Development of a Sugar Beet Processing Laboratory

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The Western Regional Research Laboratory, Albany, California, has developed a processing line capable of continuously producing sucrose from sugar beets. Funds supplied by the Beet Sugar Development Foundation, Fort Collins, Colorado, under a cooperative agreement with the U. S. Department of Agriculture have paid for a large share of this development.

The purposes of this project were three: to provide a means of relating beet composition to processing quality, to evaluate new steps or variations in traditional sugar beet technology, and to provide intermediate and final products of known history for laboratory bench studies. Of these three purposes, the first was dominant. Scale and type of apparatus were mainly determined by this consideration.

Long-term average changes in sugar beet composition are caused by changing soil fertilization practice, by differences in stage of maturity at harvest, by development of new varieties, or by new harvesting methods. The effects of these changes can be evaluated only in equipment similar to factory systems, in which conditions are under exact control.

The process is shown in Figure 1. The purposes of the various steps are the same as those for equivalent steps in sugar beet factories.

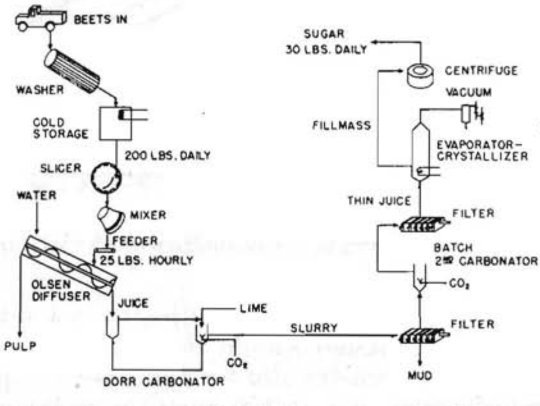

Figure 1.—Sugar beet processing laboratory at the Western Regional Research Laboratory, Albany, Calif.

[1] Western Regional Research Laboratory, Albany, California, a laboratory of the Western Utilization Research and Development Division, Agricultural Research Service, U. S. Department of Agriculture.

The capacity of the processing laboratory equipment must be such as to composite a beet sample of significant size. This size depends on which chemical component of the beet is being considered. The coefficients of variation differ considerably. The minimum sample size agreed upon is 100 beets or about 200 lbs. For 95% certainty, 100 beets selected at random will be representative of a large population within 10% in regard to sucrose, marc, total anions, oxalic acid, total nitrogen, malic acid, raffinose, amino nitrogen, and galactinol. The coefficient of variation will exceed 10% only slightly in the case of glutamate (4, 11)[2]. Figure 2 shows coefficients of variation observed in random sampling of a large population for the principal components of sugar beets versus sample size. The population includes beets of two varieties grown in three different states under two levels of fertilization. This study will be separately reported by Dr. R. L. Hurst and others (11).

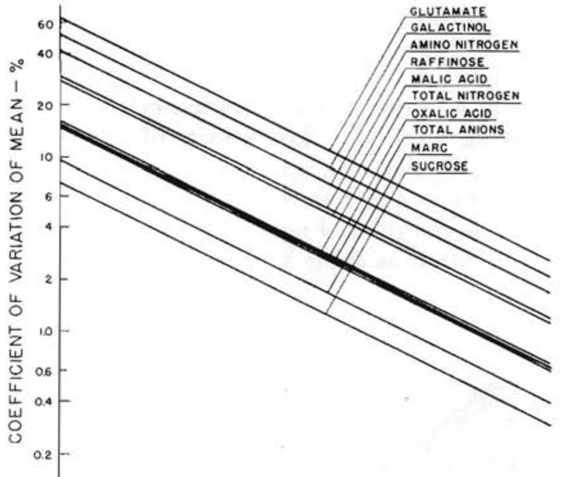

Figure 2.—Relation of sample size to coefficient of variaton of means for random sampling.

Although 100 beets as a daily composite is a minimum, the processing laboratory design should not demand a much larger quantity since the convenient size for experimental planting and sampling techniques is close to 100 beets for each condition. Because of start-up and shut-down losses, the rate of processing of beets should be the minimum for the 100-beet sample, compatible with an eight-hour work day. In accordance with these

[2] Numbers in parentheses refer to literature cited.

conditions, the laboratory was designed for 20 pounds of beets per hour. Such a scale, 1/5000 of factory, is too small for evaluating processing equipment directly and demonstrates the subordination of the secondary objectives to composition studies.

Continuous operation of the diffusion, carbonation, and evaporation units was considered essential. The remaining steps —washing, slicing, filtration, second carbonation, and crystallization—were designed for batch operation. The continuous steps were matched and integrated. The apparatus was sized so that retention times were suitable at the chosen flow rate. Accurate control of all conditions for each step was emphasized in design. Facilities for measurement and analysis were as extensive as the processing equipment itself.

Truck load lots of field or experimental beets are washed by tumbling them through high-pressure sprays inside a horizontal rotating cylinder composed of widely spaced steel slats. About 2 tons of beets per hour can be cleaned. The beets are packed in moist wood shavings in 40-pound lots in wooden boxes (2). If the beets delivered are intended for several experiments, the washed beets are sorted into size classes, and a proportionate weight of each class is packed in each box. This compensates for composition trends with beet size. A fungicide dip improves storage life.

The boxes of beets are stored in a forced-air-circulation cold room which is maintained at 1° C. Boxes are removed for experiment according to a random sequence. Beets are washed free of shavings and then sliced.

The cossette cutter, shown in Figure 3, is a three-foot drum rotating at 155 r.p.m. in the vertical plane. Around the drum are spaced 14 standard 46 division cossette knives, one knife to a block. The tangential knife speed is about factory average, 20 ft./sec. Beets are forced against the knives by a volute curving to a small angle with the knife drum. The length of a perfect cossette, containing 100 grams of beet, can be calculated for any knife setting. Real cossettes have a greater length per 100 grams, since they have less than the maximum possible cross-section dimensions. The actual length observed was found to be constant at 170% of the calculated length. Typical cossettes are comparable to factory cossettes when sharp knives are used, i.e., 22 meters per 100 grams for 2.25 mm. up and back knife settings.

About 50 kg. lots of cossettes are then tumbled in Tygon-lined, covered, concrete mixer in the cold room. After 10 minutes, successive 50 gm. samples have the same variation in sucrose content by polarization as portions of one 50 gm. sample subsampled after blending.

The cossettes are fed to a small Bruniche--Olsen continuous countercurrent diffuser, which, as modified, has proved very satisfactory on the job (3). This unit consists of a round-bottomed copper trough, 6 inches wide, 4 ft. long, containing a single interrupted scroll without breaker bars (see Figure 4). A given

Figure 3.—Cossette cutter.

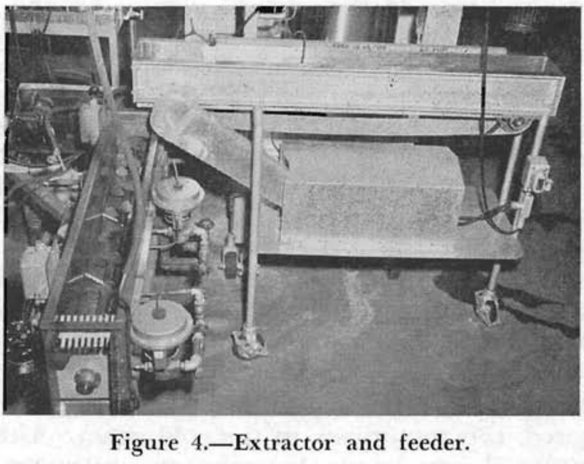

Figure 4.—Extractor and feeder.

weight of cossettes is spread between marks on a constant-speed belt which drops them through an opening in the cover at the low end of the diffuser. Exhausted pulp is lifted over a weir at the high end by means of a rotating notched plate. Preheated distilled water is metered into the trough bottom at the high end, and juice leaves through a perforated, wiped plate at the low end. Temperature is maintained by jackets, the steam to which is controlled by two bulbs in the cossette mass. The cold cossettes are raised to the diffusion temperature of 70° C. within three minutes or four inches of travel.

Various important factors affecting the operation of this Olsen diffuser were evaluated in a series of experiments. Each factor was fixed at the level resulting in the largest number of theoretical contacts (1). An equivalent dimensionless figure, Silin's constant (8), is better known in the beet sugar industry. Optimum conditions according to this basis are the following: A trough slope of 1° to horizontal, liquid level at scroll shaft height, scroll speed of 1⅓ r.p.m., and beet retention time of 40 minutes. The attack angles of the interrupted flights of the scroll were adjusted to produce the same retention time with beet feed rates which varied from 9 to 12 kg./hr. Sucrose remaining in the exhausted pulp ranged from 0.10 to 0.30% for percentages of juice rate to beet rate from 140 to 120. Table 1 shows the low relative efficiency of the Olsen laboratory diffuser compared to other units. These figures are all based on our own observations.

Table 1.—Relative Efficiencies of Diffusers.

	No. Theoretical Contacts	Silin's Constant
Laboratory Olsen, Albany, Calif.	10	4.0×10^{-4}
Laboratory Roberts, Albany, Calif.	13	5.2
Factory Roberts, Alvarado, Calif.	16	6.7
Factory Olsen, Eaton, Colo.	20	9.1

The labor saving, the true countercurrent action, and especially the reproducibility dictated the use of the Olsen diffuser for experimental work despite its inefficiency. In a long series of experiments with different feeds, the efficiency of this unit had a standard deviation of 0.4 theoretical contact.

The hot diffusion juice flows into a modified model Dorr carbonator which is based on a development of R. A. McGinnis at Spreckels Sugar Company (9). A schematic drawing of the carbonator is shown in Figure 5. This device continuously limes

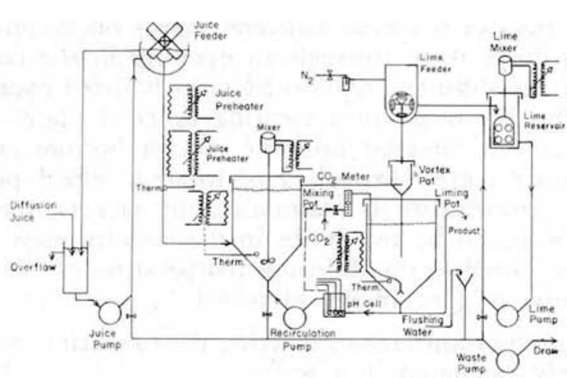

Figure 5.—Model Dorr carbonator.

and carbonates up to 3 gallons of diffusion juice per hour. Automatic temperature and pH control are provided. Homogenized milk of lime and bottled carbon dioxide are used. The details of this apparatus together with examples of measurements and analyses are given in another report (6).

First carbonation slurry is batch filtered in Buchner funnels, through paper. The filtrate is saturated with carbon dioxide for 5 minutes while boiling, then boiled for 3 minutes without further gassing. The second carbonation juice is again filtered through paper to yield "thin" juice suitable for evaporation (5).

Thin juice can be concentrated continuously in a 3-cubic-foot evaporator-crystallizer, shown in Figure 6. This is a vertical stainless-steel cylinder 14 inches in diameter, 4 ft. 6 in. high, connected by 4-in. tubing to a direct contact condenser and a two-stage vacuum system. The evaporator is drained through a 3-in. plug cock. Proof stick samples may be removed for analysis.

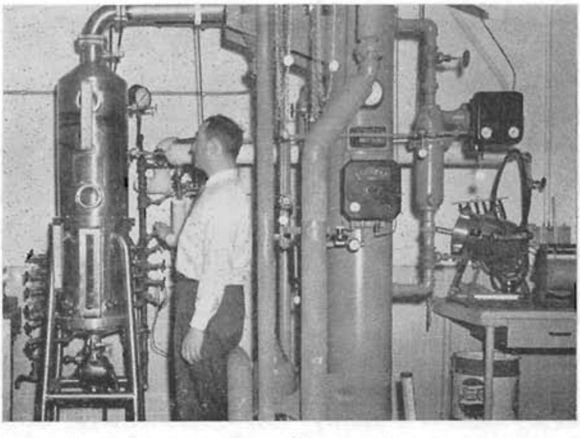

Figure 6.—Evaporator-crystallizer and vacuum system.

Steam may be used in the jacketed bottom and in any of 5 spiral submerged coils, totaling 6 square feet of heating surface. Volumes from 0.3 to 30 gallons can be boiled under pressures from 1.3 to 30 inches Hg absolute at evaporation rates up to 450 lbs. water per hour. Large head space and an entrainment separator permit handling of foaming liquids. The performance of this evaporator has been good and may be predicted by

$$U = 22 \left(\frac{\Delta tN}{\mu} \right)^{0.3} \left(\frac{1}{1 - .027h} \right)$$

where U is overall heat transfer in Btu/hr./ft.^{2}/°F.

(Δt) is overall temperature difference in °F.

N is number of surfaces in use.

μ is boiling liquid viscosity in centipoises.

h is average liquid height above hot surface in inches.

Crystals can be produced in the evaporator, or the nearly saturated juice can be canned and stored. Such juice can later be evaluated as to crystallization velocity and ultimate sucrose solubility in laboratory-scale dilatometers (10).

Four men are now required to operate the laboratory, one of whom must be highly skilled in all operations. This excludes labor for some analytical services such as moisture determination or Kjeldahl and Van Slyke nitrogen measurements, but does include labor for alkalinities, lime analysis, percent refractive dry substance, polarizations, sedimentation rates, filtration rates, colors, lime salts, colloid content, and pH.

The laboratory is in operation at present (7). Considerable additional equipment and parts, however, are necessary, and will be acquired in order to improve reliability and to reduce the excessive labor needed. New equipment is being built to embody proposed improvements on traditional processing steps. Such proposals will be evaluated by comparison with the standard line described.

Summary

A very small pilot plant for crystal sugar production from sugar beets has been construed in order to measure the effects of changing beet composition on processing qualities. Continuous extraction, purification, and evaporation were adopted. The rate of continuous processing is limited by the diffusion and carbonation steps. This limiting rate was chosen by consideration of the minimum beet sample size which represents a very large number of beets with respect to the most variable known component within the beet. In order to process this sample con-

veniently in one day, the throughput chosen was nine kg. of beets per hour. The number of ideal contacts within the model diffuser is compared with commercial diffusers. Operation of the model carbonator and evaporator is described.

Acknowledgments

The authors wish to acknowledge the ideas and efforts during this long project of many people in the Engineering and Development Laboratory and in the Field Crops Laboratory of the Western Utilization Research and Development Division.

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