CHEMISTRY

Suggested Procedure For Obtaining Lower Temperatures During Sugar Beet Storage

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Better conservation of the sucrose beets during their storage rerains an extremely important problem. If the domestic beet sugar industry is to attain an overall economy of operation permitting successful competition with other sources of sugar, it is definitely necessary to eliminate a large part of. the sugar loss usually occurring in piled beets. Further, this objective most be reached in spite of extending the storage period to permit longer operation of the factories. Only rough approximations can be made as to the present annual loss but certainly it amounts to tens of millions of pounds of sugar. It seems possible that as much as two-thirds of this loss is preventable.

It is well established that at temperatures between 32° and 40° F. the respiration of the beets and the destructive action of microorganisms are very slow and the resulting sugar losses correspondingly low. Both respiration and spoilage increases rapidly with increases in temperature. Therefore, the primary problem is to find practical means of obtaining low- temperature storage so that the quantity of trash, beet growth, beet quality, topping level, and other variables which seriously affect storageability at higher temperatures, become unimportant. This report deals with a preliminary experiment made in the 1945 campaign near Salt Lake City, Utah, which yielded promising results.[3] It was only a 75-ton experiment so it. cannot be taken as conclusive, and the engineering problems involved in the adoption of the procedure to large-scale operations have only been casually considered. However, the principles underlying the experiment are believed to be basically'sound and it seems proper to give this summary of the work in spite of its preliminary character. For the sake of brevity a review of pertinent literature will be omitted.

Discussion of Principles

The first fact of which use was made concerns the excellent storage temperatures which nature supplies during the nights of the harvest period. To assure a clear picture of this. Weather Bureau temperature records for a representative location in each of eight states

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Table 1.—Day and night temperatures during harvest months (average for 1943 and 1944).

Location	October				November			
	Mean maximum °F	Mean minimum °F	Typical hot day Maximum °F	Typical hot day Minimum °F	Mean maximum °F	Mean minimum °F	Typical hot day Maximum °F	Typical hot day Minimum °F
California, Stockton	80	44	96	47	68	38	70	34
Colorado, Fort Morgan	67	32	83	28	54	20	78	22
Idaho, Idaho Falls	61	34	77	34	44	25	59	26
Michigan, Lansing	59	41	77	48	45	30	63	42
Montana, Missoula	60	30	82	40	42	28	55	26
Nebraska, Scottsbluff	69	32	90	40	53	19	78	31
Utah, Salt Lake City	67	45	86	49	53	33	60	46
Wyoming, Torrington	67	30	83	27	55	20	75	24

for October and November 1943 and 1944 are presented in table 1. It will be seen that even though the October temperatures are the means for the entire month, rather than for only the latter part when storage piles are started, the mean night minima temperatures in most of these states is below 40° F. The smallest difference between day and night temperatures during these months are in Michigan but the night temperatures are quite satisfactory. In November the night minima temperatures are mostly below 30° F. It is obvious that if the storage piles remained at these night temperatures the sugar losses would be low. However, the generally high daytime temperatures, the heat from respiration of the beets, and the heat from the decaying green trash tend to keep a beet pile well above night temperatures. While at night the heat rising from the piles pulls in the colder night air, in the daytime this accumulated colder air tends to drain out of the pile (due to its higher specific gravity) and the warm air drawn in is cooled by contact with the beets and in turn flows out. Of course, the temperature inside a large pile of beets changes very slowly ; however, the general effect of this "breathing" of the pile, as it is often called, results in a temperature in the pile which is usually above daily mean temperatures. As will be seen, the experiment performed makes use of the colder night air to some extent and was designed also to reduce the loss of the accumulated cold air during the daytime. Finally, in line with the recent publication of this Department on the merits of whitewashing the outside of beet piles (2)[4] use is made of this procedure to reduce further the warming up of the exposed beets by the sunshine.

Experimental

To provide retention of cool temperatures in the beets, once they are obtained, the ideal is a four-walled storage bin with only the top

[4]italic numbers in parentheses refer to literature cited.

open. In practice it was necessary to use a three-sided bin and make a temporary closure of the one end which could be removed for the purpose of reclaiming the beets. The experimental bin was constructed of 4-inch lumber, the dimensions being 10 feet high, 15 feet wide, and 20 feet long. The walls were well braced. The inside walls were lined with tar paper, using a cement to make the finished job as air tight as possible. To provide for the use of night air for cooling, two shallow air ducts were dug in the floor of the bin. Those duets were about 6 inches deep and 12 inches wide and were spaced about six feet apart and equal distances from the ends of the bin. They extended under the oue side wall and across the floor to within a couple feet of the opposite side. They were covered with steel flume covers spaced about 3 inches apart. Outside the bin the two ducts were brought together into a header box which had a vertical 7-inch pipe outlet for connection to a blower. These outside portions of the ducts were covered with lumber, tar paper, and dirt to make them air tight. A quarter-horsepower blower was attached. After a couple of days the motor was equipped with a time clock so that the operation of the blower could be set for the selected hours.

The bin was filled from a piling conveyor with trucked beets as received. The first beets were considerably bruised by the 10-foot drop, and the trash and dirt not removed by the cleaner appeared to be greater than normal. When the bin was slightly less than half full, ten 30-beet samples, protected in heavy wire baskets, were spaced in the bin at scattered positions. This was at about 5 feet above the ground. The filling of the bin was then continued until it was overflowing. At the open end the beets were repiled by hand to give a steep slope which was then covered with a large tarpaulin and tar paper. The sides and bottom of these coverings were attached to walls and ground to give as nearly air-tight protection as possible. The beets on top of the bin were somewhat leveled off and spray whitewashed with a mixed slurry of slaked lime and lime cake.

The samples placed in the experimental bin were selected as follows: A portion of an arriving truck load of beets was dumped and from this were selected three samples at a time, placing a beet of similar size and type in each sample simultaneausly. One of these three samples was put in a waterproofed sack and used for the initial analyses. The second sample was used for placement in the bin and the third for placement in the regular factory storage pile adjacent to the bin. This process was repeated until there were ten samples for each purpose. All samples were weighed to within a quarter of a pound, the weight averaging about 75 pounds per sample. The 10 samples used for the original analyses were washed and reweighed to obtain an average dirt tare which was applied to all weights. *

The experimental bin was filled on October 16, 1945, a few days before the regular factory pile was started. Six days later the set, of samples for the factory pile were placed, five samples at each of two levels in the center of the pile, that is, about 25 feet in from the sides at 5- unci 10-foot levels, respectively. In both the bin and pile the bulbs of recording[1] thermometers were placed adjacent to the special beet samples, three in the bin and two in the factory pile. The cables were protected by pipes, but the bulbs of the thermometers extended into the beets. The exposed outide ends of the pipes were sealed to prevent flow of air.

The day the bin was filled was relatively warm, the initial temperature of the beets being 60° F. The blower was not yet installed and by the next noon the temperature had risen to 63° F. That second night, forced ventilation was used from 5 p. m. until 9 a. m. the next morning, and the temperature in the bin was lowered by 10 degrees. For the next 5 nights the blower was operated by the time clock from midnight until 6 a. m. The temperalure was then down to 40° F. and the use of the blower was discontinued. The temperatures remained below this point for the following week in spite of daytime temperatures in the 70's. Relatively high night temperatures then gradually raised the temperature to 45° and the blower was again used for 3 hours per night for 5 nights. However, as the first nights of this period were above the bin temperature the effect was to continue the temperature rise. Then as night minima were again low the temperature in the bin was quickly brought down below 40° F. and remained below 85° F. for most of the following storage period without further use of the forced ventilation with night air. although daytime temperatures were frequently in the GO's. The whitewashing was renewed once, after about 2 weeks of storage.

The experience in this second period of using[1] the blower demonstrated the desirability of a thermometric control on the blower so that it would be in service only when the outside temperature was below the storage temperature. Such an arrangement should also preclude operation of the blower when outside temperatures were more than a few degrees below freezing.

At the time of placing the samples in the factory pile it was rainy, cool weather and initial temperatures were not as high but they remained above 50° F. for around 2 weeks and at all times remained 1.0 or more degrees F. above 1 he temperatures in the bin. The mean temperature for the entire storage period in the bin and in the pile were 35° F. and 45° F. respectively.

Experimental Results

Unfortunately, from the viewpoint of the direct comparison of the pile storage and bin storage, it was necessary to reclaim eight of the samples from the fadory pile after a period of 51 days. The 10 bin samples and 2 remaining samples from the pile were reclaimed after 77 days. Even at the 51-day period the beets of the factory pile showed scattered spoilage, although the samples in the pile were not affected. At the 77-day storage period the spoilage in the pile had increased markedly but the samples recovered again were little affected. On the other hand, 1he beets in the bin were all in excellent physical condition, free from spoilage and as firm as fresh beets. Even where the trash was excessive under the piling cone the condition of the beets was perfect. The special samples for test were likewise sound and when split were clear and white even to the tip of the roots.

The comparative results of storing beets in the factory pile and in the experimental bin are presented in table 2. The values given are the means of the number of samples indicated and in the case of the reclaimed beets are calculated to the original weight basis. For the samples from the factory pile which had sustained considerable weight loss, an adjusted normal weight was used roughly equivalent to a normal weight on the fresh weight basis so that the effect of the marc would be the same as when testing fresh beets. True sucrose and raffinose were estimated by the double enzyme method and the corresponding formula. In addition the true sucrose and raffinose were estimated on the basis of the determination of the total reducing sugars after invertase inversion and after the invertase-melibiase inversion. The differences in these values were calculated to raffinose and the remainders, after correction for direct reducing sugars and the raffinose were calculated to sucrose. In table 2 the results by this procedure are designated as "'chemical" data, as opposed to the results obtained by polariseopic methods.

Discussion

It is evident from the data as given in table 2 that greater losses of sugar were sustained by the beets in the factory pile in 51 days than in the experimental bin in 77 days. In order to compare the results more correctly it is necessary to calculate to a daily rate basis. This has been done, and the values obtained for the pounds of sugar lost per ton of beets per day are summarized in table 3.

It may be noted that the figures for true sucrose and solids are a mean of 5 methods of estimation on the 10 samples at each condition. For the sucrose. 1 hese methods were true sucrose by polarization and

Table 2.—Comparative results on beets stored in factory pile and in experimental bin.

	Initial analyses	Reclaimed beets (on fresh weight basis)					
		Factory pile				Experimental bin	
Duration of storage, days	......	51		77		77	
Number of samples	10	8		2		10	
Weight shrinkage, percentage on beets	......	8.7		8.9		2.4	
		Analyses	Change	Analyses	Change	Analyses	Change
Apparent sucrose (direct polarization), percentage on beets	16.97	16.22	-0.75	16.01	-0.96	16.66	-0.31
True sucrose (polariscopic), percentage on beets	16.67	16.05	0.62	......	......	16.36	-0.31
True sucrose (chemical), percentage on beets	16.58	15.90	-0.68	......	......	16.12	-0.46
Reducing sugars, percentage on beets	0.09	0.18	+0.00	0.33	+0.24	0.14	+0.05
Raffinose (polariscopic), percentage on beets	0.18	0.11	-0.07	......	......	0.10	-0.08
Raffinose (chemical), percentage on beets	0.27	0.33	+0.06	......	......	0.28	+0.01
Total sugars (polariscopic), percentage on beets	16.94	16.34	-0.60	......	......	16.60	-0.34
Total sugars (chemical), percentage on beets	16.94	16.41	-0.53	......	......	16.54	-0.40
Total dry solids, percentage on beets	23.98	23.23	-0.75	23.28	-0.70	23.40	-0.58
Diffusable dry solids, percentage on beets	19.49	18.89	-0.60	18.89	-0.60	19.07	-0.42
Total sugars: reducing sugars (chemical), percentage on beets	17.78	17.22	-0.56	......	......	17.36	-0.42
Marc (non-diffusable solids), percentage on beets	4.49	4.34	-0.15	4.39	-0.10	4.33	-0.16
Total nitrogen in juice, percentage on beets	0.166	0.165	......	0.167	......	0.168	......
Non-protein nitrogen in juice, percentage on beets	0.106	0.119	+0.013	+0.116	+0.010	0.118	+0.012
Ratio non-protein to total nitrogen	63.8	72.1	+8.3	69.5	+5.7	70.2	+6.4
Apparent purity	87.1	85.9	-1.2	84.8	-2.3	87.4	+0.3
True purity (polariscopic)	85.5	85.0	-0.5	......	......	85.8	+0.3
True purity (chemical)	85.1	84.2	-0.9	......	......	84.6	-0.5

Table 3.—Summary of storage losses (expressed in pounds per ton of beets per day of storage).

	Factory pile	Experimental bin
Apparent sucrose	0.28	0.08
True sucrose, (mean of 5 methods)	0.26	0.12
True solids, (mean of 5 methods)	0.22	0.11
Inversion loss	0.04	0.01
Respiration loss*	0.22	0.11
Respiration loss**	0.10	0.11

*Estimated from respiration data of Pack for 45° and 35° F. respectively.
**Estimated from respiration data of Barr, Mervine, and Bice.

by the chemical method, total and diffusable solids plus the sucrose equivalent of the increase in reducing sugars, and the total sugars determined as reducing sugars plus the sucrose equivalent of the increase in reducing sugars. In a similar manner in addition to the loss of solids determined by total dry solids, diffusable dry solids, and total sugars as reducing sugars, there were included the values for the true sucrose changes minus the increase in direct reducing sugars. All 10 samples from the factory pile were included in these general averages. By statistical analysis the differences between pile and bin storage are highly significant when put on the basis of the same period of storage.

There is a difference between sucrose loss and actual sugar solids lost. The former includes inversion as indicated by increases in reducing sugar content as well as the sucrose destroyed by respiration (or action of microorganisms). The loss of true solids is primarily just the sugar consumed during the storage. From the viewpoint of practical recovery of sugar the total loss is the more important value, that is. inversion of sucrose is as surely a source of loss as complete destruction of the sucrose. However, from the viewpoint of plant physiology it is of interest to note that the actual consumption of sugars (loss of solids) corresponds to the respiration rates determined by Pack *(3)* and by Barr, Mervine, and Bice *(1)* for the temperatures of 45° F. and 35° F. respectively.

If in addition to the direct losses indicated by the values presented one also considers the effect of the changes in purity on the recovery of the sucrose, the resulting comparison shows a decrease of 0.28 pounds to recoverable sugar per ton per day in the case of the beets in the pile as contrasted with a figure of 0.10 pound for the beets in the bin. Irrespective of the means used for obtaining this 10-degree F. reduction in storage temperature it is certain that such a differential in temperature will produce this saving in sugar. Taking as an example a 50,000-ton pile of beets stored for 50 days, this means a conservation of 450,000 pounds of sugar. Taking the domestic industry as a whole a general reduction of storage temperatures by 10 degrees would save in the vicinity of 20 millions pounds of sugar. These estimates are conservative because they do not include any loss due to spoilage; also at any temperature level above the range found in this experiment the saving resulting from a 10-degree lower temperature would be greater.

No claim is made on the basis of the preliminary small-scale experiment such as this that the particular techniques used are practical or will for certain produce a 10-degree reduction in the storage temperature of a large pile. However, from this experiment and comprehensive basic studies which have been carried on at Salt Lake City the past 4 years and from the evidence reported in the literature, it seems certain that the following conditions must be met: (1) The direct sunlight should be reflected by a while coating on the surface beets; (2) the beets should be cooled below 40° F. as promptly as possible after piling and the low night temperatures prevalent during the harvest can be utilized to do this; (3) the sides of the pile should be protected by air-tight walls 1o prevent loss of the cooling produced at night and to generally restricl circulation of air.

It is believed that the use of forced ventilation should be restricted to that actually needed to get the desired low temperature. Once at the low temperature the heat of respiration will be low. and with the daytime heat shut out or reflected the beets will remain cool and in humid atmosphere which will keep both weight and sugar losses at a practical minimum. Tn locations where night minima are above 40° F. the acception of a slightly higher storage temperature is possibly unavoidable, but it is possible that compared with the normal pile storage the advantage of eooling will remain.

Summary

The experiment under discussion compared beets stored in a special bin with corresponding beets stored in the adjacent factory pile. The special bin was essentially air tight on all four sides and was provided with air ducts in the floor through which cool night air was forced several hours each night for the first 6 nights to reduce the beet temperature to near the freezing- point. The forced ventilation was then discontinued and. since the sides of the bin prevented loss of cold air through drainage, the bin temperature remained satisfactorily low for the 77-day duration of the test. Additional protection against heating by the daytime sunshine was provided by whitewashing the open top surface of the bin.

A differential of 10° F. between the two storage conditions and the reduced circulation produced by tbn bin kept weight shrinkage

at a low level. In spite of considerable bruising in filling the bin and in spite of what appeared to be an abnormal amount of trash and dirt, the beets in the bin were reclaimed in excellent physical condition. The special samples of known initial composition lost only 0.12 pound of sucrose per ton of beets per day of storage as compared with 0.26 pound per ton per day in the factory pile.

The application of these principles, of reduced circulation of air through the beets and the use of the cold night air for cooling the beets immediately after piling, to large-scale storage may, at. a moderate cost, conserve a very considerable part of the sugar normally lost.

Literature Cited

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