A Small-Scale Technique for Simulating Large-Pile Conditions in Cooling and Storing Sugar Beets

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THE PRIMARY PROBLEM in reducing sugar losses during storage in commercial piles of sugar beets is to find a practical means of reducing the temperature of the beets and to find a way to eliminate "hot spots" that are usually caused by the presence of excessive amounts of trash and dirt in parts of the pile. It is practically impossible to cool storage piles by means other than the circulation of cool air through the piles. Since night temperatures during the warmer part of the storage period are usually 20 degrees to 35 degrees Fahrenheit cooler than day-time temperatures, rapidly increasing use has been made by the industry of the method of forced ventilating beets with cool night air, demonstrated by the writers in 1945 (1).[3]

Recognition of the large quantities of heat given off by commercial storage piles of beets (2) and the important influence that temperature has on respiratory heat output makes it necessary that we accumulate technical data to answer some of the following questions:

1. Since respiratory heat rises progressively through upper layers of beets in a pile what is the practical limit to height in relation to cooling with forced ventilation?

2. How much resistance does a normal column of beets have to different rates of air flow? What effect does dirt and trash have on air flow when uniformly distributed and when relatively concentrated?

3. How much natural draft is induced through piles at various temperature differentials inside and outside the piles?

4. What is the lowest temperature than can be safely used to force-ventilate beet piles? Is the safe temperature related to beet turgidity and if so to what extent?

5. How important is evaporative cooling to the forced-ventilation method of cooling beets?

6. What is the relationship of temperature, relative humidity and dew point to cooling efficiency?

It is obvious that information regarding most of these practical questions can not be secured unless the amount of air in relation to the tonnage of beets is known with some degree of accuracy, and also unless the path

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of the air-stream is confined to the beets under study. Commercial piles of beets do not allow such restrictions and are, furthermore, too expensive to use for some of the experimental treatments. The described research equipment was designed to gain as much technical information as possible without using large tonnages of beets.

Two insulated storage columns were constructed in three sections each. A general view of the columns and accessory equipment is shown in figure 1. Each section is 8 feet high, 3 feet inside and 44 inches outside diameter.

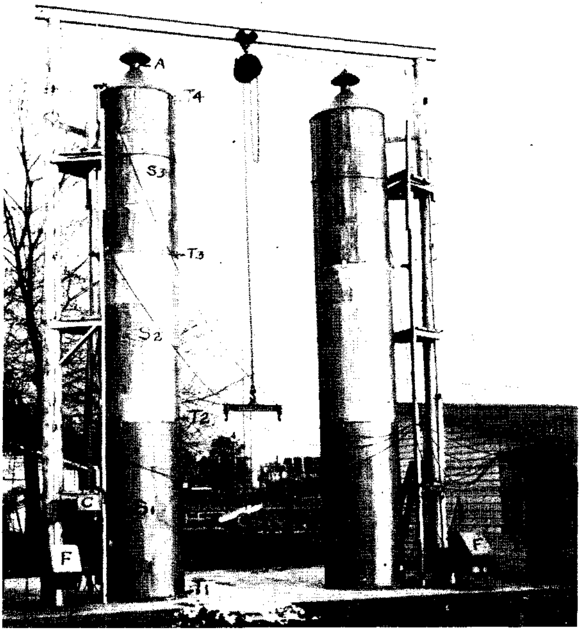

Figure 1. Experimental sugar beet storage columns with accessory equipment.

A. Anemometer and automatic closure (closes when not ventilating) T_1, T_2, T_3, T_4—Elevations for measuring beet temperatures, air pressures, wet and dry bulb temperatures of ambient air by means of Friez electrically ventilated psychrometer. S_1, S_2, S_3—Eight-foot sections. C. Thermostatic controls (mercoid—2 in series to run blower only between set temperatures, e. g. 26°-33° F.). F. Multi-blade blowers. R. Resistance thermometer recorder. T. Three-pen recorders record temperatures of air at top and bottom of columns as well as outside air temperatures.

Four inches of rock-wool insulation are packed between the inside and outside shells which are made of 1/8-inch steel plate. Grating bars 6 inches apart and 2 inches high in the bottom support 2-inch mesh wire screen on which the beets are placed in each section. Each section is, therefore, independent as far as filling, weighing and emptying the beets is concerned. Each section weighs about 1/2 ton and holds slightly more than 1 ton of beets when fully filled.

Resistance thermometers are inserted through 1-inch pipes 1 foot from the base of each section. Each thermometer is inserted in the center of a beet and the temperature is continuously recorded on a strip chart multiple recording instrument. Air temperature, pressure, humidity and dew point of the ambient air are made through another 1-inch pipe near the base and extending between the grating bars to near the center of each section and also in the top of each column. Four short strap-iron guides, welded to the top of each section allow the sections to be stacked upon each other without slipping. An air-tight seal between sections is made by means of caulking putty. Strap-iron loops inside and near the top of each section provide means of attaching the 2-ton chain blocks for lifting. The chain blocks are attached to a trolley mounted on an 8-inch "I" beam between two 28-foot poles spaced 19 feet apart. Each column is 24 feet high and covered by an insulated cap equipped with a ring for sealing to an anemometer for measuring air flow through each column.

Ambient air temperature, humidity, dew point, and moisture content measurements are made by means of an electrically ventilated psychrometer attachable to the base of each section and cap. Attachment is made through a flexible gas mask tube. Evaporative cooling can be calculated by the moisture content increase between any points in the column. This determination has been simplified by preparing a table of the moisture content in pounds per 1,000 cubic feet of saturated air at different temperatures (3). The amount in saturated air multiplied by the percentage relative humidity equals the moisture content at any given conditions. (table 1).

Multi-blade blowers deliver air to the bottom of each column through 6-inch tile pipes set in the concrete slab. The blowers are driven by electric motors equipped with adjustable "V" belt pulleys. The motors are located outside the ventilating air-stream. The inlet side of each blower is equipped with a metal ring suitable for attachment to a humidity chamber or air-washing device. Adjustable dampers regulate the air supply to the blowers.

To gain the maximum value of cooling temperatures available without injuring the beets, one fan motor has been connected through two mercoid thermo-regulators connected in series. The mercoid switch is reversed in one regulator. One regulator turns on at temperatures below a set maximum (e.g. 33° F.), the other regulator stays on until a set minimum (e.g. 27° F.) is reached. Since the two regulators are connected in series and are on simultaneously only between 33 degrees and 27 degrees Fahrenheit, the beets are ventilated only between these set temperatures. A counter-balanced damper closes the column when the blower is off to prevent circulation of air that is too warm or too cold.

Table 1.—Weight of 1,000 cubic feet of saturated aqueous vapor at different temperatures.

Temperature °F.	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
10	0.111[1]	0.117	0.122	0.128	0.134	0.141	0.147	0.154	0.161	0.169
20	0.176	0.185	0.194	0.203	0.212	0.222	0.232	0.242	0.253	0.265
30	0.276	0.289	0.302	0.313	0.326	0.338	0.351	0.364	0.378	0.392
40	0.407	0.422	0.438	0.454	0.471	0.488	0.506	0.524	0.543	0.562
50	0.582	0.603	0.625	0.647	0.669	0.693	0.717	0.742	0.767	0.794
60	0.821	0.849	0.877	0.907	0.938	0.969	1.001	1.034	1.069	1.104
70	1.140	1.177	1.215	1.255	1.295	1.337	1.379	1.423	1.468	1.514
80	1.562	1.611	1.661	1.712	1.765	1.819	1.875	1.932	1.991	2.051
90	2.113	2.176	2.241	2.308	2.376	2.446	2.518	2.592	2.667	2.745

[1]Values in this column are for the temperatures 10°, 20°, 30° F., etc. The interpolated values are shown in the other nine columns.

Use of table: To find, for example, the weight of aqueous vapor in 1,000 cubic feet of air at 36° F. and 78 percent R.H., take the value from the table at 36°F, which is 0.351, and multiply by 0.78.

0.351 x .78 = 0.274 pounds per 1,000 cubic feet.

Experimental Results to Date

The experimental equipment described was obtained too late for many of the studies planned for the first year. All beets were at temperatures near the freezing point when the columns were filled November 21, 1947. However, air-resistance data, natural ventilation rates in relation to temperature and limited data on moisture content of the air passing up through the column at different rates can be reported. A few other observations that may aid further planning are reported. Air was blown through the empty column at rates up to 150 cubic feet per minute and the pressures were carefully measured. Tinted xylol (Sp. G. 0.86) was used in the manometers. Air was again blown through after filling each column with 3 tons of unwashed beets. Graphs were prepared from the pressure and rate of ventilation data. Pressures for a given rate of ventilation were read from the graphs. The pressures measured at the different levels of the empty columns were the same for a given rate of ventilation because practically all resistance was caused by forcing the air through the 4-inch annemometer openings in the top. When the columns were filled with beets the pressures progressively decreased from bottom to top, the pressure in the top of the column was the same as that for the empty column. The data in table 2 are therefore, pressures at the base of the columns expressed in inches of water pressure.

Table 2.—Air pressure at various ventilation rates at the base of a 24-foot column containing 3 tons of sugar beets.

Cubic feet per minute		Inches water pressure at base of column		
Total	Per ton of beets	Empty column	South column filled	North column filled
25	8.3	0.01	0.01	0.02
50	16.7	0.02	0.04	0.05
75	25.0	0.04	0.07	0.08
100	33.3	0.07	0.11	0.13
125	41.7	0.11	0.17	0.20
150	50.0	0.17	0.26	0.28

It can readily be seen from the data in table 2 that resistance to the flow of air in a column of beets is practically neglible unless excessive trash is present. Even at a rate of 150 C.F.M. the resistance of the beets amounted to only 0.09 to 0.11 inch water pressure. The mean velocity of air through the column filled with beets was only 53 linear feet per minute at a ventilation rate of 150 C.F.M. Since beets are quite large in size and actually occupy only about 60 percent of the volume of a filled column the airspaces are relatively large. The low pressures developed are perfectly reasonable.

Natural draft of air through the columns of beets was measured at several inside and outside temperatures. The direction of flow depended on the direction of the inside and outside temperature differential. For example, when the average temperature differentials between beets and outside air were 4.5 degrees and 8.5 degrees Fahrenheit the corresponding natural ventilation rates were 15 and 28 C.F.M. respectively. This further indicates very free circulation of air.

The consistency and precision of the determination of the total water content of air was greater than expected. At wet-bulb temperatures above 32 degrees Fahrenheit this determination is rapid and fairly reproducible.

It was observed that moisture uptake was quite rapid at normal ventilation rates in columns of beets and that the moisture uptake between different elevations could be determined with a fair degree of accuracy. If a relatively constant degree of saturation of the air is attained under dry-air conditions it should be possible to approximately calculate the evaporative cooling obtainable under more humid conditions and thus make data obtained at Salt Lake City useful for other climates. This observed rapid moisture transfer also indicates some danger from ventilating cold beets in the bottom of a pile with air having a higher dew point than the bottom beets. Such a practice would moisten the surfaces of the beets and enhance the development of molds.

The beets were kept in the columns until April 21, 1948, a total of 152 days. From February 3 one column (south) was left open to natural ventilation and the other (north) was thermostatically controlled. The north column was ventilated only between set temperatures. The lower limit was set at 25 degrees Fahrenheit and the upper limit was set at 34 degrees Fahrenheit until March 16. As warmer temperatures prevailed the upper limit was raised. The volume of air used was 35 C.F.M. per ton of beets.

On the morning of February 12 the air temperature was as low as 4 degrees Fahrenheit. At 8:00 a.m., when the air temperature was 10 degrees Fahrenheit, 30.4 C.F.M. of air was flowing up through the 4-inch outlet of the south column. The beets in the bottom of this naturally ventilated column reached a temperature of 18 degrees Fahrenheit. Although the beets for about 2 to 3 feet up in the column were frozen the losses were not as great as expected. Two samples of these previously frozen beets showed 13.5 percent and 12.7 percent direct polarization (as recovered basis). The beets above this point were in excellent condition.

Greater weight and sugar losses occurred in the north column indicating that the beets in that column were ventilated excessively. The total sugar losses (direct polarization) in pounds per ton per day in the top center and bottom sections, respectively, were 0.224, 0.313 and 0.256 for the north column and 0.154, 0.107 and 0.285 for the south column. Reducing sugar determinations showed that the respiration loss was higher in the north column and the inversion loss was greater in the south column.

No mass spoilage occurred in either column except for the greater losses shown by the frozen beets in the south column. Only a few individual beets were partly or almost completely spoiled. Beets next to spoiled ones were apparently healthy, indicating very little transfer of spoilage but rather that some beets were much less resistant to spoilage or possibly had been slightly frozen before they were placed in the columns.

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