Investigating natural cooling of piled sugar beet

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Abstract. The paper examines the processes of natural cooling of a medium-storage pile containing 3,650 tons of sugar beets. Adiabatic cooling and related processes are established to have a predominant effect on reducing the temperature in the pile while in storage. Piled sugar beet is cooled due to some natural water evaporation from the surface of sugar beets, followed by moisture saturation of the outside air. Such cooling leads to an uncontrolled decrease in the quality of beets, which has negative implications during further processing. A formula is presented for calculating post-harvest yield loss in sugar beets piled with one slope being across the prevailing wind.

1. Introduction

Storing sugar beets is a technological challenge in sugar production. Yet, there is no fully developed regulation on storage issues. Decisions made by agricultural producers to ensure sugar beet safety are often subjective without further analysis of storage outputs. Medium-term (more than 1 month) and long-term storage (more than 2 months) in small piles after harvest is widely implemented [1-5]. Accounting for post-harvest yield loss in piles is hampered due to their fragmentation over a large territory of an agricultural enterprise, as well as due to an uncontrolled impact of internal and external factors affecting the pile during storage [6-8].

An alternative to field piles is storing beets in practical piles, as well as in long-term storage piles. The difference between practical piles and field piles is that the former is higher from 3 to 6.5 m, which reduces the environmental impact on most of raw materials [9].

| Type | Field (short-term) | practical (medium-term) | Forced ventilation (long-term storage) |
|------|-------------------|-------------------------|---------------------------------------|
| Height $H$, m | 2.5-3 | 5-6.5 | 5-6.5 |
| Top base width $B$, m | — | — | 8-10 |
| $M_b/S_p$ | 0.35-0.42 | 0.7-0.9 | 1.05-1.35 |
A decreased effect of the ambient conditions is provided by changing the ratio of the mass of the pile $M_b$ to the surface area $S_p$ \[^8\]. Table 1 shows a comparison between different types of piles. In ventilated piles for long-term storage, due to a different method of forming the pile, the cross-section has a trapezoid shape, which makes it possible to further reduce the environmental effect.

2. Materials and methods
The effect of convective heat and mass transfer between the environment and the pile on the safety of beets was explored in November 2020 in Kursk region, when the ambient temperature fluctuates around zero within 24 hours \[^7\]. To exclude the impact of active ventilation, a practical pile without ventilation with a height of 6.5 m and a mass of 3,650 tons was considered. November was chosen to conduct a study, as the most favorable temperature background for storing sugar beets. In the same November, there is a low level of solar radiation, which is accompanied by a short daylight hours. The period from November 15 to 26 was selected with an ambient temperature in the range of -4.8 to + 4.7 °C and a median value of -0.2 °C. The relative air humidity varied from 61 to 98%, the average value was 71.3%. The temperature of beets from the fields was from +3 to + 7 °C. The target beets were piled across the prevailing southeastern wind, the average wind speed was 2.4 m/s. The temperature inside the pile was measured every 3 hours using thermal rods immersed 1 meter deep into the pile.

Figure 1 and 2 show graphs of fluctuations in the ambient temperature and the sides of the pile and changes in wind speed. At the beginning of the research (from November 15 to 17), there was no temperature difference between the sides of the pile.

![Figure 1. Fluctuations in the ambient temperature and in the windward and leeward slopes of the pile.](image1)

![Figure 2. Wind speed changes.](image2)

Until November 15, the piled beets were “treated” after transshipment, during which the processes occurring inside sugar beets were stabilized following the action of harvesting machinery \[^10\]. From November 18, the temperature began to vary on the slopes of the pile. In the course of the studies, the temperature differed in the range from 0.2 to 2.2 °C, with a median value to be 1.93 °C. The temperature difference in the pile arose due to a windward position of one of the slopes. From 23 to 26 November, the ambient temperature was higher than that of sugar beets. A rise in ambient temperature triggered a rise in the temperature of raw materials.

The subject of research is those factors that provided the temperature difference between the sides of the pile. For an unventilated pile, the heat balance equation is as follows \[^4\]:

$$Q = Q_{br} + Q_s - Q_c - Q_e$$

(1)
where $Q_{br}$ is the heat released during “breezing” of the mass of sugar beets, W; $Q_c$ is the heat entering the pile from solar radiation, W; $Q_e$ is the heat removed from the pile due to the convective movement of air masses, W; $Q_s$ is the amount of heat spent on water evaporation from the beet, W.

The heat was removed from the pile based on two processes: convective air movement and water evaporation from the beet surface. To determine the amount of heat during convective heat transfer, the process was presented as heating followed by moisture saturation of the air. The flow rate of the outside air was subject to the wind speed. The air blew through the pile, taking on the temperature inside the pile. The moisture saturation limit of the outside air depends on the microclimate in the pile. In sugar beet piles, due to self-regulation processes, the relative humidity was maintained at a level of 96-98% [5-9]. While in storage, convective air movement ensured moisture removal from the pile, which was compensated by the release of moisture on the surface of roots.

Then the amount of heat removed from the windward slope of the pile can be presented in the form of the equation [10]:

$$C_b m_b dT_b d\tau = L_a \rho_a C_a dT d\tau + C_v (d_k - d_p) dT d\tau + W S_p r d\tau$$

where $C_b$ is the heat capacity of sugar beet, J/(kg·°C); $m_b$ is the mass of beets, kg; $dT_b$ is the start-end temperature difference of the sugar beet, °C; $L_a$ is the amount of air entering the pile, calculated based on the porosity, ambient pressure and wind speed, m$^3$/h; $\rho_a$ is air density, kg/m$^3$; $C_a$ is heat capacity of air, J/(kg·°C); $dT$ is the start-end air temperature difference, °C; $C_v$ is the heat capacity of water vapor, J/(kg·°C); $(d_k - d_p)$ is the difference between the moisture content of the air, kg; $W$ is the evaporation rate, kg/(m$^2$·s), depending on the wind speed; $S_p$ is the evaporation area in the pile, m$^2$; $r$ is specific heat of evaporation, J/kg.

3. Results and Discussion

Figure 3 shows a graph characterizing a change in the heat balance depending on changing environmental factors for the windward side of the pile.

![Figure 3](image)

**Figure 3.** Changes in the heat balance during storage of the target section of sugar beet pile

The “plus” sign signifies the flow of heat into the pile and the heating of the target section of the pile, while the “minus” sign – that the heat was removed and the inside was cooled. For 12 days of research in the second half of November, a total of about 6.3 kW of heat was removed from 1 m$^3$ of the outer layer of the pile, and 0.43 kW of heat was received. The share of heat removal from the pile by heating the supply air was 24.9% of the total amount of the heat removed, while the moisture saturation of the air – 55.5%, and the water evaporation from the surface of sugar beet roots – 19.6%, respectively. This heat balance ratio is typical for November.

In October (when the beet is harvested), the ambient temperature, as indicated by the findings, commonly exceeds the temperature of beets. The main tool for regulating the temperature inside the
pile is the removal of heat from it due to water evaporation from the surface of sugar beets, followed by moisture saturation of the supply air. Accordingly, the main tool for ensuring the safety of sugar beets during natural cooling of the pile is the processes associated with the loss of moisture in the piled beets. In fact, the natural cooling through the pile by the outside air has an adiabatic character.

For a sugar factory, the loss of piled beet during storage is a negative phenomenon. Beets that have lost their turgor are more difficult to process: the load on transport augers and beet-cutting knives increases, while the efficiency of diffusion devices decreases. Figure 4 is a graph of moisture loss during storage. For 12 days of research, due to natural cooling, 50.3 kg of moisture or 7.6% of the mass of 1 m$^3$ of the pile was lost. Figure 3 shows a graph of moisture loss from a volume of 1 m$^3$ of a beet pile on its windward slope. The target pile, only due to its one side being across the prevailing wind, according to calculations, lost 28.4 tons of moisture, which was 0.8% of the total mass of the pile for 12 days of observation. The calculation disregarded the remaining losses that include losses during the “breezing” of piled sugar beets.

![Figure 4. Moisture loss in the target section of the pile](image)

Notably, calculations were performed for a pile with a height of 6.5 m and a ratio of the mass of stored raw materials to the surface area of the pile in contact with the environment, $M_b/S_p = 0.89$. The temperature in the pile layer at a distance of 1 m from the slope surface was measured. This layer accounted for 23% of the total mass of beets in a pile. For 38 days of storage, the total losses in the considered medium-term pile with a height of 6.5 m amounted to 3.4%, including losses for the “breezing” of beets, solar radiation, convective heat and mass transfer and evaporation of the opposite slope of the pile.

A formula resulting from the correlation analysis of data was compiled to calculate the loss of beet mass only on a slope located across the prevailing wind [5]:

$$M' = (-0.01057 + 0.0959T_b - 0.0712T_{env} + 0.1626v) \cdot \frac{0.89M}{S_p}$$

where $T_b$ is the temperature of the beet, °C; $T_{env}$ is the ambient temperature, °C; $v$ is the wind speed, m/s; $M_b$ is the weight of the pile, kg; $S_p$ is the surface area of the pile, m$^2$.

In field piles, the ratio of raw material mass to surface area is less and amounts to 0.42. On average, a layer 1 m thick accounts for 58% of the total mass of beets in a pile. Accordingly, losses in field piles should exceed storage losses in medium-term unventilated piles. In field piles, losses can often reach 15-27%, depending on the climatic zone and weather conditions in a particular season.

For storing sugar beets for a period of more than 1 month, in order to reduce the loss of beet mass, medium-term and long-term storage piles should be positioned with their end facing the prevailing wind. The advantage of long-term storage in piles with an active ventilation system is an increase in the ratio of the mass of raw materials to surface area up to $M_b/S_p = 1.35$, which reduces the aggressive
environmental effect. Active ventilation systems control the intensity of heat and mass transfer between the environment and the pile, avoiding uncontrolled hyperventilation.

Once applied to a small-sized field pile, with the ratio $M_b/S_p = 0.42$, the above technique results in the expected loss of beet mass of 6.5% of the field pile mass for 12 days of storage in November in favorable temperature conditions. For one month of storage, this value can be 16.3%.

4. Conclusion
Medium-term and long-term storage of sugar beets in field piles after harvest is accompanied by large losses of beet mass and reduces the sugar yield per hectare, which is especially sensitive for companies involved in the production and processing of sugar beets (vertically integrated companies). When forming the piles, they should be located with their end facing the prevailing wind. To reduce losses and dependence on environmental impact, it is necessary to switch to storage in large piles with a decreased outer layer. From natural cooling of sugar beets in field piles after harvest, it is necessary to switch to cooling through an active ventilation system with dosed air supply to the pile.

References
[1] Nikitin A V and Smykov R A 2019 Enhancing the economic mechanism of poultry subcomplex of regional agro-industrial complex in the conditions of import substitution International Journal of Recent Technology and Engineering 8(2) 4648-4651
[2] Brizhanskij L V, Brizhanskaya Yu A, Lasica A M and Dorohova A M 2020 Effect of low intensity laser radiation on sugar content in sugar beet root crops obtained from seeds treated with a quantum generator Journal of Physics: Conference Series 1679(2) 022026
[3] Zavrazhnov A I, Gorshenin V I, Solovyov S V 2019 Resource-saving Technology and Equipment for Sugar Beet Production (Saint Petersburg: Lan) p 164
[4] Putilina L N and Lazutina N A 2020 Sugar beet 5 23-27
[5] Zavrazhnov A I, Zuglenok N V, Zavrazhnov A A, Tolstoshein S S and Koltsov S M 2020 Mathematical modeling of the temperature regime in a ventilated pile of sugar beet IOP Conference Series: Materials Science and Engineering 919(6) 062067
[6] Zavrazhnov A I et al 2020 Rural machine operator 5-6 35-36
[7] Zavrazhnov A I and Koltsov S M 2020 Science in Central Russia 6(48) 30-36
[8] Shpaar D et al 2006 Sugar Beet (Growing, Harvesting, Storage) (Moscow: dlv agrodelo) p 315
[9] Gronkovskij A A 2004 News of higher educational institutions. Food technology 279-280 (2-3) 77-80
[10] Makarychev Y A and Ivannikov Y N 2016 Methods Experiment Planning and Data Processing (Samara: SamGTU) p 131