Pilot Plant Scale High Pressure Steam Peeling of Sugarbeets[1]

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ABSTRACT

Pilot plant runs extending from fresh beets to final product sugar were made using control beets and beets peeled to average peeling wt. losses of 4.1, 6.1, and 8.9%. Peeling was accomplished using a short (13-30 sec), high pressure (1825 kPa) steam treatment followed by contact with rotating brushes. Peeling removed dirt, petioles, and field trash from the beets. Peel was low in sugar content (11.2-24.2% dry basis) and purity (41.4-48.1%). Differences among treatments were most significant ($p < 0.05$) in quality of thick juices and less so in preceding stages back to cossettes. Purity, color, nitrogen, and ash were significantly lower in thick juices from peeled beets but Ca, Mg, Na, and K content were not significantly different. Thick juice purities of 93.9, 94.6, 94.9, and 95.2% were obtained from control beets, and beets peeled to the 4.1, 6.1, and 8.9% peel loss levels, respectively. Sugar loss on peeling and content of several components were proportional to the degree of peel removal and could be described by linear regression equations. Apparent product sugar quality (conductivity ash, turbidity, color) was higher from the peeled beets. Apparent extraction calculations were lower for the peeled beets but losses may be offset by other process advantages.

Impurity levels are higher in the skin and crown than in the interior of the sugarbeet. Removal of these areas should improve the quality of the remaining beet. Laboratory studies, completed on beet and juice samples made from beets peeled with high pressure steam (Edwards et al., 1988), showed that thin juice purity increases of up to 1.6%, compared to the control, could be obtained. In other work, Madsen and Nielson (1982) reported purity increases of up to 4.2% for beets peeled by rotat-

ing wire brushes.

The objective of this work was to determine the effect of peeling on beet fraction quality and yield using pilot plant scale equipment and technology identical to that in commercial factory operations. The process was carried through to final product sugar. The beets were peeled by a high pressure steam peeling technique, as was used in the laboratory experiments (Edwards et al., 1988), with secondary peel removal by a roller-scrubber machine.

MATERIALS AND METHODS

Beet Selection and Storage.

Approximately 2250 kg of fall sugarbeets from central California were selected at random from one truckload of beets harvested from the same area of a single field. Beets were placed into 40 l. open weave nylon bags or 80-400 l. open stainless steel containers and stored at 2-5°C. Beets were removed from refrigerated storage the night before a pilot plant run.

Pilot Plant Equipment.

High pressure steam peeler. The microprocessor controlled peeler (Odenberg K + K, Sacramento, CA, Model 100) had a 100 l. pressure vessel which resulted in a machine capacity of up to 40 kg of sugar beets per charge. The peeler was operated with 1825 kPa (265 psia) saturated steam. The vessel door and steam inlet and exhaust valves were hydraulically operated. The vessel rotated at 9 RPM during the steam cycle.

Roller scrubber. The roller scrubber (Lyco Manuf. Co., Columbus, WI, Model 7000) was used to remove the peel which was loosened during treatment in the steam peeler. A variable speed central screw conveyor (46 cm dia x 284 cm long) transported the steam treated beets down the length of the machine. Seven rolls, 13 cm in diameter and parallel to the axis of the conveyor, were arranged to form the bottom and sides, like a trough around the conveyer. Each of the rolls was rotated at up to 400 RPM using an hydraulic drive. The surface of four of the rolls was covered with an abrasive grit (No. 20), while the remaining three had bristle brushes. Each roll could be put in any one of the seven roll positions. As the beets were transported down the length of the machine, they contacted the surface of the rotating rolls, which removed the loosened peel. The amount of peel and flesh removed depended on the length of the steam treatment, central conveyor RPM (residence time), roller RPM, type of roll covering, and the position of the roll around the conveyer. Peel was flushed from the machine by about 25 kg of tap water recirculated by a pump through spray nozzles located above the central screw conveyor. This roller scrubber model has a capacity range of 500-10,000 kg/hr when used on vegetable root crops.

Cossette cutter. The cossette cutter, previously described (Morgan et al., 1959b), consisted of fourteen standard 36-division

knives arranged evenly around the circumference of a 91 cm diameter drum rotating at 155 RPM. The knives were set at 1.5 mm up and 2.25 mm back.

Blender. The twin cone blender (Patterson Kelly Co., East Stroudsberg, PA) had a capacity of 35 kg of sugar beet cossettes. The blender was operated at 25 RPM.

Diffuser. The diffuser was an inclined Bruniche-Olsen continuous countercurrent type with a cossette capacity of 9-12 kg per hour (Morgan et al., 1959a), depending on the inclination of the interrupted flight screw. The screw had no breaker bars. The round bottomed diffuser trough was 5 cm wide and 120 cm long. Heat was added by conduction through three steam jacketed sections along the trough length.

Juice Purification System. Juice was purified in a laboratory scale Dorr system with a capacity of 12 l per hour (Eis and Sackett, 1959). During first carbonation, the recirculation ratio from the primary to secondary tank was 6 to 1 which gave an average juice retention time of 20 minutes. First carbonation juice was then pumped into a minature Enviroclear clarifier. Anionic polyacrylamide was added to the feed at the 2 ppm level. Underflow at 20-25% dry matter was discarded. Overflow juice entered the second carbonation tank where the alkalinity was brought down to 0.01% CaO with additional CO_2, and then flowed into a small continuously operated pressure leaf filter which used the same cloth as the factory operation. Masterflex pumps were used to provide constant flow rates within the system.

Evaporator. The natural recirculation evaporator had a capacity of about 2.5 l. The evaporator was constructed of glass except for the jacketed heating section, which was copper. The evaporator was operated at 45 cm vacuum with 200-275 kPa steam in the jacket. Thin juice feed was bled into the system continuously. The evaporator receiver was emptied when it was approximately two-thirds full of 60-62 Brix juice. Thick juice from the evaporator was later filtered through the previously mentioned single leaf pressure filter.

Pan Evaporation System. This system has been described previously (Eis and Sackett, 1959). Approximately 8 l. of thick juice were needed for a pan boiling cycle in the electrically heated, naturally circulated calandria. The massecuite was dropped into a centrifuge (IEC, Size 2) with a perforated basket for affination.

Hydraulic presses. A Carver press (F. S. Carver Co., Menomonee Falls, WI, Model C), or a Norwalk press (Norwalk Foundry and Machine Co., St. George, UT, Model 200) was used to dewater spent pulp from the diffuser. Forces of about 350 and 600 kPa were used in the Carver and Norwalk presses, respectively.

Pilot Plant Runs.

The number of pilot plant runs possible was limited. It was decided that the information generated by peeling to three differ-

ent peel removal levels was more valuable than from two levels, even though it might be less significant statistically. Consequently, two pilot plant experiments were conducted at each of the 4, 6, and 9 per cent peel loss levels along with the control runs using unpeeled beets.

For each pilot plant run, approximately 200 kg of beets were washed by hand, using bristle brushes, and divided into 22.6 kg batches. Each batch was subjected to the high pressure steam peeler treatment and then passed through the roller scrubber machine. Each batch was weighed before and after peeling. Sugarbeet peel was collected from the interior of the steam peeler and from the sides, cover, and baffles of the roller scrubber. The recirculated washwater was collected, screened to remove intrained peel, weighed and sampled. The total peel fraction was weighed and sampled. All samples from the pilot plant runs were either analyzed immediately or frozen with dry ice and stored in a freezer for later analysis.

The peeled beets were sliced in the cossette cutter and then mixed in the twin cone blender for two minutes. After sampling, the cossettes were taken to the diffuser. Cossettes from this batch were fed to the diffuser until the next batch arrived, approximately 45 minutes later.

Cossettes were spread in a layer of uniform thickness on a slowly moving conveyer belt which emptied into the diffuser. The feed rate, which was adjusted by changing the thickness of the layer, was maintained at 8.2-9.1 kg/hr. The diffuser was maintained at a temperature of 70 ± 2°C and a draft of 120. Extracted pulp was collected, placed in nylon bags, and dewatered using the hydraulic presses to obtain pressed pulp and pressed pulp water. The pressed pulp water was added back to the diffuser. Supply water for the diffuser (ca. 220 ml/min) was approximately 2/3 tap water and 1/3 pressed pulp water.

Raw juice from the diffuser was subjected to the normal Dorr system for juice purification. Lime (12% CaO in 5% sucrose solution) was added at the rate of 1.6% on first carbonation juice to maintain an alkalinity of 0.10 %CaO. Second carbonation juice was maintained at an alkalinity of 0.01% CaO. Temperatures of 85°C and 95°C were used during first and second carbonation, respectively.

Collection of thin juice for concentration in the laboratory evaporator was begun about 3 1/2 hours after the diffuser startup and continued for the next 7-8 hours. No sulfite was added to the juice prior to evaporation. Thick juice from the evaporator, at 60-62 Brix, was cooled and stored at 5°C until sugar boiling about a week later. About 12 1 of thick juice were prepared.

Sugar boiling was accomplished at 10 cm of vacuum (61°C) using about 8 1. of thick juice. First strike massecuite was centrifuged at 1500-1800 RPM in the perforated basket. Affination was accomplished in the spinning centrifuge with a fine spray

of hot distilled water. The washed sugar was dried by mixing it in the kitchen mixer for 15 min. at ambient temperature. About 700 g. of final product sugar were produced per boiling.

Juice quality and sugar quality from the pilot plant have previously been shown to be equivalent to that from the factory operation (Eis and Sackett, 1959; Eis, 1962).

Sampling.

In general, 6-7 samples, spaced throughout the run, were taken of cossettes, raw juice, and thin juice. Morning and afternoon composite samples of pressed pulp and pulp press water were collected. Replicated peel loss tests produced 6-8 samples of peel and peeled beets from each pilot plant run. Three samples of unpeeled beets were also taken during each peeled beet run. Single samples of both well-mixed thick juice and product sugar were taken.

Analytical Methods.

Many of the analytical methods have been described previously (Edwards et al., 1988). Sugar content of juices and brei was determined by polarization using an Autopol II Saccharimeter with a 200 mm tube on samples prepared by ICUMSA methods (Schneider, 1979). Total dissolved solids (°Brix) were determined with a Bellingham and Stanley Model RFM-81 digital refractometer. Dry matter content was determined by an AOAC method (AOAC, 1980). Sodium, potassium, magnesium, and calcium were determined by atomic absorption (Perkin Elmer 303 AA spectrophotometer). Saponin content in raw juice was determined by the method of Nagornaya et al. (1966). Total nitrogen content was measured by gas chromatography (Kirsten, 1983) using an Automatic Nitrogen Analyzer (Carlo Erbo Stramentazione, Milan, Italy, Model 1400). Invert was measured by a modified version of the Lane and Eynon (1932) method (Anon, 1982).

Conductivity ash was calculated as 0.0005 x Conductivity units of a 50 g sugar /200 ml distilled water sample. Conductivity was determined by a resistance bridge (Anon, 1961). Floc in product sugar was measured qualitatively by noting the presence or absence of a precipitate 4 hr and 24 hr after the heating of a sucrose solution made by mixing 70 g of sugar and 163 ml of distilled water and adjusting the pH to 2 (Anon, 1966). Floc in thick juice was measured similarly, starting with 250 ml of 30 Brix syrup (Anon, 1966). Color and turbidity were measured with a sphere photometer (Bernhardt et al., 1962) (Phoenix Precision Instrument Co.). Color of thin juice and product sugar were determined by ICUMSA methods (Schneider, 1979), except that the solution of product sugar was not filtered, so that turbidity could be measured. Lime salts were determined as %CaO on solids by a chelation method (Anon, 1964).

Statistical Methods.

Experimental data were subjected to analysis of variance

followed by Duncan's multiple range test at $P < 0.05$ (Steele and Torrie, 1960), and to linear regression analysis.

RESULTS AND DISCUSSION

Preliminary runs were made with various steam peeler-roller scrubber combination treatments so that appropriate starting conditions for the pilot plant runs could be determined. Runs were made with steam treatments of 10-40 seconds, and roller scrubber settings of 200-400 RPM roll speed, 10-30 sec residence time, and least abrasive and most abrasive roll placements. Peel removal in the roller scrubber was quite good, so that steam treatment times could be reduced to approximately one-half those found necessary in the laboratory experiments (Edwards et al., 1988). Many combinations of processing parameters would produce the desired peeling weight losses (4,6,9 wt %). Generally, changes in steam treatment time had a greater effect on peel loss than a change in a roller scrubber variable. When the rolls were placed in the most abrasive arrangement, the shoulder of the beet was rounded rapidly, which was undesirable. Peel removal appeared more uniform at 400 RPM than at 200 RPM, perhaps because the beets were kept rotating more consistently as they traveled down the length of the center screw. Changing the residence time in the roller scrubber was the easiest method of effecting small changes in the amount of peel removed.

The conditions actually used in the pilot plant runs, and the results achieved, are shown in Table 1. Roller scrubber RPM was kept constant at 400 RPM. Steam peeling time and beet residence time in the roller scrubber were each increased to obtain higher peel losses. For a roller scrubber residence time of 30 sec, the steam treatment time had to be increased to 30 sec to obtain a peel loss of 9%. By making small adjustments in steam time and/or residence time during the course of the runs, overall mean peel losses were kept very close to the desired average values, as shown in the Table. However, as in the laboratory experiments (Edwards et al., 1988), at a given peel loss level, the range of peel loss values from individual determinations taken throughout the run was large. The amount of sugar lost to the peel fraction was significantly different at each level of peeling. The amount of sugar lost to the peel fraction was dependent almost solely on the amount of peel loss, and was approximately equal to one-half of the peel loss. The regression equation describing the relationship is as follows: sugar loss(% of original) = [0.55 ($\pm$0.02) x peel loss (wt %)] $-$ 0.11 ($\pm$ 0.14), R^2=0.99.

The composition and purity of the process fractions are shown in Table 2. It was expected, as peel was removed, that the resulting peeled beets would be enriched in sugar and lower in impurities than the original beets, and that such changes would be related to the degree of peel removal, as was found in our laboratory studies (Edwards et al., 1988). These expectations

Table 1. Pilot Plant Peeling Conditions.*

Peel Loss Target (wt %)	Peel Loss†‡ Actual (wt %)		Steam Treatment Time (sec)		Roller Scrubber Conditions§			Sugar Loss** (% original)
					Roller	Residence Time (sec)		
	Mean ± S. E.	Range	Mean	Range	RPM	Mean	Range	Mean ± S. E.
4	4.1 ± 0.1	3.4- 4.9	13.1	13-15	400	22	20-26	1.9^{A} ± 0.3
6	6.1 ± 0.1	5.4- 6.9	17.4	17-19	400	30	30-32	3.1^{B} ± 0.2
9	8.9 ± 0.1	7.4-10.3	29.4	28-30	400	30	30	5.0^{C} ± 0.1

* In a column, means with differing superscripts are significantly different at $P < 0.05$.
† Ave of 2 pilot plant runs, 12 determinations per run.
‡ Range of all individual determinations at given peel loss level.
§ Roller positions: abrasive rolls 1,2,3,7; bristle rolls 4,5,6.
** Average of 2 pilot plant runs, 6-8 determinations per run.

Table 2. Composition and Purity of Process Fractions from Peeled Sugarbeets.

Fraction	Analysis*	Unpeeled Control	Peel Loss (% orig. wt.) 4.1	6.1	8.9
Cossettes,	Sugar[†],%	15.6^{A}	16.3^{B}	16.4^{B}	16.3^{B}
	Sugar[‡],%	72.2^{A}	73.8^{A}	74.4^{A}	73.8^{A}
	Purity,%	87.3^{A}	87.5^{A}	88.7^{A}	88.9^{A}
	Nitrogen[‡],%	0.52^{A}	0.44^{B}	0.49^{AB}	0.47^{AB}
	Ash[‡],%	2.78^{A}	2.31^{B}	2.28^{BC}	2.17^{C}
Peel	Sugar[†],%	—	0.64^{A}	0.86^{A}	1.96^{A}
	Sugar[‡],%	—	11.2^{A}	14.4^{A}	24.2^{B}
	Purity,%	—	41.4^{A}	44.5^{A}	48.1^{A}
	Nitrogen[‡],%	—	1.84^{A}	1.80^{A}	1.62^{B}
	Ash[‡],%	—	9.69^{A}	7.74^{A}	9.00^{A}
	Color[§], ICUMSA	—	120	180	440
Wash water	Sugar[†],%	—	0.22^{A}	0.34^{B}	0.51^{C}
	Purity[‡],%	—	51.2^{A}	59.1^{B}	67.1^{C}
	Nitrogen[‡],%	—	0.005^{A}	0.006^{A}	0.006^{A}
	Ash[‡],%	—	14.5^{A}	11.8^{B}	6.4^{C}
	Color[§], ICUMSA	—	46	79	86
Pressed pulp	Ash[‡],%	4.30^{A}	3.02^{B}	3.03^{B}	3.38^{AB}

* In a row, means with differing superscripts are significantly different at $P < 0.05$.
† Fresh weight basis.
‡ Dry basis.
§ Single Determination.

were only partially fulfilled by statistical analysis of data on cossettes. Sugar (fresh weight basis) was significantly higher in the peeled beets ($P < 0.05$), but differences in dry basis sugar were not significant. There were uniform apparent increases in purity from the unpeeled control through the highest peel loss levels, but the differences were not significant. Ash content in the cossettes, which should be inversely proportional to purity, was significantly lower in the peeled beets and did decrease significantly with increased peel removal. Lowered ash content in peeled beets carried through to the pressed pulp. Ash levels may be the analytical indicator of the visual observation that peeling was an effective method of reducing the amount of dirt on the beet. Peeling also removed virtually all petioles and field trash from the beets.

In the wash water fractions, most parameters were significantly different at different peel loss levels. Regular progressions of parameter values also were found in the peel fraction, but only differences in dry basis sugar and nitrogen were significant. The wash water samples had low sugar concentrations but had purities of 51 to 67 percent, much higher than that of the peel. This suggests that sugar was extracted into the wash water more rapidly than the impurities, as found in normal diffuser operations. The sugar was extracted into the wash water rapidly since the contact time in the roller scrubber was 30 sec or less and over half of the sugar lost during peeling was recovered in the wash water. In the roller scrubber, the wash water was in contact

with both the peeled beets and the peel. Therefore, some fraction of the total sugar lost during peeling was from the surface of the peeled beets. It is not known how significant these sugar losses were.

Composition and quality of the sugar juices from the pilot plant runs are shown in Table 3. Results from the thick juice samples were the most significant statistically, probably because each sample was the accumulated true average of all juice made during a run. Perhaps most important is the finding that thick juice purity can be increased significantly by peeling, and that the amount of the increase is proportional to the degree of peel removal. Purity increases of 0.7, 1.0, and 1.3 percent (absolute) were obtained from peeled beets at the 4.1, 6.1, and 8.9 percent peel loss levels, respectively. The results compare favorably with our previous laboratory work (Edwards et al., 1988), but remain considerably lower than reported in other work (Madsen et al., 1979; Madsen and Nielson, 1982). Color levels, nitrogen content, and ash content in thick juice could also be significantly reduced by peeling. Overall, apparent invert sugar levels were lower from peeled beets, but increased with increased peel loss. This effect, if real, may be due to the increased contact time between the beets and the high pressure steam at the higher peel loss levels. The same effect was observed for thin juice. For diffusion juice and thin juice some apparent trends may be seen but, in general, differences among treatments were not statistically significant. The exception was saponin content in diffusion juice. Saponin content was significantly lower in diffusion juice from peeled beets, and was inversely proportional to the degree of peeling. Saponin is an active foam stabilizer in diffusion juice, and the cause of floc in product sugar.

The linear relationship between sugar loss and peel loss has already been discussed. Data from other components whose values appeared to change proportionally to the degree of peel loss were also subjected to linear regression analysis. The resulting regression equations with slopes significantly different from zero and with R^2 figures of 0.65 or higher are listed in Table 4. Components in the wash water fraction had the highest R^2 values.

The distribution of minerals in the thick juices was affected little by peeling. Mineral content of the thick juices on a total nonsugar or impurity basis is given in Table 5. Statistically, no differences were found in mineral content among the thick juices from control and peeled beets, with the exception of the magnesium content in thick juice from beets peeled at the 6% level. It is felt that this value is an aberration. Because these four cations determine final molasses purity to such a great extent, we believe it is safe to conclude that there will be no significant difference in the final molasses purity from unpeeled beets.

Because of the improved thick juice qualities obtained from the peeled beets, a similar improvement was expected in final

Table 3. Composition and Quality of Sugar Juices from Peeled Sugarbeets.

Juice	Item*	Unpeeled Control	Peel Loss (% orig. wt.) 4.1	6.1	8.9
Diffusion	Purity, %	87.6^{A}	88.3^{A}	88.6^{A}	88.2^{A}
	Saponin§, mg/g	9.1^{A}	8.1^{B}	7.5^{BC}	7.1^{C}
Thin	Purity, %	93.4^{A}	94.3^{A}	94.4^{A}	94.8^{A}
	Lime salts†, %CaO	0.033^{A}	0.024^{A}	0.018^{A}	0.020^{A}
	Invert sugar‡, %	0.13^{A}	0.08^{A}	0.10^{A}	0.14^{A}
	Color, ICUMSA	900^{A}	740^{A}	770^{A}	540^{A}
Thick	Purity, %	93.9^{A}	94.6^{AB}	94.9^{B}	95.2^{B}
	Invert sugar‡, %	0.12^{A}	0.04^{A}	0.06^{A}	0.09^{A}
	Color, ICUMSA	1300^{A}	1030^{AB}	1140^{AB}	750^{B}
	Nitrogen§, %	0.25^{A}	0.25^{A}	0.24^{AB}	0.22^{B}
	Ash§, %	2.17^{A}	1.96^{A}	1.80^{B}	1.80^{B}

* Within a row, means with differing superscripts are significantly different at $P < 0.05$.
† % CaO on total solids.
‡ % Invert sugar on sucrose.
§ Dry basis.

Table 4. Regression Equations of Fraction Components Dependent on Degree of Peel Loss.*

Fraction	Component	Regression Equation Coefficients A ± SE	B ± SE	R^2
Cossettes	Ash†, %	−0.073 ± 0.019	+2.71 ± 0.05	0.91
Peel	Nitrogen†, %	0.20 ± 0.05	+0.31 ± 0.28	0.69
	Sugar†, %	2.7 ± 0.6	−0.53 ± 4.2	0.82
Wash water	Purity, %	3.2 ± 0.4	+38.5 ± 2.6	0.94
	Sugar‡, %	0.060 ± 0.006	−0.026 ± 0.040	0.96
	Ash†, %	−1.65 ± 0.02	+21.5 ± 1.1	0.96
Diffusion juice	Saponin†, mg/g	9.1 ± 0.2	−0.24 ± 0.03	0.91
Thick juice	Purity, %	0.15 ± 0.03	+93.9 ± 0.1	0.82
	Nitrogen†, %	0.0036 ± 0.0008	+0.25 ± 0.01	0.73
	Ash†, %	−0.049 ± 0.013	+2.3 ± 0.1	0.68

* In the form AX + B where X = peel loss, wt. %.
† Dry basis.
‡ Fresh weight basis.

Table 5. Mineral Content of Thick Juice Nonsugars*,†

Peel Loss (wt. %)	Magnesium (meq % x 10^{-2}/total nonsugars)	Calcium	Sodium (meq %/total nonsugars)	Potassium
Unpeeled control	24^{A}	135^{A}	310^{A}	302^{A}
4.1	22^{A}	231^{A}	306^{A}	312^{A}
6.1	33^{B}	234^{A}	314^{A}	308^{A}
8.9	20^{A}	167^{A}	317^{A}	332^{A}

* Duplicate analyses.
† In a column, means with differing superscripts are significantly different at $P < 0.05$.

sugar quality, which is shown in Table 6. Compared to the controls, there were apparent decreases in conductivity ash, turbidity, and color in samples from the peeled beets. Statistically, however, the values were not different. No floc was found in any of the product sugars. This was unexpected because the visual floc level in at least the control thick juice sample was high enough to normally produce floc in the product sugar.

Based on the sugar losses during peeling and the thick juice purities from the pilot plant runs, calculations of projected factory extractions and nonsugar flow rates at the three peel loss levels were made. The calculations assumed a 5% miscellaneous sugar loss during processing, a 60 purity final molasses, and no recovery of product sugar from peel or wash water fractions. Steps in the calculations and the results are shown in Table 7. The crystallization yield was lowest for the control beets and increased regularly with increasing peel loss level. This increased crystallization efficiency as a result of the higher thick juice purities from the peeled beets. Apparently, however, more sugar was lost during peeling than could be compensated for by the increased crystallization efficiency, which resulted in lower projected extractions from the peeled beets. Projected extraction was highest for the control beets and decreased uniformly with increasing peel loss level. Table 7 also shows that peeling substantially reduces the flow of nonsugars through the factory. Compared to the control, the flow of nonsugars is reduced by 14.5, 21.0, and 27.4% by peeling to the 4.1, 6.1 and 8.9% levels, respectively.

Some advantages and disadvantages of high pressure steam peeling of beets can be deduced from the results of these experiments. Those currently perceived are listed in Table 8. Peeling removes skin, dirt, field trash, petioles, and soft deteriorated flesh from the surface of the beet. The microbiological loading of cossettes to the diffuser should be reduced, perhaps reducing sugar losses during diffusion. The pulp made from peeled beets should produce a cleaner, whiter, blander sugarbeet high-fiber product for human consumption than the normal process. The added value of this product could more than compensate for all the perceived disadvantages of peeling. With possible lower

Table 6. Quality of Sugar from Peeled Beets*,†

Peel Loss (wt. %)	Conductivity Ash (% on solids)	Turbidity	Color ICUMSA	Floc
Control	0.010	6.3	18.7	None
4.1	0.008	6.0	14.5	None
6.1	0.008	4.5	16.0	None
8.9	0.008	4.5	11.5	None

* Single sample, single analysis per run.
† Within columns, there were no significant differences between treatments at $P < 0.05$.

Table 7. Calculation of Extraction and Nonsugar Flows Using Peeled Beets

Item	Unpeeled Control	Peel Loss (% Orig. Wt.) 4.1	6.1	8.9
Original sugar, kg	100	100	100	100
Miscellaneous loss (5%), kg	5.0	5.0	5.0	5.0
Sugar losses to peel, kg	—	1.9	3.1	5.0
Remaining sugar, kg	95.0	93.1	91.9	90.0
Remaining sugar purity*, %	93.9	94.6	94.9	95.2
Nonsugars, kg	6.2	5.3	4.9	4.5
Nonsugars decrease, % control	—	14.5	21.0	27.4
Sugar to molasses, kg	9.3	8.0	7.4	6.8
Product sugar recovered, kg	85.7	85.1	84.5	83.2
Crystallization yield‡, %	90.2	91.4	91.9	92.4
Apparent extraction, %	85.7	85.1	84.5	83.2

* Basis 100 kg sugar in beet, 60 purity molasses, 5% miscellaneous sugar losses.
† Thick juice purity.
‡ Percent of sugar entering crystallization recovered as product.

Table 8. Advantages and Disadvantages of High Pressure Steam Peeling of Sugarbeets

Advantages
1. Removal of skin, dirt, field trash, petioles, deteriorating flesh.
2. Lower juice saponin content.
3. Reduced cossette load through factory.
4. Reduced non-sugar load through factory.
5. Higher thick juice purity.
6. Higher apparent sugar quality.

Disadvantages
1. Capital cost.
2. Steam cost.
3. More complicated system.
4. Apparent lower extraction rate.

levels of colloidal clay and suspended organic matter in the diffusion juice, purification costs may be reduced due to lower lime and CO_2 costs and possibly improved juice filtration rates. Cossette cutter maintenance costs should be lower because the peeled beets should contain less abrasive material. Lower saponin levels in the diffusion juice should reduce the requirements for antifoam agents.

Total throughput of sucrose in a factory could be increased significantly by using peeled beets. Since peeled beets are higher in sucrose than raw beets, for a given slice rate, there would be a greater throughput of sucrose using peeled beets. The throughput could be increased even more in those factories in which nonsugar elimination is the rate limiting production factor, for nonsugars are reduced up to 27% in peeled beets, allowing even higher slice rates for a given factory. Based on nonsugar

loading calculations in Table 7, and assuming other design factors did not become rate limiting, beet slice rate could be increased by up to 38% (6.2/4.5 x 100) using beets peeled at the 8.9% level. Alternatively, if factory throughput was not changed, then the nonsugars from the peeled beets would have a 38% longer residence time in the crystallization process. Such longer residence times should improve projected extractions by allowing crystallization to lower molasses purities. How the addition of a beet peeling operation would affect beet sugar production is dependent to a large extent on the design characteristics of the plant under consideration.

Higher thick juice purities increase the crystallization efficiency of the process, as previously noted. Regarding factory operation, it means that sugar end costs could be reduced because less sugar would have to be recrystallized to produce sugar with a quality the same as from the original unpeeled beets. Or, higher quality sugar could be produced for possible new markets.

Peeling obviously has disadvantages too. The capital required to install the operation is substantial. We have estimated that $2 million would be required for a 5000 ton per day plant. The steam required for peeling is another cost. Steam requirements are estimated at 2% of beet weight, but up to half that amount could be saved by available steam recovery systems. Peeling makes the overall factory operation more complicated. Peeling equipment, however is highly automated and runs largely unattended in other industries. Finally, and perhaps most seriously, this works suggests that the amount of sugar recovered as product per ton of fresh beets is lower from peeled beets.

The advantages of peeling, which we have discussed, appear to be significant enough to warrant further work. Much remains to be learned about the peeling process and the processing of peeled beets. Such work needs to be carried out on a pilot scale in a continuous process. Foremost should be efforts to reduce the amount of sugar lost to the peel and washwater fractions so that extraction values are increased. One approach would be to reduce or eliminate the use of water during the peel removal step. This could be done using centrifugal-type peel removers which are available only in large sizes. Alternatively, the wash water could be partially recycled so that the concentration of sugar is higher. This would reduce the rate of leaching of sugar from the surface of the peeled beet by decreasing the sugar concentration gradient.

No work has been done on the processing of the peel and wash water fractions. To date it has been assumed that the peel would be pressed, perhaps after heating and lime addition, and the wash water concentrated by evaporation, and then both added to the normal press pulp for drying. The cost of steam to peel the beets is a considerable expense. Work must be done to determine the exact quality and amounts of steam needed for

efficient peeling. If lower quality steam, such as steam exiting the turbines, could be used, the economics might be improved considerably. The recovery and reuse of steam from the peelers should also be examined. Crystallization studies of thick juice from peeled and unpeeled beets need to be undertaken to determine what crystallization rates and molasses purities can be expected in commercial practice under different operating conditions. Juice purification parameters need to be optimized. Finally, diffusion juice from peeled beets should be considered as a improved starting material for ultrafiltration or other advanced purification techniques.

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