# VENTILATION AND FREEZING OF SUGARBEET STORAGE PILES

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**Using ambient air, portions of commercial piles of sugarbeets were ventilated and then deep frozen. Ventilation and freezing were accomplished using fans and an above ground duct system. Pile temperatures and sugar loss data were compared to a nonventilated check pile. Data analysis indicates the ventilation and freezing were successful in minimizing sugar losses in storage, while a check pile experienced very significant sugar losses.**

The Agricultural Engineering Department at North Dakota State University and the American Crystal Sugar Company worked jointly on a project to mechanically ventilate and then freeze sugarbeets in storage. This work was performed during the 1976-77 storage season.

## BACKGROUND INFORMATION:

The primary purpose of ventilating and freezing a sugarbeet pile is to reduce the loss of sugar due to respiration and microbial activity. Presently, the estimated loss of sugar is 0.5 pound per ton per day (2). These losses primarily depend on the temperature of beets in storage and the level of bruising the sugarbeets have sustained. If the beets have been stored for a full normal processing campaign of 150 days, the average daily sugar loss for a plant processing 5,000 tons of beets per day would be 187,500 pounds, based on the 0.5 pound per day loss.

The total harvested beet production in North Dakota in 1976 was 149,800 acres (4). Personnel of the sugarbeet industry anticipate the Red River Valley will be the leading sugarbeet production area in the near future. Three sugar processing plants are located in North Dakota and a total of six in the Red River Valley.

Since most of the harvesting in the Red River Valley is done within a three-week period, the processing of all the beets during harvest is not economical. The sugarbeet industry has designed its plants to process only a small percentage of the sugarbeets during harvest and to store the remainder of the crop at the plant sites or other remote gathering points.

Since the cells of the stored sugarbeet are living, they respire to maintain life. This results in the reduction of sugar and the production of heat. Barr et al. found daily losses to be temperature dependent (1). While daily sugar losses at 32°F were 0.2 pound per ton, the losses at 95°F were 2.6 pounds per ton. If no ventilation is used, the heat from respiration causes a rise in temperature, which results in an increase in rate of respiration.

Mechanical ventilation with natural air can be used to reduce and maintain the beet pile temperature. Research reports indicate sugar losses significantly reduced through mechanical ventilation. The primary problem with mechanical ventilation systems is the nonuniform air flow throughout the pile. Proper duct design to obtain a uniform pressure distribution in the air ducts can reduce the problem in some cases.

Although mechanical ventilation of the beet pile has greatly reduced sugar loss, some sugar reduction is apparent at 32°F. Soviet Union researchers report that daily losses can be reduced to zero by freezing the beets. They found that respiration in the sugarbeet cells ceases at 19°F. Thawing of frozen beets occurred at 23°F. Once the beets thaw their immunity to microbes is greatly reduced. Storing of thawed beets after freezing must be avoided at all costs. Sugar losses while frozen were negligible. The processing of the frozen beets has caused no significant problems. In the future, personnel of the sugarbeet industry feel that freezing the beets in storage will be necessary to minimize sugar losses in storage.

Examination by Ramirez of a 40-year history indicates that pile ventilation may be divided into four separate phases (5).

**Phase 1:** This is the time period between October 5 and October 20, when daytime highs and nighttime lows range from 65°F to 55°F and 40°F to 30°F, respectively. During this time period the mechanical ventilation system can be operated primarily during the nighttime hours to maintain root temperatures at approximately 36°F.

**Phase 2:** This is the time period between October 21 and December 15, when daytime highs range from 60°F to 26°F and nighttime lows range from 30°F to −10°F. This period presents the greatest challenge with respect to maintaining beet root temperatures at approximately 36°F because of nighttime freeze temperatures and daytime thaw temperatures. American Crystal proposed a conceptual solution to this problem which involves drawing air through the pile with even numbered fans with

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diversion of warm exhaust air to the inlet of the alternate odd numbered fans for mixing with ambient air. The net effect of this alternate fan internal circulation pattern is to stabilize pile temperature at 36°F.

**Phase 3:** This is the time period between December 16 and January 25, when period daytime highs range from 28°F to −4°F and nighttime lows range from 12°F to −10°F. During this period, beet piles are frozen by direct ventilation using sub-freezing air. The root temperature is reduced to an absolute minimum during this time period by progressively lowering the root temperature as nighttime ambient air reaches a minimum.

**Phase 4:** This is the time period between January 26 and mid-March, when daytime highs range from 16°F to 38°F and nighttime lows range from −8°F to 28°F, respectively. All air ventilation ceases during this time period because root temperatures would be increased rather than minimized, due to increased nighttime low temperatures.

**PROCEDURE:**

A review of literature indicated that a ventilation system under the sugarbeet pile using ambient air would be the most economical and efficient means of controlling the environment within the stored sugarbeet piles. These designs called for permanent ducts to be placed within and below existing reinforced concrete piling pads. Evaluation of this design indicated the cost of modifying the existing pads could not be justified for this experimental research project. Further, once installed the ducts would be permanent and need for modification indicated by this project would be difficult and extremely costly. Therefore, the plan to place ducts within and below the concrete pads was dismissed.

After dismissal of the underground ducts, work was begun on the design of an above ground system which would perform the same function of ventilating and freezing the sugarbeet piles. Additional criteria were set for this new design. It was determined that the ducts should be sectionalized, easy to store, easily repaired, and made of light, strong, and relatively inexpensive material. Both wood and metal were considered for use in construction of the ducts. However, past experience in the use of metal indicated several problems; the metal ducts are easily damaged when they are removed from the pile, they are difficult to repair, and beets tend to freeze to the cold metal. The design criteria then resulted in a duct designed to be constructed primarily with 2 x 6 lumber and ⅜" plywood. Each duct was 8' long and shaped like a triangle with the bottom open. The air outlet slots are located near the lower edge of both sides. The air slots are 2" wide and 8' long, providing a slot cross sectional area equal to the cross sectional area of the duct. The ducts are hinged at the apex so they can collapse to a total thickness of 8½" for storage and to facilitate removal from the sugarbeet pile at the time of processing.

American Crystal Sugar Company had 80 usable 7½ hp fans, rated at 10,000 CFM each, on hand. These were available for use in this project.

Ventilation ducts were installed in a small portion of two piles of sugarbeets. These pile sections were informally labelled the "straight" ventilation pile, which contained approximately 16,000 tons, and the "recirculation" ventilation pile, which contained approximately 18,000 tons, after the anticipated ventilation process to be used in each pile. The "straight" ventilation system was designed to force ambient air into the piles (Figure 1). The "recirculation" ventilation system was designed for two modes of operation. One mode of operation was identical to the operation of the "straight" ventilation system; the other mode was to have the capability to mix warm air from within the pile with cold ambient air in proportions such that the air entering the pile would be approximately 36°F to permit cooling of the pile and at the same time to prevent localized freezing (Figure 2). The two ventilated piles were adjacent to each other and a check pile was established adjacent to the "recirculation" pile.

Thermistors, electrical resistance devices used to monitor temperature, were installed at four pile depths to measure temperature within the two ventilated piles and the check pile. The thermistors at the four pile depths were labelled "level 1," "level 2," "level 3," and "level 4." Each line consisting of four levels was labelled a "row." A set of eight rows with four levels per row was called a "station." Three "stations" were installed in the "recirculation" pile and two "stations" in the "straight" ventilated pile. Three stations with three "rows" per station were installed in the check pile.

The ventilation system was designed for an air flow rate of 20 cfm per ton. Using two fans per run (20 - 8' duct sections per run) and an estimate of 50 tons of beets per foot of pile length with a pile width of 150 feet, the runs were spaced 20 feet on center. Using the available fans, 16 runs and 18 runs were placed in the "straight" and "recirculation" piles respectively.

The American Crystal Sugar Company piling crews took random samples of sugarbeets from each of the three piles at the time of piling and at the time of processing. The samples were preserved in cold storage until such time as they could be analyzed.

Material acquisition and a labor shortage resulted in a delay in the completion of the duct and control system for the "recirculation" ventilation system until midway through Phase 2. These factors, and the shortening of the time period of Phase 2 because of ideal temperatures for freezing, resulted in the "recirculation" ventilation system being operated as such for only two days.

Deep freezing was started on December 6, 1976. Low ambient temperatures provided excellent conditions to deep freeze sugarbeets. Freezing continued throughout the period according to Phase 3.

The process of removing the frozen sugarbeets from storage started on March 6, 1977 and was completed on March 16. Less than ideal conditions were encountered during the removal process due to above normal temperatures and precipitation in the form of rain.

Payloaders were used to remove the sugarbeets from the storage piles. Because the beets were completely frozen, they did not roll down the pile as sugarbeets were removed from the lower portion of the pile. Rather, the sugarbeets were frozen together and would form a straight vertical wall from ground level to the top of the pile. Because the sugarbeets were frozen together and to the wooden ducts, it was virtually impossible to remove the duct sections without causing extensive

Figure 1. "Straight" ventilation system.

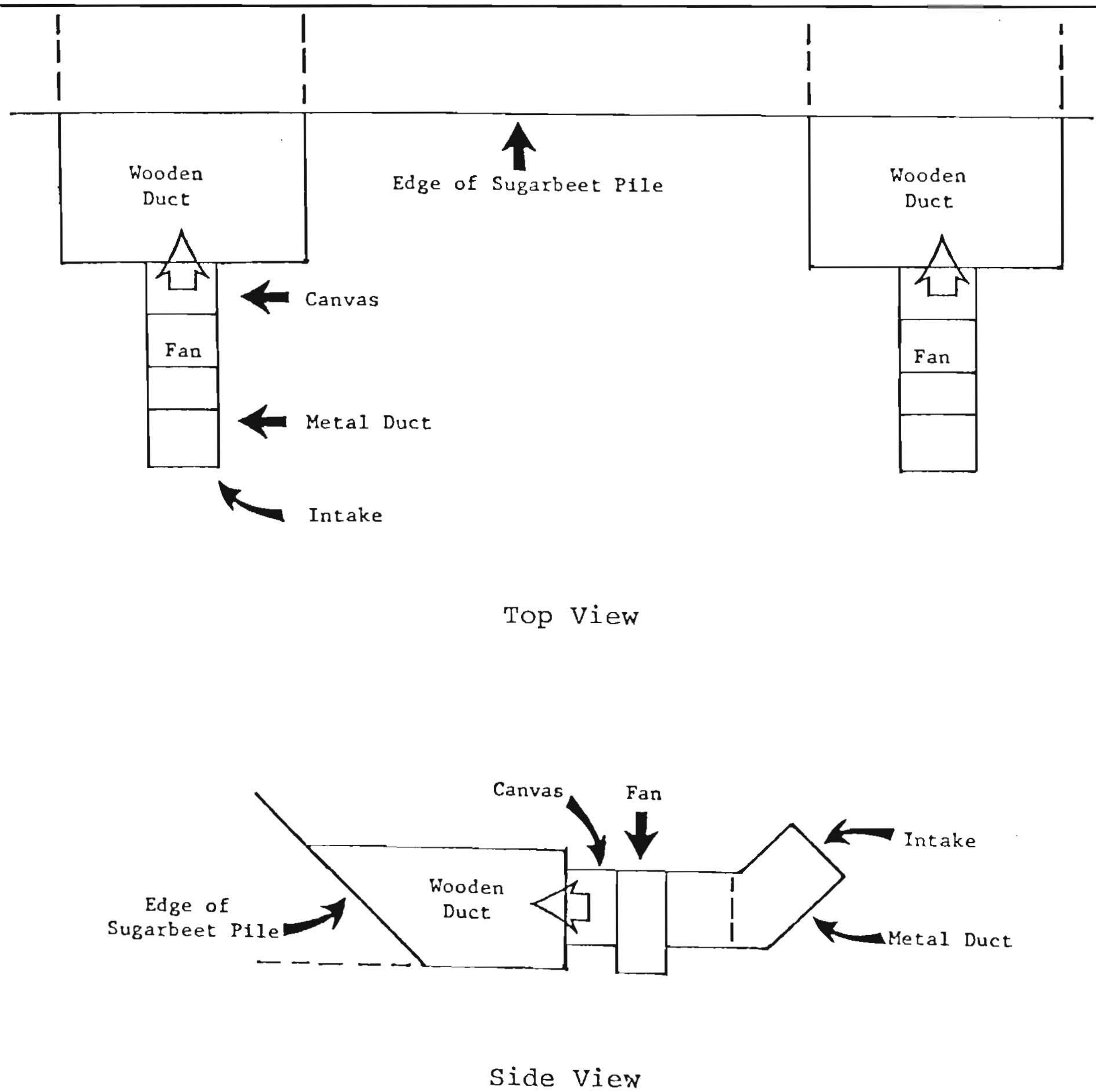



Figure 2.. "Recirculation" ventilation system.

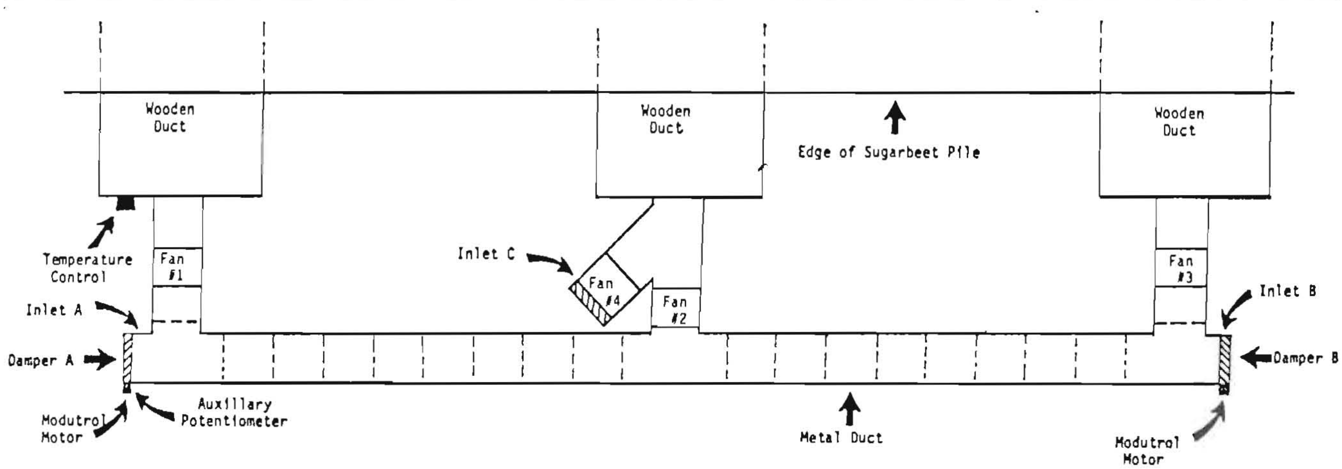


Figure 3. Placement of one thermistor "station" within a pile.

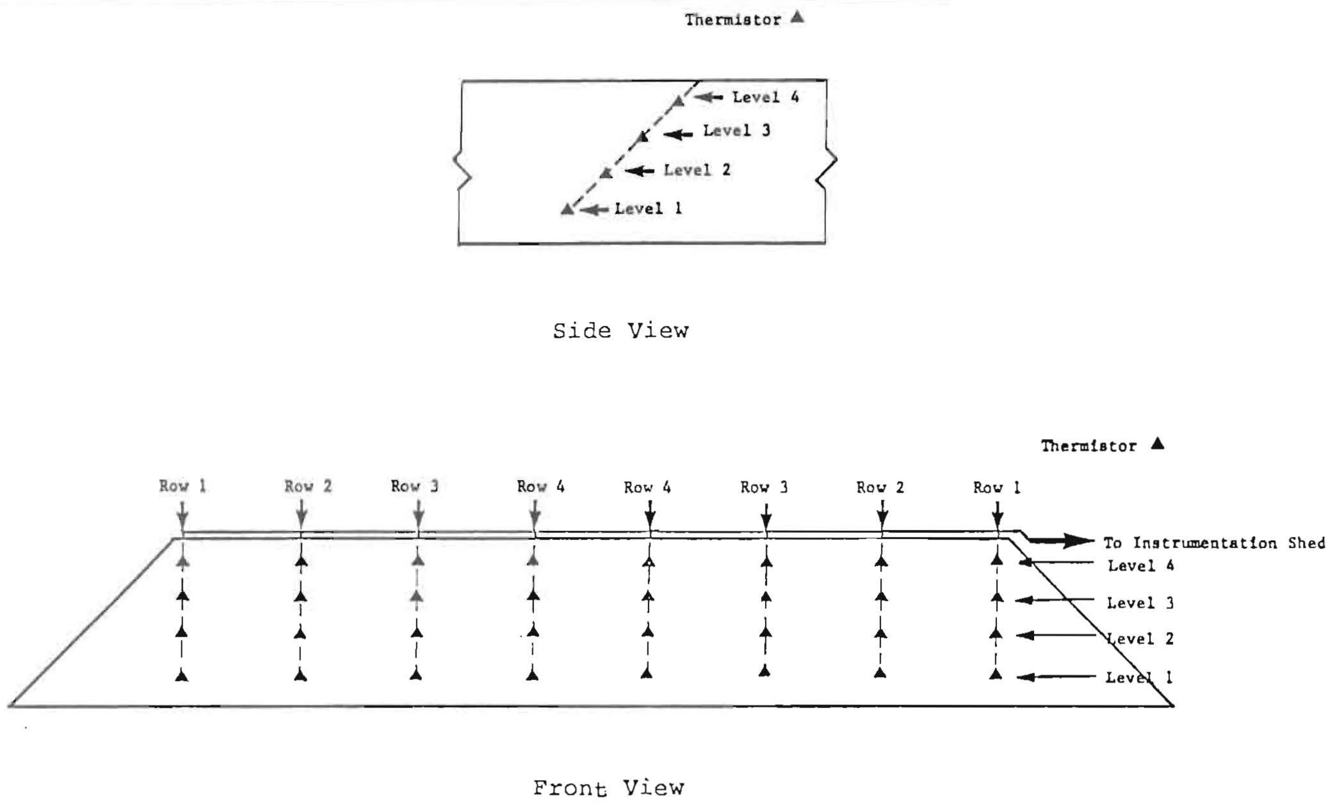
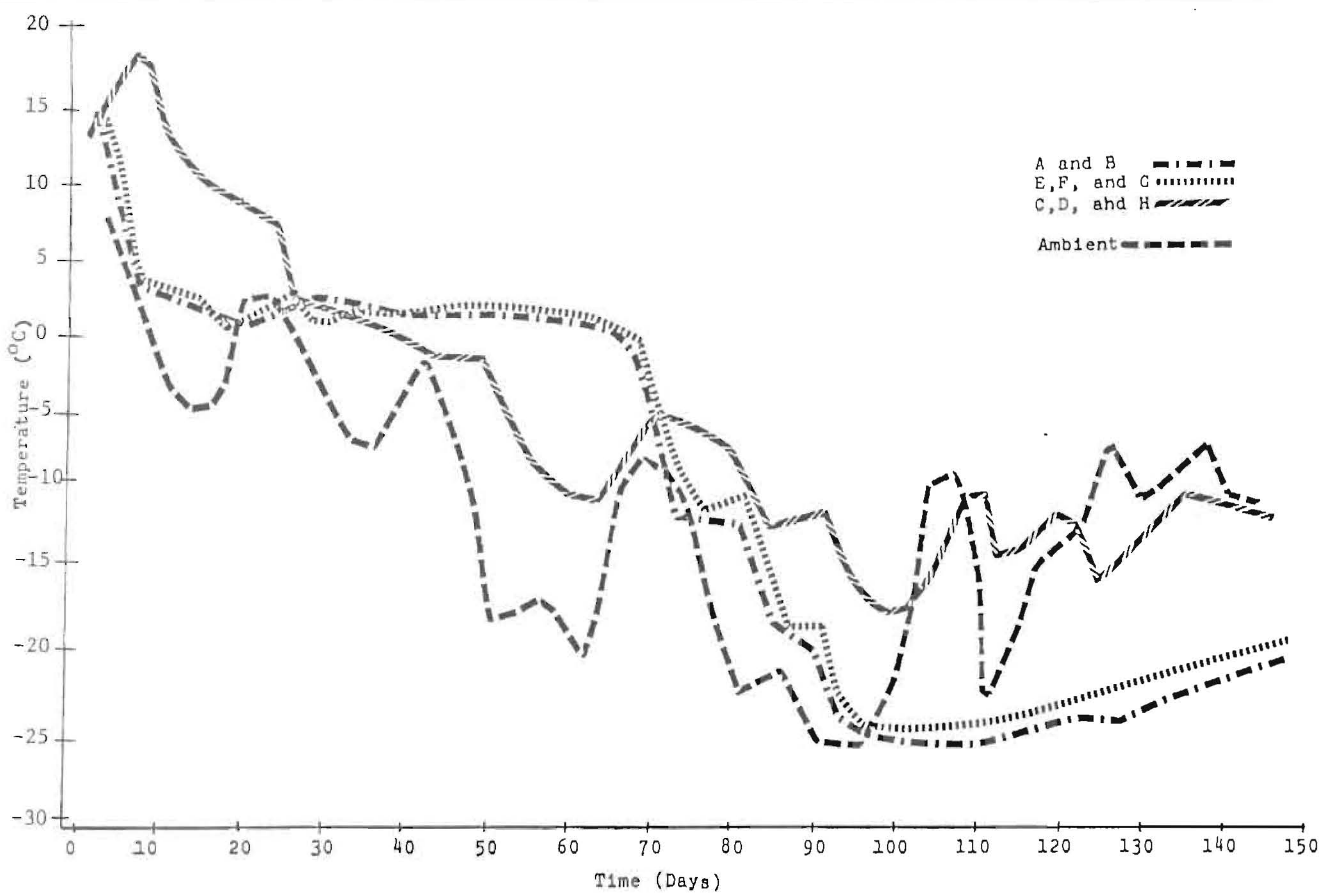



Figure 4. Mean temperature of stations and ambient temperatures versus time.



damage to the ducts. Even removing the sugarbeets by running the payloader parallel to and between the duct runs was slow and difficult because there was only 6"-12" of clearance between the ducts and the payloader bucket. The narrow clearance and slick, frozen surface made accurate alignment impossible. Additionally, many of the duct sections at the ends of the runs were frozen 4"-6" into ice. The ice resulted from melting snow and rain collecting in low areas and freezing. As a result, virtually all of the duct sections were destroyed in the process of removing the sugarbeets from storage.

## RESULTS:

The average temperature of the two ventilated piles was above 55°F after piling but was reduced to below 40°F by the seventh day of ventilation (Figure 4). During the same time period the average temperature of the check pile increased by 12°F to an average temperature of 70°F. This is a difference of 30°F between the temperature of the ventilated and check piles. A large difference in temperatures between the check and ventilated piles continued until the partial removal of the check pile 20 days after piling. During Phase 2 of the operation, the average temperatures of the ventilated piles fluctuated between 33°F and 38°F. Within 24 hours of the initiation of the freezing operation, the average temperature of the "straight" ventilated pile was less than 25°F and the average temperature of the "recirculation" ventilated pile was less than 28°F. Within 100 hours of the initiation of freezing, the mean temperatures of both ventilated piles were below 20°F. The pile temperatures were then progressively lowered until the average temperature of the ventilated piles was below −10°F. The average pile temperatures slowly warmed from this low at 101 days after piling to 0°F at the time of processing.

A total of 150 samples, half taken at the time of piling and half taken in March 1977, were analyzed for sugar content by University personnel at the Red River Valley Sugarbeet Growers Association facilities. An equal number of samples were used from the two ventilated piles and the check piles. Unfortunately, many of the samples were lost to experimental error. Vosper's statistical analysis of the data not lost to experimental error indicates a significant loss of sugar did occur in the check pile during storage which did not occur in the ventilated pile sections. This analysis indicates that the ventilating and freezing of sugarbeet piles significantly reduced extractable sugar loss compared to a check pile (6).

Approximately 575 additional samples equally divided between the three piles and between going into storage and removal from storage were analyzed by American Crystal Sugar Company personnel. Statistical analysis of this data verifies Vosper's work by indicating no statistically significant loss of sucrose on beets (GLC)% for the ventilated piles but that there was a statistically significant loss in the check pile. Further analysis of the data utilizing the K (potassium) - Ratio method of measuring sugar shrink as reported by Bichsel (3), indicates a sugar loss of 55.53 lb/T of stored sugarbeets. This represents a daily sugar loss of 0.372 lb/T for the 150 day storage period. It must be remembered that this number represents the sugar loss from the best sugarbeets in the check pile, since much of this pile had to be processed soon after piling in an attempt to salvage some sugar from the deteriorating portions of the pile. The loss in the ventilated piles was essentially zero.

## CONCLUSIONS:

Based on both temperature data and sample data analysis, the ventilation systems were very successful in ventilating and freezing the sugarbeet piles to minimize sugar loss. It was possible, through careful ventilation system management, to maintain pile temperature at about 36°F. Data indicate that the "straight" ventilation system adequately ventilated and froze the pile, therefore the additional labor and equipment cost of approximately $560 per duct run for the "recirculation" system can not be justified.

The thermistor readings clearly indicated the presence and movement of a cooling front in the sugarbeet piles during ventilation. Ventilation air was forced into level 1 of the piles. The warmer air at level 1 was moved upward into the pile and replaced by a layer of cooler ambient air. The warm air moving upward as the cooling front moved upward initially had a warming effect on the upper portions of the piles. The movement of this warm air to the top of the piles was most noticeable during the initial freezing period.

The ventilation systems froze the sugarbeet piles within 100 hours of the initiation of operation according to Phase 3. The systems were then successful in further reducing the average pile temperatures to below −10°F.

Installation of an above ground ventilation system proved to be feasible. However, the intact removal of the wooden duct sections was not possible. It was also found that the duct sections were not structurally adequate for the loads imposed by the sugarbeet piles. Therefore the duct sections would require structural redesign if the experiment were to be repeated.

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