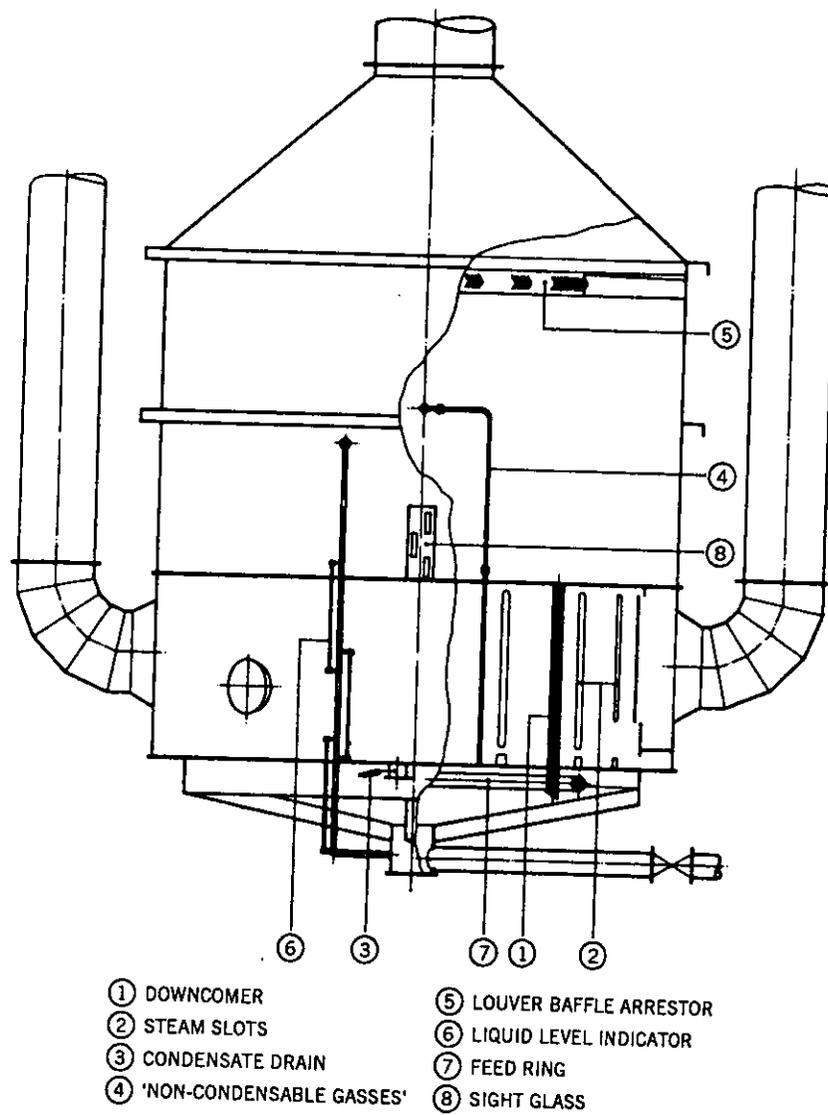
(B)

Figure 6.5. (*Continued*)

also used for both thin juice and high Brix process materials. Töbe[22] discusses the various designs of falling-film evaporators (Fig. 6.9), their construction, and how to avoid tube vibrations because of heating tube lengths of up to 10 or 12 m. In cane sugar juice, to achieve maximum juice concentration of 65–70 Brix and at 64 C (147 F), the falling-film evaporator is excellently suited due to its good heat transfer coefficiency. Comparison of

22. *Sugar*, April 1987, pp. 36–40, and personal communication, 1991.

The Crystallization of Sugar*

PART (A) THE VACUUM PAN BOILINGS

7.1 The Vacuum Pan Station.   The function of the vacuum pan is to produce satisfactory sugar crystals from syrup or molasses. The concentration of the feeds used in the pans is usually 60–65 Brix, and may reach 74 Brix in refinery. High densities reduce the steam consumption and cut down the duration of the cycle, but too high a density may involve the danger of producing conglomerates and false grain.

The parameters of massecuite boiling related to vacuum pan design are found through experiments by Bouillard,[1] showing that the evaporation rate during massecuite boiling decreases with increasing Brix, tube length, and hydrostatic head, but increases with higher vacuum, steam pressure, and purity.

7.2 Calandria Pans.   The coil pans are now obsolete. Almost all vacuum pans are now calandria pans. A calandria pan is a single-effect evaporator with large-diameter short tubes and a large downtake for the circulation of heavy viscous massecuite. Syrup and molasses in certain proportions develop sugar crystals, beginning with the heating surface being covered just sufficiently to obtain circulation, and finishing with a full load called a *strike*. (Figure 7.1 shows a conventional calandria pan, except that not all calandria pans are equipped with a mechanical circulator.) The construction of a calandria pan with its accessories are given in detail in the 11th edition of this Handbook (Secs. 10.3 and 10.4).

The normal graining volume of modern pans ranges from 30 to 32% of the finished strike capacity.

There are different designs of pans, such as pans with fixed calandria and pans with floating calandria. BMA has a lenticular calandria pan, and Fives-Cail Babcock has a horizontal pan, each with different models and sizes.

7.3 Low-Head Pan.   The so-called low-head pan has many features that have been adopted by manufacturers throughout the world.

Nelson[2] reports the installation of a 30,000 gal (110 m^3; 4010 cu ft) pan in Inkerman Mill (Fig. 7.2). The pan is normally operated with a steam flow of 18,200 kg/h at a vacuum of 660 mm Hg. The surface-to-volume ratio of this pan is 5.18 m^2/m^3 and the footing volume of the pan is 32%. Nielson's specifications of the pan are given in Table 7.1.

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*by **J. C. P. Chen**

1. SASTA, 1985, pp. 43–47.
2. QSSCT, 1974, pp. 207–210.
3. ASSCT (QL), 1985, pp. 195–200.

After observing many pan boilings during the last 20 years, Sullivan[3] is impressed more with the straight-sided pan which performs consistently better than the ''low-head'' pan whose outer shell is larger than the calandria diameter.

7.4 Materials of Construction for Vacuum Pans. Raw sugar pans are usually made of steel plate, where formerly cast iron was the common material for the bodies. Copper tubes form the best heating surface, although steel tubes are still in quite general use. The steel tubes rust on the steam side, reducing the heat transfer materially.

For refined sugar pans, to avoid rust specks in the refined sugar, particularly after shutdowns, most of them are made of noncorrosive metals, stainless clad, nickel clad, all stainless, copper-bearing, or other special steels.

To prevent rust formation during shutdowns, many refineries leave the surfaces with a coating of syrup and sugar by omitting the steamout operation after the last strikes. The steaming out (frequently a boiling out with water) is then done just before the startup.

7.5 Entrainment Arrestors and Condensers. Examples of arrestors are given by Wright[4] in Fig. 7.3. The louver type (Fig. 7.3A) has low pressure drop, high efficiency, and low maintenance costs; flow reversal baffles are illustrated in Fig. 7.3B.

Lionnet[5] measures the vapor velocities, which is one of the factors controlling entrainment. Results obtained show that under steady operations, the entrainment from pans does
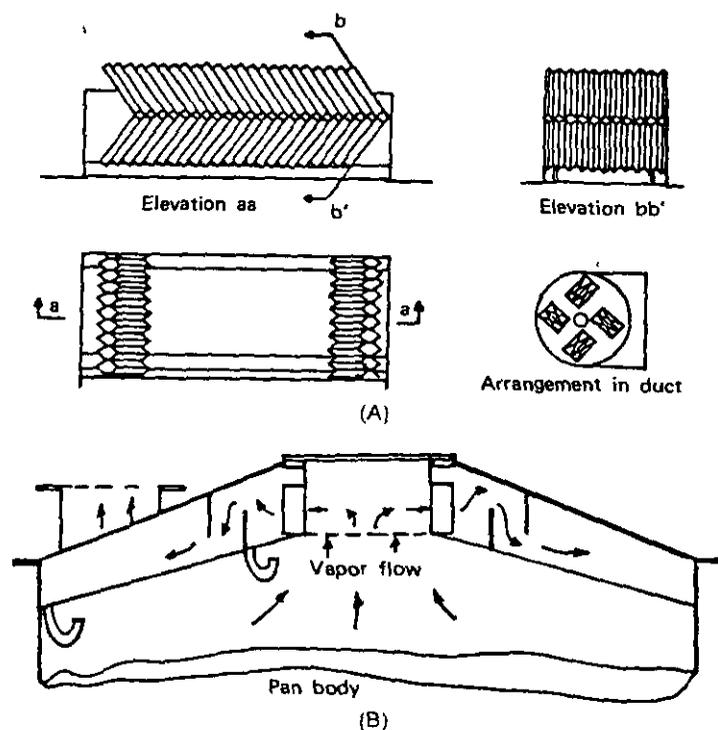

Figure 7.3. Entrainment arrestors. (A) CSR louver-type; (B) baffle-type.

4. STR, 1974, **2**, p. 146.
5. SASTA, 1984, pp. 90–92.

not result in heavy losses of sugar. Only under unsteady operations, such as vacuum fluctuation, changes in flow, and cutting over, do high sugar losses occur.

Pan condensers are conventionally of the external direct contact condenser of the baffle or rain type. There are also other types, such as internal condensers and surface condensers. (See Sec. 10.9 of the 11th edition of this Handbook.)

7.6   Definitions Used in Pan Boiling. Syrup or *meladura* (Spanish) is the concentrated juice from the evaporators. The mixture of sugar and mother liquor discharged is called *massecuite*, the mother liquor *molasses*. *Seed magma* consists of low-grade sugar mingled with syrup or molasses stored in crystallizers, from which it is drawn into the pans to start a high-grade strike. The quantity used for each strike, called a *footing*, is enough to cover the calandria. Each panful of massecuite is called a *strike* (*skip* or *skipping* in some refineries). Transferring massecuite from one pan to another is called *cutting*. The word *proof* is synonymous with high concentrations where sugar crystals form and grow. *Making grain* is the process of initiating the formation of sugar crystals.

PAN CIRCULATION—NATURAL AND MECHANICAL

7.7   Importance. The most important characteristics of vacuum pan operation are circulation and temperature conditions.

The speed of massecuite traveling through the tubes of a well-designed and operated pan of the calandria type, with its downtake one-half of the pan diameter, was calculated from observations as follows.

Time	Speed	
	ft/sec	cm/sec
First hour	1.53	46.6
Second hour	0.63	19.2
Third hour	0.15	4.6
Fourth hour	0.03	0.9
Fifth hour	0.02	0.6
Sixth hour	0.01	0.3

To determine the temperature conditions of the massecuite passing through the tubes at such slow velocities, a sensitive thermometer was mounted on the side of the pan above the upper tube sheet and in line with the center of a tube, providing readings of the variations of temperature between the center of the tube and its inner periphery. Even at the beginning of the strike, differences of 4 F between the two points in question were observed, gradually increasing as the circulation slowed down, and reaching a peak of 30 F.

In order for ebullition to take place, temperatures in the tubes of a calandria pan must be obtained that correspond to the vacuum, lowered by the superposed hydrostatic head because of the weight of the massecuite above the point under observation. To this must be added the bpr at the purity and density in the pan. The plot of Fig. 7.4 is based on 100 purity.

The first curve indicates saturation vapor temperature; the second the boiling point of massecuite at the surface of ebullition for a supersaturation of 1.325. Each successive line shows the boiling point corrected for the reduced vacuum due to the superposed hydrostatic head caused by 1 ft (0.3 m) of additional massecuite. As this temperature is increased by

THE PROCESS OF SUGAR BOILING

7.25 Basic Principles. Sugar boiling involves the same principles and entails the same problems, whether the pans are controlled by hand or by instruments.

The first step is to make grain: In the raw sugar industry, grain is generally made for low-grade strikes; the grain strike is transferred to a storage crystallizer from which footings can be drawn to start low-grade strikes. One grain strike may be sufficient for three low-grade footings. By having two storage crystallizers instead of one, compounding the operation permits making grain for nine strikes. This procedure saves much time by providing three times as many nuclei, each adsorbing sucrose at the same rate, and building up volume three to nine times as fast.

It is preferable to make grain at a vacuum not exceeding 25 in. (63.5 cm) at sea level, which means operating temperatures of 150–160 F (66–71 C), depending on purity. At those temperatures, the viscosity will be lower and the rate of crystal growth faster.

The pan is closed, the vacuum is raised, and the full amount of injection water is turned on the condenser to give a fast rate of evaporation with the liquor, syrup, or molasses before graining. Steam is turned on after the heating surface is covered with liquid. The pan must not be loaded too high, since this will slow operations because of the effect of the hydrostatic head. After boiling starts, feeding should be continuous to hold the level slightly above that required to form grain, closing off the feed before nucleation starts.

7.26 Graining by Full Pan Seeding. Graining by the old method and by shocking are given in the previous edition (11th) of this Handbook, Sec. 10.31, 10.32.

The best method of obtaining good seed grain is full pan seeding by adding at the proper moment the full amount of grain of predetermined size to equal the total number of grains in the finished strike. No grain is formed in the pan at any time, and the concentration must be held in the crystal-growing or metastable phase. Seed is introduced as soon as the saturation point is reached, as indicated by instruments. To determine the proper amount of fines of a given grist to introduce into a pan to make a strike of sugar of a certain size, proceed as follows:

1. Find the weight of sugar expected from the strike.
2. Count and weigh about 500 crystals of this grade sugar.
3. Count and weigh 500 crystals of the seed powder to be used.
4. Dividing (3) by (2) and multiplying by (1) gives the weight of seed.

After this has been determined and tried, minor corrections can be made to take care of variations.

Suppose a grain strike is to be boiled for three C strikes; the grain size of the footing must be such that it will give C sugar of 0.35 mm. The diameter of the crystals must therefore be 0.35 divided by the cube root of 3, which gives 0.243 mm.

If the commercial sugar is 1.05 mm and the C sugar 0.35 mm, this means a weight development of

$$\left(\frac{1.05}{0.35} = 3\right)^3 = 27 \text{ to } 1.$$

This, in turn, signifies that, for each pound of C seed used, 27 lb (12.3 kg) of commercial sugar will be produced.

If the diameter of the C sugar crystals is greater than the assumed 0.35 mm (e.g., 0.50

mm), the amount used for commercial strikes footings will be more than that just given. To obtain 1.05 mm commercial sugar from this, the increase in size would be 2.0:1, and the increase in weight, $2.1 \times 2.1 \times 2.1 = 9.26$ to 1, which is three times as much C sugar seed in the commercial strikes, and less C sugar melted.

The advantage lies in increasing the size of the C sugar, as long as it does not increase the purity of the final molasses. The handling of larger C sugar crystals would be faster and the purity higher.

A magma footing containing 0.35 mm crystals occupying one-third the strike volume of the pan is developed into a full strike, and the diameter of the grain has now grown to $0.35 \times 3^{1/3} = 0.35 \times 1.44 = 0.506$ mm. Two-thirds of this primary footing strike are discharged into the primary footing crystallizer just below the pan floor.

With the footing left in the pan, again a full strike is made, and the grain size is now $0.506 \times 1.44 = 0.73$ mm. This is all discharged into the secondary footing crystallizer to be used as footings for commercial strikes.

Starting with a footing having 0.73 mm crystals again, this is developed to a full strike in the ratio of 3:1, giving a commercial strike whose crystal size is $0.73 \times 1.44 = 1.05$ mm.

C-strike grain footings	0.243 mm
C sugar and magma	0.350
Primary footings	0.506
Secondary footings	0.730
Commercial sugar	1.050

The seed slurry is prepared[30] with a laboratory ball mill, by mixing 1 lb of powdered sugar with 1 quart of isopropyl alcohol, and ground for 24 h. The relative size of seed is shown in Fig. 7.25, and the relative weights of seed to final product, with similar populations, are given in Fig. 7.26.

Seed size above 15–20 μ needs a larger amount of seed than a size below 5 m. Typical slurry volumes, as recommended for beet sugar,[31] are:

White pans	130–150 ml/1000 cu ft massecuite
Intermediate pans	160–220 ml/1000 cu ft massecuite
Raw pans	450–600 ml/1000 cu ft massecuite

It should be understood that the slurry volume is to be adjusted according to individual variances, such as pan circulation, vacuum uniformity, specifications of ball mill, etc.

Patterson[31] recommended, for low-grade boilings, ball-milling 24 h with two parts isopropyl alcohol to one part of granulated sugar. Two lb of sugar is needed for a 1000 cu ft seed strike with a finished grain size of 0.24–0.25 mm. Then, this strike is enough for four C strikes (total 4000 cu ft) with C sugar of 0.30–0.40 mm.

A particle size analyzer, invented at Sheffield University, England, was developed by Malvern Instruments. Hogg et al.[32] try to develop the techniques of on-line measurement of crystal size and concentration. The instrument uses an He/Ne laser ($= 0.6328$ μm) to illuminate particles in an optical cell [Fig. 7.27(A)], and then the particles produce a diffraction pattern of rings focused on a photodetector [Fig. 7.27(B)].

30. McGinnis, 1982, pp. 402–403.
31. *Sugar J.*, June 1985, pp. 10–12.
32. *ISJ*, 1986, **88**, p. 194.
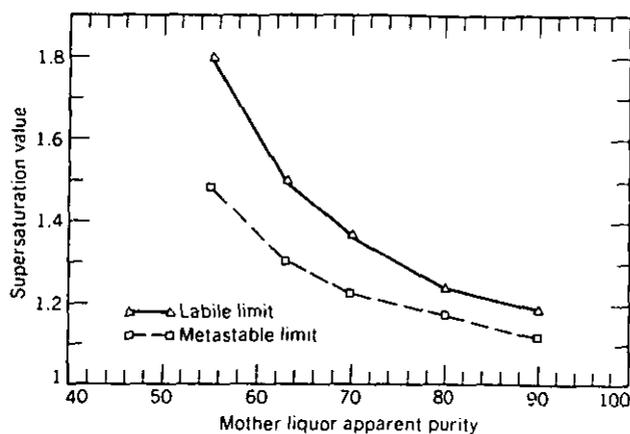
Figure 7.29. Supersolubility curves. (Penklis and Wright)

lower the quality of the sugar as a whole and make thorough drying in the granulators more difficult.

1. Conglomerates form more readily at higher purities.
2. Low purities almost never conglomerate.
3. If the fines selected for seeding are conglomerated, the resulting final product will be conglomerated also, since conglomerates are never destroyed.
4. Conglomeration takes place at the upper edge of the metastable zone, just before the occurrence of false grain. In other words, if false grain has been formed, the occurrence of conglomerates is almost certain.

Fines used for seeding should be made by crushing well-formed coarse sugar. The broken pieces will not be conglomerated. They will revert to perfect shape rapidly because of the physical forces compelling definite crystal form; hence, fines so made for seeding grow more rapidly than powdered sugar from the dust box of the granulator.

If grain is started by seeding low-purity molasses with powder prepared as suggested earlier, there will probably be no conglomerates whatsoever. This has important application in the boiling systems discussed in Secs. 7.39 and 7.40.

7.28 Conditioning of Pan Feed Molasses.   Molasses coming out from the centrifugal station is seldom free from sugar crystals, either from false grains in the previous boilings or from a broken screen of a centrifuge. These crystals need to be dissolved and the molasses needs to be heated and diluted to the normal recommended level of 75 C and 75 Brix, before being fed into the vacuum pan. Such conditioning may involve excessive use of dilution water and high-pressure steam. Mishra[37] develops a compact unit, small in size, and without moving parts. It permits continuous conditioning of the feed material without dilution water and continuous heating to desired temperature. With this conditioning in C boilings, some 30% reduction of boiling time and 1.5 units of improved exhaustion have been realized.

7.29 Bringing the Mass Together.   After grain has been secured, or after a foot-

37. Chen, 1985, p. 314, Fig. 10.31 (A) & (B).

ing has been taken for a new strike, the most difficult and important step is to bring this mass together. Not enough crystal surface exists to adsorb sucrose as fast as it is made available by evaporation because the small grains are widely separated and a critical condition exists. The vacuum must be held extremely high and the evaporation restricted to the ability of the crystals to grow. Instruments are most helpful at this point because they indicate supersaturation or bpr. If no instruments are available, the operator must depend on his or her sense of touch on a proof-stick sample. If the rate of evaporation is too fast and the supersaturation of bpr rises to near the danger point, the following measures can be taken:

1. Lower the vacuum about 3 in. (7.6 cm), raising the boiling temperature 19 F (10.5 C); this will lower the supersaturation well within the metastable zone, making the crystals grow faster by more than 100%, reducing the rate of evaporation by nearly one-third, and avoiding immediate danger.
2. Feed water into the pan to hold the evaporation down to what can be tolerated, as indicated by the supersaturation. This is what is called *movement water*. As the crystal surface increases, the amount of water can be reduced and finally closed off. This has the advantage of not disturbing the vacuum at all. The small amount of added water to be evaporated is not significant. The procedure is in wide use in many localities.
3. Feed more liquor into the pan to obtain the same results as if water were fed. This is the least desirable procedure because it increases the amount of mother liquor in the pan, and thus retards the operation by introducing the need to concentrate this liquor.
4. If the pan is equipped with vacuum control and a mechanical circulator, the steam pressure can be reduced or even cut off altogether because the movement of the massecuite in the pan will continue undisturbed no matter what happens to the evaporation. Reducing the steam pressure in the pan, thus slowing down the rate of evaporation, is dangerous unless the pan is equipped with automatic vacuum control.

7.30   Tightening the Mass.   It is not advisable to increase the volume of the strike until the crystals have grown enough to nearly fill the void spaces occupied by the syrup or mother liquor, when the massecuite is said to be *tight*. The rate of crystal growth is faster under these conditions. When crystals are close together, they rub and remove the partially exhausted syrup or molasses adhering to their surfaces and replace this film with a fresh one. Especially with high purities, when a strike is tightened within reasonable limits on reaching a certain critical point, the bpr suddenly drops several degrees, showing that the mass has lost fluidity, not because of the increase in the concentration of the mother liquor, but because its volume is approaching that of the voids between the crystals.

This optimum point is a phase just preceding heavy shaking by the pan caused by lack of fluidity. If the pan vibrates excessively, the strike is too tight and must be fed faster. The automatic feeding systems in use, including those with mechanical circulation, regulate the feed in proportion to the power load on the drive by other appropriate means.

Feed control regulates the operations so that the maximum rate of crystal development is obtained and the formation of conglomerates and false grain is avoided. False grain results if strikes become too loose. On white sugar, good results have been obtained by a steam-flow meter on the pan, regulating the feed to give maximum steam flow after the strike has been brought together.

As the work progresses, the rate of sucrose absorption by the crystals becomes greater

than the rate at which feed is concentrated by the pan, and it is then permissible to raise the vacuum slowly at the rate of not more than 1 in. every 5 min.

When the market calls for changing the Pol of the sugar product, so changed the sugar purity, and so also the massecuite flow. Wright[38] in Australia uses an SRI program to estimate pan stage flow changes. He relates the higher Pol sugars with molasses purity rise. For instance, at 99.4 sugar purity, each part of "wash off" impurities removed took off a 0.3 part of additional sucrose. He uses the data of Jullienne[39] (South Africa), showing the relationship in Fig. 7.30(A). Then the relationship between sugar purity and massecuite flow quantity is established as in Fig. 7.30(B), and finally the effect of sugar purity on massecuite flow change % per 1% sugar purity is also established as in Fig. 7.30(C).

7.31   Final Concentration.   When the volume of the strike has reached the full capacity of the pan, the final concentration is effected by shutting off feed and allowing the evaporation to proceed until the necessary Brix is attained. This is determined by taking a sample from the proof-stick and forming a cone or a ball of massecuite in the palm of the hand or on the thumb, and noting how quickly it flattens. A good sugar boiler can determine the correct proof within one-half point Brix.

This determination can be made by control instruments when they attain a certain bpr or supersaturation, determined by experience. With mechanical circulation, the reading of the power developed by the driving motor gives exact results after calibration.

A consistency monitor devised by Ziegler[40] consists of a propeller-type rotor driven by a small d.c. motor. The current increases with an increase in resistance of the mother liquor in which the propeller is turning. The force required to move the propeller is measured by appropriate means, thus recording the tightness of the massecuite.

Jullienne in South Africa[41] determined the pan exhaustion performance of A-strike boilings, and found that the Brix of the massecuite at strike has a strong positive effect, i.e., at a maximum level when the massecuite is boiled to "tightness" resulting in the maximum striking time. He related that an increase of one point in the massecuite Brix at strike yields the same crystallization as 8 C of cooling in a crystallizer.

Broadfoot[42] also found similar results by choosing process conditions to ensure that the viscosity of C massecuite is held at manageable levels. His results show that by processing a massecuite of higher I/W (impurity/water ratio), improved exhaustion is possible, especially when RS/ash ratios are low.

7.32   Steaming Out and Washing Out.   The massecuite adhering to the inside of the pan after discharge must be completely removed before beginning the next strike; otherwise, the crystals may disturb the graining operations described previously. Formerly, steam admitted into the pan heated and dissolved this grain, but water sprays have been found to be more desirable because they keep the heating surfaces cleaner and result in less color. The sprays should reach all parts of the heating surface and shells, and the water should be hot, impinging with considerable force.

7.33   Temperature During Boiling.   The present tendency is toward cooler pans because of less inversion and color. The former practice was to make refined white sugar at about 180 F (82 C) and plantation whites somewhat cooler. To avoid color increment, almost all refineries make their strikes at 150 F (66 C) or under. Raw sugar is also boiled

38. ASSCT (QL), 1989, pp. 184–190.
39. SASTA, 1983, p. 44.
40. *Sugar J.*, December 1981, p. 10.
41. SASTA, 1984, pp. 42–46.
42. ASSCT (QL), 1984, pp. 279–286.

(A) On A-molasses purity

(B) On material flows

(C) On massecuite flow changes
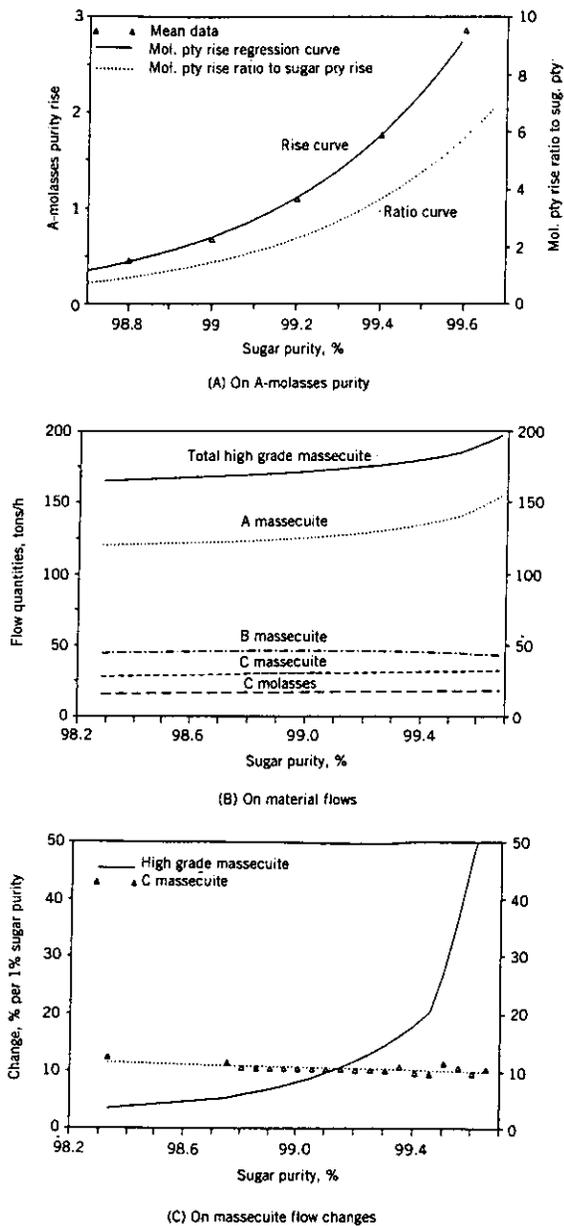
Figure 7.30. Effects of sugar purity.

at lower temperatures than formerly. The viscosity is lower at high temperatures and crystallization relatively simpler, but with full seeding for the establishment of grain, the advantage disappears. Low grades are always boiled at high vacuum, and therefore low temperatures, to avoid the danger of froth fermentation and to favor the subsequent work of the crystallizers, whose cooling capacity is usually limited.
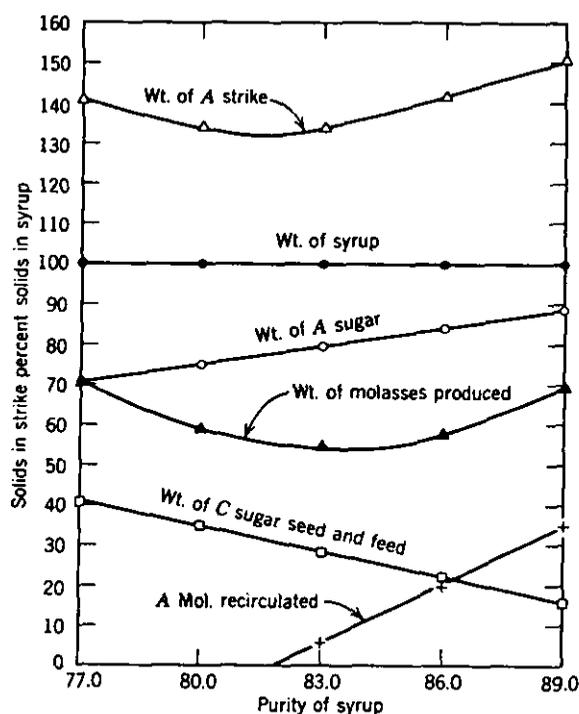
Figure 7.31. Solids in and out of *A* strikes (new two-boiling system).

Refinery "soft sugars" are always boiled at the highest vacuum attainable, producing a velvety soft grain, which the market demands.

7.34 Brix and Evaporation. In the past, the advice of sugar boilers was followed regarding the concentration of feed syrup or molasses going to the pans. Recently, prevailing densities approach or exceed 70 Brix. The apparent Brix of the strikes themselves in a raw sugar factory is about as follows:

Grain strikes	90.0
A strikes	93.0
B strikes	94.0
C strikes	96.0, up to 100.0

Assume that 100 lb (45 kg) of solids is introduced into the pans as syrup or molasses, and concentrate this to the final Brix of the various strikes as outlined. Figure 7.31 gives the amount of evaporation to concentrate from various densities of feed to the final densities. If feed is at 55 Brix instead of 70 Brix, the amount of evaporation required will be double.

PAN BOILING SYSTEMS

7.35 Selection of System. In the cane sugar industry, the sucrose available in the syrup is crystallized in several stages, conducted at descending purities. The procedures followed in carrying out the pan operations constitute the pan boiling system, which may

consist of two, three, or four stages. The last boiling requires the most time, the final step being crystallization in motion, where the massecuite is cooled slowly before being purged in the centrifugals (see Chapter 8). The selection of the system depends on local conditions and preference.

7.36 Designation of Massecuites. In raw sugar practice, the different grades of massecuite are designated by letters (*A, B, C*, etc.) or by numbers (first, second, third, etc.). The molasses purged from the massecuites takes the same symbols (i.e., a *B* massecuite yields *B* molasses; a third massecuite, third molasses). Sugars yielded by the massecuites are *A* sugar, *B* sugar, or first sugar, second sugar, and so on. Refinery massecuites usually, although not always, are called liquor strike, syrup strike, high remelt, low remelt, and so on.

7.37 Seeded Footings. The quantity of seeded footing for each massecuite depends on the crystal size ratio between the footing and the massecuite to be boiled. Zarpelon[43] recommends the volumetric ratios of seeded footing to eventual massecuite: for *A* massecuite 1:9 or *even* 1:6 if the purity is very high, for *B* massecuite 1:9–1:12, and for *C* massecuite 1:9. However, as already mentioned, the quantity of seeds necessary for boiling a strike is governed by the size ratio of initial crystal to finish crystal. If it is expected to double the size of the seeds during boiling, then the amount needed would be 2 to the power of 3, or a 1:8 volume ratio of footing to massecuite.

Troino et al.[44] find that the optimum relative initial charge (i.e., ratio of footing volume to final massecuite volume) is that at which all of the boiling tube is wetted by the time the massecuite is brought together. Their experiments show that maximum heating surface utilization in *A* strike is achieved at approximately 1:3, and a final massecuite level no greater than 180–190% of tube height. For optimum boiling, they recommend that the tube height should not be greater than 1 m (3.28 ft), but to increase the pan diameter.

7.38 Improvements in Boiling High-Grade Strikes. If more exhaustion is achieved in the high-grade strikes, the low-grade pans will do less work. In South Africa, Singh[45] shows how steps have been taken to increase exhaustion of *A* massecuites by a programmable computer. The strikes are retained in water-cooled crystallizers. The purity drop from massecuite to molasses was 17.1 points, and a further drop through crystallizers 3.9 points, which in total meant that 80% of crystallization work was done in the pan. The results obtained were from controlling *A*-strike Brix by maintaining a striking time of 15 min, and from tighter and consistent boilings by pan automation. The benefits are: volumes of *B* and *C* massecuites reduced, undetermined losses reduced because of less recirculation, steam saving based on better exhaustion, and raw sugar color improved.

7.39 Boiling Systems. The various boiling systems, such as the conventional three-boiling system, the two-boiling system, and the double-Einwurf* system, are compared and calculated by Birkett[46] showing the massecuite volumes and steam requirement (Figs. 7.32, 7.33).

By adapting a proper boiling system, some nonsugars, especially those that affect product quality standard, can be reduced. For example, Chen and Tseng[47] studied ash distri-

43. SIA, 40, Abs. 1978, 78–1431.

44. *Referativ. Inform. Zakonch. Nauch-Issled. Vuz. UkSSR, Pishch. Prom.*, 1972, **6**, pp. 21–22 (via *ISJ*).

45. SASTA, 1989, pp. 85–89.

*Einwurf means a crystal within a crystal.

46. ASSCT (US), **8** (NS), 1978, pp. 139–147.

47. *Taiwan Sugar*, July–August 1986, pp. 24–26.
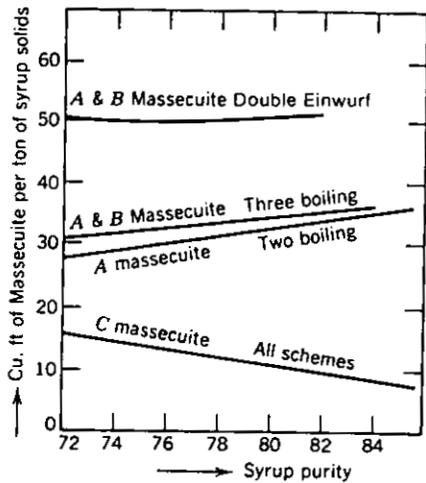
Figure 7.32. Massecuite volumes for various raw sugar boiling schemes (*C* sugar purity = 84).

bution in massecuite, sugar, and molasses in four boiling systems (Fig. 7.34), and related that ash content in raw sugar could be reduced by 32% if a suitable boiling system is chosen.

7.40 Two Boilings vs. Three Boilings. Eisner-Goddard[48] compared straight two-boiling and simple three-boiling systems, showing the total solids (dry) that are in circulation (t/100 t cane) in Figs. 7.35 and 7.36.

The two boiling systems show that the total solids in the massecuite is $18.1 + 7.4 = 25.5$ t, which in three boiling, is $14.4 + 6.9 + 5.85 = 27.15$ t; thus, there is an increase of about 7% total solids in the three-boiling, with a consequential increase in the recirculating quantity of mother liquor and more steam consumption.
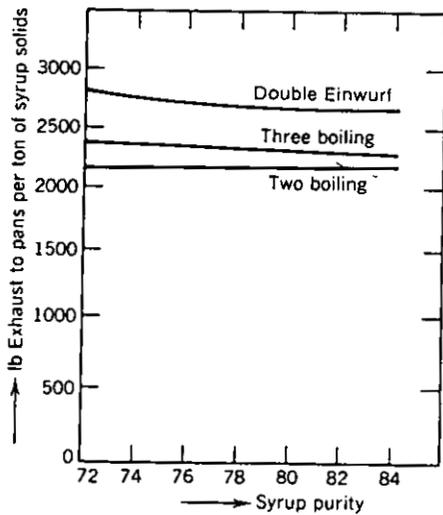
Figure 7.33. Steam requirement for pans for various boiling schemes (*C* sugar purity = 84).

48. *Basic Calculations for the Cane Sugar Factory*, 1988 (Publisher: Fletcher and Stewart, England).
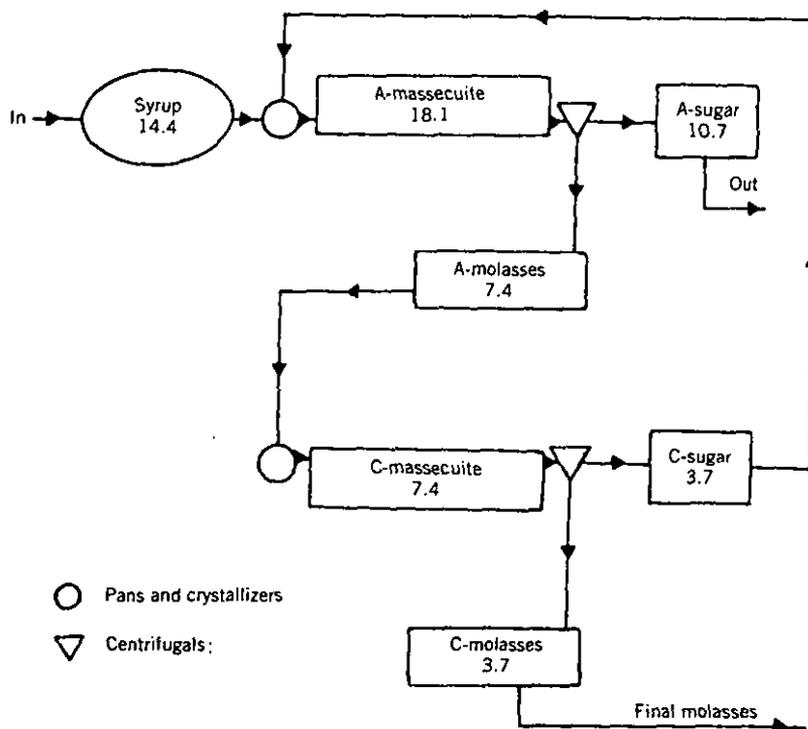
Figure 7.35. Straight two-boiling system.

However, when juice purity is over 80, it is not economically practical to use a two-boiling system because of the amount of boiling back, resulting in more and higher viscosity of massecuite to handle.

7.41   Specific Heat of Sugar Solutions.   Exact figures for the specific heat of sugar solutions are not generally required for routine calculations. The subject has been studied by many investigators, among them Gucker and Ayres.[49] The specific heat that they found for a 65% sucrose solution at 20 C is 0.6406; for a 50% solution, 0.7213; for a 30% solution, 0.8299; and for a 10% solution, 0.9428. Those values and others which they give are almost a straight-line relationship.

7.42   Pan Additives

Surfactants.   Surface active chemicals were introduced into the sugar industry in the late 1960's. Kritchersky[50] explains the theoretical aspects of the surface active additive on crystallization systems, the effect of an additive (α-methyl glucoside ester) on viscosity and surface tension, and also the results of its application in evaporators.

Little was known about surfactants until Chen presented comparative test results in 1968,[51] showing the shortening of boiling time in low-grade pans, improving fluidity of mother liquor, the purging property of massecuite, and the purity of purged sugar (bigger

49. *J. Am. Chem. Soc.*, 1937, p. 447; *ISJ*, May 1941, p. 158.
50. ISSCT, 1965, p. 1785.
51. ISSCT, 1968, pp. 1808–1815.
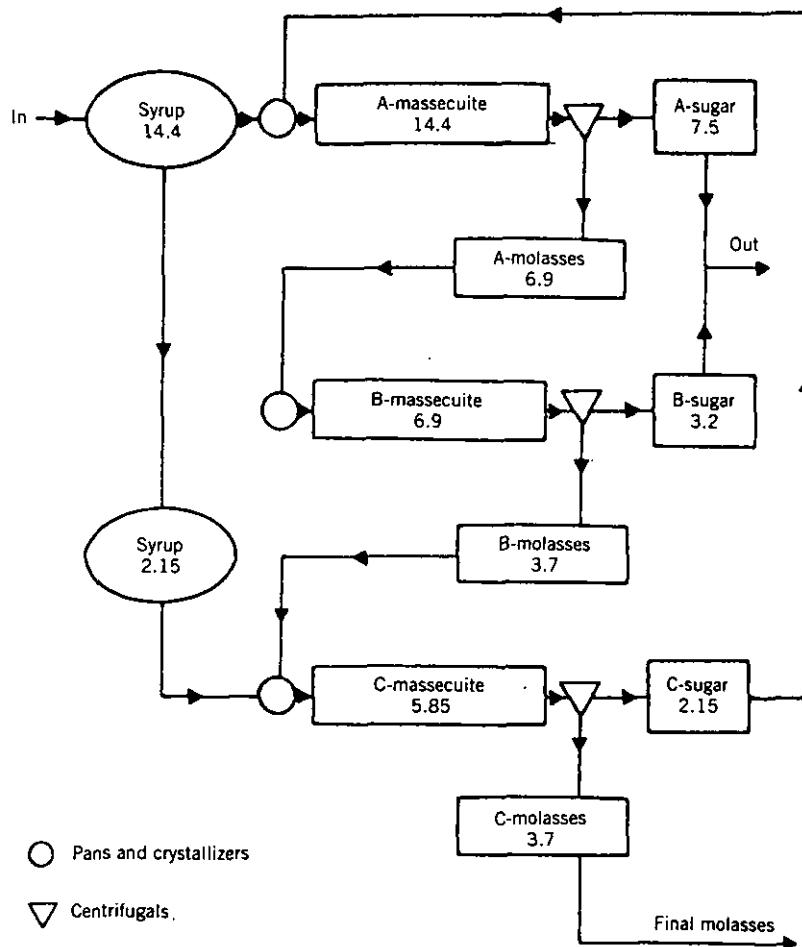
Figure 7.36. Simple three-boiling system.

and more uniform grains with less ash content), and increasing the purity drop from massecuite to molasses (better recovery efficiency).

There are now various surfactants for pan boiling, such as Hodag CB-6, Fabcon Viscaid, Midland PCS-5002, and Mazu 400. These additives are particularly helpful when the factory is processing stale cane or freeze-damaged cane. In extreme cases, the addition of one of the additives into the crystallizer may alleviate the overloading of the centrifuge station.

Hanzawa et al.[52] tested five surfactants in a cane sugar factory and a refinery, and found that a sucrose fatty acid ester (S-570) having an HLB (hydrophile-lipophile balance) of 5 performed a remarkable reduction in molasses viscosity, particularly at 60 C. With a dosage of 50–100 ppm, it also reduced the boiling and purging times, sucrose loss, and consumption of steam and electricity, while increasing the Pol recovery and purity drop from massecuite to molasses. When refining the sugar produced, all of the ester was removed by carbonation and decolorization.

52. *JSRT*, 1982, **30**, pp. 53–63.

influenced by the same factors, and the limit to which the massecuite can be cooled depends on the ability of the crystallizer to physically handle the material at high viscosities. Viscosity, therefore, is a dominating factor in the technology of the process.

After the massecuite has been reduced to the minimum optimum temperature and the mother liquor has been substantially exhausted, the mass is too viscous for satisfactory separation of the crystals from the molasses by the centrifugal machines. Since the mother liquor of the massecuite at this point is still supersaturated, it is possible to reduce its viscosity without re-solution of the crystals by bringing it to a state of saturation, either by heating or by the addition of water, permitting more effective separation of molasses from crystals.

For low-purity massecuites from which final molasses is produced, crystallizer processing is essential if unnecessary high losses of sucrose in final molasses are to be avoided.

PHYSICAL PROPERTIES OF SUGAR SOLUTIONS GOVERNING CRYSTALLIZER TECHNOLOGY
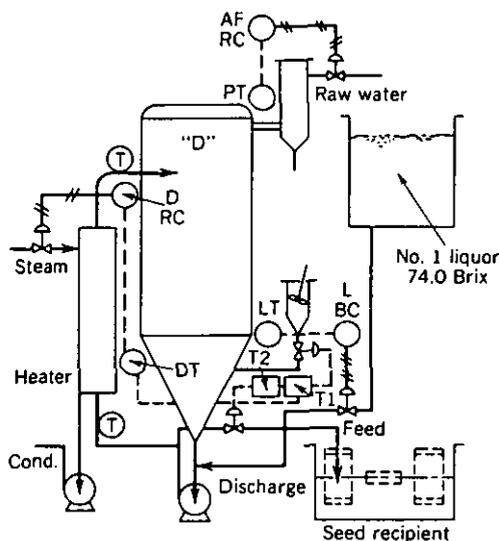
7.53 Solubility of Sucrose in Pure Water.   Sucrose is readily soluble in water, and its solubility increases with temperature. The value determined by Herzfield in 1892 is the best known and most widely used. The following equation expresses the solubility values of Herzfield's table from 0 to 100 C:

$$C = 64.18 + 0.1348t + 0.000531t^2$$

where C = sucrose at saturation (%)
     t = temperature (C).

Herzfield's results are now questioned. Subsequent investigators have reported solubilities greater than Herzfield's above 60 C (140 F) and lower than his near room temperature.[89]

Charles[90] in 1958 reported his measurements of saturation concentration at 37 temperatures (from 0.6 to 86.1 C) and derived the following equation for solubility values from 0 to 90 C:

$$S = 64.397 + 0.07251t + 0.0020569t^2 - 9.035 \times 10^{-6}t^3$$

where S = sucrose (%)
     t = temperature (C).

The solubility of pure sucrose in a saturated solution is frequently expressed as the percentage of dissolved solids by weight; but for purposes of comparing solubilities, the ratio of sucrose to water is a more significant expression. This ratio is generally stated as parts of sucrose per 100 parts of water, and is referred to as the solubility number. The following formulas convert from one form to another where.

X = sucrose per 100 water Y = percentage sucrose by weight

$$Y = \frac{100\ X}{100 + X} \qquad\qquad X = \frac{100\ Y}{100 - Y}$$

89. Chen, 1985, p. 346.
90. *Ibid.*, p. 347.

CRYSTALLIZER PROCESSING OF FINAL MASSECUITE

7.78 Cooling of Massecuites. Low-grade massecuites, after having been boiled to maximum workable consistency in the vacuum pan, are discharged to the crystallizers at a temperature of 65–70 C (149–158 F) and a supersaturation approximating 1.20. To continue crystallization to the ultimate limit of exhaustion, therefore, it is necessary to lower the temperature of the massecuite progressively to the minimum at which it can be mechanically stirred, the limiting factor being viscosity. The progressive decrease in sucrose solubility resulting from diminishing temperature maintains the supersaturation necessary for crystal growth. Crystallization should be allowed to continue at the minimum temperature until a saturation temperature suitable for centrifugal processing is attained, which is approximately 55 C (131 F). The minimum temperature to which the massecuite may be lowered varies with the characteristics of the massecuites and the crystallizer capabilities. Usually, it falls between 45 and 50 C (113 and 122 F) with high-density massecuites, and above 35 C (95 F) with lower-density massecuites.

The rate of cooling depends on the character of the massecuite, the nature of the impurities, and the design and strength of the crystallizer. Rates of crystallization of low-grade materials differ widely, and the time required for cooling at the minimum temperature likewise varies. To maintain the highest possible rate of crystallization without formation of spontaneous grain, the best conditions for cooling generally are realized when the rate of cooling is in approximate pace with the velocity of crystallization. Under these conditions, the supersaturation does not materially change during the cooling, but of course, it tapers off during the holding period after the minimum temperature has been reached.

Saska[110] develops computer programs to optimize low-grade crystallizer performance, relating retention time to final molasses purity and crystal content (Fig. 7.63).

7.79 Cooling Rates.[111] Some use fast-cooling; some prefer slow-cooling. The time

X = kg/kg solution
TDS = total desolved solids
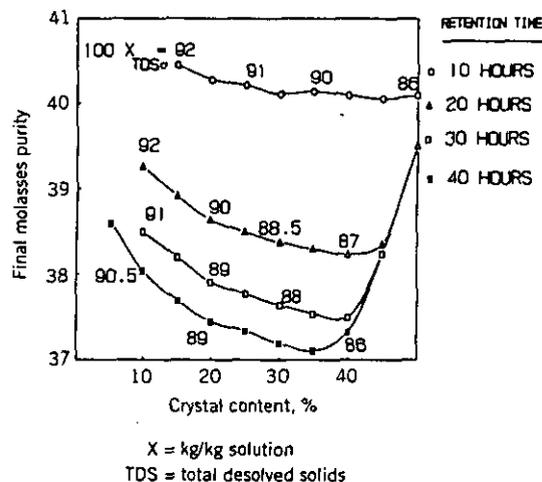
Figure 7.63. Effect of crystal content for four crystallizer holding times (10, 20, 30, and 40 h).

110. *ISJ*, 1990, **92**, pp. 23–29.
111. Chen, 1985, p. 369.

to reach the minimum temperature of 49 C (120 F) runs 9 h for fast-cooling. Others may need 16 h for slow-cooling. Generally, the cooling rate is 1.5–2 C (2–3 F) per hour.

When invert is high in low-grade massecuite, the fast-cooling does not give sufficient time for sucrose to be salted out. On the contrary, when invert is low in higher-grade massecuite, fast-cooling may cause a great increase of viscosity in the mother liquor.

In refinery, the highest yield is obtained by fast-cooling. A purity drop of 6.4 points can be achieved in the first 24 h, with only 2.8 points in the second 24 h. However, the purity drop may not be proportional to sugar exhausted because some inversion and destruction may occur during the cooling process.

Optimum results are attained when the massecuite is rapidly cooled to the minimum temperature that crystallizer equipment will allow and held at this temperature until the desired saturation temperature is reached. The cooling rate, however, must be limited to a supersaturation zone that precludes the formation of spontaneous grain.

7.80   Crystallization at Minimum Temperature.   Usually when a final masse-cuite has been boiled to a relatively high density and a good pan purity drop has been obtained, the minimum temperature to which it can be cooled falls in the 45–50 C (113–122 F) range. Lower-density massecuites, boiled at lower temperatures and pan purity drops, can be cooled to considerably lower minimum temperatures, to advantage.

7.81   Dilution vs. Reheating.   Dilution can be carried out either during processing inside crystallizers, or after the crystallization period ready to be centrifuged.

The massecuite flow inside crystallizers is affected by viscosity at low temperatures and high solid content. Where the RS/Ash is low in boiling materials, the massecuite has to be boiled to near 100 Brix, which causes more problems, especially in the continuous systems. Using water to dilute the massecuite has been common practice in several countries. Some uses dilute molasses to do the lubrication. Saska and Oubrahim[112] correlate the dilution with the massecuite viscosity and the dilution with final molasses purity, as shown in Figs. 7.64 and 7.65. They maintain that to dilute with water or diluted molasses is not recommended. To solve the problem is to consider the sizing and type of connectors between crystallizers, and also to adjust the elevation between crystallizers.

After the crystallization period has been completed, the mother liquor is still supersa-
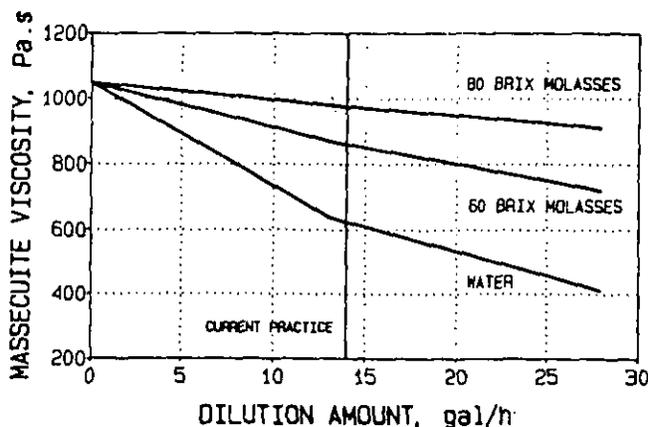
Figure 7.64. Massecuite viscosity for various amounts of the three dilution media.

112. *Sugar J.*, July 1988, pp. 6–9.

PURGING, PACKAGING, AND WAREHOUSING OF RAW SUGAR*

8.1 Purging. In sugar technology, the term "purging" refers to the removal of molasses from the crystal-molasses mixture (massecuite) discharged from a vacuum pan. Purging is usually carried out in a centrifugal machine, and the term "purging efficiency" or P.E. is a measure of the level of impurity removal that has been achieved during the centrifuging operation. P.E. is derived from the following:

$$P.E. = \frac{(\text{purity of sugar} - \text{purity of massecuite})(100 - \text{purity of molasses})}{(\text{purity of sugar} - \text{purity of molasses})(100 - \text{purity of massecuite})} \times 100$$

Purging efficiency is an important control figure in the efficient operation of the low-grade section of a factory. It is here that one attempts to achieve the maximum removal of impurities while minimizing the transfer of sugar to molasses during this impurity removal process. A brief study of the formula via appropriate calculations will highlight the formula components that are detrimental to a high level of impurity removal. Among these is the less obvious effect of increasing massecuite purity in the low-grade factory section.

Other formulae for evaluating fugal performance are

$$\text{massecuite rate} = (\text{molasses rate})\frac{DS_{mol.}}{DS_{mass.}} \left[\frac{\text{purity of sugar} - \text{purity of mass.}}{\text{purity of sugar} - \text{purity of mol.}} \right] \times 100$$

$$\text{crystal content } (\% \text{ on massecuite}) = \left[\frac{\text{purity of mass.} - \text{purity of mother liquor}}{100 - \text{purity of mother liquor}} \right] DS_{mass.}$$

where DS = dry solids.

8.2 Purging Options. Some sugar processing methods do not require the use of mechanical separation or centrifuging. Notable among these are the manufacturing of gur in the southeast Asian region and the production of various forms of microcrystalline amorphous sugars in Brazil and Portugal.[1]

The centrifuge predominates in processes where separation of the sugar-molasses com-

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1. Baikow, 1982, pp. 445-447.

ponents is required. Separation is greatly enhanced by the centrifugal effect, and the most important attribute of the centrifuge is that it is a highly efficient, time-saving device.

One alternative to the centrifuge is the Typhone filter.[2] This unit filters the massecuite on an endless, woven belt, and the process is aided by vacuum, steam, and washing sections. The belt filter concept does not appear to have received a high degree of acceptance in the sugar processing world: it is thought that the appeal for the concept decreased as the technology of crystal breakage prevention in centrifugals increased.

8.3 Centrifugal Machines. The majority of centrifugals, or fugals, used in sugar processing are classified by their mode of operation, i.e., batch fugals or continuous fugals. In most situations, batch machines are used for the separation of high-purity massecuite, while continuous fugals are used more on lower purity, higher viscosity materials.

The basket of a batch fugal is essentially a perforated drum with vertical sides (Fig. 8.1). When the basket is rotated, fluid is forced through the perforations under the action of centrifugal force. Retention of crystal inside the basket is improved by the insertion of a fine metallic screen, while the escape of fluid is assisted by the insertion of a larger slot backing screen between the working screen and the perforated basket wall. A metal casing surrounds the basket, and this catches the molasses that is spun off from the basket. Each battery of batch fugals is supplied with massecuite from a holding vessel referred to as a mingler, and each machine is supplied with a batch or charge of material at the commencement of each cycle. The time taken for this charge of material to be loaded into the basket is a good indication of the extent to which the massecuite has been exhausted in the pan. Charge times below 8 sec on raw sugar massecuite indicate that either the crystal content is too low or that insufficient water has been removed from the massecuite before it was discharged from the vacuum pan.

The continuous centrifugal of proper design can offer a dramatic capacity advantage over the batch machine, especially when processing lower-grade massecuites.[3] An illustration of one of the current units is shown in Fig. 8.2 (given in the 11th edition, p. 406). These machines work on the thin-layer filtration principle, and can effectively treat high-viscosity cane sugar massecuites, provided that the material is still fluid and that an appropriate feed system is used.

Many investigators in different countries have evaluated the purging efficiency of continuous centrifugals. Proskowetz and Chen[4] in Peru compared batch and continuous machines side by side in 1960–61 at the early stage of the development of this technology, showing that there was no difference in purged molasses between the two types of machine. The continuous machine, however, showed better sugar quality with more nonsugar removal.

More recent work in several countries has highlighted the need for continuous centrifugals to be operated at or near their maximum capacities in order to minimize the loss of sugar in molasses. It is of interest to note that, although batch machines have disappeared from many low-grade factory sections, *any loss* of sugar detected during separation is pursued with new found vigor. The attainment of molasses purity rises below one unit; however, it has never been an acknowledged attribute of the average batch fugal.

8.4 Batch Fugal Cycle. Modern batch fugals are completely automatic in operation: a fugal station attendant merely adjusts the various settings to achieve the approximate polarization and moisture of the sugar that is required. A normal batch fugal cycle is de-

2. *ISJ*, 1979, pp. 293–296.
3. Conrad, 1978, Western States Rep. 166.
4. *Sugar*, May 1961, pp. 38–40.

picted in Fig. 8.3. Its essential operational steps are: charging at low rpm, acceleration to top speed, washing and/or steaming, running at top speed, deceleration, sugar discharge, and washing of the inner basket before recommencing the next cycle.

8.5   Batch Power and Drive.   One disadvantage of the batch fugal is its high power demand during the acceleration phase of each cycle. These power demand peaks can be a disruptive element to some power grid interconnections. An essential in such situations is the sequencing of machines on a station to ensure that no more than one machine is in the acceleration phase at any one time. Most batch machines are also provided with the facility of regenerative breaking. In theory, this facility generates power to be fed back into the system during the motor's deceleration phase of the cycle: In practice, it may be found that, with conventional A.C. motors, a significant portion of this energy is dissipated as heat during the regeneration cycle.

The net power consumption per ton of material separated is influenced by the type of drive system installed, the top running speed, and by the grade of massecuite to be processed. More detailed information can be found in Hugot,[5] while Chapman[6] highlights the power consumption differences in the simple table reproduced here (Table 8.1).

8.6   Batch Fugal Washing and Steaming.   Application of wash water during spinning varies according to preference of the manufacturer or the innovations of the operator. Water can be applied manually via a dipper or hose by one of the various automatic preset timers that delivers a fixed quantity of water per second to the point of spray application. Several variations ranges from 80 to 85 C, but superheated water at 110 C is used

Speeds

n1 = discharging approx 80 rpm
n2 = charging adjustable between 100 and 250 rpm
n3 = spinning

Times

t0 = total working cycle
t1 = charging
t2 = accelerating
t3 = spinning
t4 = braking, regenerative
t5 = discharging

t6' = syrup separating "green"
t7' = } start/duration syrup washing
t8' = } alternatively water washing
t9' = } start/duration water washing
t10' = } alternatively steam washing
t11' = screen washing

* adjustable through time relays

Figure 8.3. Components of a modern batch fugal cycle. (BMA G 1500)

5. Hugot, 1986, Chapter 35.
6. Jenkins, 1966, p. 338.

TABLE 8.1
Power Consumption with Different Drives

	kWh per Ton Unwashed Sugar (Chapman)	kWh/Cycle (Lohning)
Two-Speed Induction Motor	$3.78 + 0.0103\ t$*	1.7
Ward–Leonard Drive	$2.75 + 0.0278\ t$	1.2
Schrage a.c. Commutator Motor	$2.04 + 0.0260\ t$	1.1
Thyristor d.c. Motor	—	0.7

*t = time at top speed in seconds.

in some instances.[7] More recent adaptation includes the substitution of water wash with clarified juice[8] or with high Brix syrup from the effects. Regardless of the wash variation or adaptation, the plain axiom is that washing removes impurities more efficiently during a cycle than the alternative of increasing the spinning time at top speed.

An example of washing with syrup in batch centrifugals for A-massecuite is reported by Lionnet[9] (Tables 8.2 and 8.3), showing the increase of massecuite exhaustion, the reduction of crystal dissolution by about 30%, and savings of steam consumption.

The extent of wash application is an important criterion in factories where a high standard of chemical control is practiced. Extended wash times are usually a good indicator of substandard boiling practices with respect to the Coefficient of Variation (CV) of the sugar being produced. Extended wash times also result in higher molasses purities, which in turn increase the recirculation loading on the panstage.

8.7   Effect of Massecuite Properties.   The influence of a high CV of crystal on dissolution during purging has been mentioned previously. With batch machines, the prime cause of this situation is the physical blocking of drainage channels by the movement of smaller sized grains within the crystal mass. It has been observed in extreme cases of blockage that a layer of molasses will form on the inner vertical sugar wall within the basket. Purging efficiency is greatly reduced when this situation occurs.

The crystal size distribution, the C-sugar purity, and massecuite throughput are the three main factors found by Jullienne[10] to have an influence on the molasses purity-rise across the continuous C centrifugals.

TABLE 8.2
Sugar Color Reduction with Water and 40 Brix Liquor Wash

% Color Reduction	Wash % Massecuite	
	Water	40 Brix Liquor
20	0.6	1.2
40	1.4	2.5
60	3.6	5.5
80	8.9	11.8

7. McGinnis, 1982, p. 475.
8. Attard, ASSCT (QL), 1989, pp. 199-206.
9. SASTA, 1989, pp. 90-93.
10. ISJ, 1987, pp. 16-20.

opment of a universal centrifugal that will purge all grades of massecuite. This development is still in the trial proving stages, but it offers the possibility of having a single fugal station for the whole factory. An integral part of this strategy is the positioning of one or more machines that can be diverted to either high-grade or low-grade duties to cope with changes in the quantities of the various products being processed.

8.20   Control of Density of Molasses and Syrup.   The molasses or syrup purged from the centrifugals in the raw house or refinery must be diluted and reheated in any pan boiling system requiring reuse in subsequent strikes. Other density control problems include melt liquor in the refinery, evaporator output in both raw and refined sugar processes, and commercial molasses sold at 42 Baume (80 Brix). Density control of liquid invert and sucrose syrups involves extremely close control (limits not stated, but apparently less than ± 0.1 Brix).

The complexity of modern instrumentation for these purposes is evident. Instruments may include magnetic indication of the position of a float, bubble tube controls similar to that described for automatic juice weighing (Chapter 4), electronic methods using radioactive radiation, and measurement of the electromagnetic energy required to keep a ball-plummet motionless in a liquid of varying density. Viscosity meters and refractometers are other means suggested. Many of these instruments control density to 0.05 Brix.

DRYING AND COOLING OF RAW SUGAR

8.21   Drying and Cooling of Raw Sugar.   The drying of raw sugar is not as straightforward as is the drying of refined sugar because raw sugar has to be dried to within a certain limit, guided by either the *safety factor or dilution indicator* (see Chapter 9).

Raw sugar can be dried with a fluidized bed or a spouted bed. Weilant et al.[42] demonstrate the functioning of these beds on the drying of raw sugar (Fig. 8.12). They report that the study of batch drying of raw sugar has indicated that drying times of 1 min for a fluidized bed and 2 min for a spouted bed are required to bring wet sugar to its equilibrium moisture content. The spouted bed drier is preferable for its greater stability, its resistance to shock
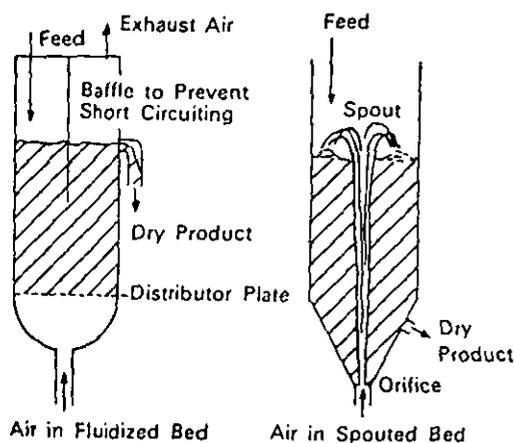
Figure 8.12. Typical fluidized and spouted beds.

42. ISSCT, 1974, pp. 1561, 1566.

loads, and its lower air requirement. However, the spouted drier seems to produce more fines than the fluidized drier. These principles may be applied in continuous driers.

Drying of raw sugar with a fluidized bed system has been successfully carried out in a South African factory with a grinding capacity of 500 tch (12,000 tcd). Mann[43] described the drying system (Fig. 8.13) and the effect of process variables on performance. The air velocity varies between 1.0 and 1.4 m/sec, the drying zone sugar temperature between 40–50 C, and the bed pressure differential 2.0–2.5 kPa. The average sugar is 35 t/h, the inlet sugar moisture 0.38%, and the outlet sugar moisture 0.11–0.16%, depending on process variables (see also Chapter 17 for refined sugar drying).

The same principle of drying can also be applied to cooling. Cooling of raw sugar is particularly important to refining quality. High temperature in storage increases raw sugar color, both in the film and inside the crystal (see Fig. 9.7 and Table 9.8).

A cooler/drier installation developed in South Africa for raw sugar is shown in Figs. 8.14 and 8.15, and results obtained are shown in Table 8.4.[44]

8.22 Sugar Dryer Entrainment Systems. Sugar dust from the exhaust air is generally removed by a wet cyclone, where water is being recycled after spraying.
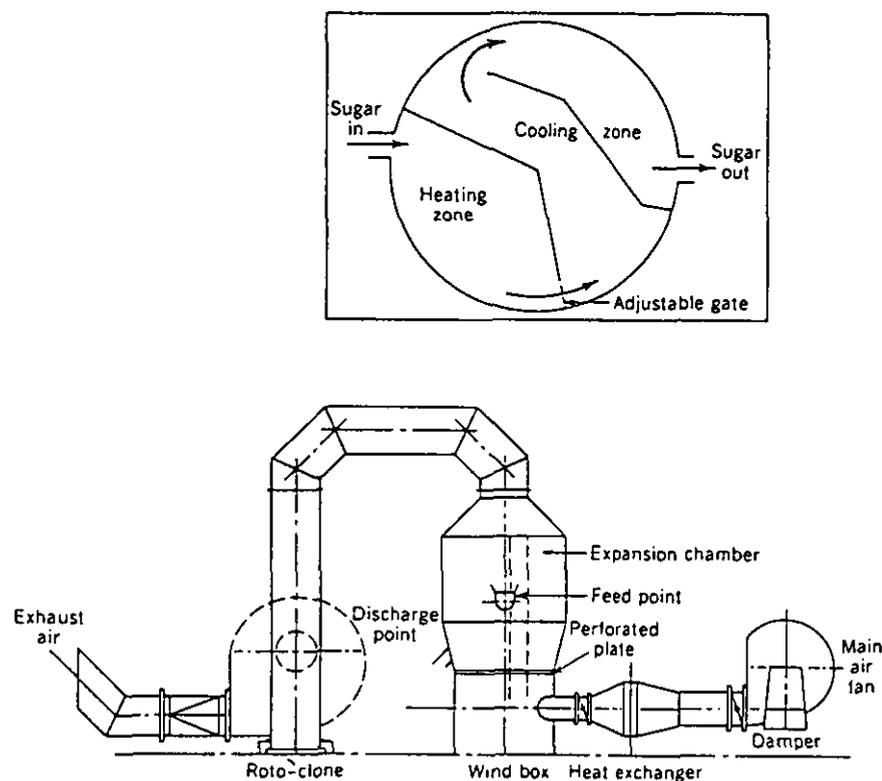
Figure 8.13. Raw sugar drying with fluidized bed system (insert: baffle arrangement).

43. SASTA, 1983, pp. 56–59.
44. De Robillard, SASTA, 1984, pp. 61–63.
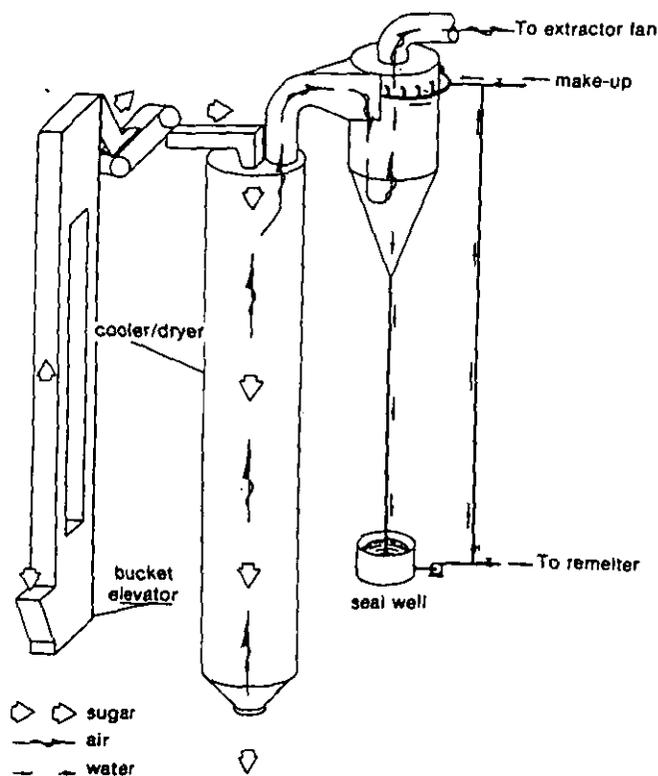
Figure 8.14. Cooler/dryer plant.

Attard and King[45] experience a new design of entrainment arresting system, using induced draught instead of forced draught, resulting in a higher air flow without excessive sugar spillage. The drier performance is shown in Table 8.5. The sweet water from the arrester is returned to *A* molasses for Brix control. In order to avoid the growth of *Leuconostoc* bacteria in the entrainment arrester area, it is found necessary to heat (85 C) and chlorine treat (conc. calcium hypochlorite) the water system once a day.

PACKING

8.23 Conveyors. Sugar from the centrifugals or driers goes to the packing bins by means of conveyors of various types. In raw sugar houses, the ribbon or screw conveyor is common, and consists of a spiral ribbon or screw that revolves in a trough, carrying the sugar with it. The cross section of the trough is usually parabolic rather than U-shaped. In refineries, rubber-covered endless belts are preferred, and in some instances, steel belts and corrosion-resistance alloys are used. Eastern Hemisphere factories prefer the so-called grasshopper conveyor—a wide, flat trough supported on flexible strips that vibrate by means

45. ASSCT (QL), 1985, pp. 189–193.

TABLE 8.5
Sugar Dryer Performance (1984)

Sugar Temp.		Air Temp.		Sugar D.I.		Flow Rates		
In °C	Out °C	In °C	Out °C	In %	Out %	Sugar tonne/hr	Air m³/sec.	Air/Sugar Ratio
58.6	31	22	47	49	31	51.3	10.35	0.87
66.6	30	23	44	80	30	50.1	12.75	1.10
61.7	32	27	44	51	30	49.9	12.75	1.10
64.4	28	28	40	93	28	49.5	12.75	1.11
66.1	28	28	43	135	30	51.5	11.55	0.97
63.0	32	28	46	183	27	57.2	6.75	0.51
63.0	32	28	44	223	31	39.8	12.75	1.38
63.7	31	29	42	112	30	57.9	12.75	0.95
67.4	30	29	47	122	34	46.6	12.75	1.18
70.4	35	29	48	95	28	48.8	6.75	0.60
63.6	32	29	45	173	21	46.1	12.75	1.20
57.7	32	30	46	62	29	54.8	8.00	0.63

of an eccentric in such a manner that sugar is thrown forward through a short arc with each vibration of the trough. The grasshopper has the advantage that no sugar crystals are broken in handling, and also some cooling occurs. Experiments have shown that little breakage of crystals occurs with screw conveyors if the cross section is such that the conveyor trough is filled only about one-third with sugar.

8.24 Packing Bins. Raw sugars are not usually dried; but the applying of steam (generally superheated) in the centrifugals is fairly common. Drying with heated air in vertical tray rotary driers, which also serve to cool the sugar, is still employed in the Eastern Hemisphere.

It is customary to deliver the raw sugar to the bin from the elevator, where the sugar strikes a spreader or fan that throws it out into the air and causes some cooling and evaporation. This arrangement is particularly important for sugar that is to be bagged, a practice that is rapidly giving way to bulk handling and storage, as described in Sec. 8.26.

8.25 Weighing Bagged Sugar. Bags holding 140–150 lb (63.5–68.0 kg) or 250 lb (133 kg) or 330 lb (150 kg) are still used in some countries, even though bulk handling is common practice. Where sugar is bagged, weighing on automatic scales with careful supervision and constant checking is sufficiently accurate for control purposes.

BULK RAW SUGAR

8.26 Handling and Weighing. Equipment for bulk handling is relatively simple. Troughed belt conveyors, which may be inclined at an angle of 22° maximum to obtain height, are common for long travel, although scroll conveyors are satisfactory for short distances. Weighing is by automatic hopper scales, delivering 10 t or more at a drop, and self-taring automatically after each weighing (Fig. 8.16). Specially designed "slingers" of the type described in Sec. 8.29 spread the sugar evenly in storage or in the hold of ships. Earth-moving tractor equipment of various designs moves the sugar into and out of the warehouse, puts it into trucks, or stows it where desired. Dump trucks, generally covered

with tarpaulins, are satisfactory and inexpensive for hauls from a few hundred yards to several miles. Unloading and loading of ships may be done by gantries of elaborate design or by clamshell buckets similar to those used for ore, grain, and other bulk materials.

Sugar can be continuously weighed while being conveyed to the warehouse.[46] The Rex electronic weighbridge is mounted in place of one of the regular idlers. When sugar passes over the weigh section, an electronic speed transducer monitors the belt speed, and together with the load cell signal, provides the necessary input to a digital electronic integrator which multiplies the weight and speed components and displays the results in actual tonnage of sugar passed over the scale, as well as also the rate of flow.

8.27   Bulk Storage.   Warehouses are specially designed for new installations, but storage in locations originally intended for bags is quite common (Fig. 8.17). Strong, reinforced side walls generally 10 ft or less in height retain the piled sugar in such storage. Bins of steel, silos of very large capacity, and circular domelike structures are all reported to be in use for bulk raw sugar. The angle of repose for loosely spread raw in bulk is about 40°, but moist sugar may have a slope as high as 50°. The angle of slide is about 35° and the angle of draining is about 55° as given by Chen[47] (Fig. 8.18). Compare these with those of refined products.

Beaubois[48] describes types of vertical and horizontal silos used for bulk sugar storage, and compares their advantages and disadvantages. In Mauritius, they finally chose two identical A-shaped silos, each 364 m (1194 ft) long and 45 m (148 ft) wide. Since each silo has a capacity of 175,000 t, the total holding capacity is 350,000 t.

The Flexair[49] high-volume, low-profile silo can be installed indoors or outdoors, and is a new design concept. It eliminates the cone-bottom discharge, but utilizes two inflatable liners that gently move raw sugar from the sides of the bin to a centrally discharge feeder (Fig. 8.19). The loads can be discharged on a first-in first-out basis.

Steele[50] presents the desired features of a bulk storage facility to minimize quality deterioration.

8.28   Bulk Sugar Compressibility and Bulk Density.   Compacting of sugar in an experimental pile of 2000 t, 30 ft (9 m) high showed that 20 ft (6 m) down the sugar had a bulk density of 62.3 lb/cu ft (998 kg/m^3). Experimental pressing, tapping, and packing the same sugar under pressure of 65 psi gave a maximum of 60.8 lb/cu ft (974 kg/m^3), showing the effectiveness of crystal movement in finding face-to-face contact.[51] The bulk density varies with crystal size, volume of measuring vessel, the shape of vessel, angle of charging funnel, and height between funnel and vessel.[51] The density obtained from large and tall vessels varied between 49.12 lb/cu ft (786.9 kg/m^3) and 53.10 lb/cu ft (850.5 kg/m^3), respectively. For designing of warehouses, 55 lb/cu ft is generally used.

This condition corrects itself when sugar is delivered to piles or silos by the slinger or spreader arrangement, which throws crystals out in a stream (Sec. 8.29). Crystal movement in the pile is avoided, and there has been little serious caking.

Bulk granular solids have a finite compressibility, even with the relatively low pressures that occur in storage. Bagster[52] tested raw and refined sugars in a compressive test machine. Results show that the compressibility/pressure function is heavily dependent on particle

46. *Sugar*, March 1983, p. 27.
47. *Sugar Bull. Taiwan*, December 1974, p. 8.
48. *Rev. Sucr. Maurice*, 1977, 56, pp. 193–198.
49. *Sugar*, September 1990, p. 15.
50. Proceedings SPRI Workshops (Bartens), 1990, pp. 82–84.
51. Opielak Przem. Spozyw., 1981, 35(2), pp. 58–60 (SIA, 1981, #81-1236).
52. *ISJ*, 1978, pp. 295–298.
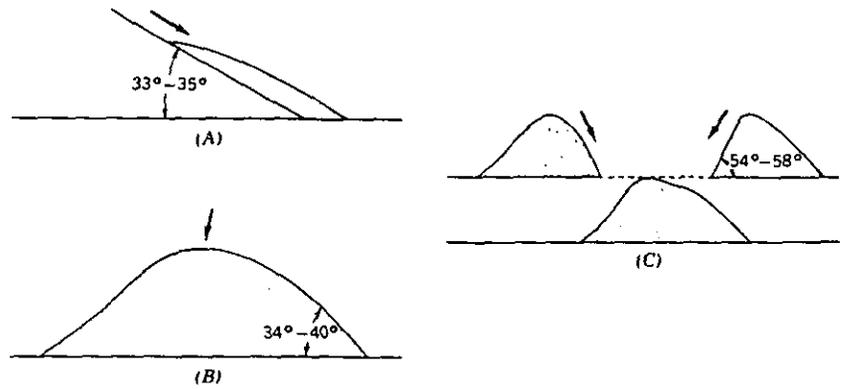
Figure 8.18. Bulk sugar storage angles. (A) Angle of slide; (B) angle of repose; (C) angle of draining.

properties and particle size distribution. Great care therefore should be exercised in using a single bulk density figure in estimating the contents of a heap of material in storage. The error involved may be tolerable in one circumstance, but not in another.

8.29 Sugar Slinger. This device (Fig. 8.20) consists of a high-speed short belt (2000 rpm) passing over two large pulleys. The sugar falls on the belt from a height, and the forward motion throws it in a stream from the end of the belt in a trajectory that may reach 90 ft (27 m). These portable machines may be pivoted in any direction; they find use in loading boxcars, stowing ships, or spreading sugar in warehouses either from the floor or from the end of conveyors.

8.30 Warehousing of VHP and VLC Raw Sugars. South Africa developed a

Flexair
18′ dia. X 18′ high
(3,500 cubic ft.)

Conventional Silo
12′ dia. X 45′ high
(3,500 cubic ft.)
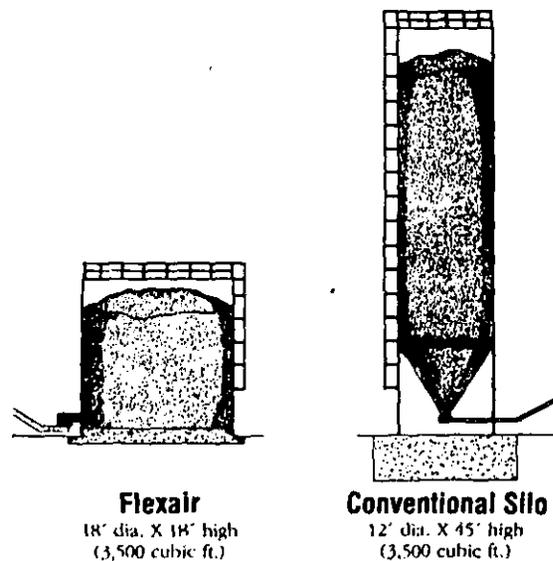
Figure 8.19. Silo design assures discharge of materials.
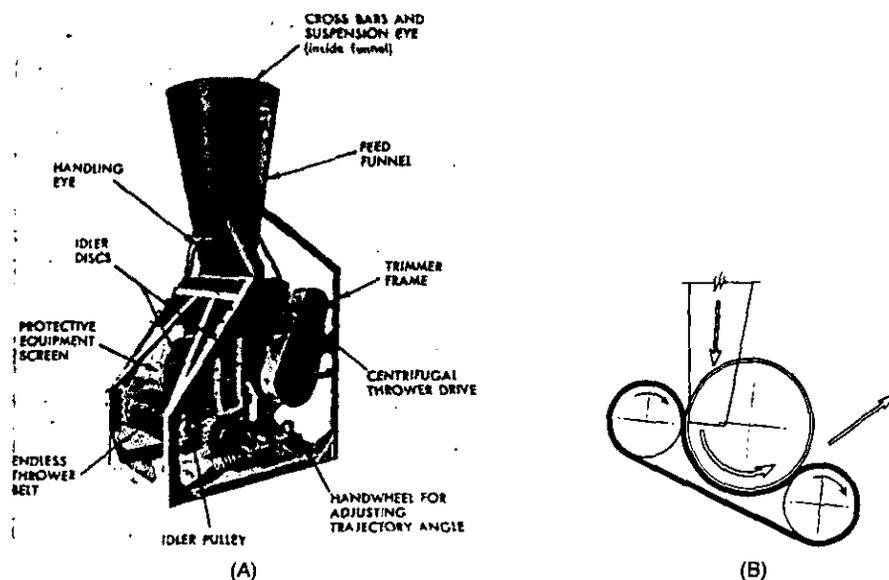
Figure 8.20. Thrower for bulk sugar handling. (A) The thrower; (B) diagram of thrower.

method of producing "painted" raw sugar, by painting molasses on sugar of very high Pol (see Chapter 9). The warehousing conditions of such sugar differ somewhat from those for ordinary raw sugar having a thicker molasses film surrounding the crystals. Kimmerling[53] reports that the sugar should be stored at slightly lower than ambient storage temperature, the equilibrium relative humidity should be around 60% (about the level of explosive hazard), and a crust 25–36 mm should be allowed to form, to protect the sugar from deterioration without moisture migration. The quality and quantity assurance of raw sugar throughput at the South African sugar terminals are stressed.[54]

Hawaii started in 1988 to produce raw sugar of very low color (VLC). Moritsugu and Goya[55] conducted tests on the storing of such sugar under different conditions, and concluded that sugar with an acceptable deterioration factor (DF) may be stored in a well-ventilated warehouse without loss in Pol and with minimum rise in color.

8.31 Warehousing of Bagged Raw Sugar. Deterioration of raw sugars is a function of the amount of moisture in the molasses film on the crystals; thus, it is essential that the absorption of atmospheric moisture be prevented after the sugar has been made. Several studies have shown that the critical relative humidity is about 65%; that is, if the relative humidity is near that point, the sugar will neither absorb moisture nor dry out in storage.

If the warehouse is too dry (e.g., the relative humidity is below 60%), the raw sugar will cake and harden to an undesirable degree. Therefore, heated warehouses for raw sugar are not customary or, in fact, desirable.

To prevent the absorption of moisture, warehouses should be dry, large, and almost airtight. The safest practice is to keep warehouses closed at all times, particularly in the tropics and in moist climates, to ensure that as little moist air as possible comes in contact

53. SASTA, 1975, p. 105.
54. SASTA, 1978, pp. 69-72.
55. Rep. HST, 1987, pp. 69-70.
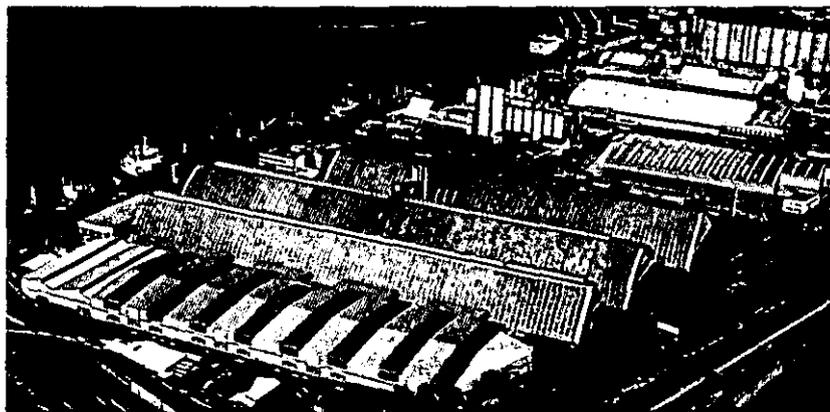
Figure 8.21. One of the largest bulk sugar terminals in the world (Maydon Wharf, Durban, South Africa). Total storage capacity 577,000 tons (520,000 bulk sugar and 57,000 bagged raw and refined sugars).

with the sugar. The atmosphere gradually comes to equilibrium with the moisture in the sugar.

8.32   Bulk Sugar Terminals.   The largest bulk sugar terminal for raw sugar may be the one in Durban, South Africa.[56] The three silos can store 520,000 tons of raw sugar (Fig. 8.21), the quantity equivalent to 50% of annual domestic consumption. At this terminal is also a new bagged sugar warehouse (floorspace 18,450 sq m), for one-ton and 50 kg bags of raw and refined sugars, that stores 57,000 tons of sugar, together with 520,000 tons of bulk storage space, making a total storage capacity of 577,000 tons of sugar.

8.33   Sugar Belt for Shipping.   The longest sugar belt in the world is believed to be the one at Lucinda Point, 70 miles north of Townsville, Australia. The deep water berth location is 5.76 km (3.58 mi) offshore[57] to accommodate 40,000 dwt vessels. The belt travels at 24.4 mi/h (39.3 km/h) (Fig. 8.22).
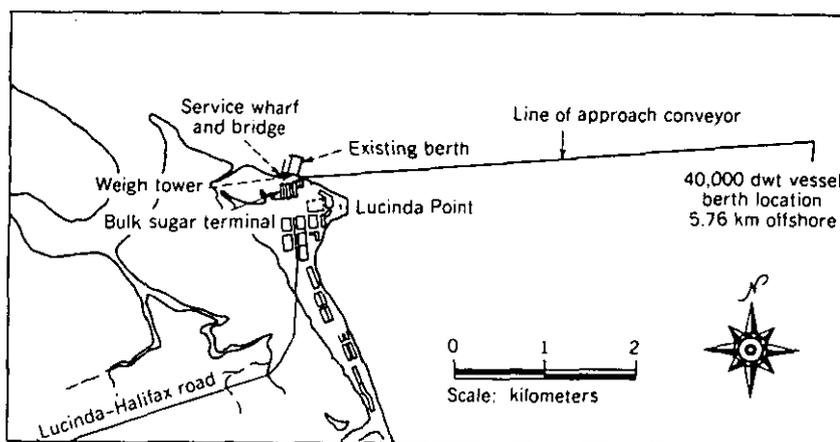
Figure 8.22. World's longest sugar belt. (Australia)

56. South African Sugar Yearbook, 1984–85, p. 198; SASJ, August 1991, p. 234.
57. *Sugar J.*, May 1979, pp. 20–21.

CHAPTER 12

AFFINATION AND CLARIFICATION*

12.1 Nature of the Industry. Economics favors the concentration of cane sugar refining into large units. Refineries are most often located near centers of high population and on waterways. The daily input or *melt* ranges from one to eight million lbs of raw sugar per day (500–4000 t/day).

Modern refineries are highly automated using computer control. The refining process may be divided into several steps. The flow diagrams of Figs. 12.1 and 12.2 represent common phosphatation and carbonation processes, named after the clarification system used.

The terms used in the refining industry are given in Chapter 21. Some terms may be same as in the raw house but carry different meanings.

12.2 Raw Sugars. The average Pol of raws supplied to the United States has risen steadily since the New York Sugar Trade Laboratory began testing in 1908, to slightly above 98 today, except VHP and VLC raw sugars (Sec. 9.28). The trend is given in Fig. 16.3, 11th edition of this Handbook.

Much of the world's raw sugar is handled in bulk. Several types of scales are used to weigh delivered raw sugar. In most refineries, the raw sugar is reweighed upon entering the process. Raw sugar scales are described in detail in earlier editions of this Handbook.

AFFINATION

12.3 Washing the Raw Crystals. Most of the impurities in raw sugar are in the thin molasses film, and only minutely occluded within the crystals. The first step in refining is called *affination* or washing, and consists of removing this adhering film. The molasses film has a purity of 65 or lower, whereas the crystal purity is higher than 99.

The separation involves mingling with a warm, barely undersaturated syrup near 75 Brix, to loosen the molasses film. The mixture is purged in centrifugals, then washed with hot or cold water, or a high purity sweetwater, after the syrup has been spun off. According to Lyle,[1] the optimal magma temperature is 43 C (109 F). Operational adjustments are often made at the affination station to accommodate the quality of the raws.

Modern affination centrifugals load, purge, wash, and discharge automatically, and operate at high speed, 1100–1200 rpm. Figure 12.3 is a flow diagram for such a station. Cycles of less than 3 min using 9–11 kg of wash water per charge are usual with good

*by **R. Riffer**
1. Lyle, 1957, p. 454.

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raws. Hot water, near 80 C, or a high-purity sweetwater is generally used. The amount of wash water used determines the degree of impurities removal. Underwashing leaves impurities on the crystals, and overwashing diminishes the *yield*, that is, the fraction of the whole raw mass recovered as washed raw. Yields are also reduced from raws with small, non-uniform grain. Performance may also be assessed in terms of color improvement.

The affination process is ideal for computer operation. Control parameters must balance the desired degree of decolorization against the target recovery at the remelt station.

Where a refinery is attached to a raw house, the raw sugar may be washed more heavily so that the refinery can be operated without an affination station. Also, where VLC raw sugar is provided all the time, the affination process of the receiving refinery can be dispensed with.

12.4   Dissolving or Melting the Washed Sugar.   The washed raw sugar is dissolved in about half its weight of water in a *melter*, a mixing tank supplied with exhaust steam. High-purity sweetwaters from other refinery stations are used in melting, but it is obviously bad practice to contaminate the melted liquor with sweetwaters having a purity lower than the washed raw itself.

12.5   Treatment of Affination Syrup.   About 10% of the solids in raws goes to affination syrup, which has a purity of 75–80 or higher and a Brix of 75. The purity is, of course, controllable, being a function of raw quality and the degree of decolorization sought. When pumped to process, the syrup is treated in one or two ways. The practice in refineries of large char capacity is to dilute some of the syrup with dark sweetwaters and send it to the clarifier station, and then through bone char or granular carbon, after which it may be used to produce a boiled soft sugar.

The simpler method is to send the syrup to the pan floor without further treatment, and use it to boil remelts. Generally, a "high" remelt is boiled first, and the syrup from this strike is boiled back in one or two stages into "low" remelts. The runoff or greens from the last boiling is the standard final molasses, or blackstrap, of commerce. The purity of the final molasses is limited by viscosity.

The low remelts are sent to the crystallizers for curing. Lower purity massecuites require a longer curing time. The sugar from the remelts goes to the clarifier station, then to char. Preferably, this sugar should follow the washed sugar liquor cycle, but this requires separate tankage and pumps.

Sugar from the high remelts is melted directly from the centrifugals; that from lower remelts is better handled by repurging. In this process, the discharged sugar is mingled with a heavy, low-purity syrup, usually the wash from the second purging, then centrifuged and washed in the centrifugals. This results in a better separation of impurities and a higher purity feed to the clarifiers. However, the use of high-speed continuous centrifugals has, to a large degree, obviated the necessity of double purging.

DEFECATION OR CLARIFICATION

12.6   General Principles.   The washed raw liquor from the melter is acidic and contains some insoluble material, such as bagacillo and soil, suspended solids, and colloids. In this last category are indigenous polysaccharides that escaped clarification in the raw house and those that were formed subsequently. Clarification of raw liquor or affination syrup is a treatment to remove insoluble and colloidal matter, including substances rendered insoluble by the treatment itself.

Brooklyn Refinery Flow Diagram

Affination
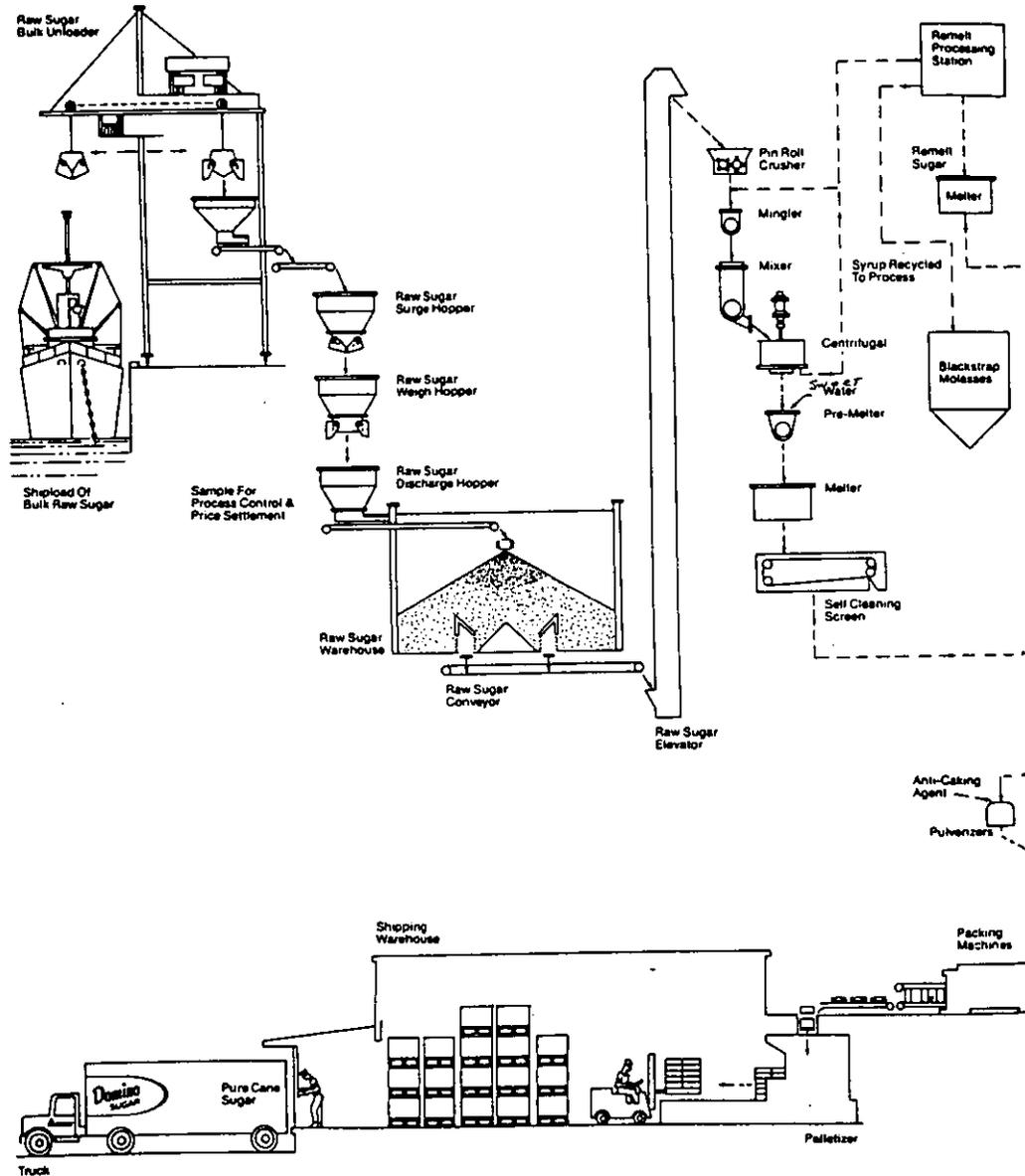
Figure 12.1. Flow diagram of a phosphatation refinery. (Domino, Brooklyn)
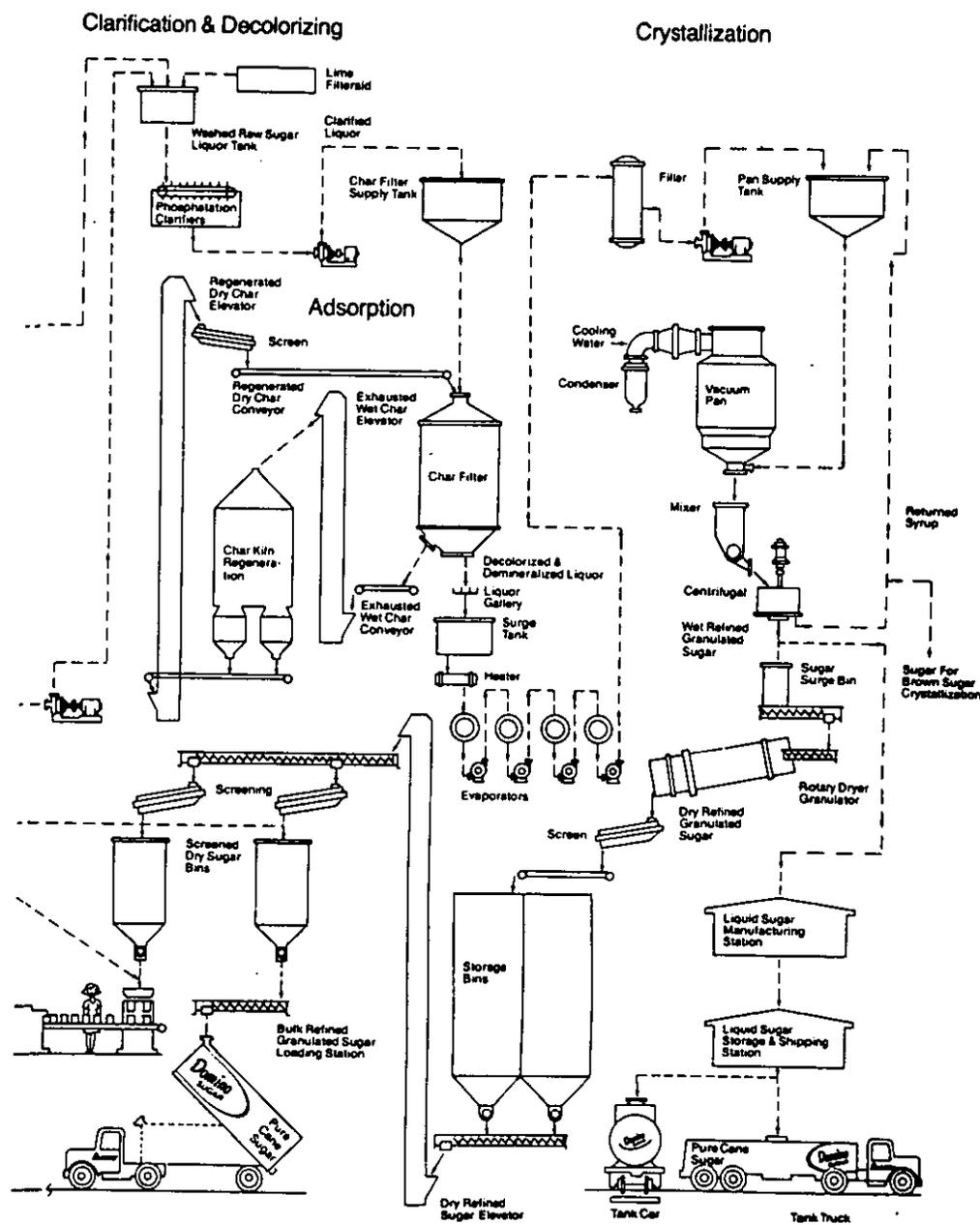
Figure 12.1. (*Continued*)

Figure 12.2. Flow diagram of a carbonation refinery. (Revere, Boston).

Two methods of clarification are used. A pressure filtration may be carried out using an inert filter aid, or chemical treatment may be employed, using lime and either phosphoric acid or carbon dioxide. It is common practice to prescreen melt liquors to remove coarse material. This technique is described in detail in the 11th edition of this Handbook, pp. 535–536.

Chemical defecation is usually avoided for affination syrups, which tend to clarify poorly and form a large volume of precipitate.

Figure 12.2. *(Continued)*

PRESSURE FILTRATION

12.7 Equipment and Materials. Several leaf-type filter designs are in use. These generally consist of a series of filter elements composed of a metal frame with a backing screen over which a fabric is stretched. Cotton has been widely replaced by nylon, polypropylene, Monel, and stainless steel cloths. The filter assembly is enclosed within a metal body capable of withstanding operating pressures up to 60 psi or higher.

The best known and most widely used leaf filter is the Sweetland press, which uses stationary elements (Fig. 12.4). The Vallez filter is of the rotary-leaf type, in which the leaves and shaft rotate slowly during operation, so that the cake builds more evenly. Other designs include the Sparkler and the Auto-Jet. These and other types are described in detail in the 11th edition of this Handbook.
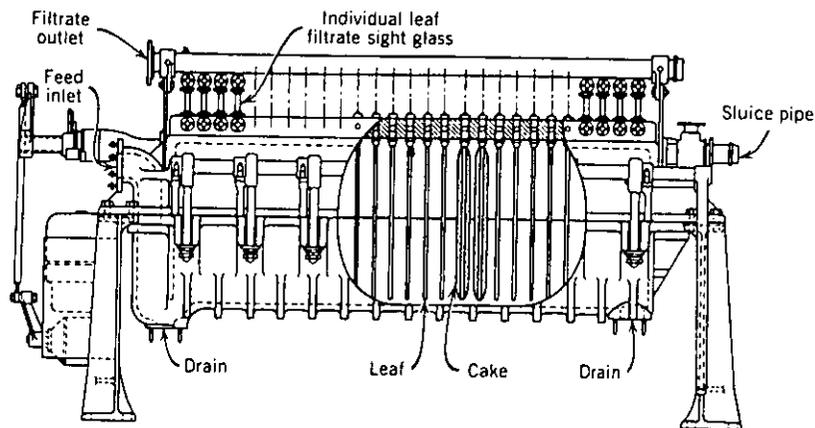
Figure 12.4. Sweetland filter. (Dorr-Oliver)

12.8   Efficacy of Pressure Filtration.   Sugar liquors are difficult to filter because of the wide range of particle sizes they contain. Since the particles are mechanically caught, those removed must be larger than the openings in the filter. The use of filter aid, usually kieselguhr (diatomaceous earth), enormously increases the capacity of the filter, which would otherwise rapidly become plugged. A schematic of a diatomite pressure filtration system is shown in Fig. 12.5.

Filtration is effective in removing insoluble suspended material, but cannot remove colloidal substances responsible for most turbidity. Colloids are for convenience sometimes
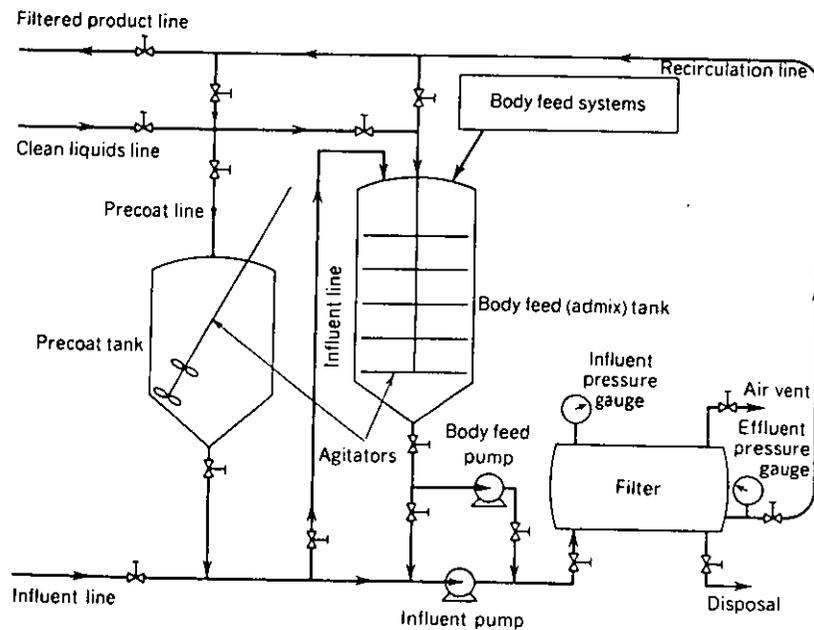
Figure 12.5. Pressure filtration system.

defined as particles smaller than 0.45 μm in diameter, but are more accurately described in terms of interaction with a solvent.

It is generally agreed that chemical defecation is preferable to a mechanical filtration that is used as the sole clarification system. Filtration is labor intensive and messy. Filter aid is costly, and spent material must be either regenerated thermally or disposed of in an environmentally sound manner. At the same time, there are important applications of pressure filtration in the refinery: as an adjunct to chemical defecation, for treatment of muds, and for a final treatment before crystallization.

PHOSPHATATION AND CARBONATION

12.9   Phosphoric Acid and Lime.   This treatment produces a calcium phosphate floc that is filtered with difficulty. Consequently, air flotation is commonly used to separate the calcium phosphate precipitate from the liquor; such systems are called *frothing clarifiers*. The scums are then removed from the liquor surface by a skimming device. If filtration is practiced, a highly porous filter aid must be used. Detailed descriptions of various clarification systems appear in earlier editions of this work.

It is common practice to express the level of phosphoric acid used as "% P_2O_5," although phosphorous pentoxide itself is never added to the process and would react explosively with the liquor. Basing the level of addition on P_2O_5, a solid, eliminates ambiguity of concentration, since phosphoric acid itself is unavailable in 100% solution.

Control of addition is usually automatic, generally in the range of 0.012 to 0.05% P_2O_5 on solids, depending upon raw quality. Lower levels, about 0.005%, are used when the precipitate is removed by filtration rather than flotation.

In automatic liming systems, *lime sucrate* is generally used, an adduct of calcium hydroxide with sucrose, for increased solubility. For normal raws of 97 test or higher, the amount of lime used ranges from 400 to 500 lb CaO per million lb of melt. The lime and phosphoric acid may be added in either order, with automatic pH adjustment to about 7.3. If lime addition is autocontrolled but acid addition is not, it may be preferable to add the acid first; this would minimize pH fluctuation if the acid level were varied to accommodate refractory liquors.

The optimal temperature appears to be near 165 F (74 C), with liquor densities at 63 Brix or higher, although higher temperatures, near 80 C, are used in some processes.

The treatment precipitates organic acid impurities as their calcium salts. Suspended and colloidal material—such as bagasse particles, soil, polysaccharides, and proteins—are entrapped and occluded within the growing coagulum. High levels of polysaccharides can overwhelm the capacity of the floc and severely inhibit clarification. Some color is removed, typically 20–35%, probably substances complexed with colorless high molecular weight material. Color removal is proportional to the amount of P_2O_5 added. Greenish iron complexes with catechols are also removed in part by the treatment.

It is common practice to add to the clarification process a small amount of polyacrylamide flocculant, which not only speeds up clarification, but also strengthens the floc against shearing forces. A high molecular weight in the additive produces high clarity, but the longer chains are more subject to cleavage. A high concentration of electrical charge in the polymer results in a high settling efficiency.

12.10   Zeta Potential vs. Refinability.   Small particles of natural origin in aqueous suspension, such as macromolecular nonsugars in a sugar liquor, typically have a negative electrical surface charge. This is true even of molecules ordinarily considered "neutral,"

such as starch. The magnitude of the concentration of charge can be expressed as the *zeta potential*, an indicator of the stability of the dispersion. A high potential is characteristic of a system that is resistant to sedimentation. Riffer et al.[2] were able to correlate raw sugar refinability with zeta potential, which can be modified by pH adjustment (and certain electrolyte additives). Nonetheless, direct zeta potential adjustment is not used as an adjunct to clarification because of the impractically low pH requirement and the reluctance to use additives, however benign. (ZP is also discussed in Sec. 5.15.)

A technical overview of a modern refinery (daily melt 900 t) using color precipitant in phosphatation is given by Chapman and Curdie.[3]

12.11 The Carbonation Process. This technique consists of precipitating calcium carbonate in the washed raw melter liquor by adding lime and then bubbling through carbon dioxide. Because the gas is acidic, the initially high pH is reduced during gassing. As the voluminous precipitate forms, much insoluble and suspended matter becomes entrapped in the crystalline calcium carbonate mass. Other impurities are adsorbed on the crystal surface or precipitate as insoluble calcium salts. Included in this last category are sulfate, phosphate, carboxylic acids, acidic polysaccharides, and certain colorants. Because of thermodynamic constraints on the solubility equilibria, none of these species are removed quantitatively.

The initially high pH, which locally can exceed 12 at the point of addition, is limited by the low solubility of lime. The optimal lime dosage is adjusted for the raw sugar quality and is based on filterability, not clarity, typically 0.4–1.2% on solids. A large excess of lime is undesirable because of scale and other problems toward which calcium ions contribute. Carbon dioxide gassing may be carried out in batches or continuously; the final pH is generally in the range 7.7–8.5.

Lamusse[4] reports that the flue gas, containing about 12% CO_2 by volume, is scrubbed to remove sulfur compounds and to be cooled to about 50 C. For oil or coal-fired boilers, the scrubbing is done in two stages, i.e., with water and then with 5% sodium carbonate solution. But for bagasse fired boiler, only with water is sufficient.

The process in essence generates a calcium carbonate filter aid *in situ*, and pressure filtrations yield a clarified liquor ready for decolorization. Diatomaceous earth is sometimes used as a precoat. The volume of mud produced is large, 10–30 times more than from phosphotation.

Toth[5] reports the successful refining of cane sugar in a beet sugar factory during with a minimum of additional equipment to its existing carbonation installation.

12.12 Color Precipitants. These additives, such as Tate & Lyle's Talofloc and American Cyanamid's Magnifloc, are organic substances with a (+)-charge on a central pentavalent nitrogen atom, belonging to a class called quaternary ammonium compounds. The four covalently bonded radicals, in the case of Talofloc, are two methyl groups and two alkyl groups, C_{14}–C_{18}, derived from tallow; the acid anion is chloride. Colorants, most of which contain (−)-charges, form insoluble adducts with the marginally soluble additive.

Addition is typically to phosphatation clarifier systems, although precipitants can also be used with carbonatation processes. The best filterability is obtained when the sequence is color precipitant/phosphatation/polyacrylamide. Color and starch removal are enhanced by the treatment, with little effect on turbidity or conductimetric ash. The use of color

2. *ISJ*, 1979, pp. 196–200.
3. *ISJ*, 1990, **92**, pp. 84–87.
4. SASTA, 1988, p. 31.
5. *Sugar J.*, October 1984, pp. 7–12.

precipitants is attractive because of the small capital investment required for installation, although operating costs are high: typical usage levels are in the range of 200 ppm on solids, about 20 times those used for polyacrylamide.

12.13   Handling Muds and Scums.   The various clarification systems yield press-cakes, muds, or scums from which entrained sugar must be recovered. Scums from phosphatation systems are generally sent to secondary clarifiers to reduce their sugar content. Two or three stage flotation separators, using polyacrylamide flocculating agents, permit countercurrent desweetening without any filtration equipment.

The latest practice, reported by Clarke,[6] at the Savannah Refinery is to sluice the sweet-land press-cake to a mud tank, at 15% solids and 10–12% Brix sucrose. 0.2% CaO (on melt) is added and the slurry is saturated with CO_2 gas (at 10 psig) at pH 10.5 to further precipitate $CaCO_3$ before filtering with Eimco rotary vacuum filters for dewatering.

Nicholas and Smith[7] in Australia compare the RVF (rotary vacuum filter) and HFPF (horizontal frame pressure filter) filters for carbonation mud. While both are similar in most aspects, the HFPF offers superior quality discard mud (25–30% against 50% moisture of RVF), lower turbidity of recycled sweetwater than the RVF (i.e., lower mud recycle), and is a more attractive financial proposition (Fig. 12.6).

Scums from frothing clarifiers can also be treated in centrifugal separators. This technique is described in greater detail in the 11th edition of this Handbook. Press filtration is also used, although phosphate scums will not filter on rotary vacuum drums without added filter aid.

High-test sluicings from pressure filtration can be dewatered in rotary vacuum filters; the cake can be slurried and reused at the affination station. Carbonatation mud can be filtered using either pressure or vacuum. Reviews and references to these techniques appear in the 11th edition.

Savannah was the first sugar refinery using carbonation in the United States. Its current daily melt is 3000 t. Kelly reports its present operation.[8]
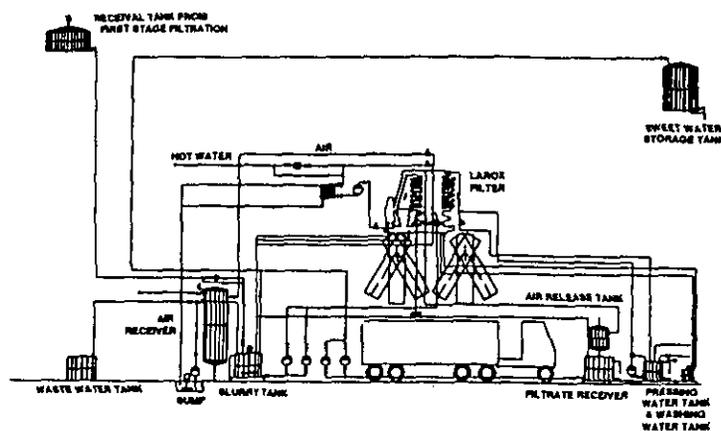
Figure 12.6. Schematic of HFPF filtration plant.

6. *ISJ*, 1988, **90**, pp. 80–85.
7. *ISJ*, 1991, **93**, pp. 9–15.
8. *Sugar*, May 1988, pp. 28–32.

The largest refinery of Amstar Sugar Corporation (now Domino Corporation) is also uses carbonation. An overview of its operation is given by Goodrow.[9]

12.14 Carbonation vs. Phosphatation. The two techniques have been compared by several investigators.[10-15] Some important differences are as follows:

1. The carbonation procedure precipitates about 30 times more calcium phosphatation. Consequently, the former does a better job of removing impurities that form sparingly soluble calcium salts, such as sulfate, phosphate, and acidic polysaccharides.
2. For polysaccharides containing few anionic functions such as starch, carbonation appears to do a better job (Roberts et al.;[14] Tables 12.1 and 12.2), although phosphatation may be more effective at removing the amylose component. Neither process is particularly effective at removing dextran.
3. The two processes may remove similar range in color, 25-50%, and both produce excellent clarity. However, the clarity from carbonation is slightly better because the final liquor is pressure filtered.

TABLE 12.1
Polysaccharides in a Phosphatation Process Refinery

Sample	Total Polysaccharides (ppm Starch on Solids)
Raw sugar	1410
Washed raw sugar	671
Affination syrup	7434
Melt sweetwater	2669
Melt liquor	614
Clarified liquor	588
Liq. off char, beginning of cycle	350
Liq. off char, end of cycle	608
Liquor to resin	494
Liq. off resin, new column	552
No. 1 liquor to pans	437
First strike sugar (wet)	150
First strike syrup	1041
Second strike sugar (wet)	284
Second strike syrup	1971
Third strike sugar	473
Third strike syrup	3712

9. *Sugar*, May 1989, pp. 33-36.
10. CSRRP, 1972, pp. 62-75.
11. SASTA, 1976, pp. 179-183.
12. CSRRP, 1980, pp. 1-25.
13. *ISJ*, 1976, p. 180.
14. *Sugar J.*, February 1978, pp. 21-23.
15. Clarke, *Sugar y Azucar*, 1973 Yearbook.

TABLE 12.2
Polysaccharides in a Carbonation Refinery

Sample	Total Polysaccharides (ppm Starch on Solids)
Raw sugar	930
Washed raw sugar	450
Melt sweetwater	562
Melted washed sugar liquor	519
Remelt liquor	2040
Melt liquor (mixture)	675
Carbonated liquor	
before filtration	394
after filtration	378
Char-filtered liquor to pans (No. 1.)	244
First strike sugar (wet)	50
First strike syrup	603

4. Carbonation produces considerably more solid waste than does phosphation. The former technique requires a higher capital investment, but uses cheaper process materials. There is also a considerable maintenance cost associated with the gas compressors used in carbonation.

5. Carbonation uses more extreme pH's and temperatures; hence, sugar losses by degradation are *potentially* higher. On the other hand, phosphatation results in a somewhat higher invert gain, about 0.025%, compared to 0.010–0.015% after carbonation.

12.15 Modifications of Phosphatation and/or Carbonation. Carbonation achieves over 50% decolorization, while phosphatation is generally in the range of 25–30%. By the use of polycationic additives (Sec. 12.12), both processes can achieve a decolorization over 70%.[16]

The combination of phosphatation–sulfitation and phosphatation–carbonation are both practiced in China[17] for refining raw sugar during the off-seasons.

Aside from adding cationic flocculant to a normal phosphatation process, Cordovez et al. experienced a further additive of H_2O_2 to the melter before mixing with the flocculant. Thus, the H_2O_2 substitutes the use of activated powder carbon. In order to avoid new color formation, 10 ppm of sodium hydrosulfite is added to the clarified liquor. Also found is that H_2O_2 is more effective with an alkaline pH.[18]

OTHER REFINING PROCESSES (CLARIFICATION)

12.16 Magnesia Process. The MSC magnesia process is developed by Mitsui Sugar Co., Japan. It uses magnesia and ion-exchange resin to replace the conventional carbonation–nchar ion-exchange method. Nakamura et al.[19] relate the merits achieved by

16. Bennett, *Sugar J.*, December 1990, pp. 7–11.
17. Fok, *ISJ*, 1989, **91**, pp. 145–147.
18. SIT, 1991, pp. 133–140.
19. *ISJ*, 1989, **91**, pp. 91–95, 106–108.

Decolorization* * *

13.1 The Nature of Sugar Colorant. Color is the principal control parameter in the sugar refinery. It is an easily measured and important specification for raw sugar as well as for refined products.

Raw sugar is not colored in the same way that, for example, iron rust is reddish. In rust, the red color is a property of the substance itself, whereas sugar is colorless, irrespective of its purity. It is the color of *nonsugar* contaminants that is responsible for the "color" of raw sugar and that of refinery products.

Nonsugars are not necessarily undesirable, and are, of course, essential components of brown sugars. Moreover, since the *amount* of impurity responsible for the measured color is rarely known, measurements are typically normalized not on the concentration of colorant, but instead on Brix, which approximates the amount of sugar present in the sample. Consequently, different samples do not exhibit Beer's Law agreement. That is, all samples containing, for example, 0.1% methylene blue, have the same absorbance, but not, for example, all 45 Brix sugar solutions.

Clarification and filtration, which remove suspended solids and colloidal matter, may be considered pretreatments for removing *soluble* impurities, such as color, by adsorption processes. These techniques also remove colorless species such as certain inorganic constituents ("ash"), as well as some complexed colloids and colorless organic nonsugars. Because of the formation of such adducts, the line between colorants and colorless constituents, especially those of high molecular weight, is not sharply drawn; thus, we observe "soluble" color removal in clarification, and polysaccharide removal in "decolorization."

13.2 Types of Colorants.[1] Colorants may be classified into several categories:

1. *Phenolics*. These are derived, to a considerable extent enzymatically, from flavonoid and cinnamic acid precursors naturally occurring in the cane, the same kinds of substances responsible for the colors of flowers. They are aromatic materials, which does not necessarily mean that they are fragrant, but rather that their molecular structure includes a specific resonant electronic system. An important characteristic of this type is *pH sensitivity*, that is, their absorbance changes markedly with pH.

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joule of red light contains more photons than one of violet light, or—to put it conversely—100 red photons per second produce fewer *lumens* than 100 violet photons per second.

13.5 Hues Observed in Sugar Samples.[2]   The natural pigments of cane are yellow to orange. Their spectral features do not differ substantially from those of brown sugar liquors, except in quantitative terms. Brown is, after all, not a color of the spectrum, but results from high absorbency. The natural pigments are precursors of more highly colored materials, formed by enzyme action early in processing, or later through chemical reaction.

The source of redness in sugar liquors appears to be *ortho*-quinones, formed by oxidation of naturally occurring phenolics such as chlorogenic acid, which is present in all refinery streams and in trace amounts even in highest purity granulated sugar. Oxidizing conditions are particularly favorable in heating operations, such as in vacuum pans and sweetwater evaporators.

Green hues are associated with iron contamination. The complexes with certain nonsugars, such as catechols, are intensely colored and display a high degree of stability. As a result, iron is readily removed in the manufacture of granulated sugar, but eliminated with difficulty from brown sugar liquors, which contain relatively high levels of chelating groups.

Extreme caramelization results in black residues resembling graphite. Thermal degradation or pyrolysis is, of course, a route to vegetable carbons, although the activated carbons of commerce that are used in sugar refining are manufactured from coal.

13.6 Types of Adsorbents.   The media most commonly used for decolorization are carbonaceous adsorbents, made from naturally occurring materials, and synthetic resins. The adsorptive forces involved typically are relatively nonspecific; that is, one would not expect such an adsorbent to completely remove one class of colorant while having little effect on another type. Such specificity generally requires highly specialized molecular structure, such as is present in enzymes, DNA, antibodies, and cell receptors. There is no reason to believe that natural selection in any organism would favor molecular structures that specifically adsorb impurities in sugarcane.

The forces involved are fairly weak, less than 5 kcal/mole. However, a large colorant molecule might be bound to the adsorbent at several sites, so the calculated total adsorptive force would require a summation. The adsorbed layers are only a single molecule thick; hence, very large surface areas are necessary for an adsorbent to be effective.

Theoretical treatment of adsorption is difficult to apply to sugar because the colorant fraction is highly heterogeneous. Each component has a different adsorptive potential, which includes both kinetic and thermodynamic contributors. As in any multistage process, the critical step is the slowest, which determines the overall rate. For sugar decolorization, this step is transport to the adsorption site, that is, diffusion. Consequently, decolorization is generally improved by flow rates as slow as permitted by other considerations.

In sum, the efficacy of adsorbents requires both a large surface area and a high degree of porosity. Bleaching-type decolorization, using peroxide or hypochlorite, is little used; such processes can destroy sugar by oxidation.[3]

13.7 Fixed and Moving Beds.   Bone char or granular carbon may be used in either fixed or moving beds. In the former case, sugar liquor is passed through the adsorbent until the effluent color reaches a control point, determined by economic considerations. Decolorization is commonly 99% at the beginning of a cycle and 90% near the end, although some refineries utilize the total capacity of the adsorbent much better than this. Typically, the effluents from many beds, all at different stages in their cycles, are combined. At the end of the cycle, the sugar liquor is displaced with water; that is, the bed is *sweetened off*.

2. Riffer, SPRI, 1990, pp. 265–290.
3. Riffer, CSRRP, 1980, pp. 84–102.

Colorants are adsorbed too strongly to be washed off, so the adsorbent must be regenerated thermally after removal to a kiln.

In a moving bed system, operation is continuous rather than cyclic, and countercurrent. Spent adsorbent is periodically removed from the bottom of the column for regeneration. Such a system requires a smaller plant and adsorbent inventory, and generates a smaller volume of sweetwater. On the other hand, there is only a single liquor stream. Moving beds are described in detail in the 9th and 10th editions of this Handbook.

13.8 Flow Rate and Pressure Drop. The fluid in a bed of adsorbent occupies only the void fraction e or porosity. The displacement volume D is the product of the total volume of the bed V and the void fraction; that is, $D = Ve$. For piston displacement, the flow rate $Q = D/t = Ve/t$. Thus, increased flow can be achieved by increasing the volume of adsorbent or reducing the contact time t. Flow is commonly expressed in bed volumes, Q/V, or in displacements, Q/D.

Pressure drops are governed by the *Poiseuille equation*,

$$P = \frac{k\mu L Q}{g\,\beta^2\,A}$$

where μ is viscosity, L is the bed depth, g is the conversion factor between mass and force, A is the cross-sectional area of the bed, and k is a proportionality constant dependent upon particle shape and packing density. The equation appears to favor short, wide beds, but such beds are very difficult to fill uniformly. With nonuniform beds, *channeling* is likely to occur: liquor takes the path of least resistance, through the larger particles, bypassing a portion of the adsorbent.

13.9 Granular Activated Carbon. This adsorbent, which contains more than 60% carbon, is made from coal heated to 1000 C with steam activation. Its decolorizing capacity is ten times that of bone char, but it does not remove ash. Furthermore, carbon has no buffering capacity; to prevent pH drop in the off-liquor, about 5% magnesite (MgO) is mixed with the adsorbent.

Granular carbon cycles are commonly three–six weeks. The sweetwater generated is of high purity and can be used in the melter. Although the sweetwater volume per cycle is greater than for bone char, this is more than compensated for by the much longer cycles. Flow rates are about twice those for bone char. The carbon burn rate is about 0.7% on melt.

Carbon is transferred hydraulically between the cisterns and the kiln. Regeneration is at 800–1000 C, with 1.5–3% oxygen plus steam. Losses average about 4% per cycle.

13.10 Bone Char. This adsorbent, which contains about 90% calcium phosphate and 10% carbon, is manufactured from degreased cattle bones heated to 700 C. The calcium phosphate portion, on the atomic level, can be visualized as an array of alternating (+)- and (−)-sites, like a checkerboard. Divalent or polyvalent inorganic impurities can be picked up on this surface by an ion-exchange mechanism. Colorants, which at operating pH's typically contain negative charges, can be adsorbed at (+)-sites or at carbon regions.

The efficacy of bone char results from its high surface area, about 1900 square *miles* within a single cistern, which is about the size of the state of Delaware.

In a typical operation, there are about 15 bone char filters per million pounds of daily melt. However, hydraulic voiding and external washing make it possible for the filters to be on the liquor cycle a significantly longer fraction of the time; for such refineries, the corresponding figure is about 8–9 filters per million pounds of melt. The liquor is supplied through a manifold system to facilitate changing from one liquor to another and to water.

Effluents from the filters are monitored at the *liquor gallery* and directed to appropriate collection tanks. The bone char operation is described in detail in the 9th, 10th, and 11th editions of this Handbook.

The principal feed to the char system is washed and clarified liquor. This may be followed by relatively small volumes of successively lower purity streams. Feed liquors are about 65 Brix. Higher densities *improve* ash removal, because less water is present to solubilize inorganics, but result in *poorer* decolorization because of slower diffusion of colorants at the increased viscosity.

A bone char cycle is commonly four–five days. The columns are sweetened off at a slow flow rate, to permit sugar to diffuse out of the pores. As the Brix decreases, ash begins to desorb, so the resulting sweetwater is of low purity. Hot water here is a hindrance: the principal inorganic constituent in the wash is calcium sulfate, the solubility of which *decreases* rapidly with rising temperature. This characteristic is partly responsible for the separation of scale from water and sweetwater containing this substance.

The char burn rate ranges from 5–20% on melt, with losses of 0.3–0.5% per cycle. Most of the heat used in regeneration is to evaporate moisture. The spent char is dried to a moisture content of about 10%, then kilned at about 550 C in a limited amount of air to pyrolyze off adsorbed organics and restore the buffering capacity. Retort-type or multiple hearth (Herreschoff) kilns are used; these are described in detail in the 11th edition of this Handbook. Kilning temperatures strongly influence the pH of effluents in the succeeding cycle.

Remaining calcium sulfate is rendered insoluble by the process, restoring the deashing capacity. In *overburned* char, the calcium sulfate is reduced to calcium sulfide. Overly high regeneration temperatures are to be avoided: the hydroxyapatite crystallites can be irreversibly altered to a less active state in a process called *sintering*.

High-sulfate liquors decolorize poorly because sulfate ions can diffuse to adsorption sites faster than sluggish colorant molecules and are more strongly adsorbed at those sites. On the other hand, high-calcium liquors decolorize well because more cationic sites are made available for anionic colorant molecules. High-calcium liquors may also display more reddish hues off char.[2]

Mixture of bone char and granulated carbon has been tested in different countries with good decoloring and regeneration results. However, some problems in regeneration/makeup are yet to be solved.[4]

13.11   Powdered Carbon.   Because the particles are finely divided and have a high surface-to-mass ratio, very short contact times suffice for decolorization. Powdered carbon can be used as a precoat in a filter press with a contact time of less than one second. One or two passes are made, then the carbon is discarded. Since no columns or regeneration systems are used, the process requires a low investment cost but results in a relatively high operating cost. Such systems are commonly used as a final polishing treatment, to remove residual color or odor.

Under special local conditions, phosphoric acid is added in the mixed juice of the raw house to produce a raw sugar of lower color and then to use activated carbon in the refinery carbonation process to improve color removal, as is practiced in South Africa.[5]

13.12   Ion-Exchange Resin.   The economic advantage of resins is that they can be regenerated chemically and wet rather than thermally and dry. Hence, fuel savings are considerable. Although resins are more costly per unit volume than carbon-based adsorbents, they can be used at much higher flow rates, thus requiring relatively smaller instal-

4. Personal Communication.

5. Jones, SASTA, 1984, pp. 54–55.

Evaporation and Pan Boilings*

The fundamentals of both evaporator design and operation and crystallization are discussed in detail in the Raw Sugar section of this Handbook. This chapter will update the latest developments in these two areas.

14.1 Multiple-Effect Evaporation.   Dark sweetwaters, wash waters, and other thin materials of too low test to be used for melting washed raw are evaporated in multiple-effect systems similar to those in the raw house, the *concentrated sweetwater* being boiled to remelt. Common practice presently employs the last body or bodies of the multiple-effect (high vacuum–low temperature) to concentrate the first-grade white liquor to 70 Brix or higher, thus economizing steam in the vacuum pans. Some refineries use the multiple effect for this purpose.

14.2 Vapor Compression.   Vapor recompression systems are being chosen by refiners more frequently when adding new or replacing older evaporators. Higher fuel costs have forced refineries to conserve energy through all available means. Vapor recompression is not new; however, improved technology in both thermal and mechanical compressors has caused these types of systems to be considered as well as the conventional multiple effect evaporators (see also Sec. 6.17).

There are two types of compressors, thermal and mechanical. The thermal compressor uses steam at a higher pressure to compress vapors to some intermediate usable pressure. The decision to use a thermal compressor is usually made when sufficient steam at a high pressure is available or if high-pressure steam is being reduced through a throttling valve. The thermal compressor has the advantage of having few, if any, movable parts and is very reliable.

The mechanical compressor can be driven by a steam turbine or by an electric motor. The choice of a steam or electrically driven compressor is influenced by the refinery's overall steam and electrical balance. Mechanical compressors are much larger than thermal compressors and require a great deal more maintenance. In addition, the initial cost is much greater for a mechanical than a thermal compressor.

Examples of applying vapor compression in sugar refineries are given in the following.

14.3 Mechanical Vapor Recompression.   Pearson and Harrison[1] in 1986 reported a mechanical vapor recompression system used to evaporate first liquor. It uses a 1500 hp electric motor to drive a radial flow compressor capable of compressing vapors at 4.6 psia to 9.7 psia for a 2:1 compression ratio. It is a single effect four stage falling film tubular evaporator. There are two calandrias, each containing 550 2-in. O.D. tubes, each

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*by T. N. Pearson

1. SIT, 1986, pp. 285-291.

PAN BOILINGS

14.9 Vacuum Pans. The vacuum pans for refinery work operate on the same principle as those described in Chapter 7. Calandria pans have replaced coil pans; noncorrosive materials, such as stainless steel, nickel-clad steel and copper, or copper-bearing steel, prevail in new installations. The heating surface is 1.20–1.30 sq ft/cu ft (3.9–4.3 m^2/m^3) of massecuite; instrumentation and automatic controls are the rule. Large pans of 1400–2400 cu ft (40–68 m^3) are the modern preference.

14.10 Continuous Boilings and Cooling Crystallizings. Continuous pan boilings and cooling crystallization are discussed in detail in Chapter 7. One of the latest developments is the BMA's evaporative crystallization tower (ECT) in which the massecuite flows by gravity, as shown in Fig. 14.7.[5]

14.11 Total Boiling. The latest development of continuous evapocrystallization (BMA) and cooling crystallizers by BMA and others have moved the pan boiling technology a great step forward (see also Figs. 7.47, 7.71, and 7.74). The principles are discussed by Austmeyer[5] and Bosse.[6] An example of a total boiling work for producing two white sugars in a two-stage crystallization, with prespinning of white sugar, and connected with after product (AP) boiling and cooling crystallization, all in one plant, is shown in Fig. 14.8.

14.12 The Importance of Pan Stirrer. Bachan and Sanders[7] evaluated an Ekato stirrer fitted to a pan boiling third massecuite. They found the decrease of conglomerates from 84 down to 55; lower moisture in sugar boiled and decreased 50% in turbidity, with no change in sugar color.

Cox[8] reports the immediate benefit of using an Ekato 5 bladed Kaplan type stirrer, and the further improvement realized by installing a four-bladed adjustable pitch helical screw propeller in a ribbon calandria pan boiling white sugar. It is concluded that the best results
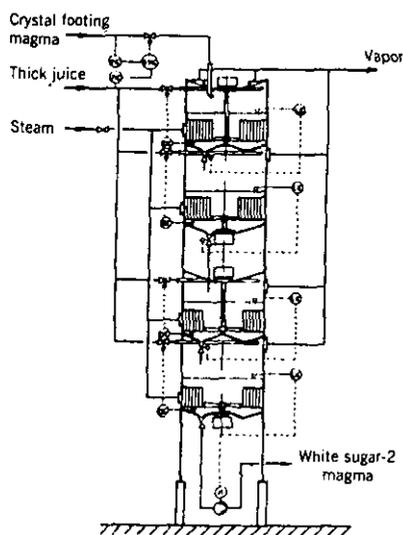

Figure 14.7. Evaporative crystallization tower (ECT)(BMA).

5. Austmeyer, *ISJ*, 1986, **88**, pp. 3–6, 23–29, 50–55.
6. Sugar, May 1986, pp. 33–56.
7. SASTA, 1987, pp. 65–69.
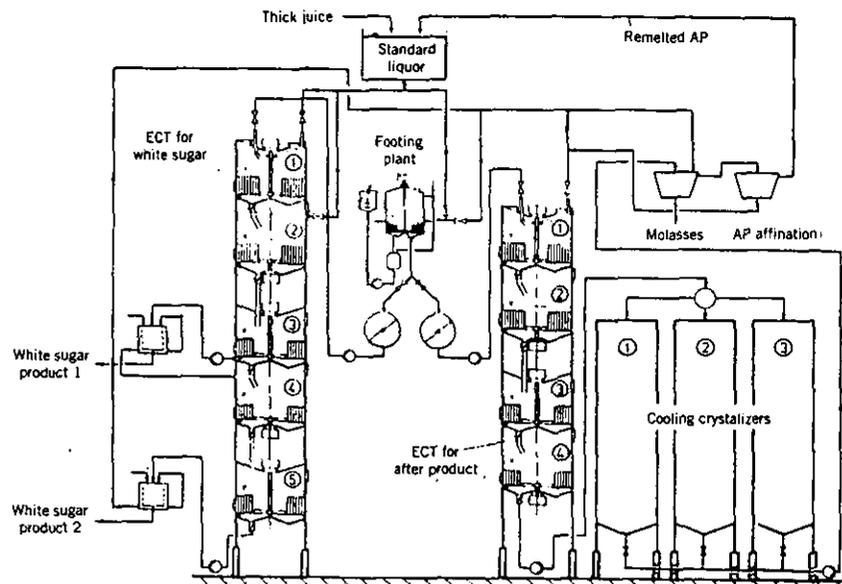8. SASTA, 1989, pp. 56–63.

Figure 14.8. A two-stage crystallization scheme with prespinning for production of two grades of white sugar.

obtained are with the four-bladed helical screw impeller (Fig. 14.9). A 60% color reduction and 8% crystal yield increase have been realized when compared with an unstirred pan. Mechanical circulation is also discussed in Sec. 7.9.

The calandria/stirrer combinations being used in Germany are shown in Fig. 14.10: (a) is for inward circulation (stirrer within calandria), (b) is for outward circulation (stirrer above calandria), and (c) is for outward circulation (stirrer below calandria).[5]

Austmeyer[5] gives the power demand for driving a stirrer during the boiling of a white sugar strike (Fig. 14.11).

14.13 Pan Boiling Systems.   The liquor that comes to the pan floor has been decolorized to an almost water white solution. It has usually been preconcentrated to about 76 Brix.

The boiling system most widely used in the cane sugar industry is the four-strike system. To a much lesser extent, the three-strike system is used. Factors such as pan floor tankage and the number of pans will influence the decision as to the type of system chosen.

In the conventional four-strike system (Fig. 14.12), the first liquor, or fine liquor as it is sometimes called, is used to boil the first strike. The runoff from this strike is called the first syrup or first jet and is used to boil the second strike. In a like manner, the third and fourth strikes are boiled to produce the number three and four sugars. These sugars are blended together to give a uniform mixture for the final product. Sometimes the runoff syrup from the fourth strike is boiled back into it in order to increase the white sugar production and to reduce the amount of syrup going to remelt if soft sugars are not being produced.

The three-strike boiling system (Fig. 14.13) has several variations. A straight three-strike system boils three strikes of sugar, each from the runoff syrup from the previous strike. This system produces a lot of syrup that must be boiled for remelts or for soft sugars. Back boiling is often used with this system in order to reduce the amount and purity of the third runoff syrup.
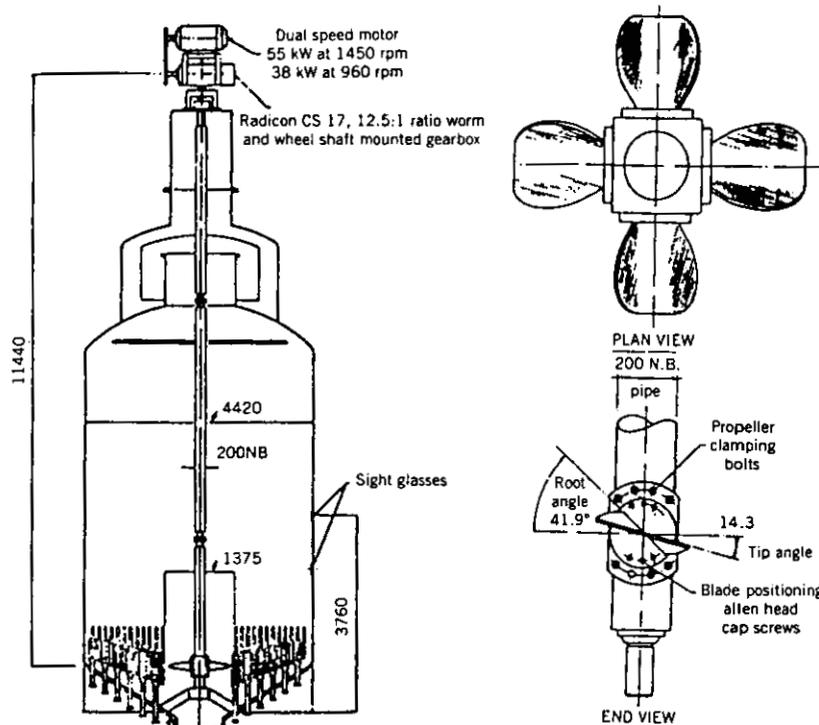
Figure 14.9. General arrangement of the Hulett helical screw impeller.

A four-boiling system with calculations of average yield of sugar solids are discussed and shown in the 11th edition, Fig. 18.1 and Table 18.1. Also, examples of in-boiling and back-boiling are shown in Figs. 18.2 and 18.3.

14.14 White Sugar Pan Operation. The boiling of white sugar has progressed from all manually operated pans to computer-controlled pans with video terminals remotely located in a central control room under the direction of one or two sugar boilers.

Continuous boiling of white sugar is being done in several refineries using different types
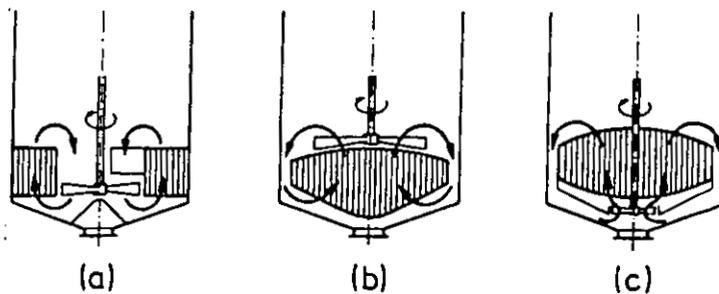
Figure 14.10. Example of stirrer installations in vacuum pans.
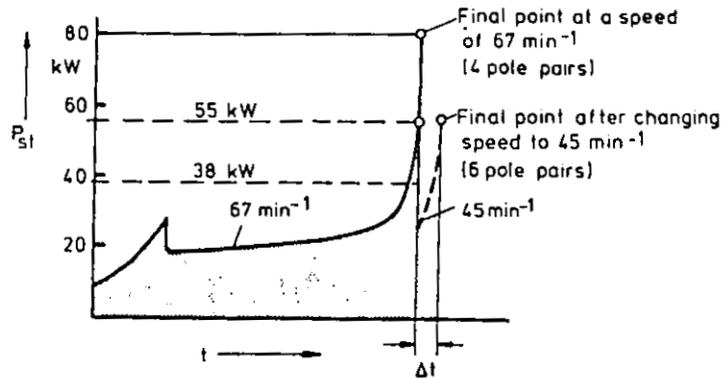
Figure 14.11. Power demand of a stirrer during a white sugar boiling.

of equipment. This is discussed in more detail in Secs. 14.10 and 14.11, and also in Chapters 7 and 30.

The typical white sugar pan varies from 1500 cu ft to as large as 3000 cu ft capacity.

14.15 The Pan Boiling Cycle.   The pan is steamed out to help dissolve any remaining crystals and to purge the noncondensibles from it; then the vacuum pump or steam ejector is started. As the absolute pressure drops, the charge valve opens, allowing liquor to enter the pan. The liquor must not be too hot nor the absolute pressure too low to cause excessive flashing of the liquor which could lead to entrainment losses. When the calandria is covered, the steam and agitator are turned on and evaporation proceeds. The seeding point is determined by refractometer, boiling point elevation, gamma radiation, rheometer, or some other means. The seed is usually made by grinding sugar in a mill with isopropyl alcohol or a saturated syrup and may have a range of 1–20 microns. During this boildown phase, the absolute pressure is usually set for 3–5 AP. Prior to seeding, the steamflow is reduced or shut off entirely. The absolute pressure is raised to 7.5–8.0 to reduce supersaturation and provide for optimum crystal growth rate. Control of the supersaturation is

Figure 14.12. Four-strike white system.

Figure 14.13. Three-strike white system.

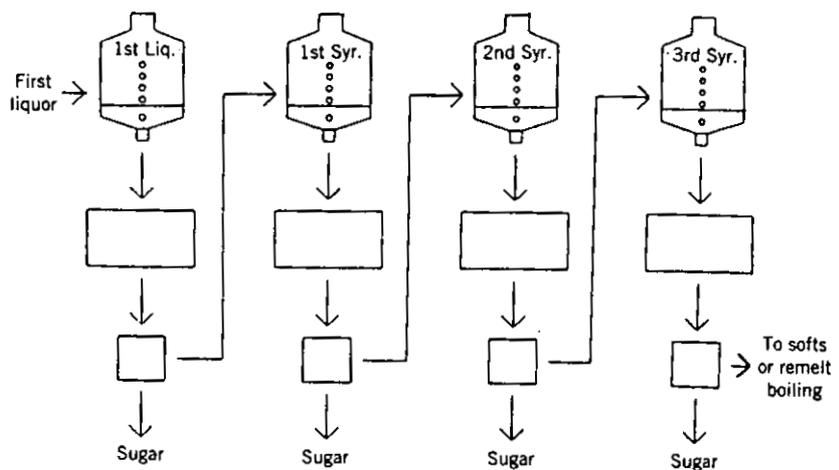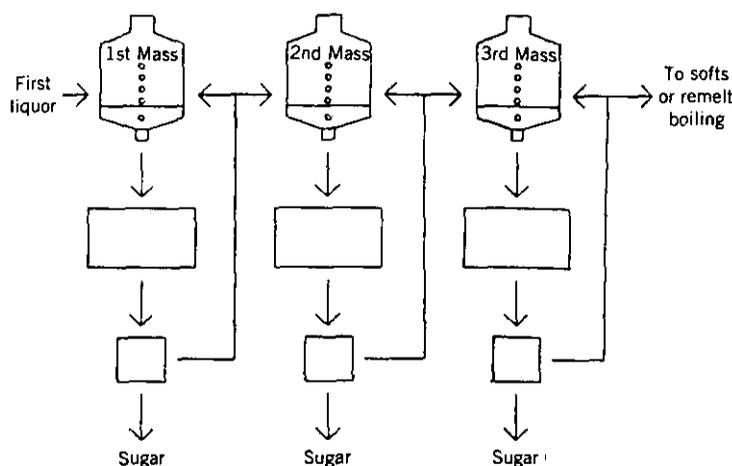critical at this point in order not to form new crystals. As the supersaturation permits, the steamflow is gradually increased. As the crystals grow in size, the mass fluidity is controlled by the agitator motor load or some other sensing device. The absolute pressure is gradually reduced to about 4 psia. When the pan level reaches the full mark, which is $5\frac{1}{2}$ to $7\frac{1}{2}$ ft above the calandria, the feed valve is shut off and the massecuite is tightened for dropping. In order to increase the yield, it should be dropped as cool and tight as the centrifugals and mixers will handle. When the dropping point is reached, the steam is turned off and the vacuum breaker opened.

When the pan is empty, it is rinsed out with syrup or water and steamed prior to raising vacuum for the next strike.

Figs. 14.14–14.17 illustrate several boiling patterns used by different refineries. There are many variables that will affect the boiling time and final results of the strike. If the feed liquor brix is low, more evaporation will have to be done in the pan, requiring additional steam usage and a higher steam pressure. Boiling the strike loose and at a low supersaturation will prolong the boiling time. Smooth movements of the absolute pressure controller are required to prevent sudden changes in the supersaturation and the formation of new grain.

The tubes of the three and four sugar pans should be inspected frequently for scaling, and cleaned as needed to prevent loss of heat transfer.

14.16   Pan Control.   All of the controls of the vacuum pan such as level, valves, vacuum, steam flow, condenser water, etc. have been automated with very few problems. The method to control the syrup feed to the pan and supersaturation, however, gives rise to many different devices. There are many papers that were given at SIT meetings that describe in detail methods used to control pan feed and supersaturation. Some of these methods and their drawbacks are:

Agitator Motor Load—This is only useful when the crystals reach about 40%, but it gives good control from this point on. It is especially useful for tightening the strike prior to dropping.

Refractometers—They are more useful for seedpoint determination, but lose their read-
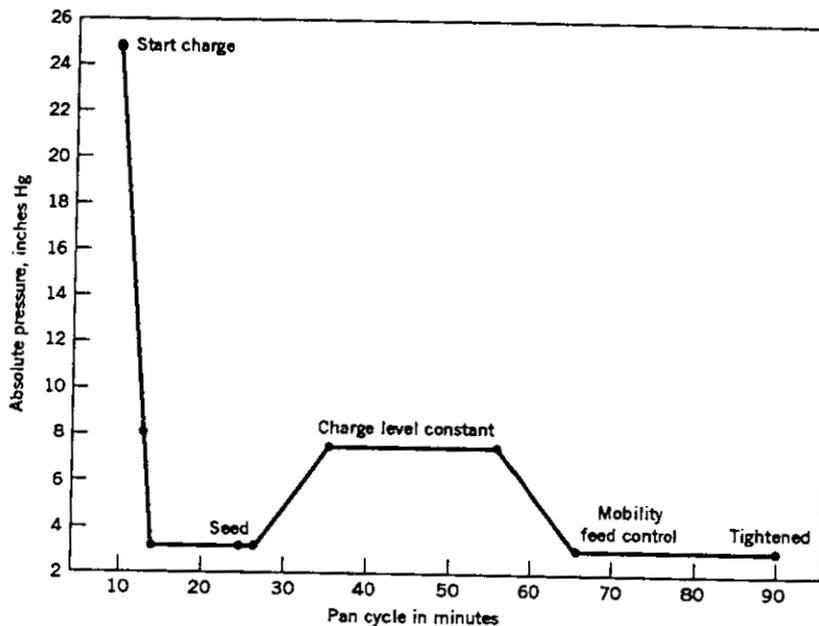
Figure 14.16. 80 min boiling time. (Refinery B)

ing due to lack of movement across the prism soon after that. Maintaining the calibration is also a problem.

Rheometers—There is a question about the sturdiness of the rotating element during heavy boiling and whether different crystal content/mother liquor combinations can give the same readings. Maintenance is also a problem.

Boiling Point Elevation—Getting accurate and representative temperature measurements as well as good absolute pressure control is very difficult.
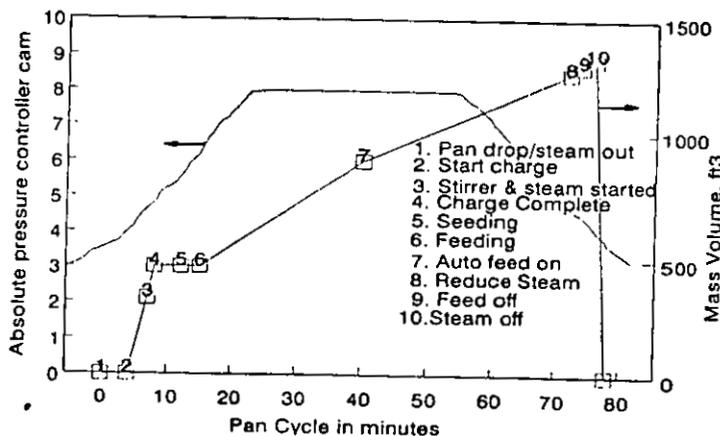
Figure 14.17. White sugar pan cycle.

Gamma Ray Densitometer—It gives good readings of the syrup density for seeding as well as the massecuite density to control feed rate. Maintenance is minimal.

Radio Frequency—Tests have shown that an RF probe can be used to control the boiling cycle. A commercial probe is being developed for further evaluation.

All of the above methods are in use, and better control of the vacuum pan boiling cycle has been reported; however, there has not been a significant improvement in crystal quality.

Literature in pan controls can be found in SIT papers numbers 489, 524C, 528, 555, 567A, 567B, 567C, and 567D.

14.17 Remelt Recovery Systems. The remelt recovery operation has the goal of producing the highest quality remelt with the lowest possible blackstrap purity. A symposium held at SIT in 1987 on remelt recovery systems in which four refineries participated revealed that each refinery has its own operating procedures in trying to achieve these goals. Each participant also commented that they were not pleased with their results, indicating that this subject is still a fertile ground for improving process results. A program aimed at improving one's results would include most of the following:

1. How syrups and filmasses are being handled.
2. How pans are being boiled.
3. A boiling scheme to maximize utilization of equipment.
4. Minimum blackstrap molasses volume.
5. Minimum sucrose loss.
6. Maintenance of vacuum pans, crystallizers, and centrifugals.
7. Proper crystal size and number of crystals.
8. Minimum recirculation of syrups.

The three-strike boiling scheme (Fig. 14.18) is the most widely used; however, there are many differences in the treatment of syrups and massecuites. One refinery used a modified two-boiling system in which the "*A*" sugars were double purged and the "*C*" sugar was mingled and used as a footing for "*A*" boilings. This was later abandoned for a three-strike system which included double purging of the "*A*" and "*B*" sugar.
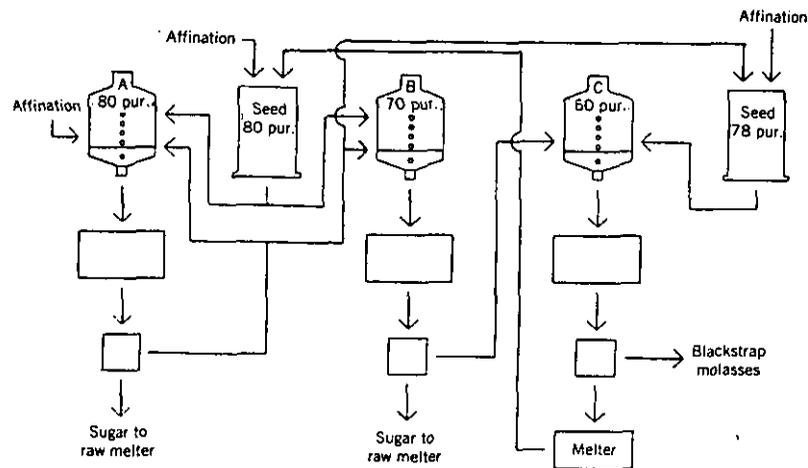
Figure 14.18. Three-strike remelt system.

Under the standard boiling scheme, a seed strike is made from affination syrup, then split to another pan or seed holder. The "*A*" and "*B*" strikes are made from this seed, and the sugar from these strikes sent to the melter. The "*C*" strike is boiled from a seed of a lower purity than that used for "*A*" and "*B*" strikes. This sugar is remelted and taken back into the remelt system, or in some cases, mingled and used as seed for "*A*" and "*B*" strikes. The "*C*" strikes are dropped to crystallizers for curing by cooling for a period of 24 hours or more, depending on the equipment and nonsugar load on the refinery.

Target purities for *A*, *B*, and *C* strikes listed below show a variation among different refineries:

Refinery	A	B	C
1	83	72–74	64–67
2	81–85	68–70	57–59
3	80	70	55–60
4	80	70	58–60

The end result is to obtain blackstrap molasses with as low a purity as possible. Most report apparent purities of 45 or lower which would be about 50 P.D.; however, one reported molasses as low as 38 P.D.

The crystallizers used in curing the "*C*" strikes are batch, batch converted to continuous flow and continuous flow. All have elements for cooling and heating. The massecuite is cooled to 38–40 C, then reheated to 50–54 C for purging.

The crystal size of the "*C*" sugar is a very important factor in obtaining good molasses exhaustion. Crystals ranging in size of 325–250 microns are desired. The drop from massecuite purity to the syrup purity in each strike is usually used to indicate how well the strike was boiled and dried at the centrifugals. A purity drop of 20 or better is desired.

Poor molasses exhaustion is experienced when the crystals elongate in the pan. Dextran, whether from the raw sugar or from the refinery, will cause elongated crystals. Boiling at high temperatures may increase the tendency to elongate. If the source of the dextran is from within the refinery, the molasses tanks will have to be emptied, washed, and sanitized to eliminate it.

Murphy et al.[9] give examples of a three-boiling system. The boilings of after-product (AP) are shown in Fig. 14.19, and the materials for AP boiling from different affinations are shown in Figs. 14.20 and 14.21.

Results obtained prove that the scheme in Fig. 14.15 is better than the scheme in Fig. 14.14.

14.18 Soft Sugar Boilings. Soft sugars are graded according to color, but modern refineries generally produce only two or three grades—light yellow, yellow, and brown. The desirable characteristics are a spongy texture, free from crystalline appearance; color conforming to the desired grade and free of gray–green tones; and flavor free from harsh, bitter, or salty taste. The refiner also desires low test and good keeping quality. These characteristics result from liquors that are low in total color, free from the greenish cast imparted by polyphenols of iron, relatively low in purity, low in ash, and high in invert sugar. One Canadian refinery uses a special ion exchange resin to remove iron compounds from soft liquor.[10] Extra phosphate treatment with press filtration is common in United

9. *ISJ*, 1991, **93**, pp. 33, 38, 52–55.
10. BCRP, 1959, p. 5.
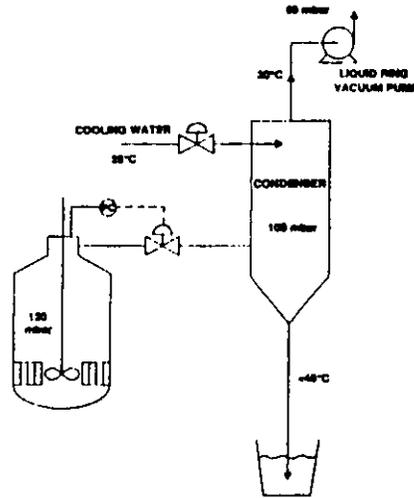
Figure 14.19. After-product (AP) pan vacuum system.
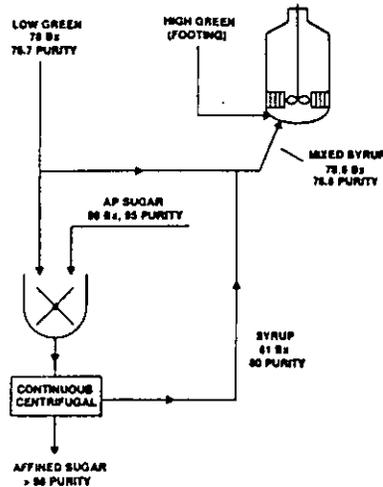
Figure 14.20. Affination with low green syrup.
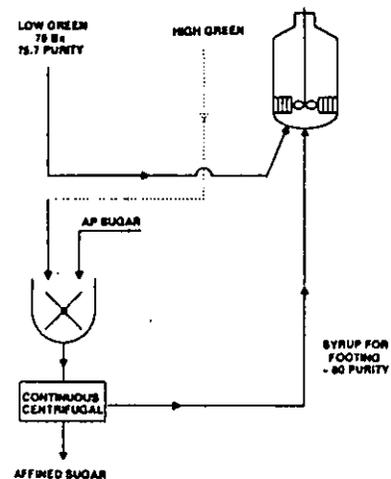
Figure 14.21. Affination with separate pan footing.

States refineries to attain color improvement in soft liquors. In Japan, white soft sugar is a popular grade.

The lighter grades are boiled from char-filtered granulated syrups and double- or triple-filtered affination syrups of about 85 purity. A footing of lighter-colored liquors combined with these syrups yields the middle grades, whereas the darker softs are from once-char-filtered affination syrups, or phosphate-treated and press-filtered affination. To attain the proper soft, spongy grain texture, the pan boiler holds soft sugar strikes to a low temperature (110–130 F, or about 43–54 C) and high vacuum.

Centrifugation*

15.1 Centrifugal Work. The operation of the centrifugals in a refinery can be categorized into three separate groups since the material processed in each operation is significantly different in viscosity and the degree of separation required for each operation is significantly different, i.e.,

1. The Affination Process
2. White Sugar Centrifugation
3. Continuous Centrifugals and Remelt Operation

THE AFFINATION PROCESS

15.2 Affination Station. The objective of the affination centrifugal station is to remove the impurities from the surface of the crystal in a syrup form while dissolving the least amount of sucrose.

The centrifugal machine most commonly used in the Western Hemisphere is the Western States batch centrifugal. The rpm of the basket is rated at 1225 rpm. The actual rpm with the standard drive runs from 1150 to 1175 rpm. With the new frequency drive, the basket rpm will be in the range of 1225 rpm.

The most common basket sizes in service are 48 × 30 in. or 48 × 36 in., and the sugar is ploughed out of the basket while running its direction in reverse. Normal basket capacity (48 × 30 in.) per machine cycle is 820–840 lbs (370–380 kg) of raw sugar, dependent on the crystal size of the raw sugar.

The cycle is in two parts. One is the process cycle which includes the charging of the machine through the point where the machine comes to a stop prior to discharging the washed raw sugar. The second is the discharge cycle from the point the centrifugal starts in the reverse direction to the point at which the plow comes back to its rest position and the cycle complete light comes on.

The core of the raw sugar crystal is high in purity (99.6–99.8) and the surface of the crystal is covered with a partially dried syrup. The syrup purity according to the country of origin will range from 45–75% sucrose.

During the past 30 years, the raw sugar producers have improved their process capabil-

*by C. F. Stowe

ities and have increased the Pol of the raw sugar from an average of 97.5 in 1960 to 98.2–98.3 in 1990. The result of the increase in the Pol of the raw sugar is an accompanying increase in the purity of the affination syrup from approximately 80.0 to 82–84 purity.

15.3 Mingling with Syrup. In this step of the process, raw sugar is mixed with syrup from a previous centrifugation of raw sugar magma. This is accomplished in a scroll-type device which has blading in it to cause a thorough mixing of these two entities. In some systems, the raw sugar is weighed into the mingler and the affination syrup is measured volumetrically into the mingler at the same point of entry. Another recently developed method is to have the raw sugar added in a constant stream and the affination syrup is added based on the motor load of the drive for the mingler. The purpose is to form a magma with approximately 8–9% moisture. At this density, the crystals will rub against one another, causing the syrup on the surface of the crystal to be softened and wetted. If the mingling process is done properly, there is little need to heat the magma. It is necessary to heat the affination syrup to 140–150 F (60–66 C). The mingler discharges into a holder or mixer with an agitator from which the centrifugals will be charged.

15.4 Affination Centrifugals. While the degree of separation of syrup and crystals is of the utmost importance, it is not needed to the extent required by the white sugar centrifugals. The affination centrifugals have loading cones in them and do not have basket valves. The basket valve lengthens the centrifugal cycle by 7–9 sec. Cycles are normally 150–165 sec. If the average time required to raise and lower the valve is 7 sec, and the basket valve in the raised position restricts the discharge of the sugar from the basket by several seconds, then the loss of production incurred by the installation of a basket valve is 6.3% of the total cycle of 158 sec.

The affination centrifugals generally operate under the best possible conditions. In most cases at the various refineries, the mixers to feed these machines are operating at a full level which keeps a constant head when loading the centrifugals. Under these constant conditions, there is less tendency to get an unbalanced load, and the uniformity of grain in the charge to the centrifugal is more constant. This generally results in fewer mechanical problems with these machines.

The following discussion is based on experience with Western States machine (Fig. 15.1).

When the gate opens to charge the centrifugal, the viscosity and gate opening should be such that the magma will hit the cone and split around both sides of the spindle. As the basket fills, the feeler in the basket will be pushed out until it hits a given point and closes the gate. At that time, there should be 1/2–3/4 in. of the basket lip showing.

If the viscosity of the magma is too heavy, the magma will drop almost vertically from the gate and some magma will be discharged through the spokes. If it is too light, the magma will charge over the loading cone, hit the far wall of the basket, and splash through the spokes of the basket.

There is a tendency when setting the gate position to load the centrifugal basket to have the gate open to its maximum position and load the basket as fast as possible. Considerable machine capacity can be lost by doing this. If the gate opening is restricted so that the centrifugal basket takes longer to load, a significant amount of syrup will be spun off during the charging, which will allow more magma to be added prior to the basket filling. It is possible to increase the magma loading by 5–10% by increasing the amount of time to load the basket.

The loading speed is set at 225–275 rpm. At too high a speed, the basket loading will be uneven, and there is danger of having excess oscillation of the basket, resulting in damage to the centrifugal. At too low a speed, the sugar wall will be much thicker at the bottom

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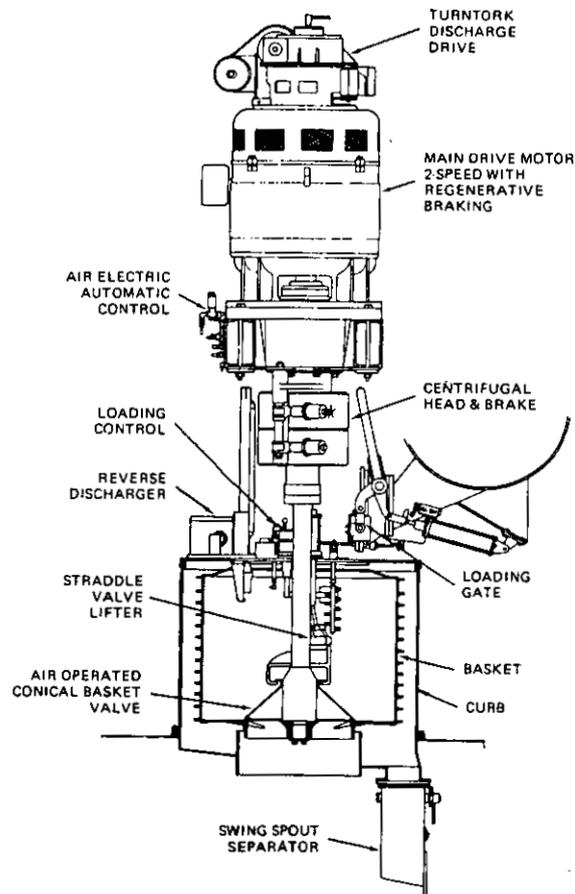
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Figure 15.1. Suspended batch-type centrifugal with reverse discharge drive. (Western States)

of the basket. In fact, at too low a loading speed, there is the possibility that some magma will get through the bottom spokes of the basket prior to the point at which the feeler will be actuated to close the gate.

Once the gate closes, the rpm of the machine will be increased until it reaches the maximum speed of approximately 1150–1175 rpm.

The latest developed suspended batch centrifugal by Western States[1] incorporates new features such as Tork-Master Variable Frequency Drive, Cap-A-Trol No Splash Cake Dectector, and a Posi-Latch Discharge Valve, as shown in Fig. 15.2.

The Tork-Master variable frequency drive is a programmable logic controller with a variable frequency power and control unit. The system delivers 100% regenerative braking to AC supply and lower power demands. It also provides means for shorter cycles and/or improved sugar quality, as well as improved loading, discharging and sugar recovery.

The Cap-A-Trol is a capacitance-type cake detector automatically sensing cake thick-

1. Conrad, Personal Communication.
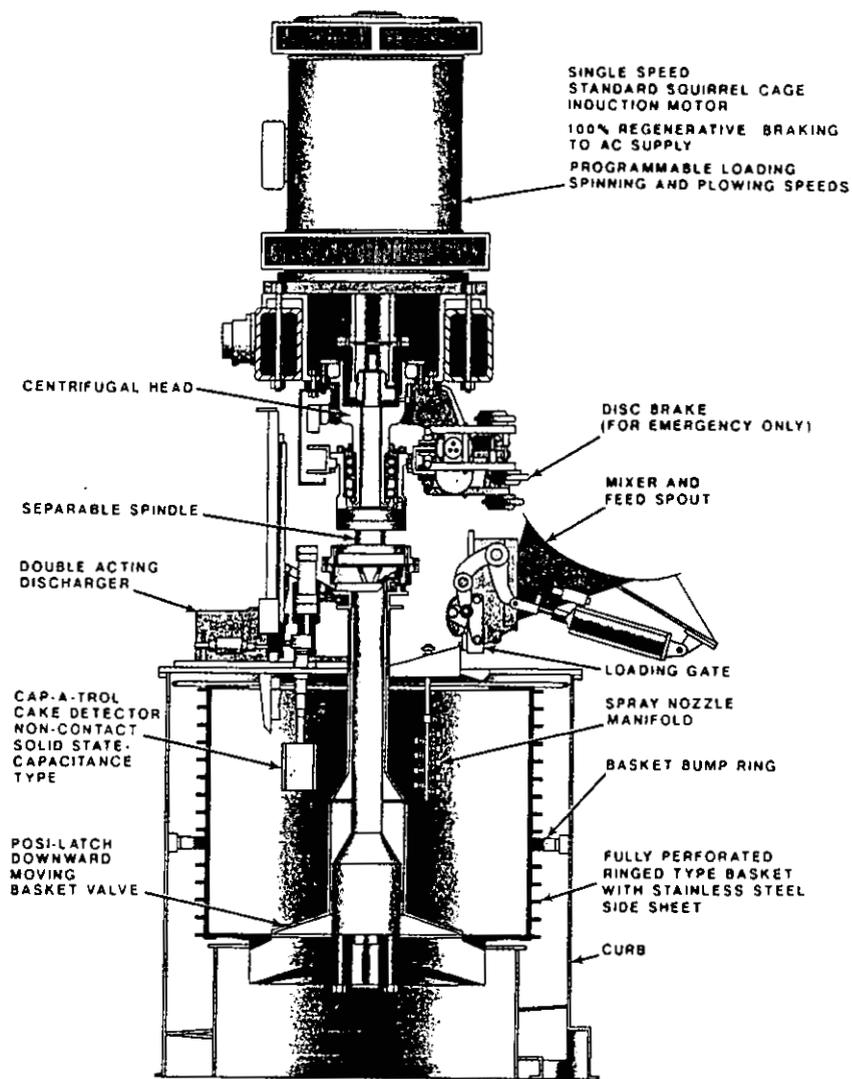
Figure 15.2. Suspended batch centrifugal with Tork-Master variable frequency drive. (Western States, 1992)

ness. It is a noncontacting, solid-state device, with no mechanical linkage to maintain or adjust.

The Posi-Latch valve is a downward moving valve providing improved sugar discharge, potentially reducing discharge time.

15.5 Centrifugal Wash. In affination centrifugals, two different washes, often referred to as the first and second washes, are generally used. Two methods are in use by refiners. In the first case, the first wash is not applied before the sugar wall is exposed. Between the first and second wash, sufficient time has to elapse before the sugar wall is exposed. If the second wash is applied before the sugar wall is exposed, a poor washing of

the sugar will occur or there is a possibility that the wash will ride on the sugar wall instead of penetrating it. In this case, one of two things happens. Either the wash will penetrate the wall at one point, causing the wash to leave the basket at that point, creating an imbalance of the machine, or the rpm of the wash on the surface of the sugar will actually become greater than the basket speed and cause an imbalance in the machine. In either case, the machine will probably be damaged.

The second method would be to initiate the first wash as soon as possible after the gate for charging the machine closed. The wash will intermingle with the affination syrup, reducing its viscosity-and-causing-faster purge rate of the syrup. The second wash is applied after the sugar wall has been exposed.

Utilizing this method, the first wash is normally applied within 1–4 sec after the charging gate closes. If the raw sugar crystals are large, it will be necessary to apply the wash as soon as possible. Once the gate closes, the centrifugal goes into low-speed windings and accelerates. Its acceleration rate is approximately 50 revolutions per second. The increasing "g" force due to the acceleration will cause the crystals to pack against the basket wall. If this occurs to any extent prior to the applications of the first wash, the first wash as a diluter of the affination syrup will not be successful.

Both methods will yield a washed raw sugar of the same color. However, with experience of many years, the second method is preferred to.

Utilizing the first method, it will take longer to purge the affination syrup to obtain a clear sugar wall for the application of the first wash than it will take to have a clear sugar wall for the application of the second wash when the second method is used. Utilizing the first method, the quantity of first to second wash is almost equal. Utilizing the second method, the first wash will be only 25–30% of the second wash, while the total wash quantity for both methods is generally equal.

What this means is that the cycle time up to the application of the second wash is significantly longer for the first method than it is for the second method. If we were to expect the same outturn from a machine using either method of application for wash, the time spinning after the second wash for the first method would be significantly shorter than for the second method. Yet this is the time period that one wants to maximize to insure that a maximum purge of syrup from the basket is achieved.

A second consideration is that not all raw sugars have large uniform grain. For mixed or fine grain raw sugar, we need to extend the cycle time to apply the first wash utilizing the first method while simply increase the first wash time 1 or 2 sec utilizing the second method. The second method is easier to control with changing quality of the raw sugar.

To achieve maximum separation of the syrup and crystals, every effort should be made to have the longest spinning time possible between the end of the second wash time until the centrifugal is braked to a stop prior to the sugar discharge.

To accomplish the final objective as previously stated, it is necessary that: (1) the lab determines the grain color of the washed raw sugar and expects that the W.S. liquor equals or better than the grain color; and (2) we make sure that it is not overwashed. Suppose a sufficient wash is used to raise the purity from 84 to 86, even though there is no discernable difference in the color of the washed sugar liquor. Assuming that the Pol of the raw sugar is 98.3, and the washed sugar liquor is 99.7, then

$$(100)(0.983) = (0.997x) + [0.84(100 - x)]$$

$$98.3 = 0.997x + 84 - 0.84x$$

$$0.157x = 14.3 \quad x = 91 \text{ lbs washed raw sugar}$$

the gyration switch is deactivated when the gate is opened. As the basket is loaded, the sugar wall forces the feeler outward toward the center of the basket. When the basket is fully loaded, as indicated by the feeler, the gate closes.

When the gate opens, a time delay relay is energized. If the machine fails to load within the time preset on the time delay relay, the gate will close, but the machine will not proceed past the loading speed and not activate the process timer. This malfunction will activate the panel alarm system.

When the gate closes under normal conditions, the zero speed switch is deactivated, taking the motor out of loading speed, and it accelerates toward 600 rpm. After a preset time, the motor is taken off the low-speed windings and goes into the high-speed windings. At the same time, timers will be energized in a specific order to control the time application and quantity of the first and second washes. Once the second wash is completed, the sequence maintainer will trigger the start to regenerative braking timer, which will result in the slowing of the machine and eventual application of the mechanical brakes. As the machine decelerates to 275 rpm, the zero speed switch contacts are energized, and at 225 rpm, the zero speed switch is deenergized, but its associated relays have caused the discharger timer to start. Therefore, the zero speed switch is responsible for initiating the discharge cycle.

15.9 Discharge Cycle.   When the discharge timer contact closes, the contactor to start the discharge motor is energized, the brake solenoid is energized releasing the mechanical brake, and the discharge clutch solenoid valve is energized providing air to the discharge drive clutch. The basket is now rotating in reverse at 30 rpm. After a set time interval, discharge timer contact closes, energizing the discharge solenoid valve. The shoe enters the sugar wall. When air is admitted to the "shoe in" cylinder, a pressure switch in the air line to the cylinder is activated, which opens the circuit for the discharge timer motor stopping it. The length of time it takes the plow to penetrate the sugar wall is not timed, but solely dependent on the condition of the plow tip, the hardness of the sugar, the air cylinder operating the plow, and the air supply. When the shoe is completely in, the time in which the plow stays in this position is a timed function. From this point on in the discharge cycle, the plow when it moves through a bed of sugar is a nontimed function. The position of the plow into the basket wall at the top and bottom of the basket and in the position to clean the spokes of the machine is a timed function.

WHITE SUGAR CENTRIFUGATION

15.10 Difference between Affination and White Sugar Centrifugals.   There are two basic differences between the affination centrifugals and the white sugar centrifugals at most refineries.

The first is the basket valve or bottom discharge on the white sugar centrifugals. Since the white sugar is the finished product, protection has been added to the centrifugal to insure the best possible separation of sugar and syrup (see Fig. 15.1). Most affination centrifugals have a loading cone, but no specific part in the bottom of the basket to prevent fillmass from going through the spokes of the basket and contaminating the washed sugar in the scroll below. The second difference is in the method of having the centrifugal recycle. The recycling of the white sugar is accomplished by a mechanism to start the cycle, while the sequence on the affination centrifugals will trigger a function during the process cycle, generally the second wash times or the timer to initiate regenerative braking. The primary reason for this is that white sugar tends to pack much faster in the basket, and an extended

cycle would lead to problems in discharging the sugar from the centrifugal basket. Where the sequencing of the centrifugals is accomplished by the triggering of a function in the process cycle, a buffer zone (nonproductive time) has to be inserted in the cycle time prior to this action.

The reason for this is that, since some of the parts of the process and discharge cycle are nontimed functions and could vary by several seconds, a machine would come out of cycle with all parts of the cycle controlled by a specific total cycle time.

Due to the fixed cycle time required for repetitive action of the white sugar centrifugals, the start of the cycle was chosen as the point at which to control the recycling of the white sugar centrifugals.

15.11 Productivity of the White Sugar Centrifugals. The white sugar centrifugals do not work under the ideal conditions that the affination centrifugals do. The affination centrifugals work under a constant head since the mingling system is a continuous system. The mixers from which the white sugar centrifugals are fed are supplied with fillmass from batch vacuum pans. Therefore, the head pressure through the charging gate will vary as the mixer runs from a full condition to empty prior to the next discharge of the vacuum pan. Continual observation by the operator in checking these centrifugals for full charges is the only way to assure efficiency and minimize damage to the centrifugals which could result from under charging.

Secondly, the battery starter timer will start only one machine at a time, and not necessarily in a specific order, so that scrolls underneath the centrifugals will not be overloaded by more than one centrifugal on a bank of machines being discharged at the same time. If one machine in a bank of machines is taking a longer time to go through a cycle, once the cycle complete light for that machine comes on, the machine will be started again by the battery starter timer. In the case of the sequence maintainer, the affination centrifugals are sequenced in a specific order, and if a part of the cycle is extended in time, the centrifugal will complete the discharge cycle, but will not restart. Therefore, the sequence maintainer does provide an indication of an extended cycle on a centrifugal, while the battery starter does not. Again, the operator's observations must be relied upon to assure maximum efficiencies.

There is one timer normally provided to give warning that a centrifugal is running with an extended cycle. This is the insurance cycle timer. The timer is actuated by the closing of the gate after charging the centrifugal, and does not reset until the gate opens for the next charging of the centrifugal. If the timer times out prior to the next loading, an audible as well as a visual alarm will be activated. In general, the purpose of this timer is not understood, and the tendency is to put too high a setting on it. It is the only built-in protection against extended cycles that is supplied with the centrifugal controls.

15.12 Washing of White Sugar. For many years, two separate washings were practiced to wash the white granulated sugar. It was accepted as a standard practice. With the inflation of fuel costs in the early 1970's, refiners started to investigate energy costs involved with these practices. With improvement in the raw sugar Pol, and improved vacuum pans which resulted in lower viscosity white fillmasses, most refiners opted for a single wash on these sugars. The wash is applied after the centrifugal has been charged and the sugar wall is exposed. Most refineries have found that the volume of wash used as a single wash was no greater than the volume of the second wash when they previously had used a two-wash system.

15.13 Total Cycle Time. On the affination centrifugals, the minimum total cycle should be 150 sec with a discharge cycle of 30 sec. This minimum cycle time is to protect the motor which cools in high speed. In the case of white sugar centrifugals, the minimum

total cycle time should be 158 sec. The addition of the basket valve which raises and lowers during the discharge of the sugar from the machine adds several seconds to the discharge time. The basket valve itself imposes restrictions on how fast the sugar can be discharged from the basket and adds another 5 sec to the discharge. Since this additional time is added to the discharge cycle and not the process cycle, an additional 8 sec must be added to the total cycle time.

The moisture of the sugar discharged from these centrifugals should be between 1.0–1.5%. To ensure minimum moisture content of a given sugar, the wash should be activated as soon as the sugar wall in the basket is exposed. This will guarantee the maximum amount of purge time between the completion of the wash and the mechanical braking of the centrifugal.

The other physical properties which will have an effect on the moisture of the sugar are the uniformity of the crystal size, the average crystal size, and the amount of conglomerates and agglomerates present in the crystals.

15.14 Safety. The centrifugal machine, if properly operated and maintained, is a safe machine to operate. However, if short cuts in maintenance or in its operation are taken, there is a chance of an accident occurring. At 1250 rpm, a force of 981 times gravity is developed on the basket wall. If screens are not properly installed or if screens are not replaced as needed, imbalance in the machine will develop, which will cause the basket to oscillate. If the basket rings, wall, and spokes are not inspected for cracks, etc., on a regular basis, the basket could disintegrate at high speed. Proper operation and maintenance will ensure that the machine will give good safe service for many years.

15.15 Continuous Centrifugals and Remelt Operation. The affination syrup, produced in the first stage of the refining process, will contain from 7 to 15+% of the sucrose content of the raw sugar melted, depending on the Pol of the raw sugar. The purpose of the remelt operation is to recover as much of the sucrose from this stream as possible and convert it into white sugar. Since the affination syrup is only 82–84 purity to begin with, each extraction of sugar will yield a syrup of much higher viscosity. With each extraction, the centrifugal operation becomes much more difficult to manage, and the quality of sugar crystals produced from it becomes poorer.

Fig. 15.5 is a cut out of a continuous machine. The sugar comes from the mixer through a gooseneck into the loading assembly of the machine. The fillmass runs into the bowl and centrifugal force moves the sugar up the wall of the basket. The first generation of the machine utilized a basket whose wall sloped 34 degrees from the vertical and had a 30 in. diameter at the top of the basket. The syrup is removed by centrifugal force through the perforations in the basket. A combination of steam and water is used to wash the sugar. The color line in the basket is normally run in the lower 30% area of the basket wall, and ideally the screen in the upper part of the basket can be seen.

There is the water rod for the machine so that when the fillmass is of higher than normal viscosity, the feed would not act like a rope and feed onto the wall instead of into the bowl. It cuts the viscosity of the fillmass sufficiently without any dissolution of sugar, and eliminates in most cases the roping effect of the fillmass. The situation is further improved by the installation of the halo steam in the gooseneck.

On the gooseneck to the machine there is a manual shutoff valve and an automatic feed valve. Once the feed is set to the machine with the automatic feed valve in the manual position and the steam and water adjusted for the loading and washing of the sugar, the feed valve is put in automatic and is controlled by the motor load. This will keep a uniform flow going to the machine. The load reading could be low and yet the feed volume high, if the viscosity of the fillmass is also low.

CHAPTER 16

Sugar Drying and Conditioning*

16.1 Drying the Sugar. The moist sugar discharged from the centrifugal machines contains about 1 % water and is conveyed to distributing bins above a sugar dryer by scroll, vibrating, grasshopper, or belt conveyors and bucket elevators. The white sugar then goes through the dryer for drying.

Farag[1] studies the parameters in the sugar drying and conditioning, indicating that the drying temperature at 145 C (293 F) yields clear and sparkling crystals as they come out from the dryer. But after conditioning, the sugar became dull and the slightest movement could produce very fine dust. On the other hand, sugar dried at lower temperature does not change in appearance after being conditioned. Results of his studies are shown in Figs. 16.1–16.3.

The sugar drier most commonly used is the granulator, two drums in series, one for drying and another for cooling. Full discussion is given in the 11th edition of this Handbook.[2]

16.2 Roto-Louvre Drier. The Link Belt Company's Roto-Louvre has several advantages over the old granulator. The Roto-Louvre drier consists of an outer cylindrical shell or drum (6 × 18 ft, 1.8 × 5.4 m) similar to the conventional granulator, but having an inner shell made of louver plates attached to full-length tapering radial plates, so that this inner shell gradually increases in diameter as it approaches the discharge end. Thus, the space between the outer and inner shells is partitioned into many hot air passages, and the only exit is the space between the louver plates.

Wet sugar is fed at a uniform rate into the inner drum, over the louver plates; while the drier rotates, the bed of sugar is slowly tilted in the direction of rotation, causing it to fall over onto the top surface of adjacent plates. The sugar travels through a spiral path to the discharge end of the drum, keeping constantly but gently in motion.

Hot air is regulated automatically by the sloping inner shell, which causes the sugar bed to be thinnest at the feed end, becoming gradually thicker as it flows forward. The thin bed offers least resistance to the passage of hot air, and consequently the greatest air volume passes through the bed at the feed end, where the sugar is wettest.

16.3 Fluidized-Bed Drier. Fluidized-bed drying for raw sugar is discussed in Sec.

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*by **C. C. Chou**
1. JASSBT, 1979, 20(3), pp. 207–216.
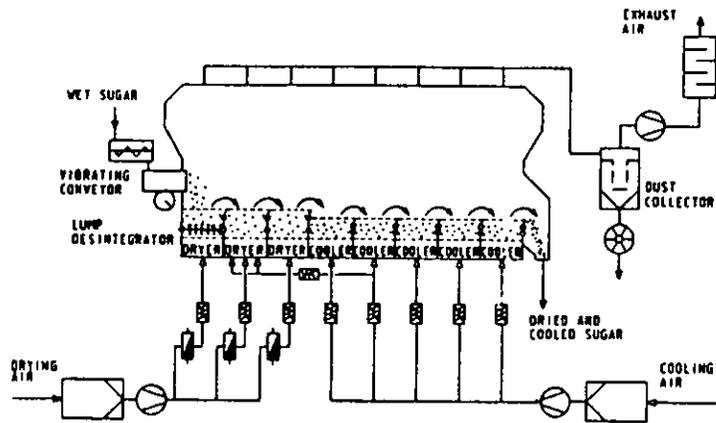2. Chen, 1985, pp. 616–617.

Figure 16.5. Configuration of fluidized-bed dryer and cooler system.

on the fluidized-bed principle is shown in Fig. 16.5.[7] Bosse[8] explains the principle of operation, design parameters, and operating results. It cools the sugar to approximately 10 degrees above the temperature of the cooling air and dries to a residual moisture of less than 0.03%. There are almost no moving parts. With low air flowrate, the amount of dust formed is minimized. The comparison of a fluidized-bed and rotary drier/cooler is given in Table 16.1.

Twaite and Randall[9] in England also report a fluidized-bed dryer/cooler (Fig. 16.6).

16.4   Dust-Collecting System.   The fine crystals drawn off by the ventilating fans in the granulators may be caught in ordinary cyclone dust collectors to be sold as superfine
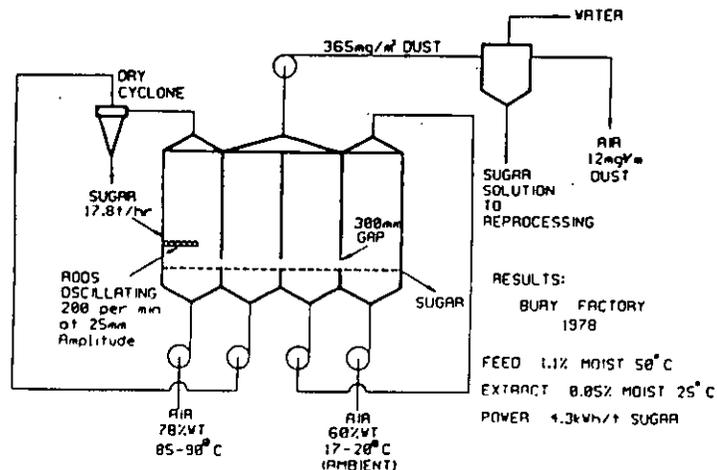

Figure 16.6. Main details of combined fluid bed dryer/cooler at Bury factory.

7. *ISJ*, 1988, **90**, p. 228.
8. *ISJ*, 1991, **93**, pp. 229–231, 237.
9. *ISJ*, 1987, **89**, pp. 130–135.

TABLE 16.1
Comparison of Essential Parameters of Rotary Dryer/Cooler vs. Fluidized-Bed

	Fluidized-Bed	Rotary
Residual moisture, %	<0.025	0.03
Temperature difference air in/ sugar out	T = 8–10 K	T = 15 K
Floor space required (for 20 tonnes/h unit)	22 m^2 (237 sq. ft)	75 m^2 (807 sq. ft)
Height (for 20 tonnes/h unit)	6.30 m (20.67 ft)	5.50 m (18.08 ft)
Dust, %	<0.5	<2
Brightness	Brighter than rotary dryer	Not so bright as fluidized-bed dryer
Total energy consumption of plant		
Electricity	4.0 kWh/tonne (3.6 kWh/short ton)	3.1 kWh/tonne (2.8 kWh/short ton)
Steam	20.0 kg/tonne (40 lb/short ton)	23 kg/tonne (46 lb/short ton)
Dryer weight (for 25 tonnes/h unit)	36 tonnes (39.7 short tons)	77.5 tonne (85.5 short ton)
Price	58%	100%

or *fruit* sugar, but a portion too fine to be caught in this way passes on to wet-type dust collectors, of which there are several designs. A dust collector frequently used is the Ro-toclone,[10] which replaces the granulator suction fan. The Rotoclone fan, at 1000 rpm, features a jet of water or sweetwater that impinges on the conical hub of the fan shaft; this disperses the liquid in a fine spray into the path of the dust-laden air entering the side of the fan casing. Arrangements with skimmer precleaners or wet centrifugal precleaners permit the collection of dry particles or reduction of the load on the Rotoclone itself as desired. The efficiency of dust removal is above 95%, and the resulting sweetwater is more concentrated than in most wet collectors.

Zaborsin et al.[11] used a vertical dust collector in which a stream of air cuts across the descending sugar at a controlled rate and "sweeps" the lighter dust particles up into a pipe leading to a wet cyclone via a horizontal and a vertical venturi tube. With sugar throughput at 20 t/h, having 2–6% dust particles, 400–1200 kg of dust was removed per hour (particle size 0.2–0.3 mm). By using a system of venturi tubes, the air discharged to the atmosphere was virtually dust-free.

In any event, great care is required to prevent bacterial spoilage of the sweetwater (in all wet dust collectors), and frequent steaming of all parts is necessary for cleaning and sterilization. The proliferation of *Leuconostoc mesenteroides* is extremely rapid in thin, high-purity sweetwaters such as are formed in collectors like the Rotoclone, posing a real danger to the system; once established, it is very difficult to eliminate. Consequently, bactericides are used by some refiners in dust system sweetwaters.

Wright[12] recommends an "in-line" cyclone-type device such as the radial spin vane separator (Fig. 16.7).

10. American Air Filter Co.
11. *Sakhar Prom.*, 1975, **24**, pp. 109–114 (via *ISJ*).
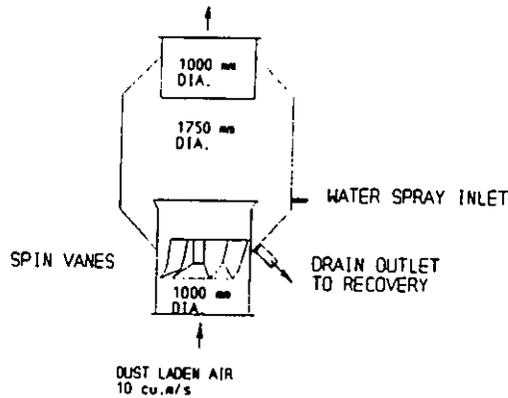12. ASSCT (QL), 1988, pp. 219–227.

Figure 16.7. Spin vane arrestor for vertical ducts for sugar dust collection. (Australia)

Dust collecting information on drying of raw sugar is also discussed in Sec. 8.22. For microbiological control, discussion is made in Sec. 26.10.

Baird and Beatts[13] worked on the integrated dryer headbox/scrubbing system (Fig. 16.8), and found it worked very well and has much to recommend it.

16.5 Screening of Refined Sugar.   The process of mechanically screening refined sugar by particle size for specific customer requirements is almost routinely done. Customer requirements in grain size distribution range from the larger brilliant sized grain to the finer fruit and Baker's Special grades of product. This particle size segregation is usually accomplished by imparting a particular gyratory motion to a screened medium, generally a wire mesh or perforated plate, which causes particles smaller than the screen opening to pass through as fines and particles larger than the opening to carry over the screen. For maximum efficiency in this mechanical screening process, the selected screen-
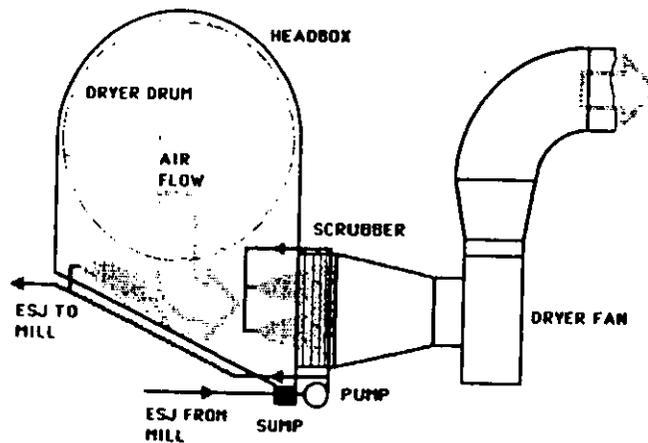

Figure 16.8. Scrubber/headbox arrangement for sugar dust.

13. ASSCT (QL), 1989, pp. 237–245.

ing equipment should be properly sloped, operated at a speed which provides good conveying action, and designed for sufficient mesh cleaning action to ensure capacity without sacrificing efficiency. The actual controlled rate of product flow across the screening area can have a significant impact on the overall efficiency of the screening operation. Too large of a flowrate floods the screen and inhibits the separation of crystals, resulting in improper grain size distribution in the final screened product.

The most commonly used mechanical screening equipment in use on refined granulated sugar is designed and manufactured by either Hummer, Rotex, or Sweco. This equipment is provided with multiple parallel sets of screens, and usually two or three grades of specific crystal sizes can be segregated and routed to storage bins for packaging or bulk shipment. These modern screening devices are considered vibrating or tapping types, consisting of flat screening frames, inclined about 35 degrees to the horizontal, which the sugar flows down while mechanical devices tap or vibrate the screening surface to cause the crystals to go through the meshes.

The older screens used for particle size segregation were of the bolter type, a revolving horizontal casing, inclined slightly, covered with wire screen of desired mesh through which the sugar fell; the tailings were discharged at the far end of the bolter. The Rotex type of screen has come into increasing use both for ordinary granulated and for large grain specialties. This type has nearly horizontal screening surfaces rotated in an endwise and sidewise motion. Rubber balls held in compartments below the screening surface bounce against the wire meshes and keep them clean.

16.6   Bulk Storage of Refined Sugar.   The storage of finished refined granulated sugar is normally done utilizing either lined steel bins or very large concrete silos having a capacity of up to 3000 tons. Not only do the bins serve to permit packing in the daytime only, but they also result in other savings, since packaging may be done in response to shipping requirements instead of packing the sugar as made and storing the finished packaged product. The refined sugar in these storage bins or silos can be aerated using a circulating countercurrent flow of air conditioned, dry air to "condition" the sugar while stored (to be discussed later). The movement, transfer, or mechanical screening of the stored sugar also serves to further condition the sugar prior to packaging or loading in bulk trucks or cars. Cooling in hollow flight conveyors, through which cold water circulates, is a method used to ensure free-running sugar in bulk hopper or airslide car shipments.

Bulk density of refined sugar after conditioning is 49–52 lb/cu ft (0.87–0.92 t/m^3). The angle of repose of refined sugar is given by Jorge[14] as shown in Fig. 16.9.

The objectives in storing bulk sugar are many, and the primary one is that when sugar is withdrawn from the storage, it meets customer requirements, without experiencing difficulties in recovering the sugar because of physical property change. During the 1988 Technical Conference in the U.K., a series of papers were presented on the theme of bulk

(a)   *(b)*

Figure 16.9. Bulk refined sugar storage angles. (a) Cane white sugar; (b) amorphus refined sugar.

14. SIA, 1978, **40**, no. 78-1522.

details on the aspects of white sugar conditioning and storage, as well as very useful data for handy references. In summary, the precautions giving satisfactory results were as follows:

1. Drying and primary cooling in conventional granulators.
2. The addition of chemically dried air, using the Kathabar system, to the cooler-granulator.
3. Additional cooling in Holo-flite cooler-screw conveyor (water-cooled) to give sugar of 90–110 F (32–43 C).
4. Storage in bins or silos that are properly insulated (Masonite, Fiberglas, air layer, or otherwise).
5. A slow movement of dry air through the stored sugar.
6. "Maturing" or weathering the sugar by allowing it to stand in storage for several days.
7. Moving the sugar from one storage bin to another to break up slight setting that may have occurred during the weathering period.
8. Sweeping the contained air out of hopper cars (also out of bins and silos) with pre-dried air before loading.

Not all these precautions are practiced by all the refineries giving the data, nor is the order of procedure the same in all refineries. Emphasis is on a well-boiled sugar of regular grain. Proper screening to remove dust and fines is also desirable.

In summary, satisfactory storage and subsequent shipment of bulk refined sugar involve allowing relatively cool sugar to stand in storage for several days, breaking up a "set" by movement or transfer, cooling the sugar to 100 F (38 C) or below, and shipping in cars that have been "swept" with predried air. Well-screened sugar of even grain is important here as in other packaging operations. The sugar before conditioning may have a moisture range of 0.04–0.06%, and the sugar after conditioning should be below 0.02% (Fig. 16.14).

After conditioning, the sugar may be conveyed into silos for loading into road tankers or rail trucks. The C & H Company[21] has two vertical silos for continuous conditioning and storage, each has a capacity to hold 6,000,000 lb (2,721,560 kg) of granulated sugar. The first silo serves as conditioning bin for a retention time of 24 h. The sugar is fed from top and discharged from bottom. Then the sugar is fed into the top of the second silo, which serves as storage before sugar is discharged from the bottom to sugar cars. The discharge capacity is 240,000 lb/h (108,860 kg/h).

The effect of stabilization time on the decreases in total and surface moisture of newly manufactured sugar was measured by Kavan and Mikus.[22] Results showed that the minimum stabilization time, in which the total moisture content decreased sufficiently, was 36 h. The stabilized sugar was substantially more resistant to caking when temperature fluctuations occurred.

16.10   Sugar Conditioning.   If a granulated sugar is not properly "conditioned," it will develop problems such as lumpiness, soft setting, "briding," and/or caking in storage. This is particularly severe in the handling of bulk systems. Two types of caking are generally recognized:

1) Efflorescent caking is that primarily due to improper processing techniques in boiling, spinning and/or drying. Thus resulting in a sugar prone to caking. An unconditioned

21. Cubelet Press, 1973, 38(6), pp. 2–3.
22. *Listy Cukrov.*, 1982, 98(7), pp. 152–160 (CSIA, 1982, no. 82-1285).

Per cent relative humidity—effective humidity

100 Approximate moisture content
     of granulated sugar
90   at various humidities

Zone of excessive moisture in sugar

80   10.00 plus at 90%

70

60

50   Moisture content shown in
     grams moisture per 100 grams
     of dry sugar
40
     Humidity surrounding sugar
30   shown as "effective humidity"
     (actual relative humidity must be
     adjusted if any temperature
20   differences exist)

Zone of negligible moisture in sugar

10

0
     0.02 0.04 0.06 0.08 0.10 0.12
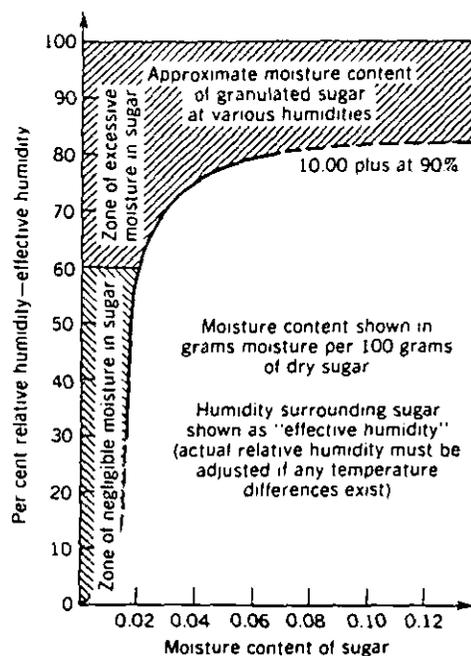   Moisture content of sugar

Figure 16.14. Approximate moisture content of granulated sugar at various humidities. (McGinnis, 1982)

sugar normally has a layer of "amorphous" sugar on the film surrounding the sugar crystal. The "amorphous" sugar would recrystallize during storage. The recrystallization and repeated migration of released moisture is the major factor associated with sugar caking.

2) Deliquescent caking results from the exposure of otherwise dry and conditioned sugar to an atmosphere having a relative humidity greater than the equilibrium relative humidity of the sugar. Fluctuations in ambient temperature would undoubtedly aggravate the deliquescent caking process.

The types of water (moisture) in sugar are classified into three categories:

a) Free water is that accumulated in the syrup film around the sugar crystal surface, at crystal contact points and in the open pores of a conglomerate structure. This type of water is easily removed upon drying.

b) Bonded moisture is that trapped by the amorphous surface layer and/or in microcapillaries of amorphous sugar and water hydrogen-bonded to polar groups. Bonded water is most detrimental to sugar handling and caking.

c) Inherent moisture is usually entrapped within the mosaic structure of a sugar crystal and some are bonded to nonsugar components. For these reasons, inherent moisture is difficult to remove and/or release.

Culp and Chou summarized methods of making conditioned sugar, ideal storage conditions for bulk sugar and for package sugar in their presentation at the Cane Refiners' Institute (Louisiana) short course as follows: