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Sugars and Carbohydrates

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I. INTRODUCTION: THE AIM OF EXTRACTION

Solid–liquid extraction is one of the unit operations of process engineering, the objective of which is to effect the migration of a substance enclosed in a solid insoluble matrix to a surrounding solvent, analogous to a desorption. In the case of sugar beet extraction (for sugar cane extraction see Secs. X–XV, and for starch extraction see Sec. XVI and XVII), sucrose is present in the form of an aqueous solution (juice) in the cellular structure of the sugar beet the solvent within the solid matrix is identical to the external extraction medium. To allow the sucrose to pass through the tissue, the semipermeability of the cell membranes must be overcome by thermal denaturation. The exit surface for the diffusion is enlarged by slicing the beet. The transport of substance by diffusion (release of sugar and entry of water into the cossettes) results from the concentration gradient existing in the cossettes. The driving force of diffusion appears to be not only the concentration gradient but rather the chemical potential. As the extraction proceeds, not only does this gradient diminish, but the concentration of nonsugar substances in the extract increases, so that the whole process must be stopped at the appropriate point. Extraction is counted as one of the major stages of manufacturing process in the sugar industry (Fig. 1).

The change over time of the mean sucrose concentration in the cossettes is determined by a number of process parameters. To a large extent these can be influenced by operational measures (draft, temperature, shape and surface of the cossettes, as well as load factor and design of the diffuser). Uncontrolled, on the other hand, are properties inherent in the cellular structure of the beet, which depend on the variety, time of harvesting and storage conditions, as well as possible diseases and frost damage.

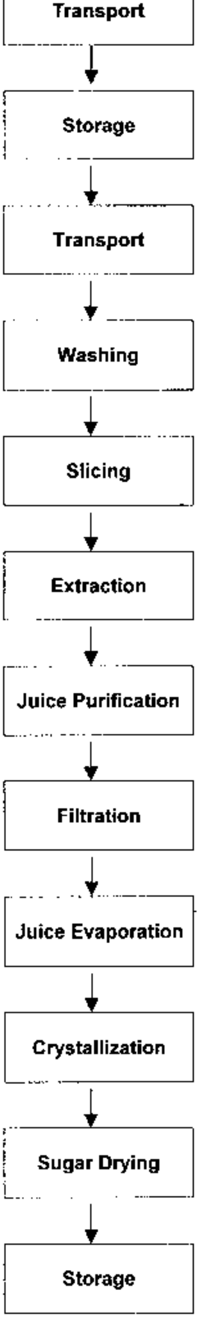


Figure 1 Block diagram of process units from beet or cane.

Over the years numerous researchers have contributed to investigate the theoretical understanding of the course of cossette extraction and to analyze the effect of changes in process engineering and design. Pursuit of the theory of sugar extraction ultimately aims at allowing the most exact simulation of the process possible within the context of process control and to achieve its optimization, not only in terms of extraction yield and juice purity, but also in the design of the installations (1).

During the extraction of sugar from the sugar beet or sugar cane the physical processes are prevailing. The soluble substances of beet cossettes and cane particles are extracted, and remaining are the exhausted pulp and bagasse, respectively. The aim of extraction should be to win an extract that contains as low as possible of nonsugars, has a high concentration, and can be further processed in an economical way. During extraction the destruction of sugar through thermal or microbiological activity should be avoided (2). The operating parameters of extraction should ensure good pressability of the pulp (3). The issue of optimization of sugar extraction is a dynamic problem. The subject is not simple because with the parameters numbering more than four their interdependence is quite complex (4). More information about optimization of beet extraction is given in Sec. VIII.

In the technical application of sugar extraction (raw material sugar beet or sugar cane) and of starch and carbohydrates (raw material corn or potatoes) there are some similarities and some differences. One similarity is that for the extraction of sugars warm water of pH 5.5–6.0 (50–55°C in the case of starch extraction from corn, 70–80°C in the case of sugar extraction from sugar beet or sugar cane) in countercurrent direction to the high concentration is used. A difference is that the solid insoluble matrix varies in every case and the techniques of extraction (diffusion, milling, wet milling) are modified accordingly.

The similarities and the differences in the process of extraction are mirrored also in the technological equipment applied in each case. In the case of sugar beet and sugar cane, the equipment used for the preparation of the raw material before the main process of extraction is different, i.e., slicing machines in the case of sugar beet (Fig. 9) and shredders in the case of sugar cane (Fig. 28), but the main extractors are similar (Figs. 16, 20, 31).

The equipment used for the extraction of starch from corn presents some similarities to the old discontinuous Robert diffusion batteries, which were used in the beet sugar industry until the end of the 1950s and are now obsolete.

II. COMPOSITION OF SUGAR BEET AND CHEMICAL BEHAVIOR OF CONSTITUENTS DURING EXTRACTION

Advances in analytical chemistry in recent decades, particularly the development of chromatographic and enzymatic methods, have considerably expanded the understanding of the nonsugar substances in sugar beet. A typical chemical composition of sugar beet is presented in Table 1.

By the marc content of sugar beet is meant the total beet components remaining after complete aqueous extraction of the soluble constituents under industrial processing conditions of temperature, pH value, and duration (6). The marc content affects the amount of pressed pulp produced and thus is relevant to the mass balance of extraction. Knowledge of the marc content or the volume of juice derived from it is necessary for the analytical determination of the sugar content in beet. Cellulose 0.9–1.2%, hemicellulose 1.1–1.5%, pectin substances 0.9–2.4%, and lignin 0.1–0.3% are the principal constituents of sugar beet marc and of the skeletal substance of exhausted pulp.

However, not to be overlooked are significant quantities of proteins (0.1–0.4%), lipids (0.05–0.1%), saponins (0.05–0.1%), and ash constituents (0.1%). More information about the behavior of the beet constituents during extraction is given in the literature (5, 7).

Invert sugar, apart from respiration of sugar, normally accumulates in the beet during storage at a rate of 10–20 g/(t.d) beet. Invert sugar can be considered as a quality criterion of beet handling and sucrose loss, i.e., treatment of the beet in the period after harvesting and during storage. It is important to note that the organic acids increase in the thin juice owing to invert sugar degradation during juice purification (8).

A. Morphology of Sugar Beet

Sugar beets, as grown for sugar production, are the storage organs of the biennial *Beta vulgaris saccharifera* in its first vegetative year. The tap roots are spindle shaped or coniform, and have white flesh with a white or bone-colored

Table 1 Chemical Composition of Sugar Beet (5)

Component	g/100 g beet
Water	73.0–76.5
Dry substance	23.5–27.0
Sucrose	14.0–20.0
Nonsucrose substances	7.0–9.5
Water-insoluble compounds (marc)	4.5–5.0
Soluble compounds	~2.5
Nitrogen-free organic compounds	0.9–1.1
Nitrogenous compounds	1.0–1.2
Inorganic compounds	0.4–0.5

rind. All sugar beets currently grown in the world have their origins in the so-called white Silesian beet, selected as new cultivar out of a multitude of folder beet strains by Franz Achard at the end of 18th century. The body of the beet, after elimination of the leaves, is divided into three zones: the epicotyl or crown, the hypocotyl or neck, and the tap root (Fig. 2) (9).

B. Ultrastructure of the Native Sugar Beet Root

The inner structure of the sugar beet tissue is similar to that of other dicot plants. The following cell types can be distinguished among others:

- Meristem cells are young cells that divide.
- Parenchyma cells are capable of dividing only in a limited way, with an average diameter of 40–60 μm. Their main function is sucrose storage, and they account for about two-thirds of all cells in the sugar beet root.
- Phloem cells are involved in the transport of dissolved organic substances.

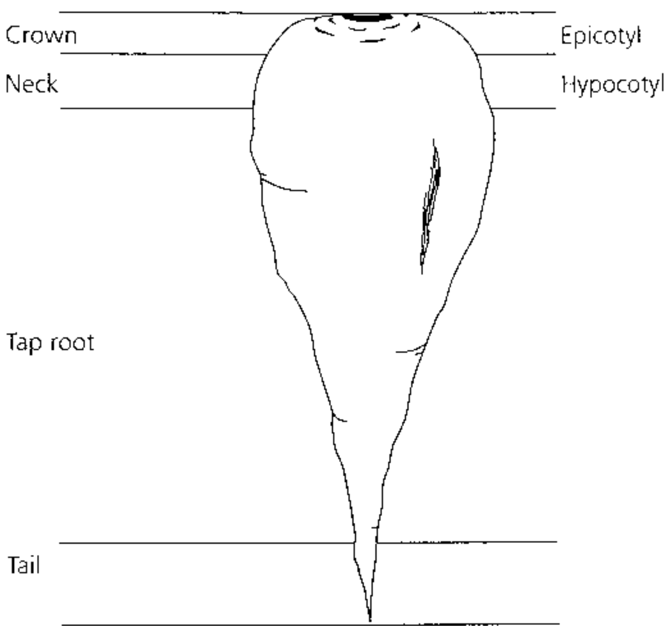


Figure 2 Beet root showing morphological and technologically important zones (40).

- Treachery elements, of 20–40 μm diameter, serve for the transport of water and dissolved ions; dead cells, the walls of which are stiffened by lignin incrustations, together form a tubular system, the xylem (Fig. 3).
- Epidermal cells cover the outer beet surface.

The vacuole accounts for about 95% of the total volume of the parenchymatous cells in sugarbeet. Bounded by a membrane, the vacuole contains almost exclusively dissolved sucrose. The remaining 5% of the inner cell space is taken up by the cytoplasm that contains the cell nucleus and other organelles (Fig. 4).

Sucrose is synthesized in the leaves of the living, unharvested sugar beet plant and transported via the vascular system along the phloem (Fig. 3) to the storage tissue of the root. Whereas the diffusion of sucrose from the cell wall through the adjacent cell membrane into the cytoplasm is only moderately impeded, the vacuolar membrane presents a barrier of extremely low permeability for sucrose. In the living cell, this barrier is overcome by active, energy-consuming transport, which produces the high sucrose concentration of about 0.5 mol/L in the vacuole. In contrast, the sucrose concentration in the cell wall amounts to only about 0.06 mol/L. The resulting osmotic pressure of 0.4–0.8 MPa, depending on the metabolic activity, pushes the cell walls together and gives them their mechanical stability (10).

In Figs. 37–40 are given computer simulations, showing the electrostatic potential profiles (Fig. 38) and the hydrophilic and hydrophobic regions of the sucrose molecule. In Fig. 41 is given the hydrophobic topographies for the amylose fraction of starch (46, 47). These computer simulations contain a tremendous amount of information. The complexity of the molecule surface of sucrose and amylose can explain the complexity of their extraction process.

C. Physical Properties of Beet

The technological value of the beet is affected not only by its components but also by its morphological and physical characteristics (11). The elastic and plastic properties of beet affect slicing and the behavior of the cossettes during the extraction process. These properties are identified above all by the elasticity modulus, the breaking stress, and the bending capacity (12).

D. Physical Properties of Beet After Denaturation

Denaturation means killing the living plant tissue. This can be done by heat, freezing, chemical action, electroplasmolysis, or ultrasound. The technological objective is to improve the material transport of the substances immobilized in the living cell through the tissue and into the extraction liquid. In industrial processing, denaturation takes place by heat (70–78°C).

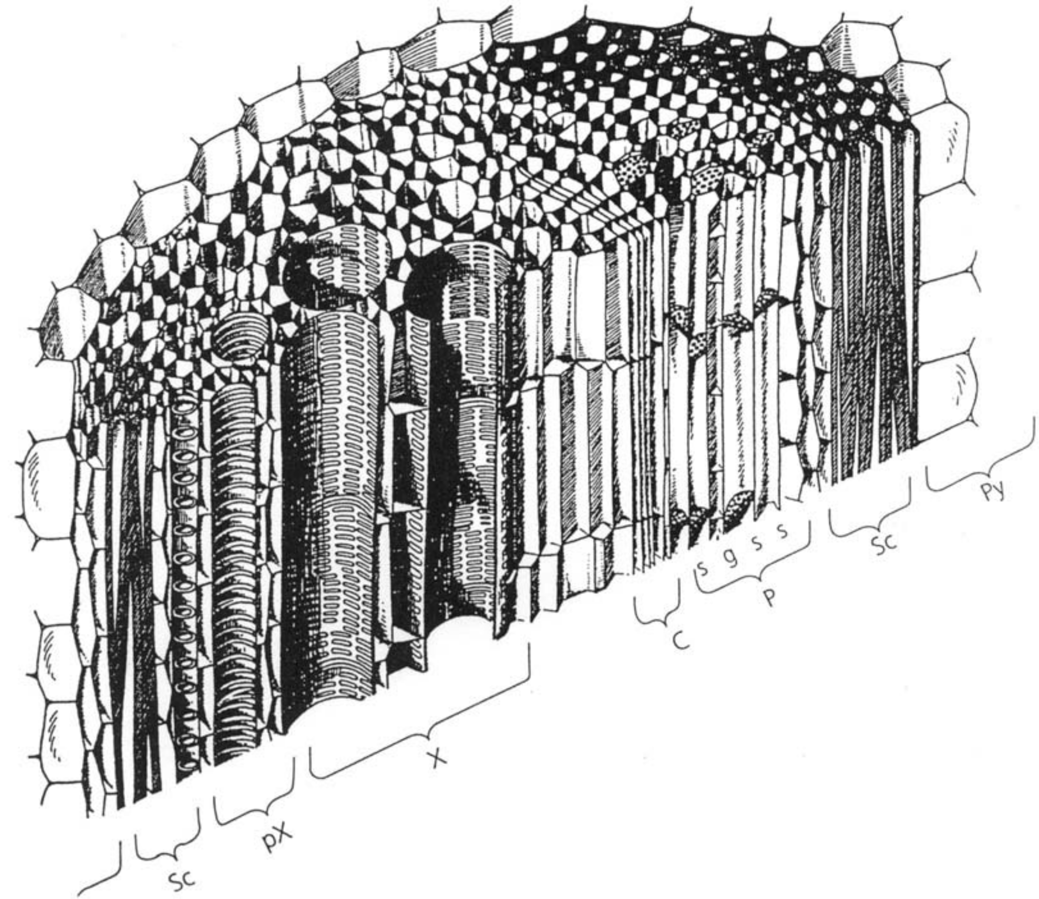


Figure 3 Vascular system of beet (40). Py, Parencyma tissue; Sc, sclerenchyma tissue; pX, protoxylem; X, xylem; C, cambium (area between phloem and xylem); P, phloem; s, sieve tubes; g, companion cell.

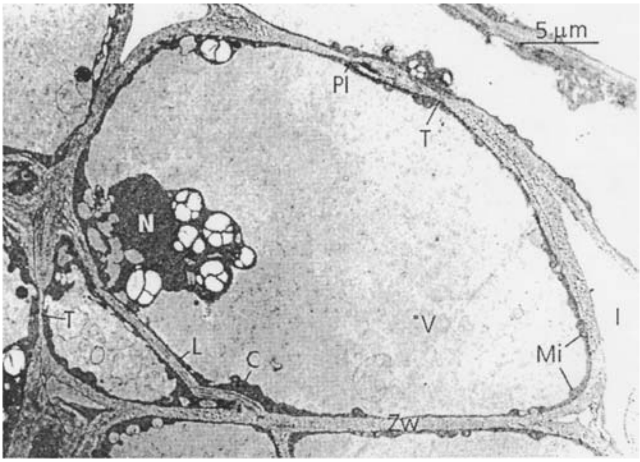


Figure 4 Parenchyma cell from a young sugar beet (4 months old), 1200 times enlarged (40). A, Amyloplast; C, cytoplasm; I, intercellular space; L, lipid vesicle; M, mitochondrion; N, cell nucleus; T, pit; Pl, plasmalemma; V, vacuole.

In principle this leads to continuous alteration of the cell tissue. Not only are the cell membranes destroyed but the cell walls also change their inner chemical structure through hydrolytic degradation reactions (molecular chain breakage and detachment of polysaccharide fragments). Despite the chemical changes caused by temperature, the cell retains its physical integrity. Thus, it continues to be a barrier to mass transport throughout the subsequent pressing process. Following denaturation the tissue has lost its strength and the cell liquid can be squeezed out because the osmotic pressure exerted on the cell wall through the membrane is absent (13).

Conventional sugar technology uses the minimal temperature stability of the cell membranes during the heating of the sugar beet cossettes to greater than 70°C in the extraction apparatus. Only remaining is the cell wall with a thickness of 2 µm, which can be considered from its porous texture as an ultrafiltration of this physical membrane. Figure 5 shows the inner structure of this physical membrane. In this scheme it is possible to recognize the cellulose fibrils and other soft polymers, between them also the pectin, where these fibrils combine in chain formations. In an electron microscope it is possible to see clearly the pores that are formed through the cellulose fibrils (Fig. 6) (14).

E. Fractal Structure of the Beet Tissue

Examination of Figs. 3, 5, and 6 clearly reveals the self-similarity in different scales that is the fractal structure of the beet tissue. The majority of the biological

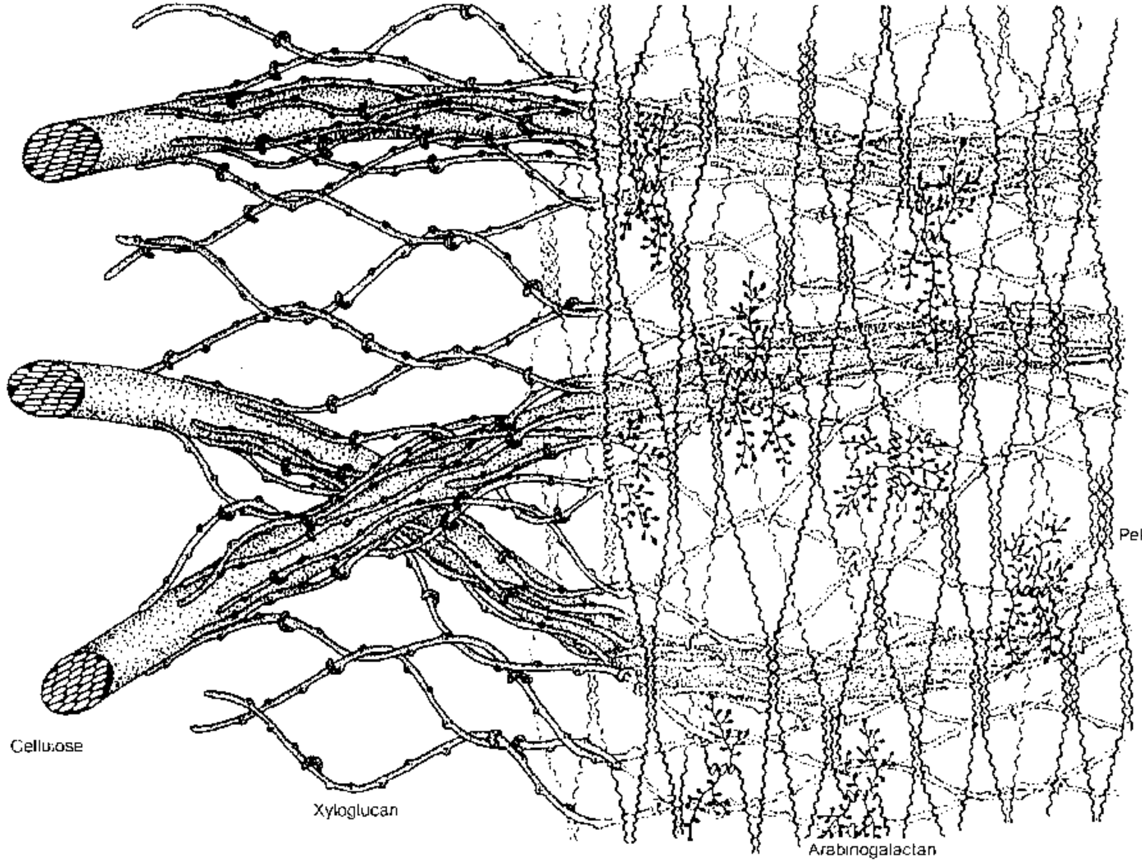


Figure 5 Inner structure of the physical membrane in flowering plants (14, 41).

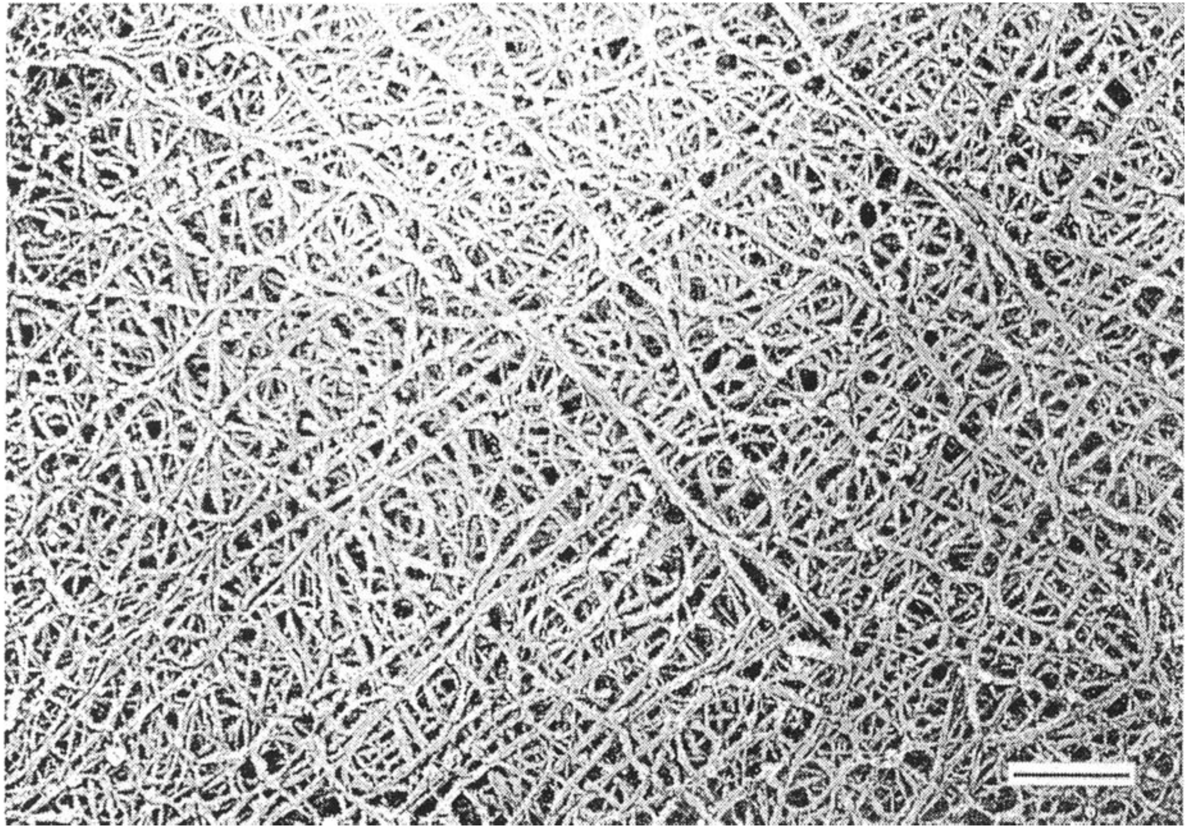


Figure 6 Electronic microscopic photo of the cellulose microfibrils in the cell wall of onions, free from pectin, beam length 0.2 μm (14, 41).

tissues have a fractal structure, and beet tissue belongs in this category (15). In a biological tissue the fractal chaotic structure ensures the following advantages:

- In very small volumes huge surfaces are found.
- In an usual Euclidean solid or surface the diffusion grade of one substance under the influence of random fluctuations is directly proportional to time. In the fractal structure the diffusion grade increases very quickly at a power of time t^n ($n > 1$). This phenomenon is called *overdiffusivity*.
- One fractal structure can be constructed in a short time from a simple algorithm, which is repeated in different scales without significant changes (16).

The phenomenon of overdiffusivity of beet tissue during extraction by hot water can explain the observed acceleration of the diffusion rate, especially in the beginning of the extraction process.

III. MATHEMATICS OF EXTRACTION

A considerable advance was made in the mathematical theory of extraction by Silin (17) when he developed equations relating the various factors affecting extraction. He started with Fick's law, a special case of Fourier's general diffusion law:

$$ds = D \cdot A \cdot \frac{dc}{dr} \cdot dt \qquad (1)$$

where *ds* is the weight of the dissolved substance diffusing through the area *A* in time *dt* and *dc/dr* is the concentration gradient of the dissolved substance.

D is the diffusion coefficient, which depends on temperature according to the Einstein correlation

$$D = \frac{k \cdot T}{\eta} \qquad (2)$$

where *k* is a constant for the dissolved substance, *T* the absolute temperature, and η the viscosity of the solution (18). The diffusion coefficient *D* is a measure of the mass transport velocity in the cossettes. In Table 2 diffusion coefficients of sucrose from beet tissues are given according to different authors. It must be noted, however, that the values for sugar beet shown in Table 2 do not refer to identical material, as would be desirable (13).

Schliephake and Wolf (19) investigated the mechanism of sugar extraction, especially during the initial stages. They defined three basic phases: osmo-

Table 2 Diffusion Coefficients of Sucrose from Beet Tissues (40)

Diffusion coefficient [$cm^2/(s.10^{-5})$]	Temp. (°C)
0.6–1.13	75
1.0–1.17	75
0.5–1.0	75
0.8–1.2	70
0.82–0.92	70
0.8–0.88	75
0.91	65–75
1.0	75

sis, denaturation, and diffusion (Fig. 33). During the initial phase, water enters the cell by osmosis. Denaturation increases the permeability of the cell wall, and the juice–water mixture is forced to flow out of the cell by the sudden change of the cell pressure. Only after the completion of those two initial reactions can diffusion be considered the rate-determining process. The duration of the initial phase depends on the extraction temperature and corresponds to the time needed for denaturation. During that time, less than 5 min under normal operating conditions, more than 20% of the sugar is extracted.

Figure 7 shows the three basic phases, as indicated by the change of the relative concentration of sugar and water in the beet slices, during the extraction with water, at two temperatures. The straight line represents the theoretical extraction, during which the water and sugar concentration should remain nearly constant relative to each other throughout the process, if diffusion is the only rate-determining factor. The maxima and the minima of the curves indicate the completion of the first two stages: osmosis and denaturation (19).

Only in the ideal case does the extraction liquid pass by the cossettes in laminar flow. In reality, there is some turbulence that is superimposed on the desired direction of the material transport along the extraction route and is characterized by the axial dispersion coefficient $D_{ax,2}$. Superimposed on this micromixing of the liquid phase is a macromixing caused by the churning of the essentially uniformly moving cossettes and which, analogous to the behavior of the liquid, can be represented by an axial dispersion coefficient $D_{ax,1}$. According to Buttersack and Schliephake (1), the extraction is described by the following partial differential equation:

$$\frac{\partial c_2}{\partial t} = \frac{\partial \bar{c}_1}{\partial t} + u \cdot \Phi \cdot \frac{\partial \bar{c}_1}{\partial z} - D_{ax} \cdot \Phi^2 \cdot \frac{\partial^2 \bar{c}_1}{\partial z^2} \qquad (3)$$

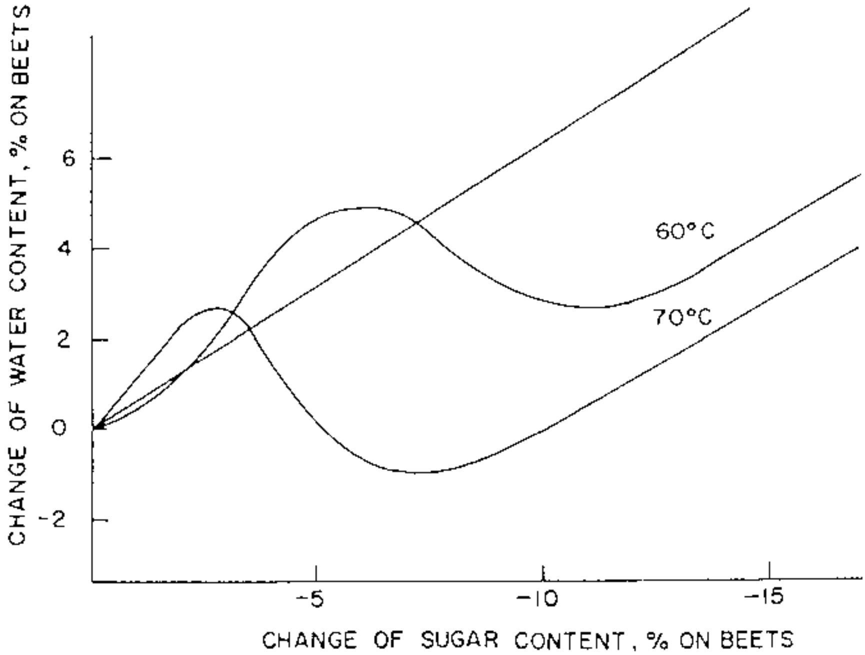


Figure 7 Change of water, with change of sugar concentration in the beet during extraction, with water at 60°C and 70°C (18, 19).

where c_1 and c_2, respectively, represent the sucrose concentration in the cossettes and in the liquid along the extraction route z, while D_{ax} is the axial dispersion coefficient comprising the effective contribution of macro and micromixing ($D_{ax,1}$ or $D_{ax,2}$, respectively). The mean cossette velocity is u_1 and Φ is the ratio of the difference velocity u (between cossettes and liquid) and the mean cossette velocity u_1.

$$\Phi = \frac{u}{u_1} \tag{4}$$

Formula (3), being a partial differential equation, has only chaotic solutions (15, 45). Buttersack and Schliephake (1) and Christodoulou (15) emphasized the complexity of the extraction process.

Other theoretical handling of extraction in beet sugar factory is given by Claasen (6), Dubourg (24), Brüniche Olsen (25), Silin (17), Ebell and Storz (18), and Schneider and Reinefeld (22). The principles of extraction was the priority subject of the 15th General Assembly of the International Commission of Sugar Technology (CITS) in Vienna 1975 (26).

IV. TECHNICAL EXTRACTION OF BEET

In all extraction systems, fresh cossettes are heated and subsequently extracted in a countercurrent of liquid and solid phases. The extraction equipment is fed at one end with fresh cossettes, and exhausted cossettes are removed at the other end. At this end, feed water is introduced and passes through the extractor countercurrent to the cossettes. An extraction plant is made up of (Fig. 8):

- Cossette production, i.e., slicing
- Cossettes heating (denaturation or scalding)
- Transport of cossettes to the extractor and removal
- A countercurrent exchange section
- Fresh water supply and separation of exhausted cossettes
- Pulp-pressing equipment
- Press water return (20)

V. SLICING MACHINES

Only two types of machine out of those which came into being more than 100 years ago were successful, namely, the disk- and drum-slicing machines.

A. Disk-Slicing Machines

The disk-slicing machine is characterized by its vertical configuration and horizontally rotating slicing disk. The diameter of the disk has been increased over the years to 2780 mm. With 32 knife blocks in total and a slicing length of 400 mm per knife box, the slicing capacity can be raised to about 4000 t/d depending on the knives used and the cossette thickness.

B. Drum-Slicing Machines

The drum-slicing machine consists of a horizontally rotating drum in which the knife blocks are carried on supporting members (Fig. 9). The knife blocks are depending on the manufacturer, fitted with two or three row boxes. The box length is 600 mm, which means that there are three knives per row, grouped side by side. With a drum diameter of 2200 mm and 22 knife blocks each with 3 rows, the maximum output of the machine is 8000 t/d, according to the manufacturer's claim.

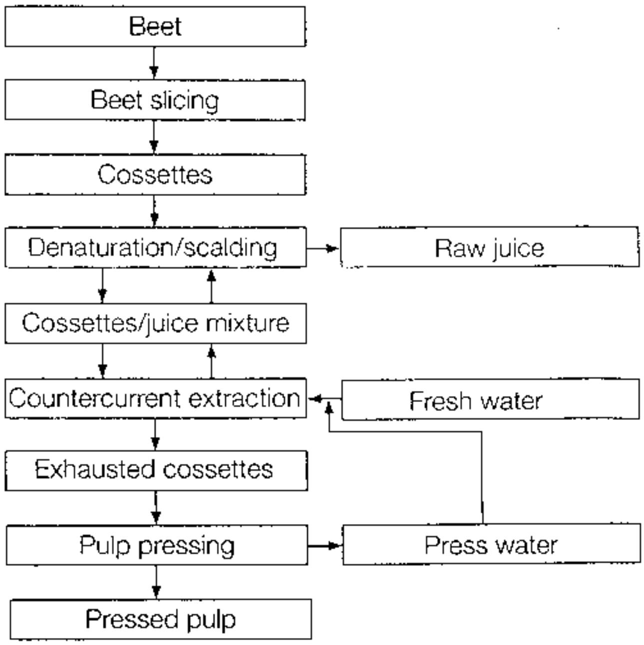


Figure 8 Block diagram of beet extraction process (40).

C. Control of Throughput

The slicing capacity of the machine is proportional to the rotational speed of the disk or drum. Control of slicing output is achieved via a belt-weighing scale that is situated in the conveyor leading to the extractor. This picks up the deviation from the preset value and transmits a signal to the rotational speed controller on the slicing machine that raises or lowers the slicing rate to the correct level. Drum and disk slicers are fitted with frequency inverters. The optimal slicing speed lies in the range of 2.0–5.0 m/s, which corresponds to a drum rotational speed of 25–50 min^{-1}.

D. Cleaning

Both disk- and drum-slicing machine are fitted with special cleaning arrangements. These consist of a blow-out device using compressed air, alone or in combination with rotating brushes or high-pressure steam. These arrangements

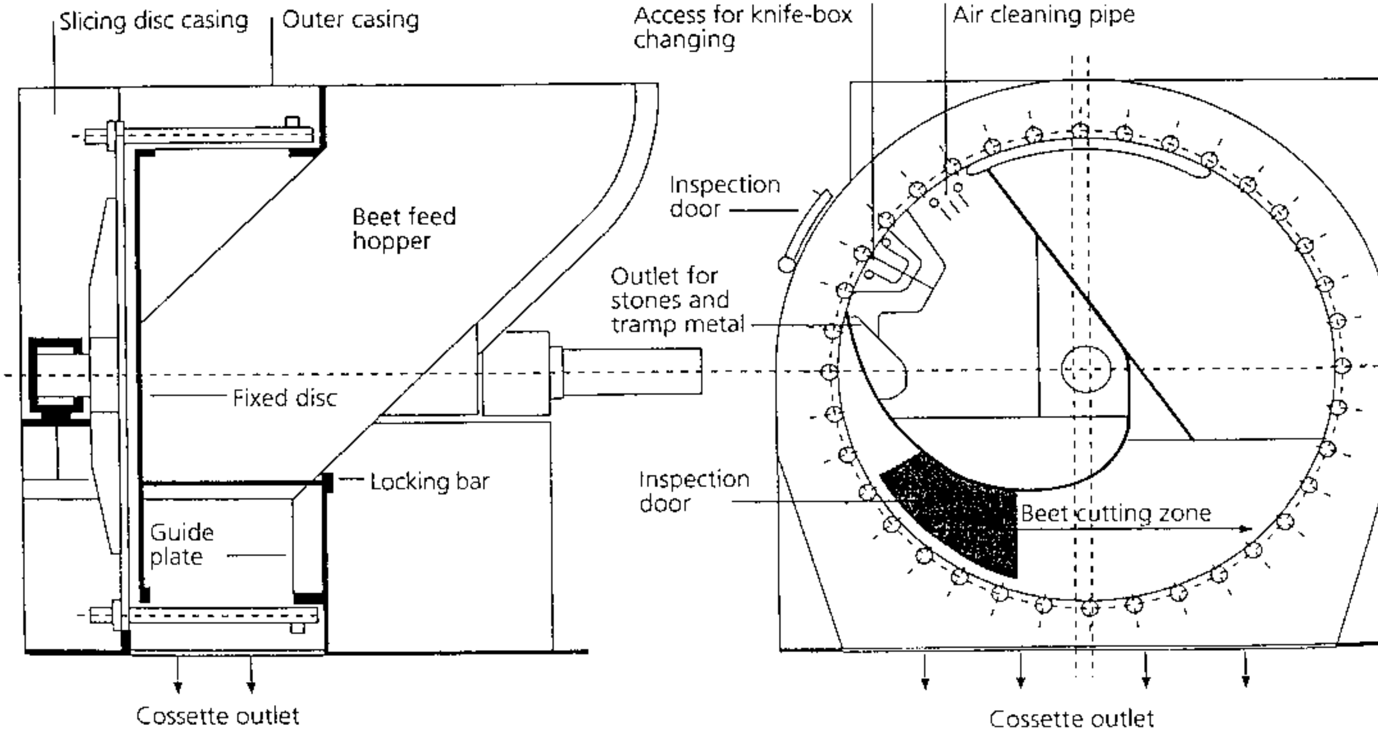


Figure 9 Drum slicing machine 2000-600-60 (Maguin) (40).

should ensure that while the machine is operating, fibers and other small fragments are removed from the face of the knives. In this way, the slicing throughout can be maintained over a longer period and the quality of the cossettes can be kept consistent.

E. Comparison of Types of Slicing Machines

Considering the situation today, it can be said with certainty not only that the drum-slicing machine yields a greater output but that its technological advantages enhance its future prospects.

F. Knives

The quality and shape of cossettes will be determined by the choice of the beet knife. Of the many types of beet knives the Königsfelder knife has been successful, mainly as a semi-cutting knife. Based on the requirements of the extraction, beet knives with different numbers of divisions are used as a corrugated splitter chevron or square cossettes as wanted; then A or B knives synchronized or offset are installed in the knife blocks (Fig. 10).

The same beet knives are suitable for disk-slicing machines and drum-slicing machines. The length of the knife can be 137, 167, or 200 mm (Fig. 11). New slicing machines, independent of the manufacturer, are presently being equipped with 200-mm knives. There are four steps in the preparation of the knives:

- Cleaning and dismounting of the knife blocks
- Straightening and dressing of the knives
- Routing of the knives and finishing by filing
- Reassembly and adjustment of the knife blocks

The first of these steps will be mainly manual. The other steps are performed either semiautomatically or automatically. The consumption of the knives depends principally on the preparation of the beet and the treatment of the knives themselves. The consumption should be of the order of 3–5 knives per 1000 t of beet processed.

G. Ventilation of Slicing Machine Operating Position

Inadequate space can cause aerosols to appear in the vicinity of the machine. Adequate ventilation should be introduced to avoid impairing the health of the operator (20).

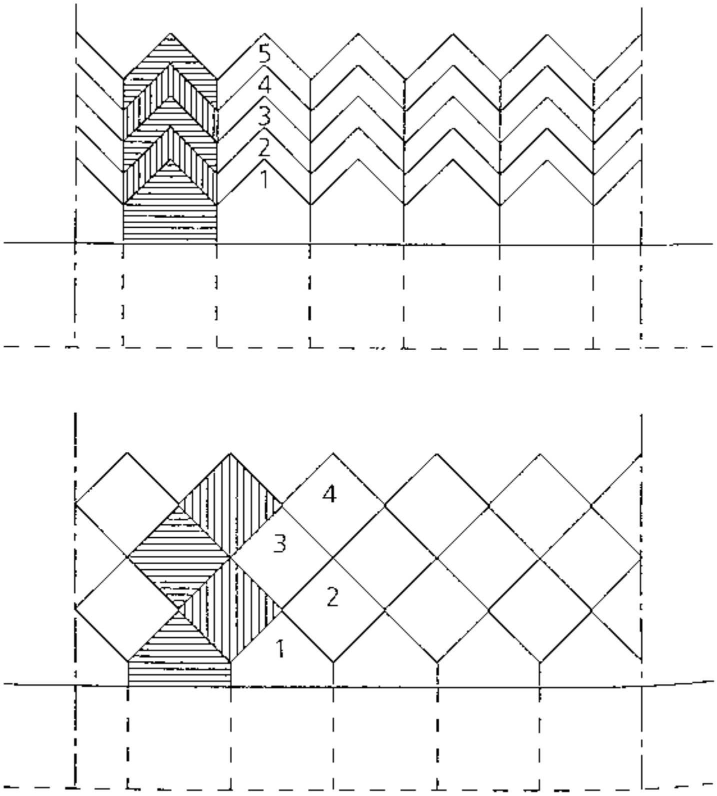


Figure 10 Cutting sequence for corrugated splitting knives (40). Top: synchronized. Bottom: offset.

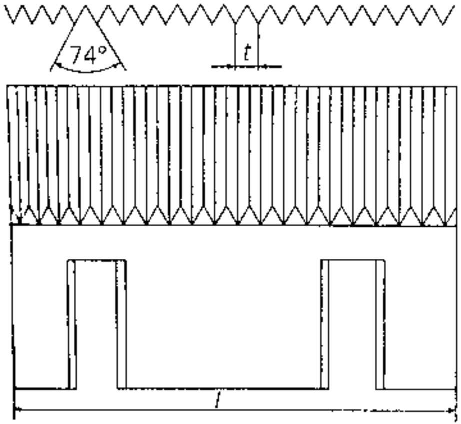
VI. PROCESS PARAMETERS OF EXTRACTION

A. Quality of Cossettes

The size and physical condition of the cossettes are of great importance for extractor performance. Since time is required for sugar to diffuse through a given distance, advantage is gained by shortening the distance. The Silin number and the Swedish number serve as indicators of cossette quality.

1. Silin Number

Length of 100 g of cossettes in meters, thus giving a standard for the fitness and surface area of the cossettes. This parameter depends on the number of



Division in mm old design. (Knife length l in mm)	≈ 9,0 15er	≈ 8,7 16er	≈ 8,0 17er	≈7,2 19er	≈ 6,3 22er	≈ 5,7 24er
137	t = 9,13 15 divis.	t = 8,56 16 divis.	t = 8,06 17 divis.	t = 7,21 19 divis.	t = 6,22 22 divis.	t = 5,71 24 divis.
165	t = 9,16 18 divis.	t = 8,68 19 divis.	t = 7,85 21 divis.	t = 7,17 23 divis.	t = 6,34 26 divis.	t = 5,69 29 divis.
167	t = 9,27 18 divis.	t = 8,78 19 divis.	t = 7,95 21 divis.	t = 7,26 23 divis.	t = 6,42 26 divis.	t = 5,76 29 divis.
200	t = 9,09 22 divis.	t = 8,69 23 divis.	t = 8,00 25 divis.	t = 7,14 28 divis.	t = 6,25 32 divis.	t = 5,71 35 divis.

Figure 11 New knife designation (Putsch), new designation, e.g., Königsfelder knife, model 1050: 200 × 87 with 28 divisions at 7.2 mm (19 in number) (40).

knife divisions, type of knife, and clearance to the fore layer; it ranges between 10 and 18.

2. Swedish Number

Standard for the permeability of the cossettes' bed. Measured by the quotient:

$$\frac{\text{Mass of cossettes} > 5 \text{ cm long}}{\text{mass of cossettes} < 1 \text{ cm long}}$$

The ratio of the portion of the cossettes >5 cm long to that <1 cm long should be greater than 10.

3. Mush Content

The mush content is the mass of cossettes <1 cm long in relation to the total cossettes' mass. This should not exceed 5%.

4. Draft

The ratio between the beet processed and the raw juice extracted expressed in percentage, either in terms of mass or volume (normally not used), is referred to as the "draft" (21).

$$\text{Draft} = \frac{\text{weight of diffusion juice}}{\text{weight of beets}} \times 100$$

Drafts used vary between 100 and 135; sugar lost in pulp and draft varies inversely. Steam cost and evaporator capacity have to be balanced against the additional sugar obtained (18). Their quality must be adapted to the extractor in use.

Percolation rate across a cylinder packed with cossettes decreases rapidly if the Swedish number falls below 10. Maximal percolation rates are obtained at values >15. The rigidity (turgidity) of cossettes has a considerable influence on cossette permeability. This depends on the quality of beet and can deteriorate as a result of storage or frost.

Process parameters that can modify cossette rigidity are the extraction temperature and the pH value, as well as the feed water pH value and the cation composition. Foaming of the liquid phase and the presence of fines can also reduce the permeability (21).

5. pH Value

The cell juice of sound beets varies between 6.3 and 6.6. In the absence of a diffuser infection the pH of the diffusion juice is about 0.1 unit lower than the pH of the cell juice. Within the diffuser a lower pH may have beneficial effects. At a pH of 5.5 the diffusion of impurities appears to be at a lower level. This might be a result of degradation of the pectins at higher pH. The exhausted pulp is firmer and permits more efficient removal of the water in the pulp presses. Considering corrosion, a pH of 6.0 or slightly below 6.0 within the diffuser appears to be a good compromise. To obtain this, not only the supply water but also the press water may have to be acidified (18).

Acids used for pH control in extraction are sulfuric, sulfurous, or rarely hydrochloric acid (a highly corrosion-resistant static mixer is needed); 95% of the anions of these acids are found in the raw juice. Sulfuric and sulfurous acids are precipitated to an extent of about 50% in the juice purification (21).

6. Temperature

The temperature levels in the extractor are generally between 68°C and 75°C. The target temperature in extraction is dictated by several variables:

- Denaturation of the beet cells.
- Protection against microbiological development, which is achieved above 73°C.
- Rate of extraction.
- Limiting of the thermal degradation of the beet marc, especially the cellulopectic skeleton. To denature cossettes should be heated as quickly as possible to 70–75°C.

Extraction accelerates as temperature rises because the diffusion rates increase with increasing temperature; for example, a fall in the sucrose losses from 0.25 to 0.20 g/100 g beet at equal draft can be mathematically forecasted for a rise in temperature from 69°C to 73°C. Sugar losses from microbiological activities also decline with rising temperatures. Extraction above 75°C is impossible because of the inherently labile nature of beet at elevated temperature. This is due to the breakdown of the cell wall substances, especially through pectin degradation.

Targeted average temperatures for normal beet material are about 70–73°C. Under technical conditions, taking into account the extraction losses, mechanical properties of the cossettes during their transport through the extractor, pressability of the cossettes, as well as the filtration properties in juice purification, one will gradually approach the optimal operating temperature. Excessive operating temperatures affect the processing of healthy beet negatively. Much more attention has to be paid to the operational temperatures in the case of deteriorated beet (21). Schneider and Reinefeld proposed a temperature profile as displayed in Fig. 12 for healthy mature sugar beet (22).

7. Time

The time during which the cossettes are in contact with the surrounding liquid is considered the extraction time. The average extraction time should not exceed

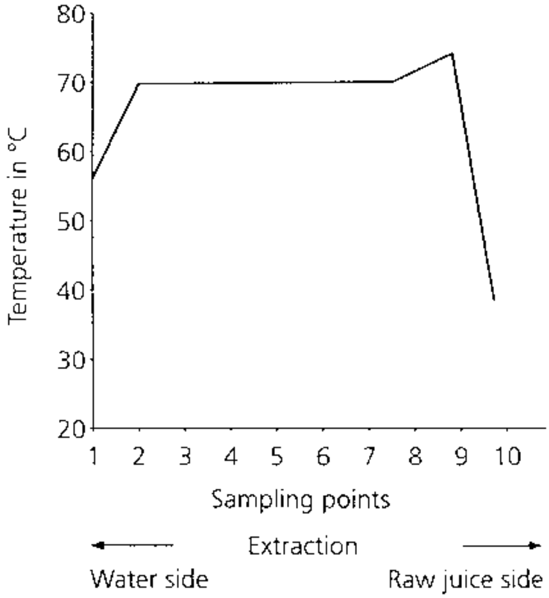


Figure 12 Optimal temperature profile for juice extraction using normal, healthy beet (40).

75 min. The breakdown of cell wall substances (e.g., pectin) increases with increasing average extraction time and poor retention time distribution. This leads to deteriorating juice and pulp quality. Short extraction times lead to improved utilization of the equipment (21).

8. Bacterial Control

The very broad range of sugar losses due to microbial activity found in practice, i.e., from 0.05% to 0.2% on beet, is certainly due to operating conditions. Minimization of sucrose losses or formation of acids, improved pulp dewatering, and avoidance of the addition of bacteriostats are arguments either in favor or not in favor of bacterial control. Bacterial control in extraction equipment is common practice with formaldehyde application as a standard procedure in countries, where its use is allowed. However, other substances, such as SO_2, carbamates, quaternary ammonium compounds, and hydrogen peroxide, have also been tested and applied. Avoiding the use of any bacteriostat has been practice in the Japanese and Austrian sugar industries. With deteriorated beet that has undergone freezing, significant activity by mesophilic microorganisms can occur. Notably, lactic acid bacteria grow under such conditions when no appropriate control is possible (23).

Hein and Pollach proposed the use of products from hops extracts to inhibit thermophilic microorganisms while avoiding the potential health hazards usually associated with the application of bacteriostats (44).

9. Extraction Water

Historically the first Roberts discontinuous batteries were fed with fresh pure water. All the extracted water from pulp straining and pressing was discarded as waste water. Nowadays for environmental as well as economic reasons the press water is reintroduced into the extraction system. The mass balance in Fig. 21 gives an example of the press water and fresh water flows. The more effective the pressing of the pulp, the greater is the mass of press water and the lower the necessary complement of fresh water. When the dry substance content of the pulp increases, its mass on beet decreases. With increasing pressed pulp dry substance content, for the same sugar losses on beet, the sugar contents of the pressed pulp and the press water increase. It is possible to introduce fresh water and press water separately. The fresh water is fed at the tail (top) of the extraction equipment and the press water at the point of the extractor where the liquid phase in the extraction equipment has the same sugar content as the press water. It is also possible to mix the two water feeds and to introduce the mixture at the tail (top) of the extraction equipment.

Condensates, used as fresh water, are alkaline and contain ammonia. It is necessary to acidify them so that the pH value at the tail (top) of the extractor is below 6. The desired temperature is obtained by mixing cold and warm condensates. In the case of feeding the extraction with mixed water, it is possible to control the temperature of the mixture by adjusting the amount of the different kinds of water without reheating (21).

10. Pulp Press Water Treatment

Pulp press water contains colloids and small pulp particles, which in some cases are eliminated by a pulp screen before passing a heat exchanger and reintroduction into the extractor. Because of the heat losses during pulp transport and pressing, press water is generally obtained at below the extraction temperature. At press water temperatures thermophilic bacteria can develop. To fight this cause of infection, heating the press water before its reintroduction into the extraction equipment is desirable. Complete pasteurization requires heating to about 90°C for the required time. In fact, this is rarely done, but some heating is always done (21).

11. Pressing Aids

To improve the pulp pressing, pressing aids are used. Generally these pressing aids are di- or trivalent cations—Ca^{2+} or Al^{3+}—which are mostly added as sulfates. These polyvalent cations increase the rigidity of the pulp. Aluminum sulfate is added as a water solution. Calcium sulfate can be produced in the factory by reacting sulfuric acid with milk of lime or carbonation lime. Natural gypsum is also used. The effect on the dry substance content of the pulp is maximal for a consumption of aluminum sulfate of about 350 g/t beet (i.e., 6 eq Al^{3+} /t beet) and for a consumption of calcium sulfate of about 1000 g/t beet (i.e., 13 eq Ca^{2+} /t beet).

The addition of such pressing aids modifies the ionic composition of the liquid phase by yielding higher concentration of Ca^{2+} or Al^{3+} throughout the extractor. Fixation of these ions begins when the cossettes mix with the juice so that the rigidity of the cossettes as well as the permeability of their mass are both improved (21).

12. Antifoaming Agents

The beet root contains surfactive components that pass into the liquid phase in the extractor. Production of persistent foam occurs by air inclusion within the cossettes' mass. Foam inhibits circulation of the liquid in the extractor, so that it is necessary to use antifoaming agents. There are many kinds of antifoaming agents, including fatty acids, that are used in the extraction equipment at levels between 0 and 150 g/t of beet (21).

13. Presence of Oxygen During Extraction

Extractor design has an influence on the aeration of the juice–cossette mixture. In this respect there are essential differences between the drum (RT) and belt (De Smet) extractors, as well as between trough (DDS) and tower extraction equipment. Oxidation of polyphenols to melanins, may be different in different extraction equipment. Polyphenols are readily oxidized to melanins, which are removed in juice purification. The total polyphenol contents in DDS and RT extractors were about 11 mg/L. The oxygen content of the cossette–juice mixture influences the composition of the metabolites in the event of developing bacterial activity (21).

14. Extractor Operation with Deteriorated Beet

The impact of alternating freeze and thaw cycles can lead to considerable degradation of the cell structure in sugar beet. Such sugar beets are not suitable for normal extractor operations. The extraction procedures must therefore be adapted to the substantially altered beet material even if extraction loss increases. Deteriorated sugar beets are unsuitable for producing desirable cossettes because the mush content increases. Percolation of the extraction fluids through cossettes having a high mush content is considerably impaired. Operation with coarser cossettes is therefore necessary to avoid mechanical problems (plugged screens, extractor plugs). Extractor temperatures are generally lowered (70°C maximum) to minimize further breakdown of the cell wall substances. It could be desirable to reduce the retention time of the cossettes in the extraction fluid, consequently reducing the average extraction time. Operating capacity is substantially reduced; 5% of the beet material is partly degraded. Periodic shock treatment with bacteriostats (formaldehyde among others, depending on approval for this application) is recommended to reduce the bacteriological activity. Without such measures being taken, the microorganisms present in the deteriorated beet, being associated with the decomposition, will increase substantially (21).

15. Diffusion Juice

The juice drawn from the extractor contains a considerable amount of colloidal matter besides a large number of fine pulp particles, which are difficult to remove by screening. It is desirable to eliminate most of the suspended matter before the juice is sent to the purification process. The color of the juice is usually gray and changes to a dark gray or almost black on contract with the air. This darkening is caused by enzymatic reactions and is accelerated in the presence of iron. However, the color of the diffusion juice is of little importance as it is removed without difficulty during purification. The nonsucrose content of the diffusion juice is related to the quality of the beets and the conditions under which the sugar is extracted in the factory. In some beet-growing areas, storage after harvesting has more effect on the quality of the diffusion juice than normal variations of the growing conditions as experienced from year to year.

The following percentages of the mineral components are extracted from the beet: 80–90% of K and Na, 10–30% of Ca, 60–80% of Mg, and about 80% PO_4^{3-} and SO_4^{2-}. Amino acids and betaine are almost completely extracted, and the protein and pectin content of the juice is a function of pH and temperature. At higher temperatures more pectins are dissolved, but the protein content appears to be at its lowest level at about 70°C.

The following organic non–amino acids are present in larger quantities: citric, oxalic, malic, acetic, and lactic acid. There are only minute amounts of lactic acid found in healthy beets' acid; its presence in the diffusion juice usually indicates a thermophilic infection in the extractor. The invert sugar content in the juice normally ranges from 0.4% to 0.8% on solids. Higher concentrations are found during processing of stored beets, up to 2.1% on solids (18).

VII. BEET EXTRACTORS

In the first sugar beet factories, the sugar juice was obtained from the beet by pressing (the procedure followed for centuries with sugar cane). While the structure of sugar cane is extremely fibrous and therefore suitable for pressing, beet tissue is soft, and not particularly permeable, which makes difficult even a moderate exhaustion of the sugar juice contained in the beets by pressing. In the efforts of finding a method other than the uneconomical one of pressing, the first to succeed were Florent Robert and his son Julius Robert. After a long period of experiment, they succeeded for the first time, in the 1864 campaign at the Seelowitz factory in Mähren, in producing juice on a factory scale by what they called "osmotic maceration" (25).

Historically, the Robert battery, also called a "batch diffuser" and now obsolete, first realized the countercurrent principle with fixed cells where the solid phase was enclosed and transport of the liquid phases was controlled through pipes connected to the cells (21).

Schneider and Reinefeld categorized the continuous extraction systems, which are all working countercurrently, in three classes (22):

1. Controlled transport of both juice and cossettes: cell–extractor (RT extractor), cross-flow filtering belt conveyor extractor (De Smet extractor).
2. Controlled transport of cossettes and uncontrolled transport of juice. This class comprises several chain-type extractors: Silver chain-type, Olier, Oppermann & Deichmann, J-diffuser, and Oliver–Morton.
3. Uncontrolled transport of juice and cossettes: tower extractors [BMA, Buckau Wolf, sloping through extractors (DDS and Silver slope type)].

A. RT extractors (RT from Raffinerie Tirlemontoise, Belgium)

RT extractors are large revolving drums, separated into "cells" by a helix attached to the interior surface. As the drum with its helix revolves, the juice, which stays at the bottom, is transported from the tail to the head end.

Thus, the cell actually moves, but it is more convenient to consider the cell the location of one turn of the drum. Fixed to the cylinder are grids that, revolving with the drum, sweep the cossettes up until they slide off and fall into the next cell. Thus, the cossettes and juice travel in opposite directions through the cylinder (35). The first extractors of this type were called Bergé extractors.

The RT2 extractor was developed from the Bergé extractor. It has a double-helix, or double-threaded, screw, with each screw having twice the pitch of the single-helix screw (21). The diameter of the drum is enlarged at the cossette inlet side. The enlarged shell is perforated and rotates inside a fixed head, which is not connected to the drum. The cossettes are flushed through the scalding pipe into the mobile head. Two grids are mounted inside the mobile head and carry the cossettes into the drum with each turn. Scalding juice, together with juice from the diffuser, flows through the perforated head into the circulating juice tank. Fresh water is introduced through the hollow shaft into the second compartment and pulp press water is added to the fourth compartment, counting from the tail end. Diffusion juice, corresponding to the draft, is pumped from the circulating juice tank to the process. The remaining juice is heated and used for scalding and flashing the cossettes to the extractor (18).

Figures 13 to 15 show the general diagram of an RT2 extractor and its associated equipment. The largest RT2 extractors (7 m diameter and about 45 m long) have a nominal capacity of 5000 t/d beet, which can be exceeded by more than 50%. It is impossible to enlarge this model because of geometrical difficulties with the slope of the cossettes passages and also because of the important empty volume inside the drum, which is expensive (21).

The RT4 extractor is directly derived from the RT2 model. In the RT4 extractor the redesigned internal structure produces a more continuous movement of the cossettes during the rotation of the drum. The capacity of such a new drum is larger and the retention times of both juice and cossettes are

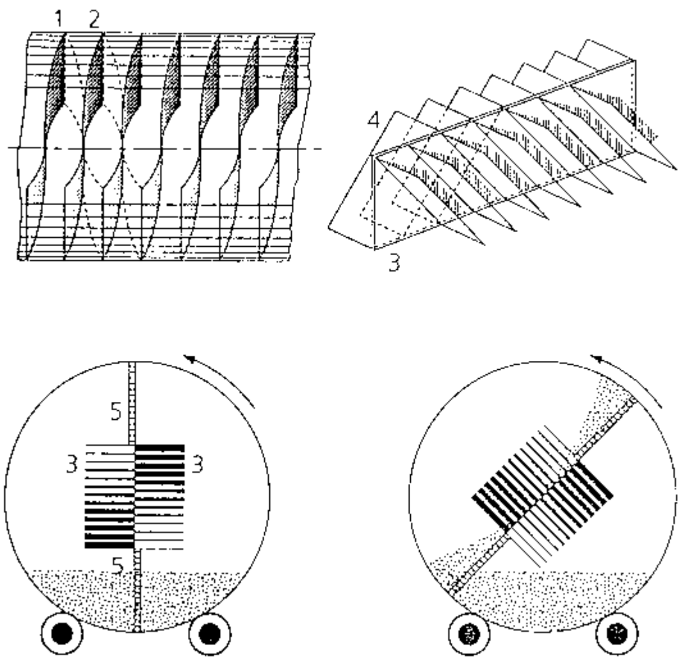


Figure 13 Constitutive elements of an RT2 extractor (40). 1 and 2, Helicoidal plates forming two separate juice channels; 3, transversal plate; 4, slopping passages for cossettes; 5, transversal screens.

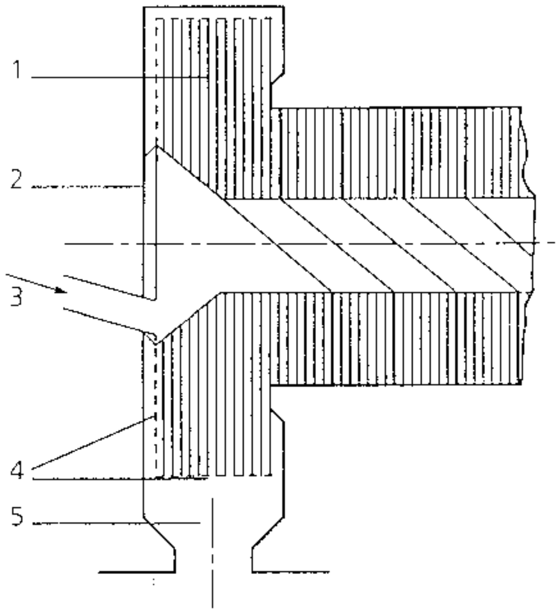


Figure 14 Juice end of an RT2 extractor (40). 1, Transversal screens; 2, front casing; 3, juice and cossettes mixture inlet; 4, frontal and peripheral screens; 5, juice outlet to the circulation tank.

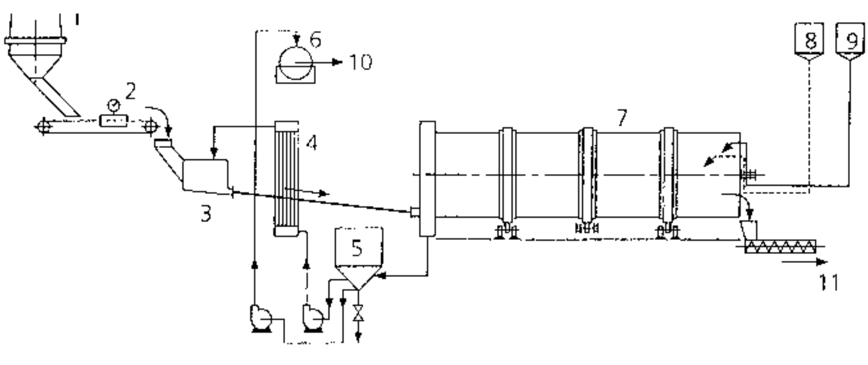


Figure 15 RT2 extractor (40). 1, Slicer; 2, cossettes belt and belt weighing scale; 3, scalder; 4, circulation juice heater; 5, circulation juice tank; 6, fine pulp separator; 7, RT2 drum extractor; 8, press water tank; 9, fresh water tank; 10, raw juice to prelimer; 11, exhausted cossettes.

shorter. Even more simplified is the RT5 extractor, in which the idle times are shorter and the mixing phase is increased by about 7.5% (27).

The most common RT5 extractor has a diameter of 6.25 m and a length of 49 m. Its nominal capacity is 7500 t/d with sugar losses of 0.20% on beet at a draft of 115 kg/100 kg beet. It is capable of processing (with higher losses and draft) up to 12,000 t/d. The largest model, of diameter 7.6 m and length 61 m, has a nominal capacity of 12,000 t/d. It is important that the quality of the cossettes gives a good juice separation, which is obtained with a high Swedish number (~15) and a small number of fines (21).

B. Plate Conveyor De Smet Extractor

This Belgian equipment is the adaptation by the industry of an extractor of vegetable oil from seeds using solvents (Fig. 16). It consists of a horizontal perforated plate belt conveyor about 30 m long, which may reach 7 m. On this conveyor, a 1-m-thick layer of cossettes is placed. The conveyor moves forward at low speed so that the cossettes are transported from the inlet to the outlet in about 75 min. Above this layer of cossettes 18 juice distributors are installed. At the tail of the extractor, the last distributors are fed with press water and fresh water (21).

The juice distributors are fed from pumps that are arranged in groups of three in one housing on a common shaft and are driven by one motor. Each pump receives the juice from the preceding slopped collecting hopper, which is installed between the upper and the lower belt. Floats are located in every hopper to prevent the intrusion of air and the excess juice is allowed to overflow into the next hopper. The cossettes are heated before they are deposited on the diffuser belt. They pass through an inclined trough and are preheated countercurrently with juice from the diffuser. The cooled juice is withdrawn from this trough and sent to the process. Heated circulation flumes the cossettes through a specially designed pipe to the diffuser belt, where the thickness of the cossette layer can be regulated by an adjustable dampening device (18).

An equipment is used that is similar to the cane extractor. If the pH value and calcium concentration of the water are at the right levels, the temperature inside the extractor can reach 75–77°C without juice percolation problems. The retention time of the cossettes is about 75 min. The average juice retention time is between 30 and 40 min. The main operating difficulty with this kind of extractor comes from foam formation. Antifoaming agents (derivatives of fatty acid and products) are generally used at levels of 100–150 g/t of beet (21).

C. Chain-Type Extractors

The first continuous beet extractors, which were constructed in around 1930, were the chain-type Olier extractor in France and the Silver chain extractor in

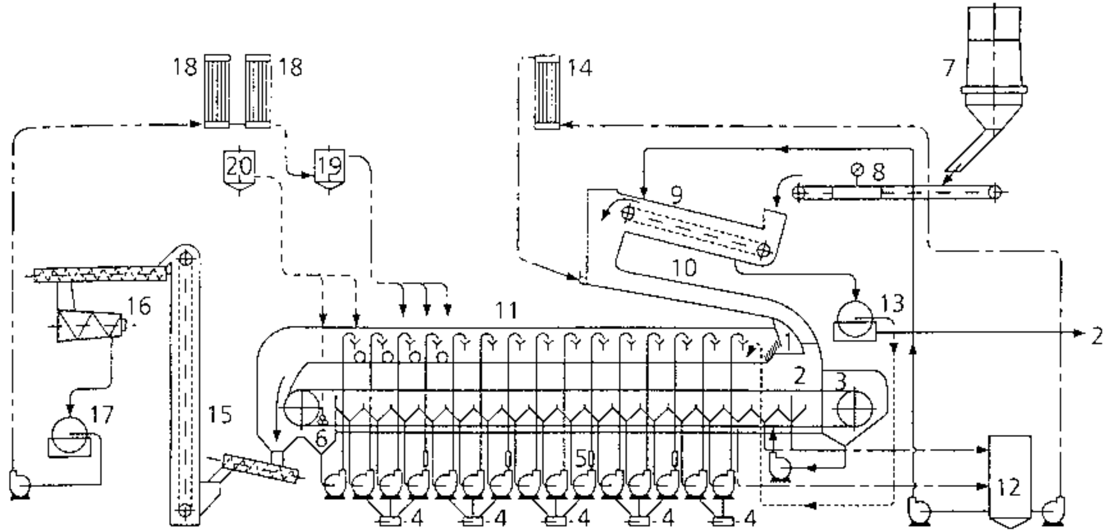


Figure 16 De Smet extractor (40). 1, Cossette layer leveler; 2, cossettes layer; 3, plate conveyor; 4, juice pumps; 5, heat exchangers; 6, flushing device; 7, slicing machine; 8, belt weighing scale; 9, raw juice/cossettes heat exchanger (scalder); 10, cossette inlet tube; 11, extractor; 12, circulation juice tank; 13, fine-pulp separator; 14, circulation juice heat exchanger; 15, exhausted cossettes elevator; 16, pulp presses; 17, press water fine-pulp separator; 18, press water heat exchangers; 19, press water tank; 20, fresh water tank; 21, raw juice to prelimer. — --- — Press water; ----- fresh water; — - —- circulation juice; ——— raw juice; ··· ··· raw juice fine pulp.

the United States (Fig. 17). They consisted of a series of U-shaped cells forming a serpentine tube. Cossettes were transported in the tube by transverse screens moved by two strong chains. The necessary heat was supplied by steam jackets fitted around the head end of the extractor. Some other systems of chain extractors were also developed (Oppermann & Deichmann, J-diffusion). These extractors are now generally out of use, chiefly because it is difficult to build for large throughputs and also because of chain wear (21).

D. Tower Extractors

Two models of tower extractors have been developed simultaneously in Germany by BMA and Buckau-Wolf (Fig. 18). The models are comparable in their principle of two main and distinct parts: the countercurrent mixer and the extraction tower. The tower is a 14- to 20-m-high cylinder. Inside the tower, a tubular shaft rotates slowly at 0.2–0.8 min^{-1}. Special steel pieces of helicoidal shape or flights are fitted on the shaft and give the cossettes their upward movement (Fig. 19). The juice and the cossettes move countercurrently in the approximately 2-m-wide space between the outer casing and the inner shaft. Steel elements (stationery flights) are fitted on the internal side of the tower wall to prevent the whole of the cossette mass rotating with the shaft.

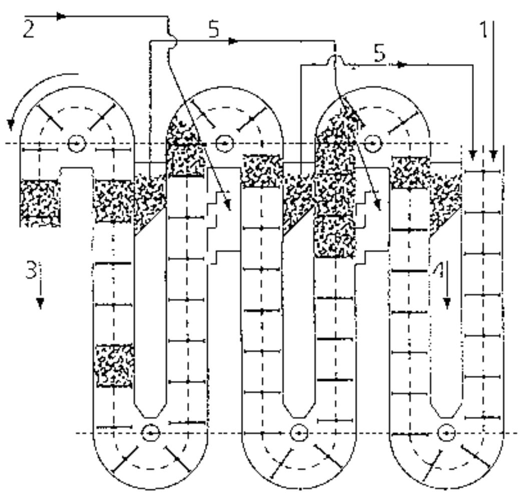


Figure 17 Silver chain extractor (40). 1, Cossettes inlet; 2, fresh water inlet; 3, exhausted cossettes outlet; 4, raw juice outlet; 5, juice transfer.

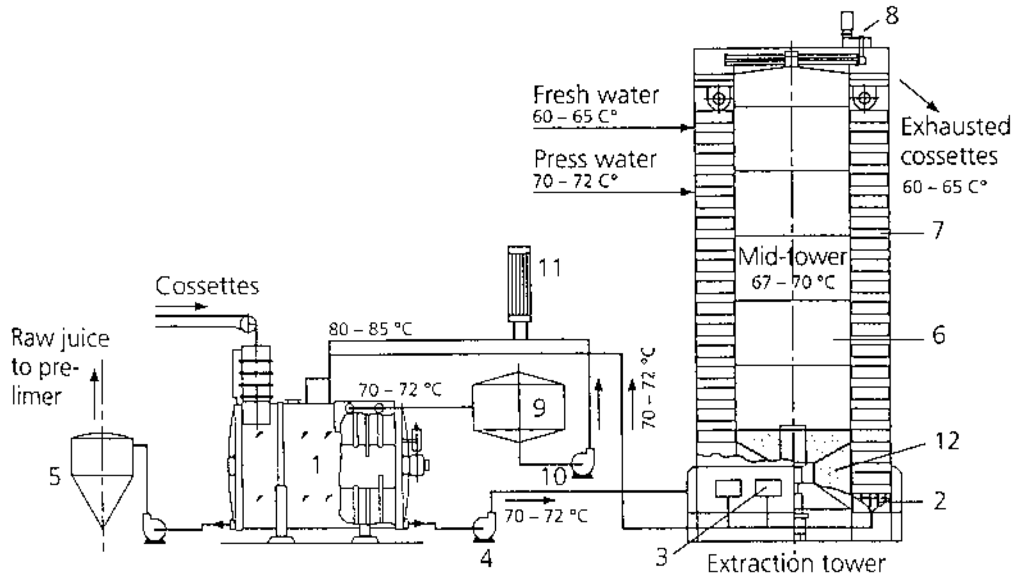


Figure 18 Tower extractor with countercurrent mixer (40). 1, Countercurrent mixer; 2, bottom screens; 3, side screens; 4, cossette/juice mixture pump; 5, sand separator; 6, tower shaft with attached flights; 7, stationary flights (wings); 8, tower shaft drive; 9, foam separator; 10, circulation juice pump; 11, circulation juice heat exchanger; 12, tower shaft ballast (water).

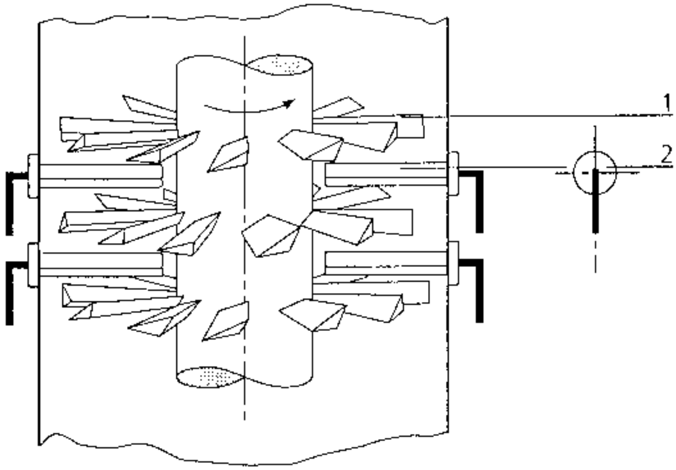


Figure 19 BMA extraction equipment—central shaft and flights (40). 1, Flights; 2, wall arms.

The juice–cossettes mixture at a temperature of 70–73°C is pumped from the countercurrent mixer by the variable-speed pump to the tower wall. The circulation juice leaves the tower through the bottom screens occupying the whole bottom section area. The BMA tower has additional side screens in the lower tower wall. A revolving "scraper" device cleans the bottom screen from the cossettes. The juice then passes a cyclone sand separator and heat exchanger and enters the countercurrent mixer.

The press water and fresh water enter through two (radial header) pipes with several inlets. The control of water feed consists of a level sensor in the tower that actuates the fresh water inlet valve. The cossettes are extracted by horizontal screws placed at a higher level than the water inlet, so that the cossettes are drained before being removed from the tower (21).

The packing of the juice–cossettes mixture depends on the rotational speed of the tower shaft. An increase in the speed reduces the packing, consequently decreasing the cossettes retention time and increasing the retention time dispersion. The consequence of these two phenomena is an increase in the sugar content of the exhausted cossettes. A lower rotating speed increases the packing in the tower and consequently the retention time, which gives better exhaustion, but it also reduces the permeability of the cossette mass and hence the throughput of the bottom screen. The necessary power for the drive of the tower shaft depends on the packing of the cossettes in the tower. The power uptake is a measure of that, as is the torque on the center shaft. The manufacturer recommends a packing of 650–700 kg of cossettes per cubic millimeter. Blocking of the bottom screens is controlled by pressure measurement above and below the bottom screens.

The Buckau Wolf tower extractors differ mainly in the following aspects:

- Position of extraction water inlets, which are placed in rotating arms attached to the tower shaft
- Configuration of the bottom screens without side screens
- Shape of the bottom scraper inside which the cossettes–juice mixture inlet is fitted
- Slope (form) and size of the rotating transport elements (flights)
- Absence of side screens
- Heating arrangement; the necessary, flow of juice is picked up at the outlet of the tower and passes through the heater before being introduced in the countercurrent mixer

Tower extractors work with cossettes of Silin numbers between 5 and 7 m/100 g. They also need a low content of fine particles to guarantee good juice transport. As in the case with DDS extractors, the rigidity of cossettes is improved by extraction water treatments such as acidification and calcium sulfate addition. Thus, it is now possible to operate these extractors at temperatures of up to 72–73°C.

The biggest extractors now constructed by BMA and Buckau have a nominal throughput of 10,000 t/d. The BMA tower has a diameter of 11 m and a height of 21.6 m. The maximal practicable throughput can exceed the nominal value by more than about 15%. The BMA tower extractor of Hohenau Sugana sugar factory has a daily slice capacity of 10,000 t. At a draft value of 109%, sugar losses of 0.23% on beet are realized with beet containing an average of 20% sugar (21).

E. Trough (DDS) Extractor

This extractor was invented by Brüniche–Olsen and developed by DDS (De Danske Sukkerfabrikker) in the early 1950s (Fig. 20). In the United States, it is known as the Silver DDS slope extractor. It consists essentially of a U-shaped sloping vessel in which two overlapping screws with opposite pitches rotate. Fresh cossettes fall from a conveyor belt to the lower end. The cossettes are transported upward by the two screws to a paddle wheel, which lifts the exhausted cossettes out of the extractor. The raw juice leaves the extractor through a screen at the bottom end. The lower section of the extractor works in a similar way to the juice-cossettes heat exchangers: the juice is cooled and the cossettes are heated. The temperature difference between raw juice and fresh cossettes is

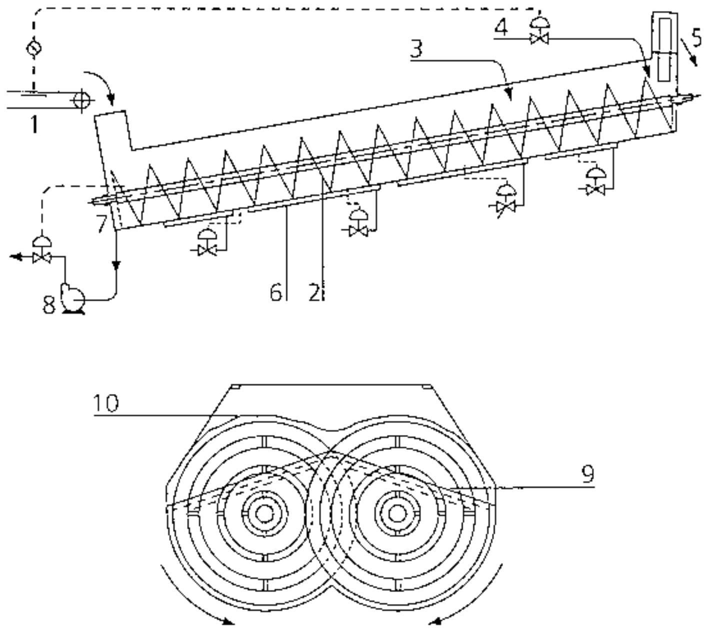


Figure 20 DDS extractor—longitudinal and cross-sectional view (40). 1, Cossettes conveyor and scale; 2, screw elements; 3, press water inlet; 4, fresh water inlet; 5, exhausted cossettes; 6, heating jackets; 7, juice screen; 8, raw juice pump; 9, cossettes level; 10, juice level.

about 15°C. The necessary heat is supplied by 12 steam jackets having temperature controls. There is no circulation juice.

At the nominal capacity of the extractor, the average retention time of the cossettes is between 125 and 140 min. The packing of the cossettes is high at about 700 to 730 kg of cossettes per cubic millimeter. The mean juice retention time is about 55 min.

For a regular juice flow, it is very important that the permeability of cossettes remain high. Figure 20 shows respectively the normal levels of juice and cossettes when the permeability of the cossettes is correct. In this case, the entrainment of the mass of cossettes by the screws gives a higher level of cossettes and juice in the middle of the extractor.

If the mush content is low, i.e., less than 5, it is possible to process cossettes with a Silin number of 10 m/100 g. The DDS extractors are, however, normally fed with cossettes having a Silin number of 7–8. The maximal nominal daily capacity of this type of extractor is 3600 t/d for equipment that is 28 m long and 8.5 m wide (21). This extractor can work with 40% overcapacity (28).

In Fig. 34 is given a general automation and control diagram of a beet extraction tower and in Fig. 35 the same diagram of a DDS beet extraction trough. In Fig. 36 are explained the symbols of automation and control used in Figs. 34 and 35.

VIII. MASS AND HEAT BALANCE OF THE EXTRACTION

All of the industrial extractors follow the general procedure in Fig. 8. Exhausted cossettes are pressed and the press water is reintroduced into the extractor. This flow of recycled water is supplemented by the addition of fresh water.

Figure 21 gives an example of a mass balance calculated according to the following theoretical conditions:

Sugar content of cossettes	17%
Marc content of fresh cossettes	4.5%
Dry substance content of exhausted cossettes	10.55%
Dry substance content of pressed pulp	25%
Draft	120% on beet
Press water purity	80%
Raw juice purity	89.5%
Known sugar losses	0.27% on beet
Unknown sugar losses	0.10% on beet

The balance shows that the mass of exhausted cossettes extracted from the extractor is significantly less than the mass of fresh cossettes. This is mainly a consequence of the leaching and pressing effect that takes place in most extractors (21).

A mass and heat balance of a DDS extractor are given in Fig. 22 (28). Initially the DDS extractor, which produced cold diffusion juice 15°C above ambient temperature, needed less heat (approximately 1% beets standard steam with 550 kcal/kg or 2300 kJ/kg heat of evaporation), whereas the other extractors (RT, tower, etc.) needed more heat (approximately 5% beets standard steam) because their diffusion juice was hot (50°C). This changed in the 1980s. By modification inside the countercurrent mixer in tower extractors the diffusion juice produced was also cold; subsequently, the heat consumption was less (1% beets standard steam) (29). See also Fig. 23 where, according to Baloh, the correlation between the steam consumption in the extraction, the draft, and the temperature of raw juice is given. The lowest steam consumption is achieved by low draft 105% on beet and low temperature of raw juice 15°C (29).

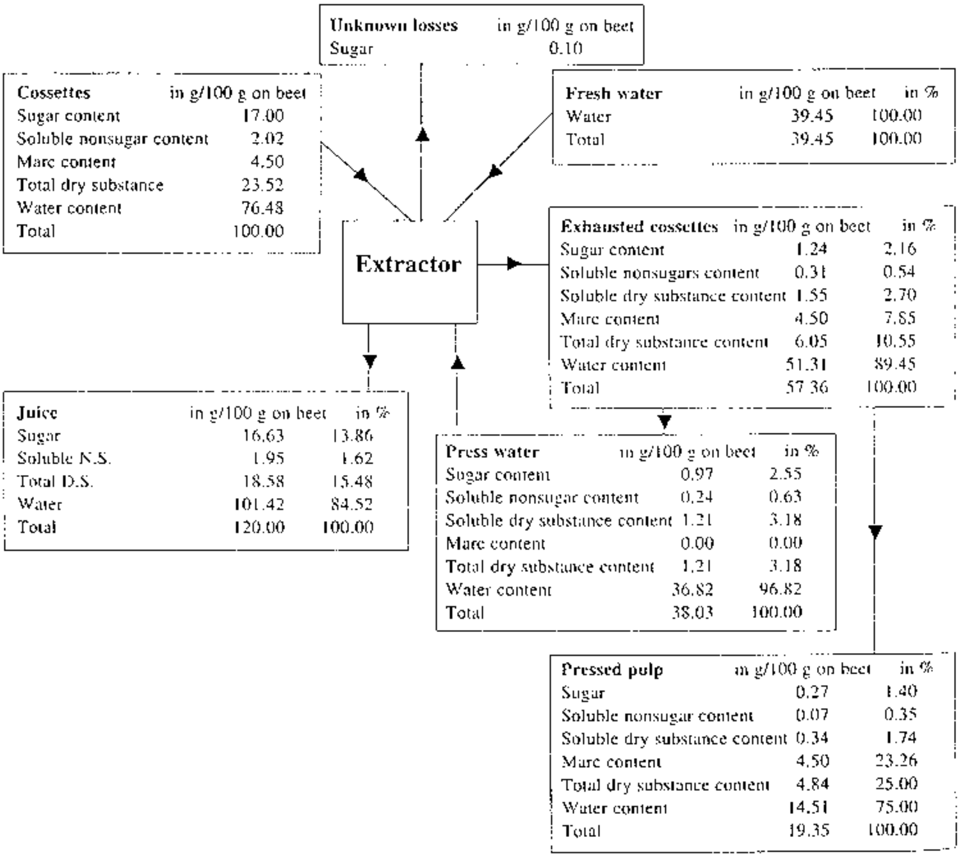
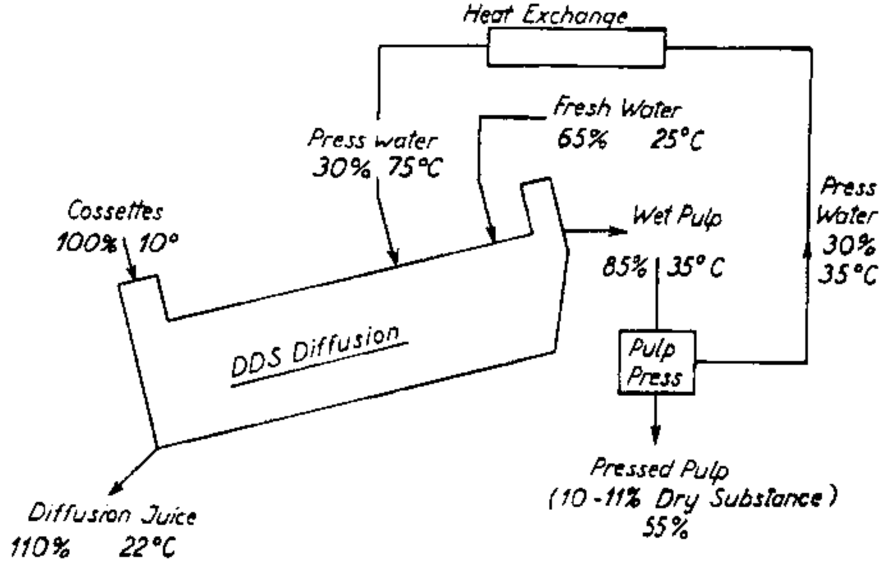


Figure 21 Example of an extraction mass balance (40).

IX. OPTIMIZING THE ECONOMIC PERFORMANCE OF BEET EXTRACTOR

Beet sugar manufacture yields three products: sugar, beet pulp, and molasses. The relative value of these products and the costs of processing materials and aids (i.e., mainly cost of fuel), as well as the processing of any additional juice product, determines the optimum draft.

Van der Poel et al. demonstrated how the final fractions of sucrose extracted can be divided between white sugar and molasses by establishing the relationship between the extraction of sucrose to that of potassium (30). Anderson assumes that 60% of the decrease in sugar loss to the pulp will be recovered



Heat Balance

Outlet.

110	kgs. juice 22°C spec. heat	0.9	2180 cal.	
85	kgs. wet pulp 35°C spec. heat	1.0	2975 -	
				5155

Inlet.

100	kgs. cossettes 10° C spec. heat	0.9	900 cal.	
30	kgs. press water 75°C spec. heat	1.0	2250 -	
65	kgs. fresh water 25°C spec. heat	1.0	1625	
				4775
				380

Heat Supply.

corresponding to $\frac{380}{550}$ ~ 0.7% steam on beets

Figure 22 Mass and heat balance of a DDS extractor (28).

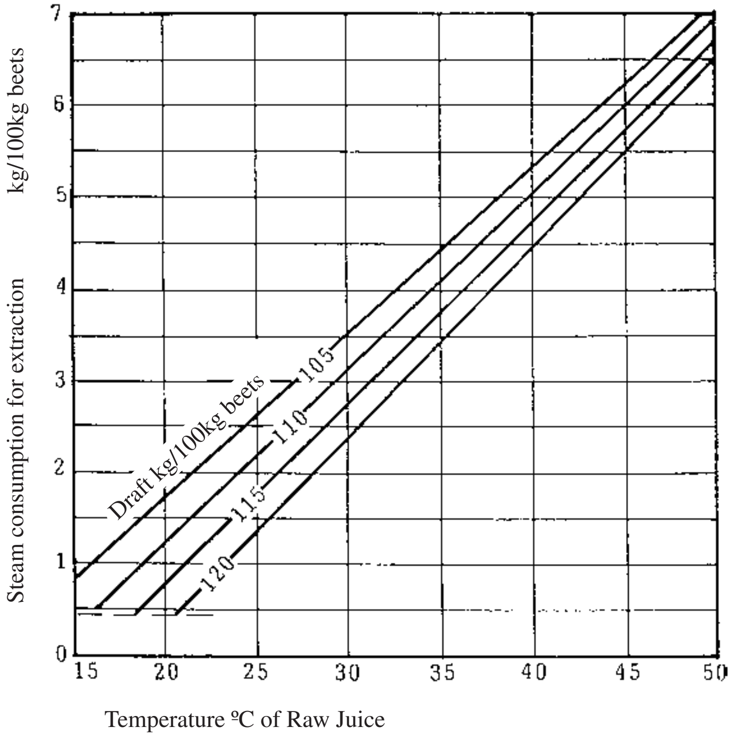


Figure 23 Correlation of steam consumption in the extraction, the draft, and the temperature of raw juice (29).

as white sugar for use in the DDS Isocost chart. Thus, the ratio of pulp, sugar, and molasses can be estimated (31).

Production costs can then be assigned to the changing level of draft and impurities, such as in purification, electrical costs for pumping, processing aids, and evaporation. The primary influence on cost is typically draft vs. evaporation cost. Combination of the values of the three products vs. the costs of processing allows the calculation of the overall economic impact of changing the extraction parameters, from which an optimum can be derived.

A typical example of an optimization calculation as used at CSM was given by Van der Poel et al. (32). The figures show the optimum value at a sugar loss in pressed pulp of 0.352% on beet and draft 120% on beet. The absolute levels of the yields are not right because many processing costs, such as personnel and maintenance, are not included. However, the differences in relation to the sugar losses in pressed pulp as well as the position of the optimum (draft and sugar loss in pulp) are correct.

Adamopoulos et al. studied the optimization of the extraction process in DDS extractor of 3000 t/d on the basis of economical criteria (cost of sugar production), concluding that the optimal values for draft are 107–111% on beets, the losses 0.11–0.24% on beets, the temperature 70–75°C (4).

Gudmundson described computer programs developed by the Swedish Sugar Company, where an energy balance can be run to judge the impact across the factory. A second program calculates the optimum between the draft and the overall factory operation (33).

Christodoulou described the result of trial test runs of pulp presses in two different factories of Hellenic Sugar Industry, Greece. Not only do the operating parameters of extraction influence the good pressability of the pulp; the type of extraction equipment does so as well (3).

Budicek and Hladikovà presented an econometric model of a sugar factory that is not limited to the extraction stage. Decision making is based on calculation of the sugar factory's annual gross profit. The model presents mass flows as well as cost–benefit calculations. Mass balances consist of processed beet, accompanying impurities, and processing aids, thus providing an overall view of the main products and byproducts, including their production costs (34).

X. COMPOSITION OF SUGAR CANE

Sugar cane is a type of giant grass belonging to the family, botanically known as "*Saccharum*," a generic name for sugar cane. One of the cultivated species of *Saccharum* is known as *Saccharum officinarum*. The wild form of the sugar cane belongs to the family, botanically known as "*Saccharum spontaneum*." The cultivated wild varieties of sugar cane have played a very important role in the evolution of new commercial varieties of sugar cane, now grown by hybridization and selection techniques. Thus, all the sugar cane varieties grown in different countries have the parents belonging to the *Saccharum officinarum* and *Saccharum spontaneum* and, to some extent, other species (Fig. 24) (35). The chemical composition of sugar cane varies widely depending on many factors. Therefore, only indicative average figures in percentage are given below (36):

- 75 water
- 25 solids
  - 13 fiber
  - 12 soluble solids
    - 10.5 sugar
      - 9.8 sucrose

0.7 invert sugar
1.5 nonsugars
0.8 organic nonsugars
0.2 nitrogenous substances
0.06 proteins
0.14 amino acids
0.1 nitrogen-free substances
0.03 carboxylic acids
0.02 starch, wax, fats, phosphatides
0.5 unidentified substances
0.7 mineral water

XI. EXTERNAL STRUCTURE OF THE SUGAR CANE PLANT

A. Stalk

The sugar cane plant consists of a number of unbranched stalks that store the sucrose. The stalks are tall and slender, roughly circular in cross-section, and bear two rows of leaves. The stalks are divided by the nodes, which are distinctive areas where the leaves are attached (one leaf at each node) (Fig. 24).

Situated within the root band is the bud. There is normally one bud at each node. The buds are situated on alternate sides of the stem. The bud is an embryonic shoot consisting of a small stem bearing miniature leaves, the outer ones of which are scales. The size and shape of the buds as well as the form of the outer scales or flange vary considerably with variety (Fig. 25).

B. Leaf

The leaves are arranged alternately a single leaf arising from each node (Fig. 26). They increase in size as the plant develops. Trash is formed when the leaf ages and dies.

C. Root System

There are three main types of sugar cane root: sett roots, shoot roots, and mature roots. The sett roots develop from the primordia in the root band of the cutting. The shoot roots develop from the root primordia on the lower nodes of young shoots (Fig. 27). The mature roots arise from root bands of shoots after the initial flash of shoot roots (37).

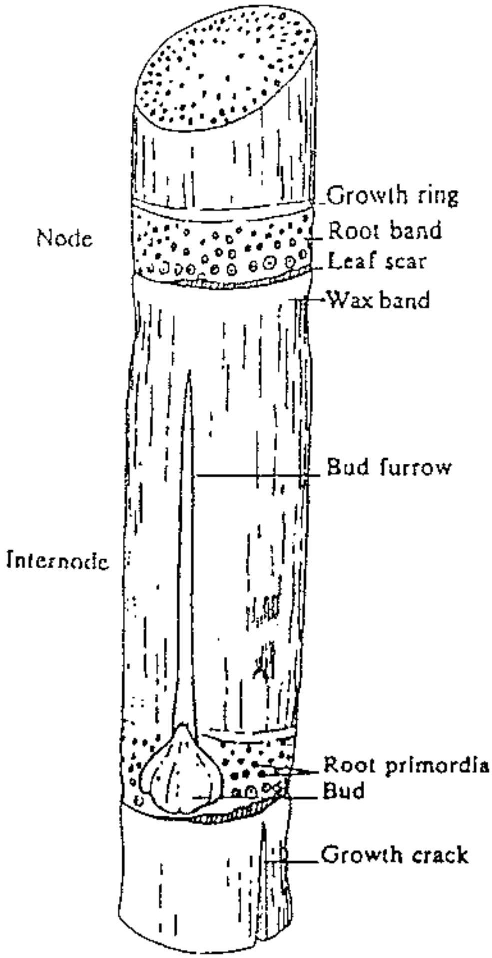


Figure 24 Parts of sugar cane stem (40).

XII. TECHNICAL EXTRACTION OF SUGAR FROM CANE

A. Cane Unloading

Since cane unloading is a materials handling problem, the methods adopted depend on the methods used for harvesting the cane and transporting from field to factory. Large factories use automated cane handling to a great extent. Where cane payment or factory control systems demand, the cane unloading station must often include weighing the cane, recording its origins and sampling for the

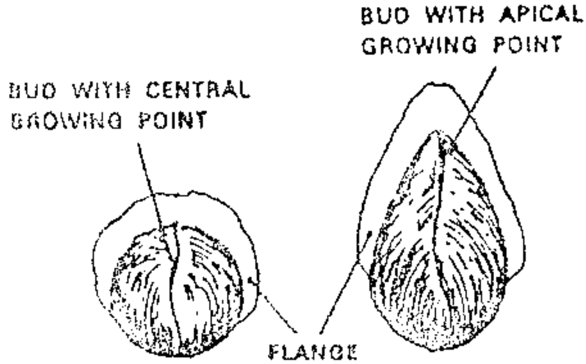


Figure 25 Buds are located in root bands on nodes of sugar cane stems (40).

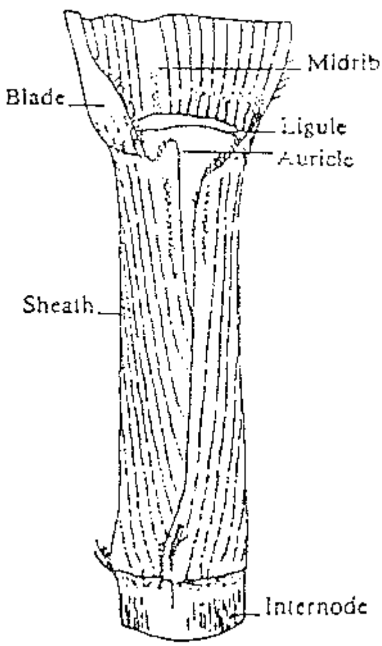


Figure 26 Structure of a sugar cane leaf (40).

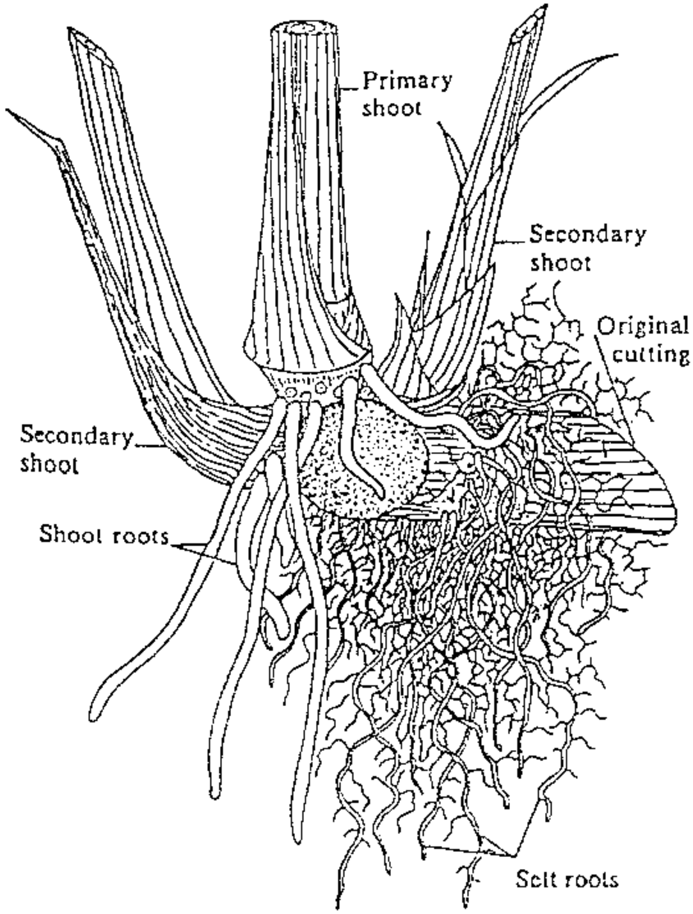


Figure 27 Young cane plant showing two kinds of roots: sett roots and shoot roots (40).

determination of cane quality. In the end the cane handling system must supply the cane to the factory cane preparation equipment in as uniform a stream as possible and at the appropriate rate. In some places—notably Hawaii—the cane is washed, but this operation can be avoided by good harvesting and handling methods.

B. Cane Preparation

For best efficiency of the extraction plant (crushing or diffusion) the cane must be as finely divided as is economically feasible. Modern factories use heavy-duty, swing hammer "shredders" to comminute the cane to a fibrous mass where the largest particles are pieces of rind of about 100 mm or shorter in length and of cross-section 4 × 2 mm or smaller. The rind is the toughest part of the stalk where the "fibrovascular bundles" are most tightly packed together. In the interior of the stalk and particularly in the "internode" sections, the fibrovascular bundles are less densely packed and there are more juice cells and juice.

C. Description of Heavy-Duty Shredders

Figure 28 is a diagrammatic representation of the cross-section of a swing hammer shredder. The swept diameter of the hammers ranges from 1500 to 1800 mm. The rotor is typically 2100 mm long, rotates at about 1000 min^{-1}, and is driven via a reduction gear box by a steam turbine of up to 4500 kW. The billets of chopped cane enter at the top [1] and slide down or are thrown against the feed plate [2]. Below the feed plate is a series of heavy grid bars [3] that retard the progress of the cane, retaining it in the range of the hammers to be broken into fine fibrous particles. The clearance between the extended hammer tips and the grid bars is often 2 mm or less. Shredded cane is discharged at [4]. A set of hammers numbers between 100 and 200, and each hammer weighs 15–20 kg.

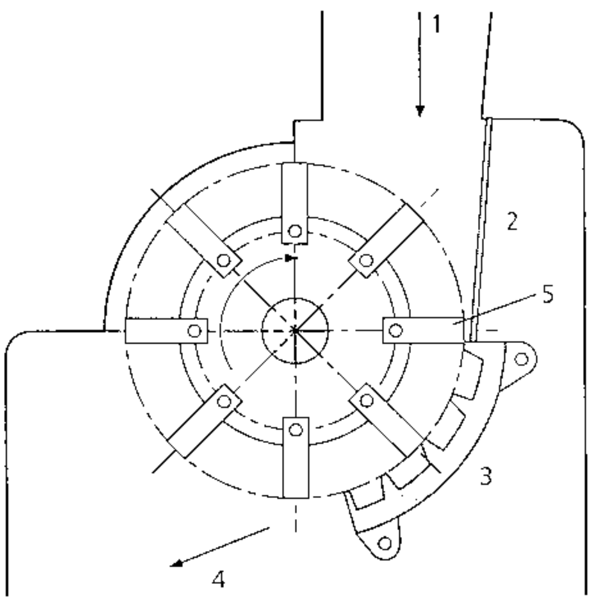


Figure 28 Schematic cross-section drawing of heavy-duty cane shredder (40). 1, Cane feed; 2, feed plate; 3, grid; 4, prepared cane discharge; 5, hammer.

Static and dynamic balancing of the rotor is essential. The hammers are hard faced by welding or have hard replaceable inserts, and a refurbished set of hammers must often be provided at weekly intervals. A high amount of soil in the cane supply requires more frequent replacement if throughput and extraction efficiency are to be maintained at acceptable levels (38).

XIII. CANE MILLS

A. Crushing Trains

Extraction of sugar from cane by "crushing" or "grinding" is carried out in a series of roller mills. The separation is carried out by volumetric reduction aided by dilution of residual juice by counterflow washing. The normal "compound imbibition" system is illustrated for a train of four mills in Fig. 29. For best results the imbibition liquid applied to the feed to the final mill is hot water—usually condensate at up to 85°C. The juice expressed from the first and second mills is sent to process and is called "mixed juice." The whole milling process is usually completed in about 20 min. Uniform application of imbibition liquid across the bagasse "blanket" is important, although the whole blanket is satu-

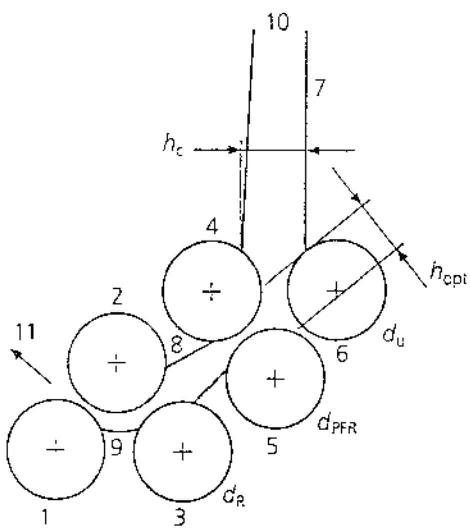


Figure 29 Schematic arrangement of modern six-roll crushing mill showing diameters and depths (40). 1, Delivery roll; 2, top roll; 3, feed roll; 4, top pressure feeder roll; 5, bottom pressure feeder roll; 6, underfeed roll; 7, feed chute; 8, pressure feeder chute; 9, trash plate; 10, feed cane or bagasse; 11, delivery bagasse.

rated with juice between the first pair of rolls at which juice is expressed and there is no evidence that premixing of imbibition liquid and bagasse improves extraction efficiency.

A modern crushing unit (mill) consists of up to six rolls arranged as shown in Fig. 30. The three main rolls (delivery–1, top–2, feed–3) are of nearly equal diameter (except for differing wear). In the best modern practice the pressure feed rolls 4 and 5 are of the same diameter as is the underfeed roll 6. Many other combinations of auxiliary rolls and other "feeding devices" have been used, but the six-roll mill arrangement illustrated gives high throughput and extraction efficiency (38).

XIV. CANE DIFFUSERS

There are a number of reports of cane diffusers (the common term diffuser is used here, although technically speaking this is an extractor) installed before 1900, and at various other times and in different countries. However, it was only with the successful introduction of beet extractors that cane extraction (diffusion) became a practical scheme.

A batch cane diffusion system operated in Egypt for more than 50 years, but since the first successful continuous cane diffusers were installed in the early 1960s, diffusers have been operated as continuous countercurrent solid-liquid systems. Early designs evolved from beet diffusers, and even the commonly used name "diffuser" came from the beet industry, although the terminology is not really appropriate in the context of extraction of juice from cane.

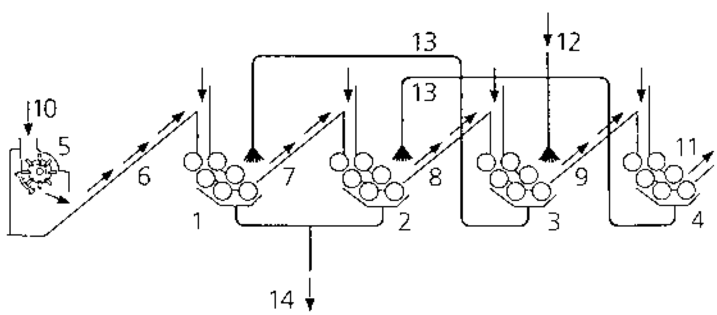


Figure 30 Diagrammatic representation of a four-mill crushing train with ordinary compound imbibition (40). 1, 2, 3, 4, Crushing units—mills 1 to 4; 5, shredder; 6, drag conveyor or rubber belt—prepared cane elevator; 7, 8, 9, drag conveyors—intermediate carriers; 10, cane feed to shredder; 11, final bagasse to boilers, storage, or otherwise; 12, imbibition water; 13, imbibition recirculation system; 14, mixed juice to process.

Differences between cane and beet extraction hinge around the considerable differences in raw material to be extracted. Although beet is conveniently cut into cossettes, it was only when adequate preparation of cane for extraction was achieved that cane diffuser installations became successful. A large number of published reports on cane diffusion from 1965 to 1975 reflected the interest generated at the adoption of cane diffusion. Since that time its adoption has been rapid in some countries, particularly in southern Africa, where roughly 80% of all cane are processed in diffusers. However, milling is still the predominant extraction process in a large number of cane sugar–producing areas.

There are essentially two variants of the process, termed *bagasse diffusion* and *cane diffusion*. The former involves a single mill ahead of the diffuser, and in the later prepared cane is accepted directly into the diffuser. Early installations favored bagasse diffusers because they represented a smaller step-change from milling, and are still required in countries where payment for cane is based on an analysis of first expressed juice. However, cane diffusers have generally shown themselves to be considerably more cost effective and are almost exclusively favored over bagasse diffusers in new installations. Therefore, this chapter covers only cane diffusers.

Diffusers must be provided with well-prepared cane. A dewatering stage, usually one or more mills, is required to dewater the very wet bagasse leaving a diffuser. In some installations a French screw press was used as a dewatering device but proved to be unreliable and subject to considerable wear. Conventional mills are now used universally for this duty. Because of the large amount of liquid to be removed, dewatering is generally done in two stages if four toll mills are used, or else in a single stage using pressure-fed mills (Fig. 30). The types of cane diffuser that have been used can be categorized as follows:

Uncontrolled transport of juice and cossettes (also called true countercurrent diffusers), e.g., DDS, Saturne.

Controlled transport of juice and cossettes (also called moving-bed diffusers). There are either cross-flow moving belt extractors, such as B.M.A., De Smet (Fig. 31), Silver ring, Huletts-type extractors, or other types such as F&S/Van Hengel or Rotocel (39).

Moving bed diffusers are also countercurrent extraction devices but operate on a staged basis. Juice is pumped onto a moving bed of prepared cane or bagasse, about 50–60 m long, in 10–18 stages. A schematic diagram of a cane diffuser is shown in Fig. 31.

The De Smet cane diffuser (Sec. VII) is essentially the same as the De Smet beet extractor. The cane or bagasse bed forms on a horizontal slow-mov-

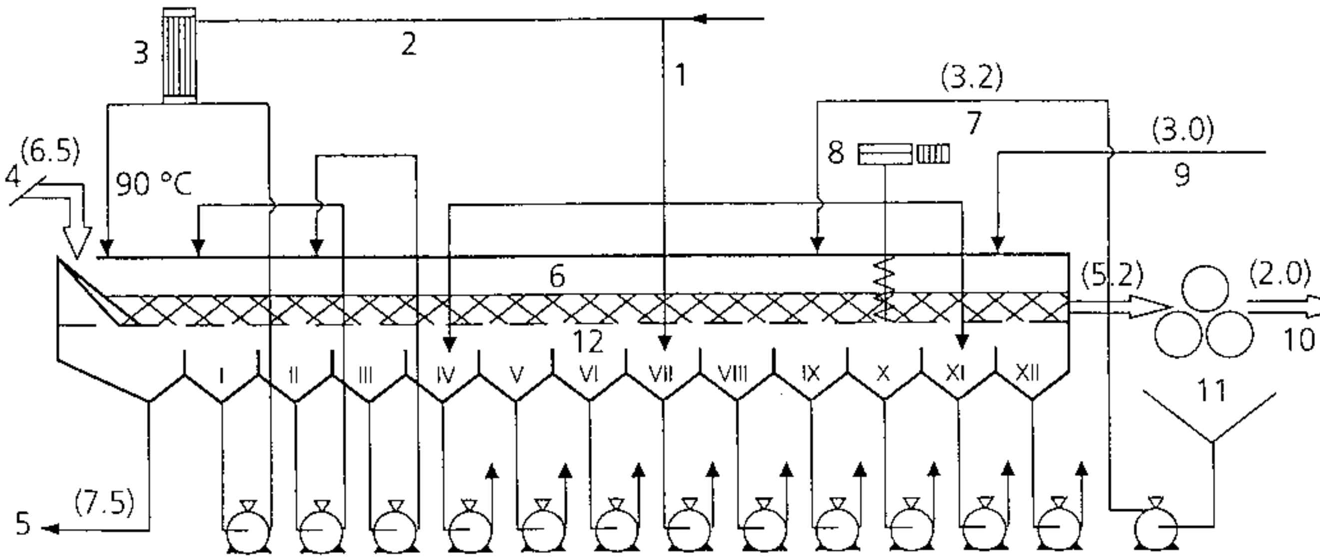


Figure 31 Schematic diagram of a moving-bed cane diffuser (40). 1, Direct injection vapor; 2, heating vapor; 3, heat exchanger; 4, prepared cane; 5, raw juice; 6, diffuser; 7, press water; 8, lifting screws; 9, imbibition water; 10, final bagasse; 11, dewatering mills; 12, stage trays. Figures in brackets: Mass flow rate referred to the fiber rate in bagasse.

ing screen. The Silver ring diffuser is essentially similar, but the screens move in a circle instead of along a straight line. The BMA and Hullets diffusers differ from the De Smet in having a fixed screen, with a series of chains that transport the cane bed across the screen. This generally results in a cheaper diffuser for the same screen area (39). The dragging of cane by chains across the fixed-screen diffuser generally results in the formation of a more compact cane layer at the screen, which affects percolation.

The processing capacity of a cane diffuser–type BMA lies between 2000 (the smallest unit) to 16,000 t/d (the biggest unit), while the same diffuser-type BMA by bagasse processing has a capacity between 3000 (the smallest unit) to 24,000 t/d (the biggest unit).

XV. FACTORS AFFECTING EXTRACTION EFFICIENCY

A. Cane Preparation

The process of breaking down the cane into small pieces is referred to as cane preparation. This is the most important variable affecting extraction in diffusers. If high extraction efficiencies are to be achieved it is essential that the cane be prepared in a heavy-duty shredder (Fig. 28) so that most of the sugar-containing cells of the cane stalk are ruptured. Laboratory and pilot plant work showed very clearly that more intensive preparation of cane makes more of the sucrose containing juice readily accessible to the extracting liquid, minimizing the amount of sucrose that has to be extracted by a much slower diffusion mechanism. Unfortunately, measurement of the degree of cane preparation is difficult and existing measures are not always reliable.

The way in which the cane is prepared is also important. Ideally the type of preparation should result in material where all cells are ruptured but where long fibers are still evident, resulting in a cane bed that is stable and open enough to allow high percolation rates to be achieved. In practice it has been found that this is best achieved in heavy-duty shredders with a minimum of knifing, since intensive knifing reduces the average fiber length.

B. Imbibition Rate

As with any solid-liquid extraction process, the more extracting liquor that is added the easier is the extraction. So it is with cane diffusion, where higher imbibition rates invariably result in higher extraction efficiencies. The amount of imbibition water added is generally related to the quantity of fiber being processed, since it is the fiber that removes with it juices in final bagasse.

There is no maximal or minimal imbibition rate for diffusion. Since high imbibition rates enable a smaller diffuser to be utilized to achieve a given extraction efficiency, the reduction in the cost of the diffuser would have to be balanced against the cost of additional evaporator capacity and/or the cost of steam. Therefore, the optimal imbibition rate for any factory is contingent on local factors at that factory.

C. Effect of Number of Stages

The use of a number of stages rather than a single big mixed tank enables higher concentration difference between sucrose in cane and true countercurrent flow is approached more closely. However, the benefit drops off as the number of stages increases and marginal improvement becomes very small.

D. Effect of Percolation Rate

Although preparation is the most important variable affecting extraction efficiency in a cane diffuser, the percolation rate is probably the next most important variable. This is the rate at which liquid percolates down through the bed of prepared cane. Laboratory and pilot plant studies have shown that an increase in percolation rate promotes the rate of mass transfer and increases the proportion of the juice in open cells that is accessible to the extracting liquid.

E. Effect of Cane Retention Time

The longer the time the prepared cane spends in the diffuser the higher will be the extraction efficiency. Provision of adequate retention time is probably one of the most important design specifications. Since the raw juice offtake from the diffuser is roughly equal to the mass of cane entering the diffuser, juice retention time in the diffuser is nearly twice the retention time of fiber, particularly if the juice trays below the diffuser are not kept empty.

F. Effect of Temperature

High temperatures are advantageous because they increase the rate of extraction. However, this effect is not as important as the effect of preparation and liquid flow rate. Nonetheless it was estimated that an increase in temperature from 75°C to 80°C would lead to an increase in extraction efficiency of about 0.2% sugar on cane. The most important reason for keeping the temperature above 75°C is to control microbiological activity. Generally, diffusers are operated at about 85°C, allowing low-pressure steam to be used for heating purposes (39).

XVI. STRUCTURE AND CHEMICAL COMPOSITION OF CORN

The gross structural features, physical properties, structural details, and composition of corn are described in the literature together with very nice photographs and microphotographs of corn particles (42). A proximate analysis of corn grain is given in Table 3 (42).

XVII. THE WET MILLING PROCESS OF CORN FOR EXTRACTION OF STARCH

Corn is abundant and relatively inexpensive; it has a high starch content and protein of acceptable quantity and quality. Thus, its primary use is for animal feed. It is also processed into valuable food and industrial products, such as ethyl alcohol by fermentation, corn meal by dry milling, and highly refined starch by wet milling. The greatest volume is processed by wet milling to produce starch products and sweetener products for foods. Nonfood products, such as industrial starches, corn gluten feed, and corn gluten meal, are also manufactured.

The wet milling process involves an initial water soak under carefully controlled conditions to soften the kernels. The corn is then milled and its components separated by screening, centrifuging, and washing (Fig. 32), to produce starch, oil, feed byproducts, and sweeteners (by starch hydrolysis). Applications for these products have shown steady growth, which has necessitated major investment to expand production facilities in recent years (43).

Table 3 Proximate Composition of Corn Grain (42)

Component (%, wet basis)	Range	Average
Moisture	7–23	16.0
Starch	61–78	71.7
Protein	6–12	9.5
Fat	3.1–5.7	4.3
Ash (oxide)	1.1–3.9	1.4
Pentosans (as xylose)	5.8–6.6	6.2
Fiber (neutral detergent residue)	8.3–11.9	9.5
Cellulose + lignin (acid detergent residue)	3.3–4.3	3.3
Sugars, total (as glucose)	1.0–3.0	2.6

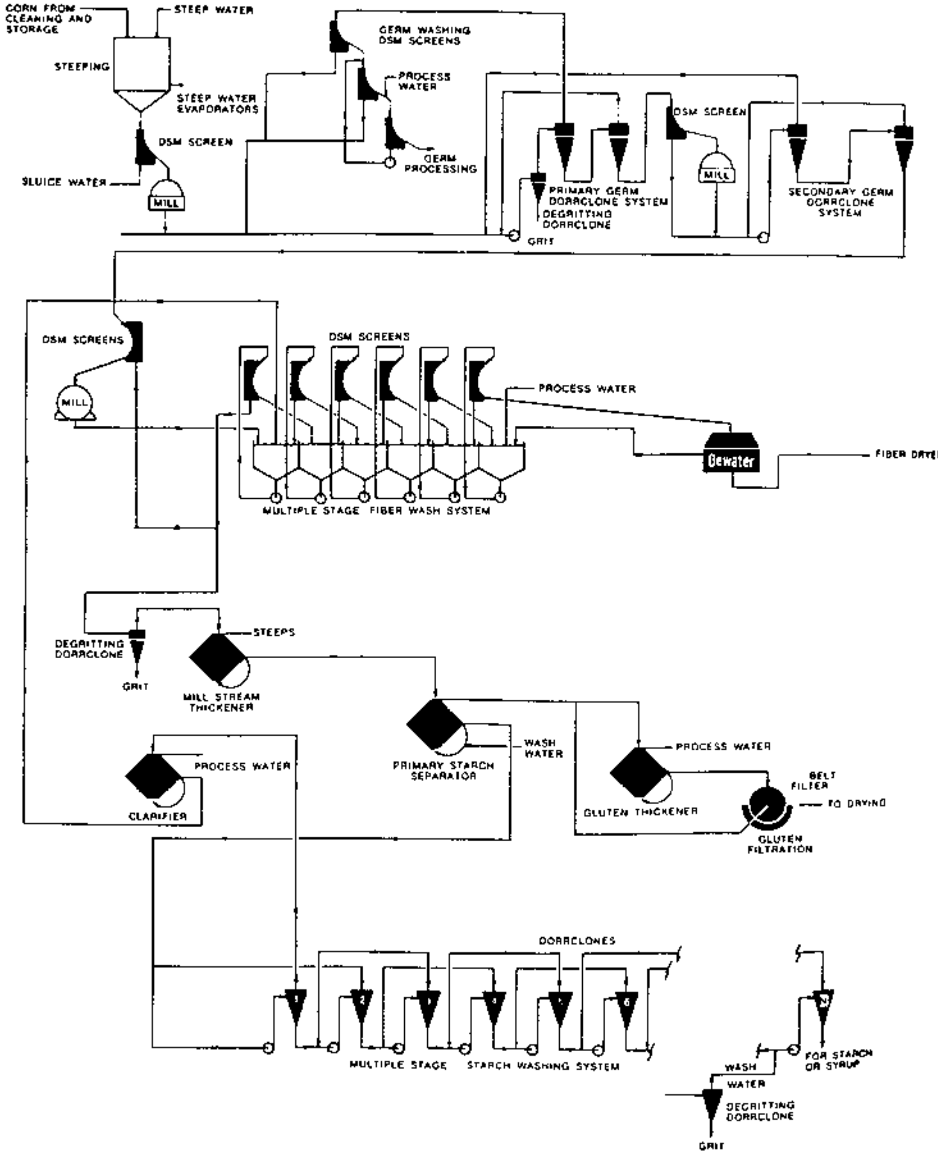


Figure 32 Wet-milling process flow diagram, showing equipment arrangement for the separation of the major components: steepwater, germ, fiber, gluten, and cornstarch (43).

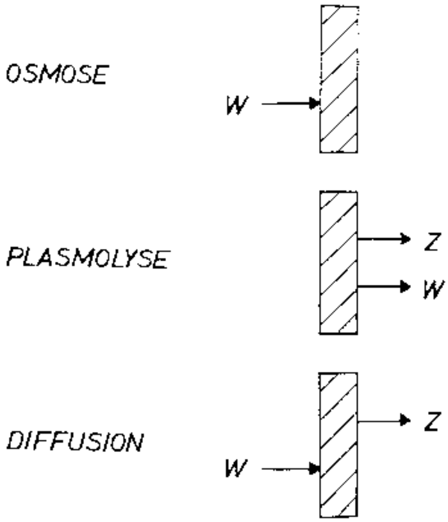


Figure 33 Direction of material transport in correlation to the basic process (schematic), W, water; Z, sugar (19).

A. Steeping

The first critical step in the wet milling of corn is steeping—the soaking of corn in water under controlled processing conditions of temperature, time, sulfur dioxide (SO_2) concentration, lactic acid content, and so forth. These conditions have been found necessary to promote diffusion of the water through the tip cap of the kernel into the germ, endosperm, and their cellular components. Steeping softens the kernels, facilitating separation of components.

Corn is shipped in bulk to the wet milling plants by truck, hopper car, and barge. It is then cleaned on vibrating screens to remove coarse material (retained on 12.7-mm × 1/2-in. openings) and fine material (through 3.18-mm × 1/8-in. openings). These screenings are diverted to animal feed. If they are allowed to remain with the corn, they cause processing problems such as restricted water flow through steeps and screens, increased steep liquor viscosity, and quality problems with the finished starch.

Steeping is accomplished by putting corn into tanks (steeps) that have a capacity of 50–330 t each. The corn is then covered with steepwater, heated to 52°C, and held for 22–50 h. Steeps have cone bottoms with screens so that the water can be separated from the corn and pumped elsewhere or recirculated back to the top of the steep. To maintain steeping temperature, the recirculated flow is heated directly by steam injection or indirectly by heat exchanger. The

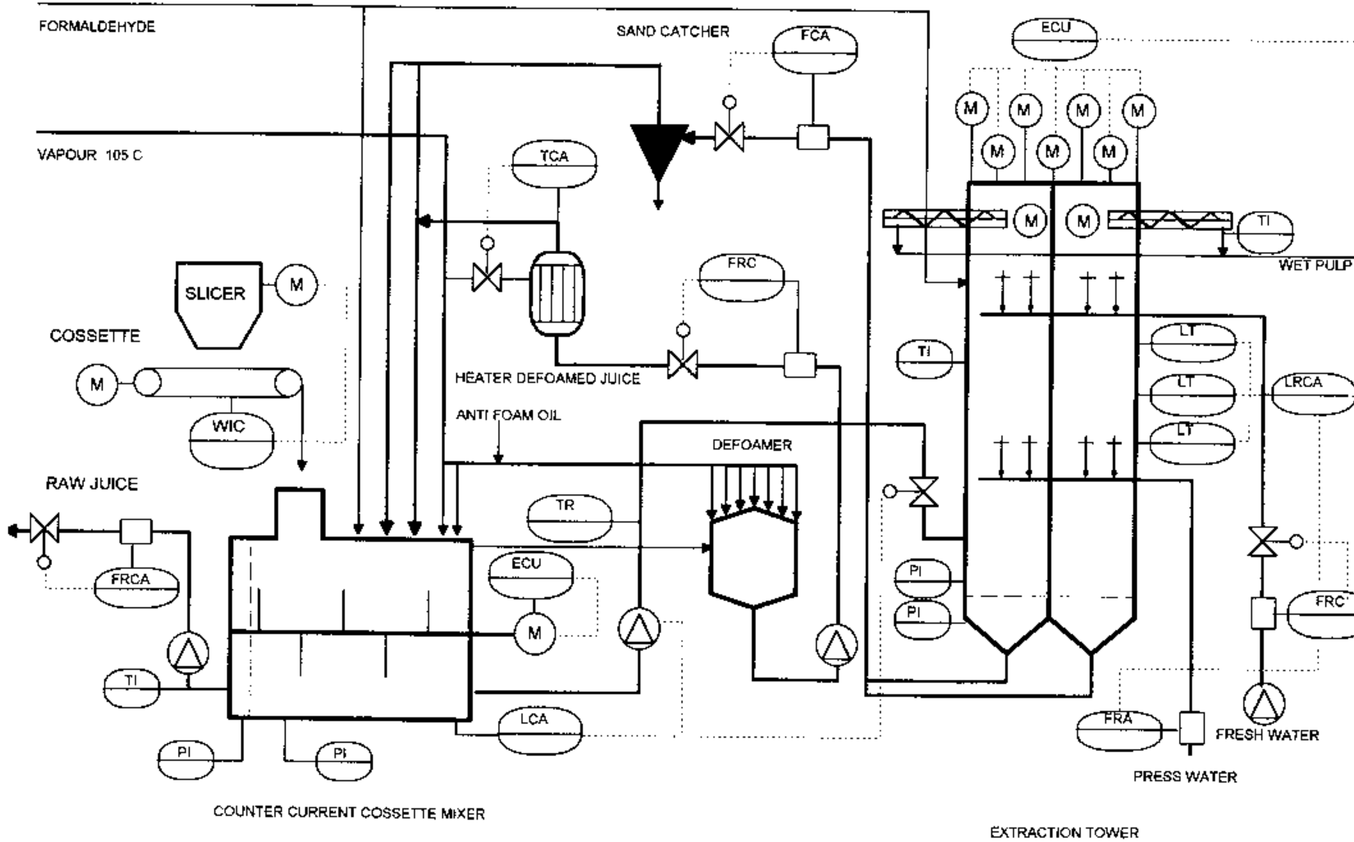


Figure 34 General automation diagram with extraction tower.

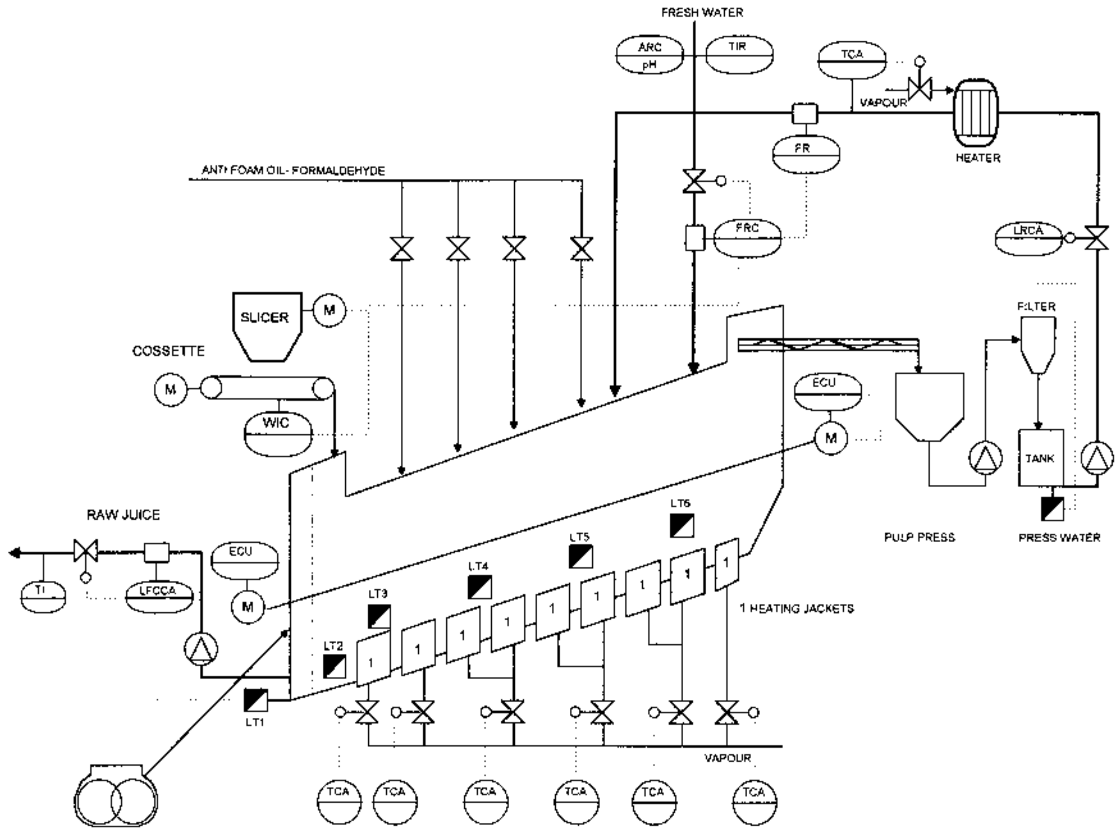


Figure 35 General automation diagram of extraction with DDS trough extraction.

M	Motor
WIC	Weight – indication-control
FRCA	Flow, recording, control, alarm
TI	Temperature Indication
PI	Pressure indication
LCA	Level control alarm
EW	Electric control unit (inverter)
TR	Temperature recording
TCA	Temperature control alarm
FCA	Floco, control – alarm
M	Motor
LRCA	Level, recording, control alarm
LT	Level transmitter
FRA	Flow, recording,alarm

Figure 36 Symbols of automation and control.

water should not exceed 55°C to avoid destroying the bacteria needed to produce lactic acid.

Steeping is a countercurrent system, utilizing a battery of 6–12 or more steep tanks. Steeps are filled one at a time as they become empty. The corn does not move—just the water, which is transferred from one steep to the next. However, steeping is accomplished in one plant by continuously adding dry corn at the top of the steep while continuously withdrawing steeped corn from the bottom.

Water for the steeps originates in the wet milling process, where it accumulates corn solubles. It is treated with SO_2 to a concentration of 0.12–0.20%. The SO_2 is purchased as a liquid or manufactured on site by burning of elemental sulfur. The SO_2 increases the rate of water diffusion into the kernel and assists in breaking down the protein-starch matrix, which is necessary for high starch yield quality.

The SO_2-treated water is added to the steep containing the oldest corn. As the water is advanced from steep to steep, the SO_2 content decreases and bacterial action increases, resulting in the growth of lactic acid bacteria. The desired lactic acid concentration is 16–20% (dry basis) after the water has advanced

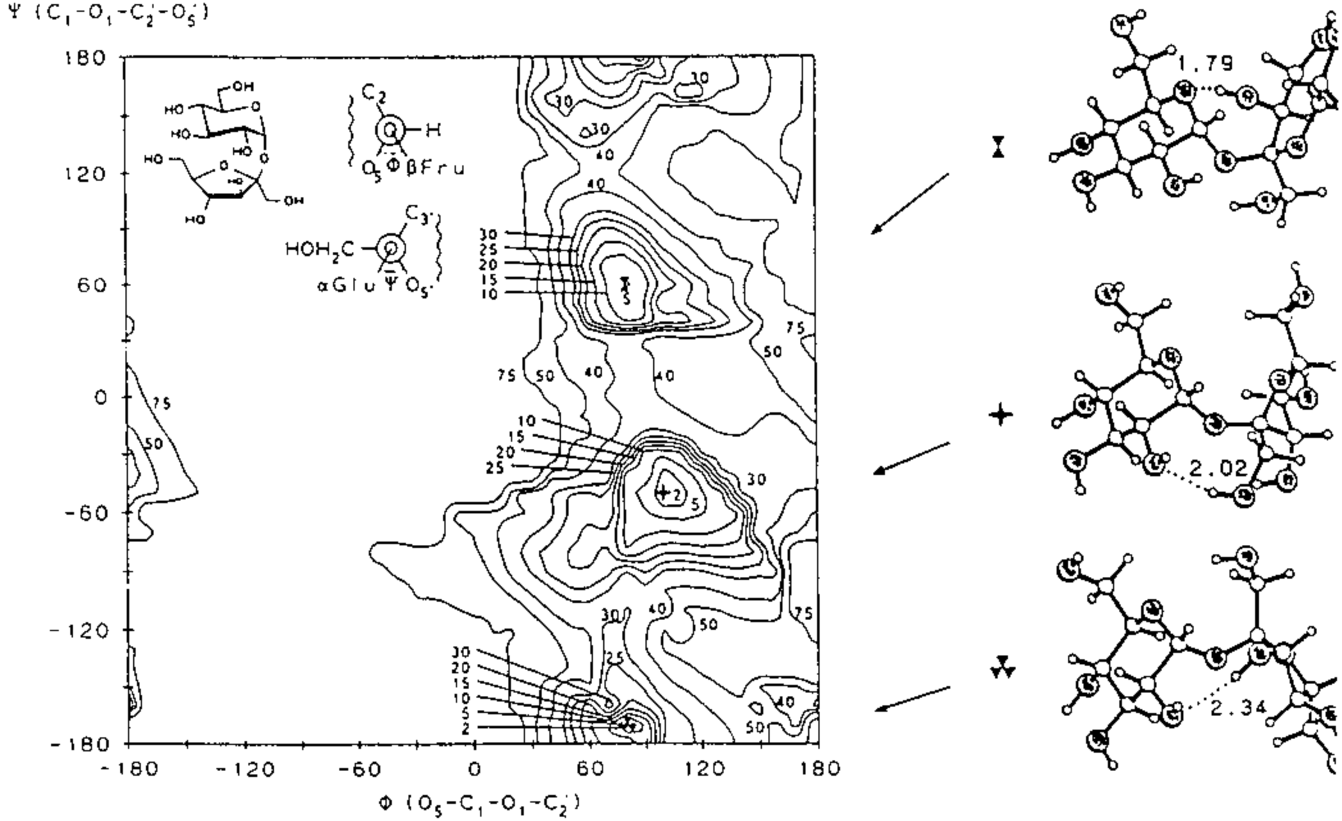


Figure 37 Fully relaxed energy potential surface of sucrose as a function of the two intersaccharidic torsion angles (46).

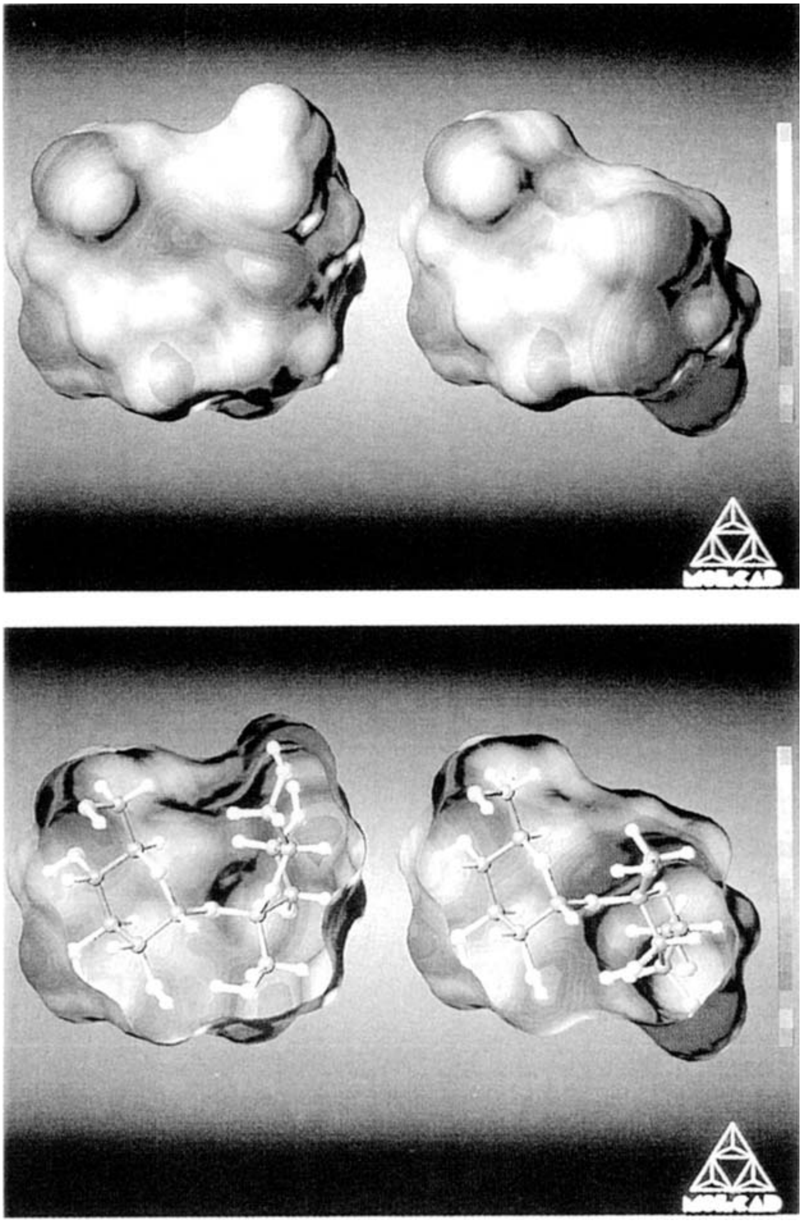


Figure 38 Representation of the molecular electrostatic potential (MEP) profiles of the two relevant sucrose conformers. The MEPs are depicted on the corresponding contact surfaces in 16-color code ranging from violet (most electronegative potential) to red (most electropositive potential) (in original) in relative terms (46).

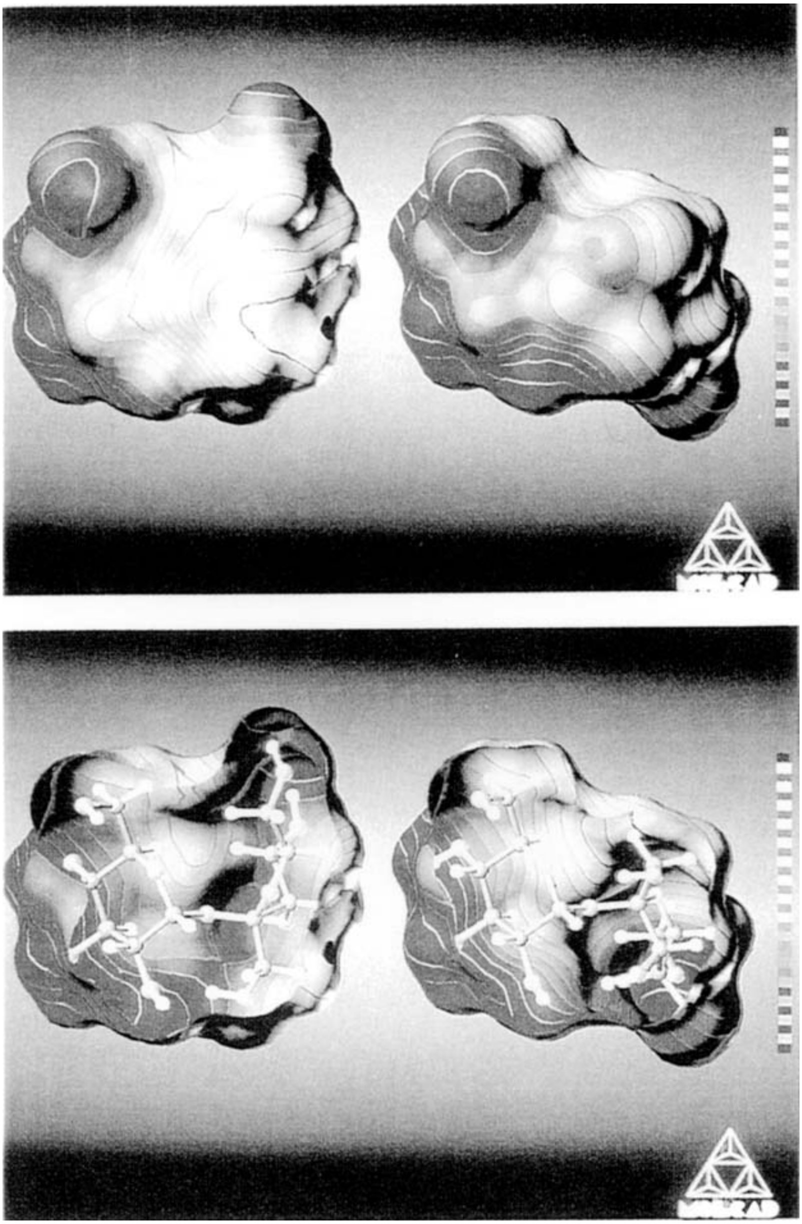


Figure 39 Molecular lipophilicity profiles for the two sucrose conformers of Fig. 37, with blue (in original) corresponding to hydrophilic surface areas and yellow (in original) to most hydrophobic regions. For both sucrose conformers, the entire "backside" of the fructose moiety is decisively hydrophobic (46).

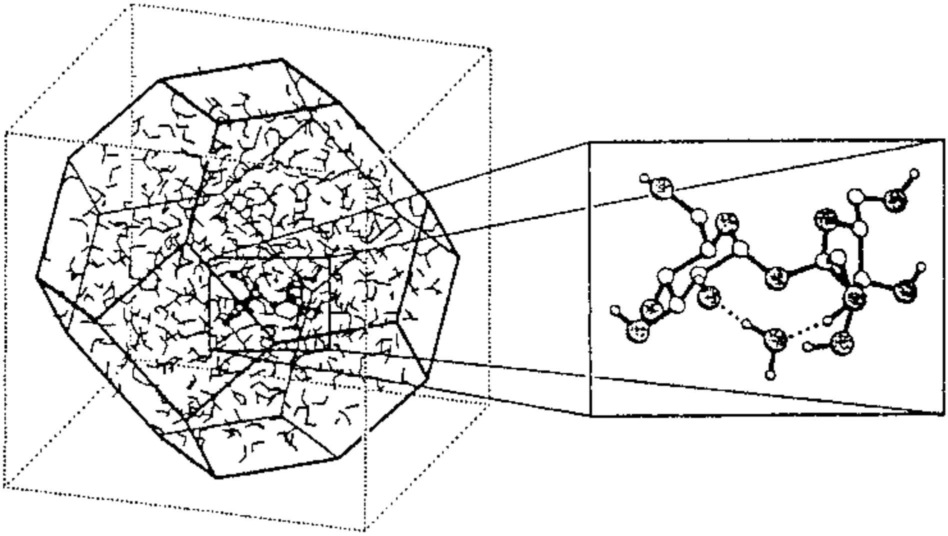


Figure 40 Snapshot of an MD simulation of sucrose surrounded by 571 water molecules (47).

through the system and been withdrawn as light steepwater. Meanwhile, the SO_2 content drops to 0.01% or less.

The volume of water available for steeping is normally 1.2–1.4 m^3/t of corn. About 0.5 m^3/t is absorbed by the corn to increase its moisture from 16% to 45% during the steeping. The remaining 0.7–0.8 m^3/t is the quantity withdrawn from the steeping system. This water contains the solubles soaked out of the corn, which is 0.05–0.06 t solids/t corn processed. It is evaporated to 40–50% solids, mixed with corn fiber, dried, and sold as corn gluten feed (42).

B. Separations

The next step of the process is the separation of kernel components (germ, fiber, gluten, and corn starch) by means of degerminating rotating mills, hydrocyclone separators, wedge-bar screens, disk-nozzle centrifuges, etc. (42). Solubles extracted from the corn during steeping are routed to evaporators where 0.6–0.7 m^3 of water per ton of corn is removed to increase the solids from 5–10% to 40–50%. The solids are then mixed with corn fiber and processed into corn gluten feed. Falling film recirculating evaporator systems are used to increase the light steepwater solids to 30%, using steam at a pressure of 1.2 kg/cm^2 or less (42). Multiple effect design, in which 1 kg of steam can evaporate several

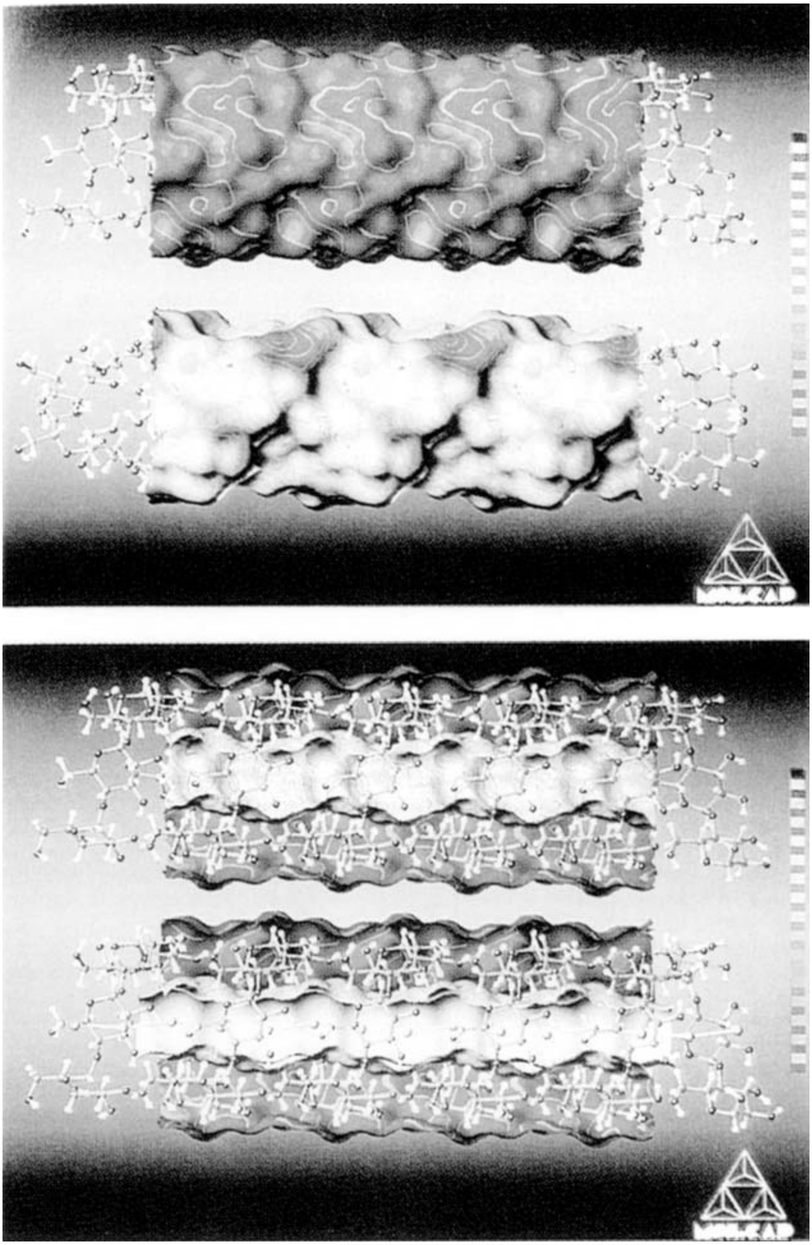


Figure 41 Hydrophobic topographies for the amylose fraction of starch (46).

kilograms of water, is necessary to minimize energy costs. Energy can be further reduced with mechanical recompression, which completely recycles the vapors, compresses them, and discharges them to the evaporator steam chest (42). A relatively pure starch slurry from the wet milling operation contains 40% solids.

C. Trends, Automation

The wet milling process and associated equipment have matured sufficiently to permit consistent, reliable separation and product quality on a 24-h basis with minimal operating labor. The most notable achievements are attained in the new large plants where television-like displays and control systems distributed by cathode ray tubes are utilized to start process equipment sequentially on demand and then to monitor and control the system.

Furthermore, the technician can be alerted, by rate-of-change or trend-in-measurement functions, to variables that are about to get out of control. This allows time to make the necessary adjustments to avoid spills and off-quality. These computer systems are the latest development in the search for reduced costs and better product quality. Better computer applications are probable as improved on-line measuring devices for protein, starch, fiber, and soluble content are perfected.

D. Utilities

Fresh water usage for a typical large sweetener plant is about 4.5–6.0 m^3/t of corn processed, of which one-fourth is consumed in wet milling. Reduction in the requirements for the wet milling portion is limited because the usage equals the need for properly steeping the corn. Greater water consumption for the finishing processes is likely because the trend is toward more sophisticated products that require more water.

Wet milling operations are high-energy users at 1.48×10^6 kcal/t of corn, even for the efficient large sweetener plants. About 20% of the total are for electricity, which indicates that most of the energy goes into fuel to make steam. As products continue to become more sophisticated, the use of energy will increase unless new technology reverses the trend.

The use of mechanical vapor recompression evaporators in new facilities and in the replacement of old equipment is reducing energy usage because it is five to six times more efficient than quadruple-effect steam evaporation. More imaginative use of heat exchangers can recover heat now being lost to the atmosphere via cooling towers. Steepwater evaporators now in service can utilize feed dryer exhausts as their source of energy.

Superheated steam is showing promise for use in drying feed materials. Most (60–80%) of the energy for the primary heating of steam is recovered in low-pressure steam for use elsewhere in the process. Not only is 20–40% energy saving possible, but there is no discharge to the atmosphere, eliminating odor and particulate problems associated with feed drying. Reverse osmosis is improving due to breakthroughs in membrane technology. When operating with a pressure differential of 35–70 kg/cm^2 they may replace steepwater and sweetener evaporators, achieving a major reduction in energy requirements.

New steeping technology may be in the offing that improves the possibility of success in concentrating the solids content of steepwater; it works by reducing the low molecular weight components such as alcohol that reverse osmosis, up to now, has had difficulty separating. Another benefit is reduced steeping time. A technology being introduced to the industry to treat wastes relies on anaerobic digestion, which has the advantage of using less energy-intensive processes and giving energy credits via recovery of methane gas, which is utilized as a fuel source. The cost of energy is being reduced by installing cogeneration. New coal-fired boilers operating at 40–80 atm drive electric generators. Steam for processing is then extracted in the 10 kg/cm^2 range, and steam for low-temperature heating (of water, for evaporation, etc.) is extracted at exactly 2 kg/cm^2 absolute (42).

GLOSSARY (7, 40)

Bagasse	Cane fiber leaving cane mill/diffuser after extraction of juice, e.g., first mill bagasse, etc., to final bagasse
Beet	Sugar beet root, botanically the thick main root with hypocotyl in which sugar is stored
Beet brei	Beet sample prepared for analysis is the form of fine particles
Beet knife	Rectangular piece of steel designed to slice beet into cossettes
Beet tail	Elongated lower part of the beet
Beet tops	Beet leaves and petioles, which may or may not be accompanied by crowns or pieces of crowns that are removed in the field at the time of harvest
Beet washer	Installation for cleaning beet (e.g., jet washer, revolving-arm washer, drum washer, cyclone washer)
Cossettes	Beet slices produced by a beet slicer
Cultivar	A horticulturally or agriculturally derived variety of a plant, as distinguished from a natural variety [*culti*vated + *var*iety)
Denaturation	Deliberate alteration of beet cells, often by heat, in preparation for extraction

Draft	The ratio percent weight of raw juice produced to the weight of cossettes introduced into the extractor
Deteriorated beet	Beet of reduced suitability for processing due to external causes, e.g., frost
Diffusion	Gradual mixing of the molecules of two or more substances, as a result of random thermal motion
Diffusivity	Rate at which a substance diffuses between the opposite sides of a unit cube when there is unit concentration difference between them. Also called "diffusion coefficient."
Dry substance	In most cases a moisture-free substance
Exhausted cossettes	Cossettes leaving the extraction plant
Extraction	Process of obtaining juice from sugar beet or sugar cane; the term "diffusion" should be used only for the physicochemical process
Extraction fresh water	Water introduced into the extraction in addition to press water
Extraction losses	Quantity of sugar entered but not contained in the raw juice as a percentage of the beet or cane mass
Flume water	Water used to transport beet
Imbibition	Mixing of water or juice with bagasse during cane milling
Invert sugar	Mixture of (close to) equal parts of glucose and fructose resulting from the hydrolysis of sucrose (inversion)
Juice purification	Partial removal of nonsugar substances from the raw juice while producing a thin juice
Knife block	Box-like device used to hold a number of knives in the disk or drum of a slicing machine
Molasses	The sugar-bearing product of the sugar whose purity has been reduced to the point that further crystallization of sugar is not economical feasible without special treatment of molasses
Mush content	Portion of cossettes shorter than 1 cm
Nonsucrose content	Difference between dry substance content and its sucrose content
Nonsugar	Common overall term for substances contained in the raw materials and products of the sugar industry except sucrose (sugar) and water
Osmosis	Passage of a solvent through a semipermeable membrane into a more concentrated solution (Fig. 33)

Polarization	Term customarily used in sugar analysis for the optical rotation of a sugar industry product measured under defined conditions (ICUMSA*), as a percentage of the rotation of pure sucrose, measured under the same conditions
Press water	Liquid effluent from the pulp presses
Press water pulp	Particles of exhausted cossettes contained in the press water
Pressed pulp	Pressed, exhausted cossettes, leaving the pulp presses
Purity	Sugar content as percentage of dry substance content
Raw juice	Juice obtained from beet or cane after extraction, pressing, or milling, mixed juice (cane)
Raw juice draft	Mass of juice drawn from the extraction plant as percentage of mass of cossettes introduced
Silin number	Length in meters of 100 grams of cossettes
Slicer (beet)	Machine designed to hold knives in knife blocks to produce cossettes
Sucrose	Common term for the disaccharide α-D-glucopyranosyl-β-D-fructofuranoside
Swedish number	Ratio of the mass of cossettes
Wet pulp	Commercial term for partially dewatered, exhausted cossettes

REFERENCES

1. C Buttersack, D Schliephake. Extraction theory. In: RW Van der Poel, H Schiweck, T Schwartz, eds. Sugar Technology. Berlin, Germany: Verlag Bartens KG, 1998, pp. 310–327.
2. F Bonacker. Extraction. In: Die Zuckerherstellung, 3rd ed. Leipzig: Fachbuchverlag, 1984, pp. 153–206.
3. P Christodoulou. Operating parameters of extraction systems for optimum pulp pressing, Zuckerindustrie 119:1004–1007, 1994.
4. K Adamoupoulos, P Christodoulou, H Petropakis. Optimization of the process of sugar extraction from beets. Hellenic Sugar Industry Quart Bull 50–51:57–79, 1982.
5. K Bohn. Composition of sugarbeet and chemical behavior of constituents in processing. In: RW Van der Poel, H Schiweck, T Schwartz, eds. Sugar Technology. Berlin: Verlag Bartens KG, 1998, pp. 115–151.
6. H Claassen. Die Zuckerfabrikation. In: Die Saftgewinnung. Magdeburg: Schallehn & Wollbruck, 1930, pp. 45–85.

*ICUMSA International Committee for Uniform Methods in Sugar Analysis.

7. RA McGinnis, RN Sequeira. Chemistry of the beet and processing materials. Glossary of technical terms in common use in the beet sugar factory. In: RA McGinnis, ed. Beet Sugar Technology, 3rd ed. Fort Collins, CO: Beet Sugar Development Foundation, 1982, pp. 25–63, 759–782.
8. RE Watkins, PV Schmidt. Changes in the chemical composition of beet. In: RW Van der Poel, H Schiweck, T Schwartz, eds. Sugar Technology. Berlin: Verlag Bartens KG, 1998, pp. 276–277.
9. E Junghans. Morphology and physical properties of sugarbeet. In: RW Van der Poel, H Schiweck, T Schwartz, eds. Sugar Technology. Berlin: Verlag Bartens KG, 1998, p. 209.
10. C Buttersack. Ultrastructure of the native sugarbeet root. In: RW Van der Poel, H Schiweck, T Schwartz, eds. Sugar Technology. Berlin, Germany: Verlag Bartens KG, 1998, pp. 211–212.
11. K Vukov. Physics and Chemistry of Sugar Beet Manufacture. Budapest: Akadémiai Kiado, 1977, p. 595.
12. E Junghans. Physical properties of beet. In: RW Van der Poel, H Schiweck, T Schwartz, eds. Sugar Technology. Berlin: Verlag Bartens KG, 1998, pp. 212–214.
13. C Buttersack. Physical properties of beet after denaturation. In: RW Van der Poel, H Schiweck, T Schwartz, eds. Sugar Technology. Berlin: Verlag Bartens KG, 1998, pp. 215–216.
14. C Buttersack. Separation by adsorption, chromatography or membranes. Zuckerindustrie 124:846–858, 1999.
15. P Christodoulou. Possibilities of application of the chaos and complexity theory in sugar technology. Proceedings of 21st General Assembly of CITS, Antwerp, May 24–28, 1999. Berlin: Verlag Bartens KG, 1999, pp. 331–349.
16. SI Nikolis. Chaos and Information Processing. Singapore: World Scientific, 1991.
17. PM Silin. Technology of Beet Sugar Production and Refining. Jerusalem: Israel Program for Scientific Translations, 1964, pp. 88–178.
18. HO Ebell, M Storz. Diffusion. In: RA McGinnis, ed. Beet Sugar Technology, 3rd ed. Fort Collins, CO: Beet Sugar Development Foundation, 1982, pp. 119–153.
19. D Schliephake, A Wolf. Mass transport processes in the initial phase of aqueous sugar extraction from cossettes. Zucker 21:484–493, 1968.
20. H Van Malland. Technical extraction of beet. In: RW Van der Poel, H Schiweck, T Schwartz, eds. Sugar Technology. Berlin: Verlag Bartens KG, 1998, pp. 328–334.
21. J Vetter. Process parameters of extraction. Equipment for cell denaturation and the cooling of raw juice. In: RW Van der Poel, H Schiweck, T Schwartz, eds. Sugar Technology. Berlin: Verlag Bartens KG, 1998, pp. 334–348.
22. F Schneider, E Reinefeld. Ruebenzerkleinerung. In: F Schneider ed. Technologie des Zuckers, 2nd ed. Hannover: M&H Schaper, 1968, pp. 152–157.
23. K Bucholz, KM Bliesener, R Buczys, K Thieleckte, D Miehe. Bacterial control. In: RW Van der Poel, H Schiweck, T Schwartz, eds. Sugar Technology. Berlin: Verlag Bartens KG, 1998, pp. 169–170.
24. J Dubourg. Sucrerie de Betteraves. Paris: Librairie JB Bailliere & Fils, 1952, pp. 79–150.
25. H Brüniche-Olsen. Solid–Liquid Extraction. Copenhagen: Nyt Nordisk Forlag, Arnold Busck, 1962, p. 463.

26. D Schliephake, B Mechias, E Reinefeld. Retention time distribution and movement mechanisms in extraction equipment without controlled transport of cossettes. Proceedings of 15th General Assembly of CITS, Tienen, Belgium, Principles of Extraction, Vienna, Austria, 1975, pp. 31–123.
27. G Mantovani. Sugar technology–development since 50 years. In: Proceedings of 21st General Assembly of CITS, Antwerp, May 24–28, 1999. Berlin: Verlag Bartens KG, 1999, pp. 47–51.
28. Anonymous. The Danish Sugar and Sweetener Engineering Beet Diffuser, 1999, Birkorood, Denmark.
29. A Baloh. Energiewirtshaft in der Zuckerindustrie. Berlin: Verlag Bartens KG, 1991, pp. 90–110.
30. JA Richmond, D Noble. Technical accounting and process control. In: RW Van der Poel, H Schiweck, T Schwartz, eds. Sugar Technology. Berlin: Verlag Bartens KG, 1998, pp. 1060–1061.
31. K Anderson. The DDS beet extraction. Zuckerindustrie 114:136–138, 1989.
32. PW Van der Poel, NHM de Visser, CC Bleyenberg. Sugar Techn Rev 9:15–18, 1982.
33. C Gudmundson. 18th Meeting of the CITS Subcommittee Measurement and Process Control, Peterborough, 1993.
34. L Budicek, L Hladikovà. Econometric model of a sugar factory. Proceedings of 20th General Assembly of CITS, Munich. Berlin: Bartens KG, 1995, pp. 34–41.
35. J Bergé. Sucr Belge 72, 1930.
36. PJM Rao, Industrial Utilization of Sugarcane and Its Co-products, New Delhi: ISPCK, 1997, pp. 5, 12–13.
37. GM Thomson. External structure of the sugar cane plant. In: RW Van der Poel, H Schiweck, T Schwartz, eds. Sugar Technology. Berlin: Verlag Bartens KG, 1998, pp. 225–230.
38. CR Murry. Technical extraction of sugar from cane. In: RW Van der Poel, H Schiweck, T Schwartz, eds. Sugar Technology. Berlin: Verlag Bartens KG, 1998, pp. 354–381.
39. PW Rein. Control of cane diffusers. In: RW Van der Poel, H Schiweck, T Schwartz, eds. Sugar Technology. Berlin: Verlag Bartens KG, 1998, pp. 381–383.
40. RW Van der Poel, H Schiweck, T Schwartz, eds. Sugar Technology. Berlin: Verlag Bartens KG, 1998.
41. NC Carpita, DM Gibeaut. Structural models primary cell walls in flowering plants: consistency of molecular structure with the physical properties of the walls during growth. Plant J 3:1–30, 1993.
42. SA Watson. Structure and composition. In: SA Watson, PE Ramstad, eds. Corn: Chemistry and Technology. St. Paul, MN: American Association of Cereal Chemists, 1994, pp. 53–82.
43. JB May. Wet milling process and products. In: SA Watson, PE Ramstad, eds. Corn: Chemistry and Technology. St. Paul, MN: American Association of Cereal Chemists, 1994, pp. 377–397.
44. W Hein, G Pollach. New findings with the use of hop products in the sugar industry. Zuckerindustrie 122:940–949, 1997.

45. WE Boyce, RC Diprima. Elementary Differential Equations and Boundary Value Problems, 6th ed. New York: John Wiley & Sons, 1997, pp. 129, 605.
46. WF Lichtenthaler. Computer simulation of chemical and biological properties of sucrose, the cyclodextrine and amylose. Int Sugar J 97(1153):12–22, 1995.
47. WF Lichtenthaler, S Immel. The conformation of sucrose in water. A molecular dynamic approach. Liebigs Ann, 1995:1925–1937.