Factors Affecting Capacity and Design of First Carbonation Thickeners

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The Dorr Continuous Carbonation System is designed to produce a floc in beet sugar juice suitable for settling in first carbonation thickeners. The use of thickeners on juices from batch carbonation stations is not recommended in that solids formed in this system are not only difficult to thicken but also may vary so widely from one batch to the next so that continuous thickening is impractical.

Other types of continuous carbonation systems are used in Europe and in a few plants in the United States. It is beyond the scope of this paper to discuss carbonating techniques or to compare batch carbonation and the different continuous carbonation systems. Thickeners are used normally with all continuous carbonation systems but it appears that thickener capacity varies with each type of process. Therefore, first carbonation thickener operations as discussed in this paper apply only to those used in the Dorr Continuous Carbonation System.

The quality of thin juice is affected by a large number of variables some of which are under the control of the factory management. Others, resulting from the composition of the raw diffusion juice, cannot be controlled. Variations in the latter exist from plant to plant and, at any one plant, from month to month and from year to year, depending on the harvest areas, weather, storage conditions, and condition of the beets—green, ripe, frozen, or partly decomposed.

Fortunately, the effect of these variations in juice quality can be offset to a certain extent by the adjustment of other controllable variables, such as lime consumption, first carbonation alkalinity, juice temperatures, and even thickener underflow densities. In general, most investigators are in agreement that high first carbonation alkalinities, high liming, and low juice temperatures produce the best quality juice. On the other hand, some feel that the excessive detentions required in first carbonation thickeners are mainly responsible for juice degradation.

H. Elliot (2)[2] concluded from plant tests conducted in a first carbonation thickener in which detentions could be reduced by 59.5 percent of maximum, that "reduction of (detention) time in itself was not the solution to the formation of color." In reviewing the factors influencing color formation in the Dorr system, Elliot concludes, "assuming consistent lime addition, the final alkalinity has more bearing on the color of the juice than any other single factor." Experimental work (4) has shown that the higher the alkalinity, up to a certain point, the better the quality of thin juice produced, as judged by color, lime salts and colloidal content. At 80° C. the optimum alkalinity was found to be near 0.130 percent CaO on juice for saccharate milk defecation, and between 0.100 and 0.120 percent CaO on juice for milk of lime defecation.

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[2] Numbers in parentheses refer to literature cited.

During the 1953 campaign, a survey of several beet sugar factories employing continuous carbonation showed that each carbonation thickener tested was operating at maximum capacity. Each plant was carbonating at as high an alkalinity value as possible and, in straight houses, adding a minimum of lime while producing a floc which separated satisfactorily from the juice in the thickeners. At the same time, mud was discharged from the thickeners at the maximum possible solids concentrations.

In the Steffens houses visited, average first carbonation alkalinities ranged from .065 to .086 percent CaO on juice, lime consumptions from 2.82 to 4.60 percent CaO on beets and solids concentrations of mud from 15.0 to 24.5 percent. Average first carbonation alkalinities in the straight houses ranged from .064 to .071 percent CaO on juice, lime consumptions from 1.61 to 2.33 percent CaO on beets and solids concentrations of mud from 13.3 to 20.0 percent. Changing any one of the three conditions in each mill would have permitted adjustments in the other two while staying within the capacities of the thickeners.

Preliminary investigations revealed that the factors which influenced the quality of thin juice were also those which affected the capacity of first carbonation thickeners. Therefore, it was felt that a better quality of thin juice might be produced if first carbonation thickener capacity was to be increased, particularly if an increase in thickener capacity could be obtained in tank volumes no larger than that found in existing thickeners.

Because each machine tested was operating at maximum capacity, an unusual opportunity presented itself to determine the factors affecting capacity, and from this, to evaluate design criteria in an attempt to increase capacity.

Continuous thickeners were introduced to the beet sugar industry with the advent of continuous carbonation. Tray type thickeners were chosen over unit type thickeners because of reduced floor space requirements. Also, because of the size of foundation and covering, and the amount of insulation required, they are normally cheaper than unit thickeners of equal capacities.

The purpose of any thickener is to produce an underflow of a maximum solids concentration such that equipment required for further dewatering or washing of the solids will be of a minimum size. A further purpose is to produce an overflow of a minimum turbidity such that the quantity of suspended solids forwarded to further processing is not objectionable either by contamination of the product or by loss in capacity of equipment further along the line. In the sugar industry, it is required that these functions occur without undue holding periods of the juice in process.

In general, thickener capacity may be limited by any one of three variables—thickening area, total settling area, and detention time. A well designed thickener provides sufficient area and volume such that capacity is not seriously restricted by any one of these factors. It becomes necessary, therefore, to determine the limiting value placed upon capacity of each variable.

Tray thickeners may contain any number of compartments. However, the number seldom exceeds five because the over-all depth would become excessive if a larger number were used. The number of compartments times the tank area is equal to the total area available for settling and determines the upward displacement rate or overflow rate. Thus, a thickener containing two compartments would overflow at a linear rate twice as great as one of equal diameter containing four compartments if both were fed at identical rates.

If a slurry containing solids which exhibited an initial subsidence rate less than the overflow rate of the two compartment thickener but greater than that of the four compartment thickener were fed to both units, clarification would be evident only in the four compartment machine. Similarly, if the solids exhibited an initial subsidence rate greater than the overflow rate of the two compartment thickener, clarification would take place in both thickeners.

In the latter case, assuming that these solids were partially flocculated particles, as is the case of the carbonate floc, the degree to which clarification would take place would no longer be a function of overflow rate, but rather of detention time. Flocculation proceeds continuously throughout claification, the rate of flocculation being a function of the solids concentration at any given time. Thus, the total time available for flocculation of partially flocculated particles determines the chance for collision and coalescence and, therefore, is of major significance in determining the clarity of overflow.

The initial subsidence rate of the solids is the limiting factor of overflow rate. If this were also found to be the limiting factor of capacity, total settling area could be calculated on this basis alone whether this area be transcribed into the tray area of two or more compartments or into the floor area of a unit thickener. The total time required for flocculation to reduce the turbidity of overflow to any value desired could be provided by adjusting the overall depth of a tray or unit thickener.

The tray area of any one compartment may serve to compress solids to the desired solids concentrations, only if the compartment is properly designed. The normal type of first carbonation thickener contains four compartments, of which two (in some cases only one) are designed to thicken and discharge mud.

If capacity were limited by the area available for thickening, the capacity of a machine containing two thickening compartments should be double that of one containing a single thickening compartment. Similarly, in four compartment thickeners, if each compartment could be designed to thicken solids, the machine might attain a capacity four times as great.

Thickening area requirements of solids may be determined from batch settling tests. Coe and Clevenger (1) in 1916 showed how to predict these values. However, the test procedures of Coe and Clevenger often produce erratic results when testing first carbonation juices as the floc structure changes radically when the material is repulped.

Kynch (3) recently presented a mathematical analysis on batch settling tests. A simplified experimental procedure and interpretation, as outlined by Talmadge and Fitch (5), made it possible to check thickening capacities accurately by laboratory tests during the 1953 survey.

An excellent correlation exists between batch tests and results from actual thickener operation when the data is compared at conditions of actual continuous carbonation operation. Results obtained from batch tests were within 15 percent of operating data as shown in Table 1, indicating that the available thickening area at each plant was determining the solids handling capacity of the thickener.

Table 1.—Thickener Unit Areas Determined From Operating Data and Batch Tests.

Beet Sugar Factory	Location	Average Alkalinity % CaO on Juice	Average Lime Consumption—% CaO on Beets	Average Underflow Solids Concentration Gms./Liter	Unit Thickening Area Ft²/Tons Solids/Day Actual	Batch Tests
A—Steffens House	Idaho	.065	2.82	165	6.98	6.88
B—Straight House	Colorado	.064	1.61	145	19.4	16.5
C—Straight House	Montana	.071	2.33	227	5.23	5.20
D—Steffens House	California	.086	3.50	193	4.64	5.32

Further batch settling tests showed that thickening unit area values varied considerably with juice alkalinities, lime addition, and thickener underflow concentrations. Table 2 presents unit area requirements of floc formed at different juice alkalinities in one factory where saccharate milk of lime was added to the extent of 3.65 percent CaO on beets. Table 3 shows unit area requirements of solids formed at a juice alkalinity of .100 percent CaO on juice and where the quantity of saccharate milk of lime varied. Values shown represent thickening area requirements for average beet conditions in Steffens houses and might well pertain to any Steffens house as long as just consideration is given to lime consumption, juice alkalinity, and underflow solids concentration. On the whole, thickening area requirements are less in straight house under equal conditions.

Table 2.—Effect of Juice Alkalinity on Thickening Unit Areas Determined by Batch Settling Tests—Steffens House Operation—3.65% CaO on Beets.

First Carbonation Alkalinity % CaO on Juice	Unit Thickening Area Sq. Ft./Ton Solids/Day Underflow Concentration—°Brix 35	40	45	50
.080	4.1	5.1	6.5	8.1
.090	5.1	6.3	7.9	9.8
.100	5.8	7.1	9.0	11.2
.110	6.6	8.0	10.2	12.7
.120	7.5	9.1	11.6	14.4

Table 3.—Effect of Lime Addition on Thickening Unit Areas Determined by Batch Settling Tests—Steffens House Operation—Juice Alkalinity: .100% CaO on Juice.

Lime Addition % CaO on Beets	Unit Thickening Area Sq. Ft./Ton Solids/Day Underflow Concentration—°Brix			
	35	40	45	50
2.5	15.6	19.0	23.4	29.4
2.75	12.6	15.3	19.1	24.0
3.0	10.3	12.5	15.6	19.7
3.25	8.2	10.0	12.4	15.8
3.5	6.6	8.0	10.0	12.7
3.75	5.2	6.0	7.6	9.6

Tests conducted to determine the limits imposed upon capacity by the initial subsidence rate and flocculation rate of the carbonate particles show that these rates also varied with changes in juice alkalinity and lime addition. However, results indicate that the limiting values of these rates would not be exceeded at the maximum solids handling capacity as dictated by thickening area. Thickening area, therefore, is the most important single factor to consider in first carbonation thickener capacity.

It was felt, therefore, that if more thickening area were provided within a fixed volume, the capacity of a thickener would be increased proportionately. Further, test results indicate that this capacity increase might be used to any advantage desired in operation—obtaining higher juice alkalinity, reducing lime consumption, increasing solids concentration of mud, increasing juice throughput rate, or producing any combination of results—as long as the thickening area requirements were met. Thus, the primary design criteria of first carbonation multi-compartment thickeners is to utilize each compartment for thickening.

It might be argued that if thickening area is the most important criteria of capacity and design, it would be possible to reduce volume and, therefore, reduce objectionable detention time to a minimum. Theoretically, it is possible to reduce detention time considerably but only at the expense of obtaining a higher-suspended solids concentration in the overflow. As a result of differences in the quality of raw diffussion juice, thickening behavior of carbonate floc varies considerably, thus making it necessary to provide volume for surge capacity in the thickeners. Otherwise, any slight fluctuation in the carbonator would produce exceptionally high overflow turbidity before carbonation could be restored to normal. The volume provided for these surges is more than actually required for clarification. In this manner, thickening determines not only area requirements, but also volume requirements as well. Because more volume is present than is actually required for clarification, it is possible to eliminate the conditioning compartment, the volume of which cannot be utilized for mud storage.

The new concept in design of first carbonation thickeners is shown in Figure 1. The thickener might be considered as four separate unit type thickeners, each unit stacked one on top of the other and each receiving feed from a common source. The large tank diameter conditioning compartment in thickeners of previous design (Figure 2) has been replaced by a much smaller feed compartment to reduce detention time. The complicated center feed column has been eliminated and juice now enters the thickening compartments through centrally located feedwells of gradually

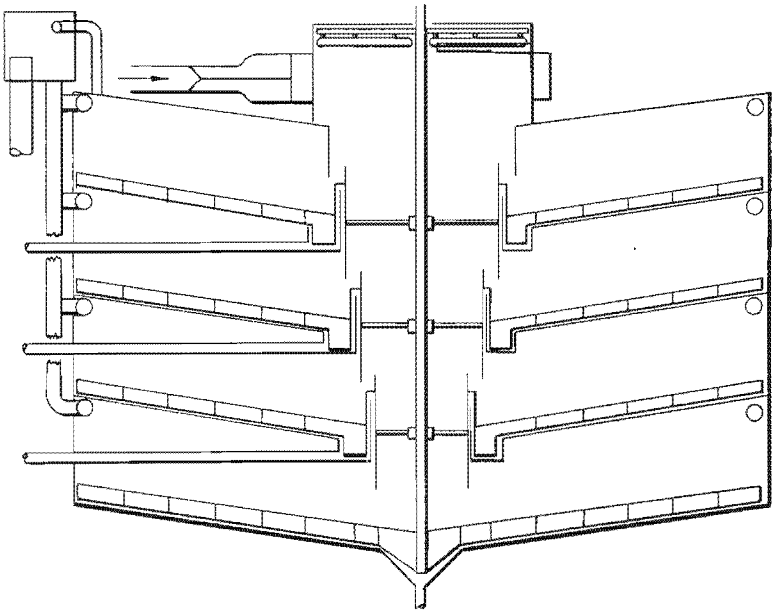

Figure 1.—First carbonation thickener of latest design.

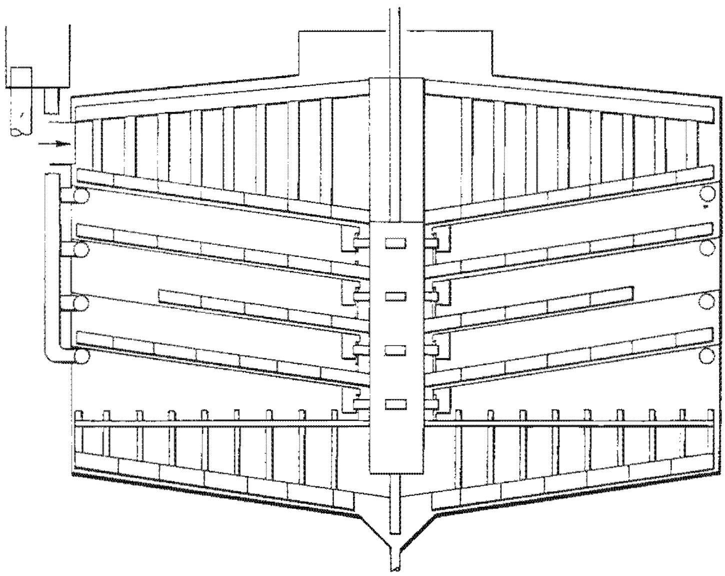

Figure 2.—First carbonation thickener of conventional design.

diminishing diameters. These feedwells are designed to maintain a uniform juice velocity of approximately four feet per minute through each and they rotate with the mechanism and are sealed at the level of the trays to form an upcast boot which retains the settled mud in each compartment. Mud is discharged from each compartment by means of individual sludge pumps.

A first carbonation thickener at the Spreckels Sugar Company's factory, Spreckels, California, was modified for the 1954 campaign such that the available thickening area was four times greater than that of the original design. Essentially, the original thickener was of the design shown in Figure 2 and was modified to that shown in Figure 1. However, due to the lack of time for conversion, certain features of feed introduction, foam removal, and overflow box arrangement had to be eliminated which would otherwise have been incorporated.

Prior to the modifications, the thickener at Spreckels was overflowing juice having a solids concentration of 5 to 10 percent solids by weight from the two lower compartments. Based upon batch settling tests, the thickener was laboring 72.5 percent over capacity under the conditions imposed. As shown on Table 4, conversion of the Spreckels thickener has made possible an increase in the tons of beets sliced per day from 5200 to 5900, an increase in first carbonation juice alkalinity from 0.067 to 0.090 percent CaO on juice, and operation with clear overflows from all trays.

Table 4.—Operation of First Carbonation Thickener Before and After Conversion—Spreckles, California.

	Operation Prior to Conversion	Operation After Conversion
Slicing Rate—Ton Beets/Day	5200	5900
Lime Consumption — % CaO on Beets	3.42	3.65
CaO to Carbonation — Tons/Day	178	215
Solids to Thickener — Tons/Day	338	408
First Carbonation Alkalinity — % CaO on Juice	.067	.090
Underflow Concentration — gms./liter	280	250
Unit Thickening Area Requirements (Batch Tests) Ft²/Ton Solids/Day	3.6	5.4
Thickening Area Available — Ft²	707	2828
Thickener Solids Handling Capacity — Tons/Day	196	408
Solids Overflowing Thickener — Tons/Day	142	0.16
Actual Increase in Solids Handling Capacity	—	2.08
Potential Solids Handling Capacity — Tons/Day (at Alkalinity = .090, lime consumption = 3.65%, underflow concentration = 250 gms./liter).	131	524
Theoretical Increase in Solids Handling Capacity	—	3.12
Potential Increase in Solids Handling Capacity	—	4.00
% — Theoretical Capacity/Potential Capacity		78

Thus, comparing the operation of the thickener before and after conversion, it is evident that the modified unit actually handled 2.08 times the quantity of solids it was originally designed to thicken. From a theoretical standpoint, based on batch thickening tests, it is calculated that the unit, prior to being modified, could have handled 131 tons of solids per day under the conditions being met by the modified machine. The modified thickener handled 408 tons of solids per day and, therefore, under identical conditions, it is calculated that the theoretical capacity of the modified unit was 3.12 times greater than that of the original design. Similarly, the modified thickener should have been capable of handling 524 tons of solids per day under these conditions. Therefore, the new unit was operating at 78 percent efficiency.

Observation of thickener performance at Spreckels indicated that a greater portion of feed juice was being split to the upper thickening compartment, causing undue turbulence which adversely affected the clarity of overflow from this compartment at high rates. Conditions were aggravated by the lack of proper foam removal equipment in the feed compartment and by lack of pipe sleeves in the overflow box, a situation which prevented control of clarified juice removal from each compartment. As a result, the entire solids handling capacity of the thickener was being limited by the clarification capacity of the upper compartment.

A second thickener was modified for the 1955 campaign at Holly Sugar Company's plant in Alvarado, California. The original thickener was identical in design to that of Figure 2, and conversion changed the machine to the design shown in Figure 1. Proper foam removal equipment was installed, and a feed diffuser was added to insure that equal quantities of juice and solids would be split to each compartment. Except for these additions and pipe sleeves in the overflow box, which are normally provided on all first carbonation thickeners, the Alvarado thickener was identical in design to the Spreckels unit.

Table 5.—Operating Data of Alvarado Thickener Correlated with Batch Settling Tests.

Period	1	2	3	4
Slicing Rate — Ton Beets/Day	1774	1777	1674	1715
Lime Consumption — % CaO on Beets	4.11	3.94	3.86	3.55
CaO to Carbonation — Tons/Day	73.0	70.0	64.6	60.9
Solids to Thickener — Tons/Day	138.5	133.0	122.4	115.5
Ave. First Carbonation Alkalinity-% CaO on Juice	.092	.092	.096	.099
Ave. Underflow Concentration — °Brix	46.5	47.0	45.8	41.3
Unit Thickening Area Requirements (Batch Tests) Ft²/ton Solids/day	11.9	11.2	13.4	13.3
Thickening Area Available — Ft²	1520	1520	1520	1520
Thickener Solids Handling Capacity—Tons/Day	127.5	135.5	113.5	114.5
% Variation — Actual to Potential Solids Handling Capacity	8.5	1.5	7.8	0.9

At Alvarado, the capacity increase of four-fold as provided by the conversion was utilized to increase juice alkalinities upward above 0.090 percent CaO on juice and to increase the average solids concentration of the mud. In addition, it was found that Kelgum, used in previous years to increase the thickening rate of solids, was not required in the new operation, thus reducing operating costs.

Table 5 presents operating thickening data correlated with batch settling tests results, the data shown being averaged results of four periods of operation at Alvarado. Under the conditions described, average quantities of solids entering the thickener during these periods check solids handling capacities as determined by batch settling tests, the variation between the two being well within the accuracy of these tests. It is assumed, therefore, that the four-compartment first carbonation thickener at Alvarado reached its full potential capacity, and that this capacity was four-times greater than that of the original design.

Operation of the two first carbonation thickeners of the new design showed that no more attention need be given this type of thickener than would be required for machines of previous designs. The stroke and revolution of each sludge pump was adjusted in a manner to produce approximately equal pumping rates. Likewise, piping sleeves were adjusted to produce equal overflow rates from each compartment. With the machine balanced in this manner, each compartment produced overflows of a low equal turbidity and mud of a high equal solids concentration.

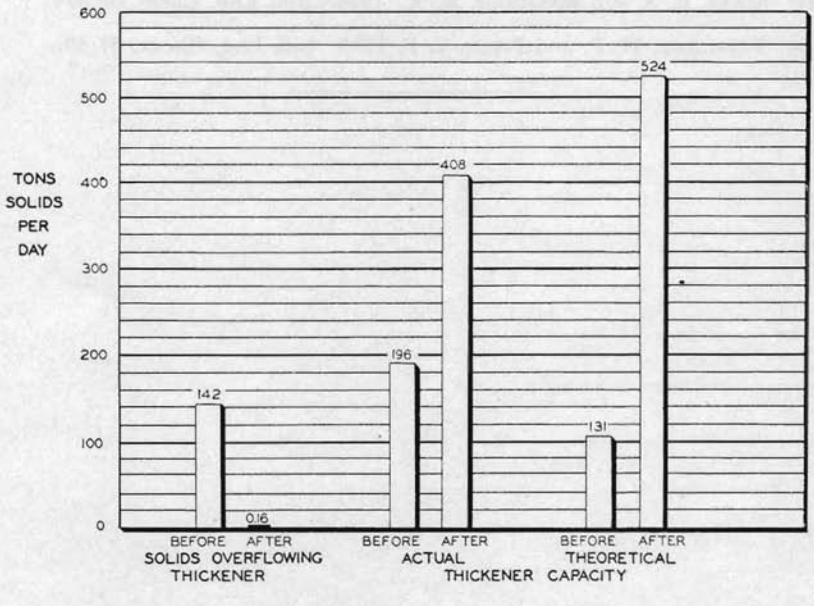

Figure 3.—Operating data of first carbonation thickener before and after conversion—Spreckels, California.

The new thickener design provides free communication from one compartment to the next compartment below. Should the thickener become improperly balanced and more solids thicken in the upper compartments than can be handled, the excess solids would overflow the upcast boot of the feedwell and descend to lower compartments. Hence, it is necessary only to watch the mud level and the mud density of the bottom compartment to determine the proper rate of mud withdrawal from each compartment.

Tests showed that the thickener at Alvarado would not overflow mud from any of the upper three compartments without first filling the bottom compartment with mud, overflowing the bottom compartment, and then filling up each compartment one at a time, from the bottom up. Operation of this type of thickener may be compared, therefore, to operating four unit thickeners, of which only one thickener need be watched for signs of adjustment in pumping rate or in changing carbonator conditions.

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