Effect of Cossette Liming on Dewatering of Beet Pulp

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INTRODUCTION

The increasingly high costs of energy are of great concern to the sugar beet processing industry, since it is one of the most intensive consumers of energy in the food industry. Unger (13) estimated that of the over 2.6 x 10^6 Btu required to process one ton of beets, approximately 25% of the energy is used to dry pulp, 4.5% to produce CaO, and 50% to cncentrate thin juice. Avlani, Singh, and Chancell (1) estimated 23% for pulp drying and 44% for concentration of thin juice.

Liming beet tissue before extraction of sugar could reduce energy requirements in one or more of the major energy-consuming areas of beet-sugar production. It has been thought for many years that adding lime to sugar beet tissue might lower overall lime requirement in processing beet sugar, and a number of approaches to the problem of treating beets with lime prior to diffusion have appeared to the literature. As early as 1905, Weinrich (15) proposed processing limed brei to remove sugar. Extensive tests of pressing juice from limed brei, as an alternative to diffusion, were carried out by Borghi (5) and by Bonelli (3, 4). Weinrich (16, 17) also proposed pressing brei or chips which had been limed and then neutralized.

A number of researchers have proposed diffusion of cossettes combined with some form of lime treatment. Susic (12) proposed diffusion of cossettes which had been treated with a mixture of lime and sugar, while Goodban and McCready (9) proposed treatment of cossettes with powdered lime followed by normal diffusion, which Bobrovnik et al. (2) studied further.

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Loof and Pohl (10) suggested diffusion of cossettes in dilute lime water. Degtyar (7) found that with rotting beets, addition of lime to the diffusion water improved processing characteristics, and Vukov and Tegze (14) studied treatment of poor quality whole beets with milk of lime, $CaCl_2$, NaOH, and CaO.

As far as can be determined, liming of sugar beets before or during sugar extraction has never been used commercially in the U.S. However, most of the research and attention occurred during a period when beet-sugar research was not focused on reducing energy consumption through process modification. Now, the changing energy situation has encouraged us to take another look at the possible advantages of beet liming.

One of the important potential advantages of beet liming is that the chemical action of basic calcium ion on beet tissue produces a firm tissue due to cross-linking of Ca^{2+} with deesterified pectin molecules in the cell-wall tissue. The cross-linked pectin keeps the pulp rigid even after diffusion, permitting improved physical dewatering of the pulp in presses prior to drying for cattle feed (11). Physical dewatering by pressure is a much less energy intensive operation then dehydration by heat, so any extra moisture reduction accomplished by pressing can reduce overall energy consumption in beet-sugar production.

Other papers will describe the chemical reactions of lime on beet tissue, especially pectin, and the effect of beet liming on the juice purity, lime salts, color, filterability, and other characteristics. In this paper we shall report the effects of various methods of liming beet tissue on dewatering characteristics of exhausted beet pulp, as a potential energy-saving method for drying of pulp.

EXPERIMENTAL PROCEDURE

Beet Form

In this study, cossettes were used as the cut beet form. Other forms of cut beets, such as juilienne strips of approximately equivalent cross section which were produced with a special attachment to an Urshel dicer, were used at times, but they proved greatly inferior to cossettes in reaction to liming. Cossettes were cut in a pilot plant cossette cutter designed and constructed in this laboratory. For liming conditions at other than ambient temperature, the cossette cutter was chilled with ice or heated with hot water before use.

Beet Liming

Cossettes were limed by one of several methods:

1) The cossettes were mixed with dry, powdered $Ca(OH)_2$, either in a double cone mixer or in a pill coater, for 2-3 minutes. Good contact of $Ca(OH)_2$ with beet tissue was obtained in this time without excessive breakage of cossettes. The remainder of the total equilibration time was carried out at rest at whatever temperature was used.

2) Cossettes were dipped into a thin slurry of $Ca(OH)_2$ in thin juice (0.5-1.0%, calculated as CaO) for several minutes, then pulled out and drained. The remainder of the total equilibration time was carried out at rest at the same temperature as the slurry.

Shear and Dewatering Tests

Shear tests were carried out with a L.E.E.-Kramer Shear Press usually fitted with a 3000 lb proving ring. The standard cossette sample was 100g placed into a standard shear-compression cell, with a power rate of travel of ¼"/sec.

Static dewatering tests were carried out in two presses. For small samples and lower pressures, the Succulometer, a small hydraulic press made by the United Company, Westminster, Maryland, was used. It accepted 75g samples and could apply a force 4450 Newtons on a round die of 5.72cm inner diameter, for a pressure of 1730 KPa. For larger samples and higher pressures, we used a Carver Laboratory Hydraulic Press with a Cage Press attachment (Fred S. Carver, Inc., Menomonee Falls, Wis.). A total force of up to 44,500 N could be applied to a 8.89cm die, for a pressure of 5700 KPa.

Other Analyses

Total solids were determined by drying at 110°C for 16 hours. Sugar analysis was carried out by first extracting the sugar in ethanol by the Standard AOAC method followed by colorimetric analysis of total sugar as recommended by Dubois et al. (8). Analysis of calcium was carried out by atomic absorption using a Perkin Elmer 303 AA Spectrophotometer on samples prepared by a modified dry ashing method of Champman and Pratt (6).

Sugar Extractions

In preparing extracted pulp samples for dewatering tests, a number of methods were used to extract sugar. When the exhausted pulp was the desired product, samples of beet cossettes were placed in cheesecloth bags or in wire baskets and suspended in slowly flowing hot water for up to one hour to completely extract the sugar. Also, many of the samples of exhausted beet pulp were produced as a byproduct of extraction runs designed to produce typical raw juice in a bench scale type of semi-continuous extracter using muiltiple containers. Removal of sugar from the pulp was not quite as complete in this extraction scheme as in the first method, but so far as could be determined, there was no difference in the nature of the exhausted pulp.

RESULTS AND DISCUSSION

Shear Strength of Tissue

It has been qualitatively stated in the literature (9) that liming beet tissue produces tougher pulp, which should be advantageous in dewatering pulp prior to drying. Shear strength tests of both extracted and unextracted cossettes confirmed this over a wide range of process conditions. Shear strength tests were carried out with both dry liming and wet-dip liming, and with several temperatures, equilibration times, and amounts of lime. Table 1 summarizes the results for a few process conditions. Limed but unextracted cossettes were tougher than unlimed controls from the same beet samples except at 33°C process temperature; extracted cossettes were much lower in shear strength than initial samples, but pulp from limed cossettes was consistently much tougher than the controls. Cossettes limed (dry or dip) and equilibrated for 30 minutes were only slightly tougher than cossettes equilibrated for 15 min, indicating that

Table 1. Shear Strength Values for Cossettes.

Sample	Liming Conditions			Shear Force (lb)	
	Lime Conc. (%)	Equil. Time (min)	Liming Temp. (°C)	Unextracted	Extracted (75°C for 60 min)
<u>Dry Liming</u>					
Control	--	--	22	1188	135
Limed	1.0	15	22	1558	268
Limed	1.0	30	22		365
<u>Dip in slurried lime</u>					
Control	--	--	6	1175	171
Limed	4.0	15	6	1680	383
Limed	4.0	30	6	1787	460
Control	--	--	22	1268	137.5
Limed	4.0	15	22	1587	360
Limed	4.0	30	22	1708	282
Limed	2.0	15	22	1350	490
Limed	2.0	30	23	1287	550
Control	--	--	33	1137	183
Limed	2.0	15	33	1112	380
Limed	2.0	30	33	1050	415

an equilibration time of 15 minutes is satisfactory. Shear strengths of extracted cossettes which had been equilibrated for 30 min before diffusion were consistently about 10% tougher than those equilibrated for 15 min. Further, dipping for 6 minutes instead of 3 minutes did not appear to increase the shear strength of extracted or unextracted beet tissue, and those results have been omitted.

Dewatering of Limed Beet Pulp

The increase in toughness of limed cossettes vs. unlimed cossettes indicated that limed pulp might be easier to dewater by pressure than normal unlimed pulp, which is mushy. In current factory practice, extracted pulp from the diffuser is dewatered in large screw presses to about 22% solids, then dried in rotary kilns. Similar presses were not available for laboratory scale operation, but simple batch pressing tests were made in an effort to approximate the effects of the continuous presses. The Carver hydraulic press with a Cage Press Attachment was preferred, for it could produce final moisture levels more in line with industry results than the lower pressure "Succulometer" hydraulic press. Since some samples were so soft that they could not be pressed in the Carver Press, Succolometer tests were made on almost all samples to provide consistency.

Dry liming. The original procedure used for cossette liming was mixing cossettes with fresh, dry, powdered $Ca(OH)_2$. In early experiments on pectin deesterification (11), it was found that 1.0% lime (calculated as CaO) was sufficient to produce maximum pectin deesterification. It was also established that a total equilibration time of 15 minutes was more than sufficient to allow OH^- and Ca^{2+} to pentrate the cossette and react with the pectin.

Dewatering results on dry-limed and extracted cossettes corroborated the belief that deesterification and calcium cross-linking of pectin would facilitate mechanical dewatering of pulp. Table 2 shows the results of pressing limed and extracted beets in a Carver Press for 5 minutes at 5700 KPa. In all cases, the cossettes were mixed with powdered $Ca(OH)_2$

for three minutes and equilibrated at rest for another 12 minutes. At extraction temperatures of 75°C and 60°C, addition of 0.5%-1.0% lime on the beets improved dewatering characteristics over control values. Addition of 0.5% lime on the beets allowed mechanical removal to only 75% of the moisture of the control while with 1.0% lime addition, water could be pressed out to only 60% of the control moisture level. However, liming at the 1.5% level did not significantly improve dewatering compared to the 1.0% level. These results strengthened the belief that 1.0% lime was the optimum lime level for energy reduction, for the extra lime, which costs energy, would only be justified if it produced greater energy savings elsewhere in the process.

Table 2. Dewatering of Dry-Limed, Extracted Cossettes in a Carver Press*.

Extraction Temp. (°C)	Treatment Temp. (°C)	CaO on Beets (%)	Solids in Press Cake (%)
75	21	0.0	25.7
		0.5	34.3
		1.0	43.1
		1.5	42.2
60	4	0.0	26.1
		0.5	33.7
		1.0	38.1
		1.5	39.9
	23	0.0	25.0
		0.5	28.2
		1.0	36.2
		1.5	34.2

*Pressed for 5 min at 5700 KPa after extraction for 50 min.

Wet liming. Another feasible method of liming cossettes was to dip the cossettes into a slurry of $Ca(OH)_2$ in beet juice. This procedure has more process parameters to investigate than dry liming. There are possible effects of concentration of $Ca(OH)_2$ in the slurry, the dip time, the total equilibration time, and the temperatures of the dip solution and the holding period after the dip.

Table 3 gives results of experiments designed to show the effects of dip time and total equilibration time on dewatering of extracted cossettes in the Succulometer. From Table 3 it is apparent that there were no significant differences among dip times of 3, 6, or 10 minutes, or between total equilibration times of 15 or 30 minutes. There are no trends in the data.

Table 3. Effect of Dip and Equilibration Times on Dewatering*.

Lime in Dip Sol'n (%)	Dip Time (min)	Total Equil. Time (min)	Solids in Pressed Cake (%)
1	3	15	15.9
		30	17.1
	6	15	16.5
		30	16.0
	10	15	14.8
2	3	15	21.6
		30	22.4
	6	15	22.5
		30	18.5
	10	15	21.2
		30	20.8

*Pressed in hydraulic press for 10 min at 1700 KPa after extraction for 50 min at 75°C.

However, it is quite apparent that a dip slurry of 2% lime produced extracted pulp which could be dewatered to much higher solids contents (around 21-22%) than with a 1% lime slurry (around 16-17%). This was somewhat surprising because $Ca(OH)_2$ is not soluble even at the 1% level in beet juice, and even after dipping, suspended $Ca(OH)_2$ was present in the dip solution.

Since only dissolved Ca^{2+} and OH^- should diffuse through the cossette and react with pectin, undissolved $Ca(OH)_2$ should not have a great effect, except to readily provide a source of new Ca^{2+} as Ca^{2+} already in solution precipitates pectin.

The effect of amount of lime in the dip slurry on dewatering of pulp was studied over a wider range, and results are shown in Figure 1. All cossette samples were cut from beets at 22°C, dipped in 22°C slurries of varying quantities of $Ca(OH)_2$ in thin juice for 3 minutes, equilibrated for a further 12 minutes out of the dip, then extracted in 75°C water for 50 minutes. The extracted pulp was then pressed in a Succulometer press for 10 minutes at 1700 KPa. From 0 to 4% lime (calculated as CaO) in the slurry, there was a rapid and almost linear increase in solids content of the press cake, but larger percentages of lime did not improve dewatering of the pulp. Thus, it appears that a slurry with 4% lime (about 5.4% $Ca[OH]_2$) would produce maximum dewatering with the least use of lime, at least at lower pressure.

Temperature effects. The effect of beet, liming, and equilibration temperature of dewatering of exhausted pulp is shown in Figure 2. Dewatering conditions were the same as those for Fig. 1, 1700 KPa for 10 min. Fresh cossette temperature, dip solution temperature, and holding temperature before diffusion were always the same for a particular run. It can be seen that there was not a large temperature effect from 4°C to 33°C. On the other hand, Figure 3 shows dewatering results for similar samples pressed at 5700 KPa for 3 min. Again, there was no large temperature effect on dewatering of pulp, although dewatering may have been slightly improved at liming temperatures around 20°C. Although there was a large effect of lime addition on dewatering at lower pressures, there is little difference between 2% and 4% lime addition at high dewater pressures. It may just be that at high dewatering pressures the lime level beyond which additional lime has no effect is lower than at the lower dewatering pressures used for Figure 1.

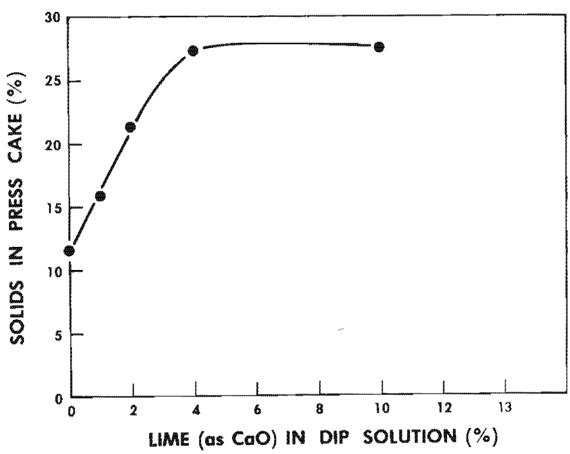

Figure 1. Effect of $Ca(OH)_2$ concentration in dip slurry on mechanical dewatering of extracted pulp at low pressure (1700KPa).

The effect of liming temperature on dewatering of exhausted pulp appears to be approximately constant, at least over the temperature ranges investigated. That is, the difference in solids in pressed pulp between 2 or 4% lime application and the control was approximately the same at all temperatures with lower pressures (Figure 2) and varied from 17% at 4°C to 20% at 33°C with the higher pressure press (Figure 3). Comparatively, liming of beet tissue at 33°C produced a better improvement of dewatering compared to the control. It might be expected that cossette liming would produce greater dewatering improvement with old, soft, and deteriorated beets than with

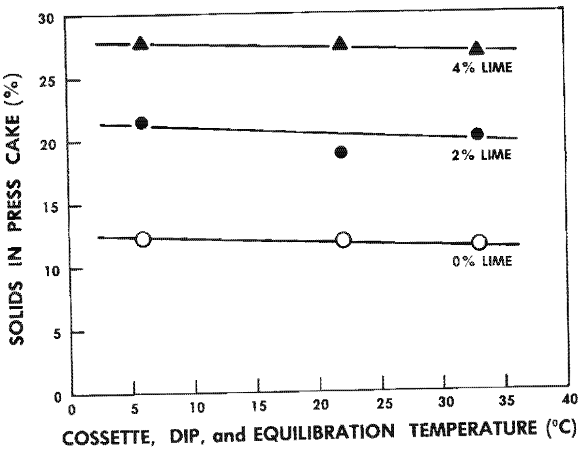

Figure 2. Effect of liming temperature on mechanical dewatering of extracted pulp at low pressure (1700 KPa).

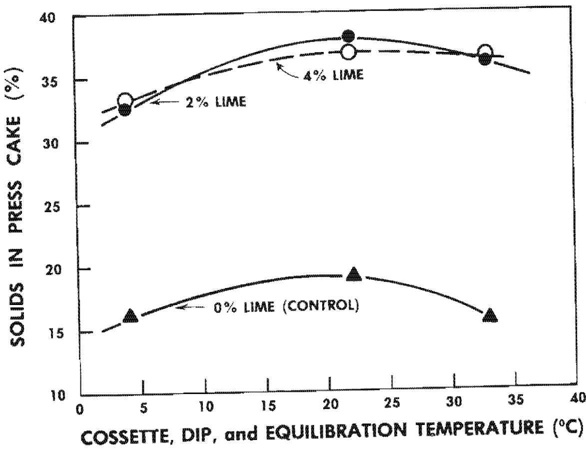

Figure 3. Effect of liming temperature on mechanical dewatering of extracted pulp at low pressure (1700 KPa).

firm, fresh beets because the precipitated calcium pectate would have more effect in strengthening the pulp of deteriorated beets than with firm, fresh beets. Perhaps this effect shows up to a limited extent in Figure 3, for beets held at 33°C are likely to soften somewhat. Addition of lime to whole beets which had rotted has been advocated by Degtyar (7) as a means of improved treatment.

Energy Considerations

Perhaps the most important area for potential energy saving in liming of cossettes lies in more complete pulp dewatering. Any additional mechanical dewatering that can be achieved through pressing limed pulp represents relatively low-energy removal of water compared to conventional water removal by evaporation by contact with hot air. Commonly, the maximum dewatering that can be achieved industrially by pressing in screw presses is to about 78% moisture.

Although equivalent screw presses were not available, the batch Carver hydaulic press gave comparable dewatering of controls when pressing was carried out at 5700 KPa for 5 minutes (Table 2). In extraction tests on cossettes which were dry-limed at 22°C, controls were dewatered to about 74.5% moisture. Thus, to obtain a dried pulp of 10% moisture from spent cossettes containing 96% moisture originally, another 11.25 g H_2O must be evaporated from the 74.5% moisture pressed controls (per 100 g of original wet pulp). The same cossettes limed at 1.0% CaO equivalent were pressed to 56.9% moisture; only 4.84 g of water would have to be evaporated per 100 g of original wet pulp to achieve the required 10% final moisture level. This represents only 43% of the heat energy required in the dryers under current conditions. With wet-dip liming at 22°C with 2% lime slurry, controls could be pressed to a moisture content of about 80.5%, while the lime pulp was pressed to about 63% moisture (Carver press). Using the same initial conditions and calculations as in the previous example, 16.05g of water would have to be evaporated from the control compared to only 6.37 from the dip-limed sample as from the control. Only 40% as much water would have to be removed from the dip-limed sample as from the control. Of course, pressing requires energy also, but any extra energy required for pressing the limed pulp to lower moisture would be small compared to heat energy for evaporation of water from the pulp.

Pulp drying currently requires about 25% of the total energy load of beet-sugar production. If suitable presses could be found to produce maximum dewatering of pulp, energy savings of at least 50% in drying operations could be obtained. This would amount to about 12% reduction in total energy consumption for beet-sugar production.

Further energy savings from the modified process, such as reduction in total amount of lime required, are discussed in other papers in this journal.

SUMMARY

A process modification consisting of contacting cossettes with either powdered or slurried $Ca(OH)_2$, followed by a short equilibration period prior to diffusion, can contribute to important reductions of energy consumption in dewatering and drying of exhausted pulp. It may be possible to achieve overall energy savings of up to 50% or more in pulp drying, representing a reduction of up to 12-14% in overall energy consumption for the beet-sugar process.

Addition of lime to cossettes precipitates calcium pectate in place in the cell walls, toughening the pulp as well as preventing degradation and solubilization of pectin fragments into the raw juice. The toughened pulp allows much easier and more complete mechanical dewatering of the pulp in presses, greatly reducing subsequent need for heat energy in driers to dry the pulp for cattle feed. In some experiments, pressing of limed pulp, using batch hydraulic presses, removed sufficiently more water that as little as 40% as much moisture would have to be evaporated from the pressed pulp as from similarly pressed control samples. It is much less energy intensive to remove water by pressing than by evaporation, since no change of state is involved.

Reference to a company and/or product named by the Department is only for purposes of information and does not imply approval of the product to the exclusion of others which may be suitable.

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