Refrigerated Air Cooling of Sugar Beets[1]

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Introduction

Since five thousand dollars in factory investment is required for each ton of daily processing capacity in a beet sugar factory, it is not economically feasible to operate the factory for only a few days a year or to process beets from which little sugar can be extracted. The sugar beet processing industry would like to lengthen the processing campaign without incurring an appreciable loss of sugar content of the beets held in storage for this prolonged time period.

Modern machinery has revolutionized the harvest of sugar beets, bringing with it the virtual elimination of hand labor, but introducing grave problems relating to factory delivery and storage of beets. Large investment in expensive harvesting and hauling units has given rise to large individual acreages that must be harvested when the fields can support heavy machinery. Beets must be harvested before the ground is frozen, but yet as late as possible, to avoid losses in yield and quality.

Outdoor piling systems with long piles about 100 feet wide and 20 feet high were introduced to store the majority of the beets arriving at the factory during the concentrated harvest. By the early 1950's the problems of heating in the pile led to universal installation of pile ventilation systems that made it possible to lengthen the processing campaign, while, at the same time, decreasing greatly the quality decline of the beets compared to those stored in unventilated piles. However, with a continually diminishing number of factories and an increasing length of the processing season, the quality of piled beets has become a problem of increasing severity.

The success of pile ventilation systems depends upon cool night air to cool the beets. Unfortunately, there are not enough cool nights in October and November in Michigan to cool the beets adequately. The beets now reach 50° F by about December 5. Average sugar losses before the beets are processed (from

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sugar company figures) are more than 40 pounds for every ton of beets piled. This loss amounts to between $2 and $3 million per year in Michigan. At individual factories, losses might average $1/2 million.

Experiments with plastic coverings, adopted on a very large industrial scale in the Northwest, have shown in the past two years that beets may be covered cheaply with plastic and, when thus covered, a remarkably constant temperature is maintained in the beets once they are cooled. In the Red River Valley of North Dakota and Minnesota freezing is essentially eliminated in covered piles. In warm periods, as during the Chinook winds of the Northwest, the beets remain cool. Millions of dollars have already been saved at a cost of no more than 6¢ per ton for covering.

A research project was developed at Michigan State University to study refrigerated air cooling of sugar beets. The factors affecting cooling rate of individual beet roots were investigated, and a system was proposed to provide cool air, by portable refrigeration units, for blowing through the beets in a covered pile to quickly lower their temperature after piling.

Equipment

A 5½ ft × 5½ ft × 8 ft chamber was constructed to measure the cooling rate of sugar beet roots subjected to various conditions of moving air. The walls were constructed of 8 in thick styrofoam panels, covered inside and out with thin sheet aluminum. Doors were placed on both front and back. The chamber was instrumented to control and record temperature, relative humidity and air flow.

The chamber was divided into two sections partially separated by a divider. The evaporator of a ½-ton direct expansion refrigeration system was located in one section. The cooling unit was equipped with a thermostatic expansion valve and an evaporator - pressure regulator. This allowed evaporator temperatures from 0 to 80° F to be maintained.

Air was drawn down over the evaporator and across the bottom of the chamber to the second section. A fan located in the bottom of the second section forced the air up through a vertical rectangular duct, across the top of the chamber and back to the evaporator. Variable air flow was achieved by driving the fan with a series - wound motor controlled by a variable voltage transformer. In order to keep heat input to the chamber to a minimum, anti-friction bearings were used on the fan and the motor was mounted outside of the chamber. Air flow was measured with a hot-wire anemometer.

Individual sugar beet roots were suspended in the rectangular duct (13.75 in × 17.75 in). Prior to cooling, each beet was brought to a uniform temperature by placing it in storage maintained at 56° F.

Cooper-constantan thermocouples were embedded at three locations along the central axis of the beet and placed in the air stream before and after the beet. One of the thermocouples was placed along the axis of the beet in the plane enclosed by the greatest circumference of the sugar beet root. The exact locations of the thermocouples in each beet were determined by taking X-rays of the beet with the thermocouples in position. Thermocouple emf's were measured by a multi-point recording potentiometer.

The beets studied were placed into one of three size ranges for purposes of analysis. Representative beets from each range and their descriptions are listed in Table 1. These same beets will be treated in the Results and Discussion section since they are typical of all beets in their respective size range.

Table 1.—Dimensions of some representative sugar beets used in air cooling tests.

Dimensions	Beet number		
	111	240	330
Largest circumference, in.	12.5	18.0	19.5
Length, in.	8.5	10.5	10.0
Diameter, in.	4.0	6.0	7.0
Volume, in.^{3}	60.8	121.3	157.3

Results and Discussion

Effect of Position on Cooling Rate

Individual beets were suspended in each of three positions in the moving air stream (Figure 1). The intent was to determine the position which gave the minimum cooling rate. This position

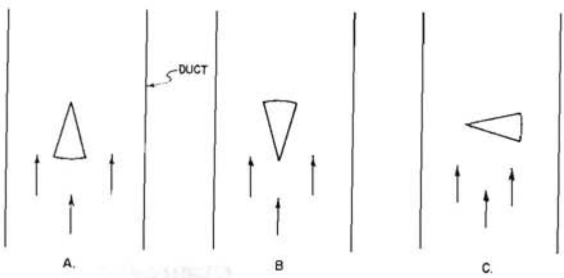

Figure 1.—Positions of sugar beets in air stream.

would be used in later experiments. However, the point in the center of each beet in the plane enclosed by the greatst circumference cooled at the same rate in all three positions. The two thermocouples positioned along the central axis at lesser circumferences did show some differences in cooling rates with position of suspension of the beet. However, since the cooling rate indicated by the thermocouple at the greatest circumference was the slowest in all cases, it would be this point in the beet upon which design of a cooling system should be based. Therefore, it was concluded that position of an individual beet with respect to the air stream had no effect on cooling rate.

Effect of Air Flow on Cooling Rate

Free stream air velocities of 5.5, 11 and 20 feet per minute in the vertical duct were chosen to study the effect of air flow on cooling rate. Air temperature was maintained at approximately 35° F with a relative humidity of 98%. The beets were at 56° F at the beginning of the cooling period.

The cooling curve for Beet No. 111 at an air velocity of 11 feet per minute is shown in Figure 2. TC 2 represents the thermocouple located in the center of the beet in the plane enclosed by the greatest circumference of the beet. Thermocouples 3 and 4 (TC 3 and 4) were at points along the central axis of the beet at smaller circumferences. Since TC 2 is at the point of slowest cooling, it will be used for discussion.

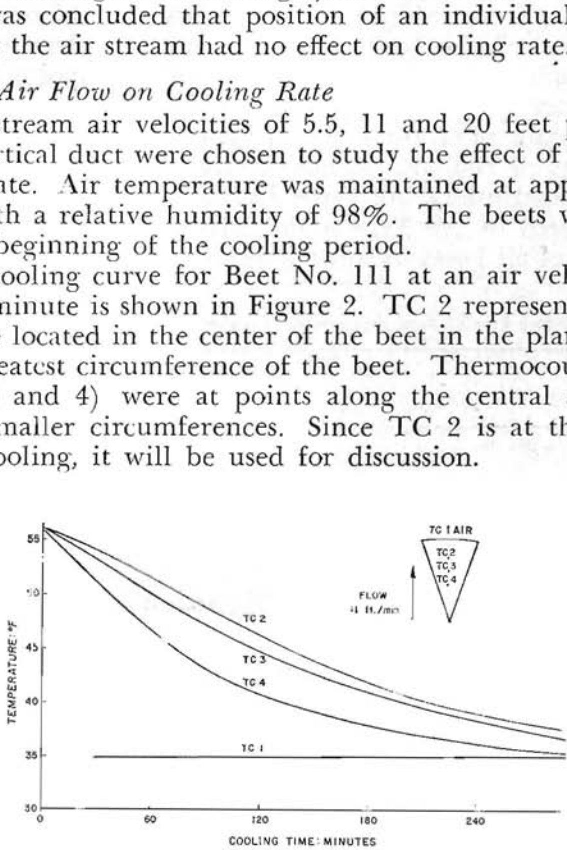

Figure 2.—Cooling rate for small sugar beet root No. 111 (diameter = 4 in) in air.

The indicated temperatures for Beet No. 111 cooled with air moving at 5.5, 11 and 20 feet per minute are plotted in Figure 3. Very little difference resulted from cooling at the various velocities. Thus, cooling rate is essentially the same for velocities from 5.5 to 20 feet per minute. The controlling factor in cooling

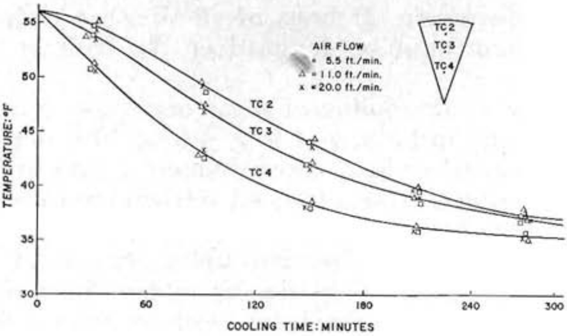

Figure 3.—Effect of free stream air velocity on the cooling rate of small sugar beet root No. 111 (diameter = 4 in).

the beet is the rate of heat transfer within the beet itself; not the rate of heat transfer from the beet to the air. Therefore, in the design of an air cooling system it is more important to provide for sufficient air to remove the heat from the mass of beets than it is to be concerned with the velocity of the air as it affects the cooling rate of the beets.

Effect of Beet Size on Cooling Rate

To illustrate the effect of beet size on cooling rate, the cooling curves for Beet Nos. 111, 240 and 330 at a velocity of 11 feet per minute have been plotted in Figure 4. Only temperatures indicated by the thermocouple located in each beet at its slowest cooling point are shown.

It can be seen from Figure 4 that size does have an effect on cooling rate; the largest beet required the longest time to cool

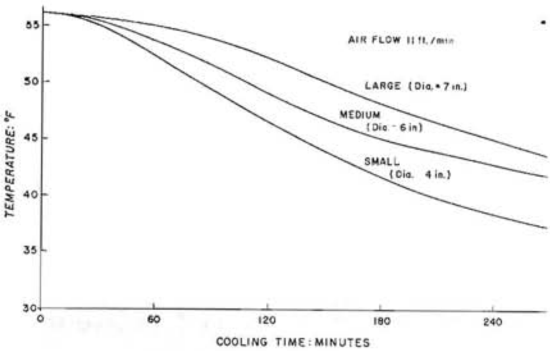

Figure 4.—Effect of root size on cooling rates of sugar beets in air at 35° F.

to a given temperature. If beets of all sizes are to be piled together, the system must be designed on the basis of the largest beets.

The studies of air cooling of sugar beet roots were extended to cooling of beets in bulk. A 4 ft × 4 ft × 10 ft deep insulated box was constructed to hold approximately 2 tons of beets. The storage was equipped with a fan and refrigeration system to provide air down to 34° F. Air flow can be varied with a damper at the inlet to the fan. Thermocouples are placed at several locations in the beets and in the air stream in various planes throughout the depth of the beets. This permits a fairly exact observation of the progress of cooling throughout the bed. Results of this study were reported by Bakker-Arkema and Bickert (1)[3].

Proposed System for Refrigeration Storage of Sugar Beet Roots in Piles

A system was proposed for conducting a pilot study of a refrigerated storage of sugar beets. The design of the refrigeration and air flow equipment was based on the ability to cool about 1200 tons of sugar beets per day. This would amount to about 30 linear feet of a pile which is 120 feet wide at the base, 80 feet wide at the top and 20 feet deep. Design conditions were chosen as those being typical at Saginaw, Michigan, during the harvest period.

The average temperature of freshly harvested sugar beets is about 55° F. The beets would be artificially cooled from 55° to 45° F in 24 hours. The beets would be further cooled from 45° to 35° F during the next several weeks using cold night air.

Refrigeration Capacity

During the beet harvest period, the average temperature and relative humidity are around 55° F and 70%. If this outside air is cooled to 40° F and 100% relative humidity, the difference in enthalpy is 5.1 Btu per pound of air.

Assuming a specific heat for sugar beets of 0.86 Btu/lb-°F (2) the total sensible heat to be removed from 1200 tons of sugar beets to cool them from 55° F to 45° F is about 21,000,000 Btu. The heat of respiration under these conditions will be about 3,000,000 Btu/day. If the average conditions of the outlet air flow from the beets are assumed to be 47° F and 98% relative humidity, 6,850,000 pounds of air will be required to remove 24,000,000 Btu in 24 hours.

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[3] Numbers in parentheses refer to literature cited.

Since 5.1 Btu must be removed from each pound of air passing through the refrigeration equipment, the refrigeration system must have a capacity of 35,000,000 Btu/day, or about 120 tons of refrigeration. It is proposed that this be divided between two units, one for each side of the pile. One 15 ton unit is proposed for keeping the beets at 45° F until cold night air becomes available to cool the beets to 35° F.

Air Flow Equipment

The requirement of 6,850,000 pounds of air per 24 hours is equivalent to 60,000 cubic feet per minute. This air can be delivered with six 10,000 cfm capacity fans. Since the resistance to air flow through a sugar beet pile is low, the static pressure of the fans does not have to be above 1½ inches of water column. The air requirement is equivalent to 38 cfm per ton of beets.

Cooling from 45° to 35° F will be accomplished with an air flow of about 10 cfm per ton of beets.

Cost Estimates

The refrigeration equipment can be purchased for $45,000 to $50,000. This includes two 60-ton units and one 15-ton unit. Each unit would be mounted on a trailer to provide for mobility along the edge of the pile and from pile to pile. If 1200 tons of beets were piled per day for 15-20 days, the cost of electricity for operating the refrigeration system would be about $2300, assuming 2¢/kwh. The operating cost for the fans for the same period would be about $700.

Assuming a 20 day harvest season, the initial investment in refrigeration equipment would be about two dollars per ton of beets stored the first year. This figure would be reduced depending upon the life of the refrigeration equipment. The electrical cost for the refrigeration equipment and the existing fans amounts to about 13 cents per ton of beets. Pile covering costs, including materials and labor, would be 5-6 cents per ton.

The entire investment in refrigeration equipment may be paid off in two or perhaps three years through improved recovery of sugar.

Conclusions

1. Position of a beet with respect to the air stream has no effect on cooling rate.
2. Cooling rate is essentially the same for free stream air velocities from 5.5 to 20 feet per minute.
3. The size of a sugar beet root affects the cooling rate, the larger beet requiring the longer time to cool to a given temperature.

Literature Cited

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