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Theoretical and economic studies of a floor duct in the form of cylindrical pipes

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Abstract. The article presents the results of studies of a floor duct in the form of cylindrical pipes (utility model patent No. 183361) at farms in Ryazan region, from September 27, 2018 to February 26, 2019. The studies included laying potatoes in three sections of the potato storage having different duct designs (section “A” is an air duct in the form of cylindrical pipes, section “B” is in the form of a front trihedral prism, section “C” is a serial air duct in the form of a semicircle). We also studied the temperature range of the potato bulk ventilated by cooling air in order to clarify the optimal microclimate parameters (temperature, humidity, flow rate) as applied to the conditions of the Central Federal District of the Russian Federation.

1. Introduction

Potato is one of the main crops in Russia. Thus on average, a Russian consumes about 85 kg of potatoes per year. Potato growing in the Russian Federation, unlike other countries, is focused on the domestic market [1, 2]. Thus, agricultural organizations and farms account for up to 5 million tons of table potatoes, up to 1 million tons of tubers to be processed and up to 1 million tons of seed-potato. Gross production of potatoes in farms of Ryazan region is 139.9 thousand tons (Table 1).

Table 1. Results of potato harvesting in Ryazan region in 2018

Crop	Harvest area, thousand ha			Gross yield (initial capitalized weight), thousand tons			Productivity, dt / ha		
	2017	2018	+/- to 2017	2017	2018	+/- to 2017	2017	2018	+/- to 2017
Potato	20.9	21.7	0.7	325.3	321.7	-3.6	155.4	148.5	-6.9
including agricultural enterprises + peasant farms	4.7	5.7	1.0	124.6	139.9	15.4	265.0	246.1	-18.8

The main task of potato production is its preservation. The preservation of potatoes presents significant difficulties, since it is necessary to maintain special conditions. The microclimate of the



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embankment has the greatest impact on potato storage. During storage, the potato gives moisture and this occurs both in the process of respiration, and during evaporation. Ample moisture loss leads to a decrease in the mass of tubers and to withering of agricultural products, as well as to a further decrease in seed quality. To avoid excessive moisture loss, it is necessary to maintain a sufficiently high relative humidity. However at the same time, it is necessary to prevent the formation of a droplet liquid, which favors the development of microorganisms and, in combination with an elevated temperature, contributes to disturbance in the rest of potatoes. The increase in temperature intensifies the vital activity of the tuber itself and increases the growth of pests, which causes a decrease in quality and increases the loss of potatoes. Lowering the temperature slows life processes and the development of microorganisms.

At the same time, an excessive decrease in temperature leads to potato subcooling, which affects the violation of biochemical processes and the physiological disorder of the tuber. Thus in potato tubers at a temperature below $+2^{\circ}\text{C}$ there is a significant accumulation of sugar, which affects their nutritional and technological qualities. According to Vysotskaya O.M. and Moiseeva N.A. an increase in temperature for every 0.1°C during storage will lead to an average monthly weight loss of 0.08%. For a uniform and stable microclimate, it is necessary to organize potato ventilation properly. However, at the same time, a certain air flow rate must be observed when it flows around tubers. Air velocity of less than 0.05 m/s leads to the loss of potatoes due to self-heating of tubers. At an air flow rate of 0.5 m/s and above, the entire boundary layer of tubers breaks off, which leads to the opposite effect (potato moisture loss).

Tuber preservation is also influenced by such factors as the density of the peel, mechanical damage, diseases and sprouting.

Potato post-harvest refinement and laying for storage are carried out according to three main technologies (through-flow, transshipment, and in-line) [1 - 4].

When through-flow technology, tubers brought from the field are stored without sorting. There are several options for storing potatoes using this technology. The first option includes a scheme: a combine harvester - a vehicle - a loader, forming a potato bulk of 5-6 m high. In this case, it is possible to create a potato bulk without the loader maneuvering. The second option presupposes loading into the potato storage with the separation of small tubers and soil using a potato-grading plant (PGP), while it is important to monitor the movement of the loader conveyor boom in a horizontal plane, since soil columns can form in the tuber bulk, which leads to rot formation [5 - 8].

2. Materials and methods

The object of research is the design of the floor duct of the potato storage, which allows distributing ventilated air throughout the potato bulk.

The subject of research is the process of storing potatoes and the movement of ventilated air through a floor air duct in the form of cylindrical pipes in the potato bulk.

3. Results and discussion

Based on the studies and empirical data, the porosity coefficient for the potato bulk was established. Porosity is the pore volume in 1 m^3 potato stacks. It is determined by the size and shape of some tubers and can range from 30 to 50%. The porosity coefficient of the bulk makes possible the active ventilation of agricultural products. At the same time, the shape and size of the tuber, and the shrinkage of the bulk itself affect porosity. The influence of these structural characteristics is established for potatoes and depends on the climatic characteristics of the area and the potato variety. Therefore, it is proposed to use the structural parameters typical for average bulks of potatoes when analyzing the operation of the ventilation system.

The bottom-ventilated bulk of potatoes has the shape of a rectangular parallelepiped (or cylinder) with height H and area of horizontal section S . The potato has averaged dimensions d_1, d_2, d_3 , while $d_1 \geq d_2 \geq d_3$. The average diameter of the potato is d and the porosity coefficient of the bulk is α . Air flow

G (kg / s) is supplied from below. When denoting ρ as the air density and w_0 as the average air velocity in the capillary over the cross section, one obtains.

$$G = \rho w_0 \cdot m \cdot \pi d_0^2 / 4, \quad (1)$$

where w is air velocity before and after bulking potatoes (Figure 1). Wherein $w = \alpha \cdot w_0$ or $w_0 = w / \alpha$.

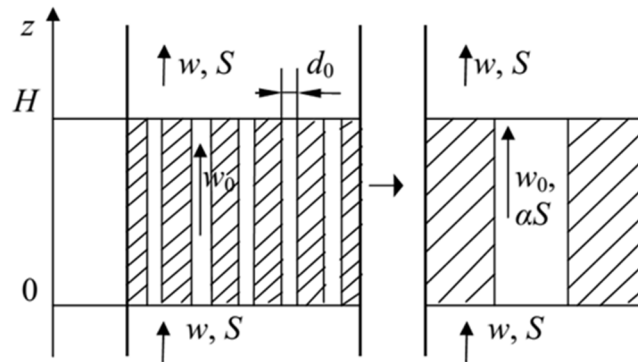


Figure 1. Model of the porous part of the potato bulk

The left part of the scheme includes a model of cylindrical capillaries for pores, the right part shows the connection of capillaries into one pipe with section αS .

The equation for the total pressure loss during operation of the ventilation system looks like:

$$(\Delta p) = (\Delta p)_{ent.} + (\Delta p)_{exit} + (\Delta p)_{cell} + (\Delta p)_{fr} \cdot \frac{H}{d_3}, \quad (2)$$

where factor H/d_3 takes into account the number of consecutive cells in the capillary, $(\Delta p)_{ent}$ is the bulk enter pressure loss, $(\Delta p)_{exit}$ is the bulk exit pressure loss, $(\Delta p)_{cell}$ is pressure loss on the cell of a complicated capillary, $(\Delta p)_{fr}$ is friction pressure loss in cylindrical capillaries, (Δp) is total pressure loss for the ventilation system as a whole.

Corresponding coefficients ζ of local losses will be found related to dynamic pressure $\rho w^2 / 2$ of the flow running onto the bulk.

The uneven distribution of air flow over the height of the bulk affects the temperature in the layers of agricultural products (potatoes), which contributes to a decrease in preservation during storage.

The uniform distribution of the air flow over the entire potato bulk is influenced by the design of floor ducts.

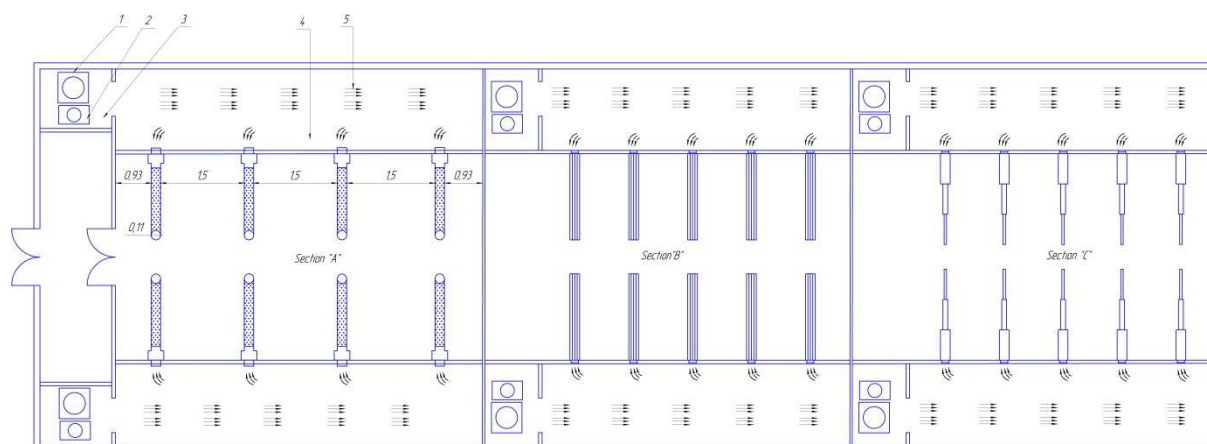
The studies on the temperature distribution in the bulk layer of tubers of variety "Gala" (Figure 2) took place in a farm of Ryazan region. The objects of the research were a serial duct in the form of a semicircle (Figure 3 - c) with a cross section equal to 0.55 m², a duct in the form of a frontal trihedral prism with a cross section of 0.4 m² [6] (Figure 3 - b) and a floor duct in the form of cylindrical pipes (Figure 3 - a) with a diameter of 0.11 m (Utility Model Patent No. 183361).

During the tests the following things were determined:

- the power consumption of potato storage ventilation systems;
- the preservation of variety "Gala" potatoes during storage.

In order to determine the loss of Gala potatoes and the energy consumption, three sections "A", "B" and "C" were mounted in the potato storage (Figure 2). Potatoes were placed in bulk in completely isolated sections (Figure 4) and the maximum height of the bulk was 3.5 meters. The specified method of storing agricultural products (potatoes) is the most progressive, since it makes possible to maintain microclimate depending on the purpose of the potato (food, seed or for industrial

processing). During the tests food potato variety Gala was used. The technology for storing potatoes included the following periods: drying, treatment, cooling and storage.



1 - fans, 2 - heating elements, 3 - power plant for air conditioning, 4 - main channels, 5 - air movement in the main channel

Figure 2. General view of sections during research

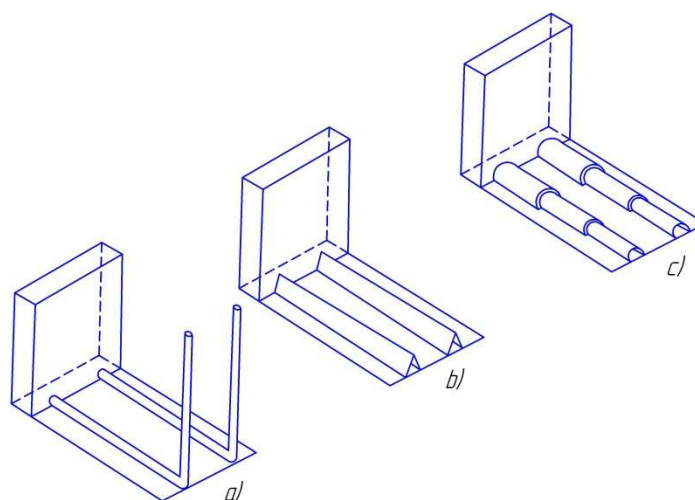


Figure 3. Design of floor ducts in relation to each of the three sections during economic tests in the household

The required temperature and humidity storage conditions of agricultural products (potatoes) for the indicated periods were provided automatically according to the specified algorithm. Ventilation in sections occurred sequentially, opening and closing flaps in the main channel. When the potatoes were unloaded from the sections at the end of the study, the tubers were sorted in the potato storage processing area [6].

The energy consumption of ventilation systems in the sections of the potato storage was calculated and analyzed every month during the economic tests. So the energy consumption for 5 months in section “A” using a floor duct in the form of cylindrical pipes (utility model patent No. 183361) amounted to 11,698 kWh. The energy consumption for 5 months in section “B” using a floor duct in the form of a frontal triangular prism was 12,451 kWh, and in section “C” using a floor duct in the form of a semicircle (serial) it was 13,275 kWh (Table 2).

The air in the storage sections during the study, passing through the potatoes, was heated, which indicated the release of biological heat and moisture by the tubers during storage. The air velocity in between tubers fluctuated in the permissible range (from 0.05 m / s to 0.4 m / s) and averaged 0.2 m / s, which corresponded to the norm [1-3].

The results of the study (Figure 4) show that the microclimate in different height of the bulk depends on the shape of the floor duct and on the ventilation gaps on its sides, which is in satisfactory agreement with the theoretical research results. Energy consumption depends on the operating time of ventilation systems, and according to the research results it was found that the lowest energy consumption was in the section with an air duct in the form of cylindrical pipes.

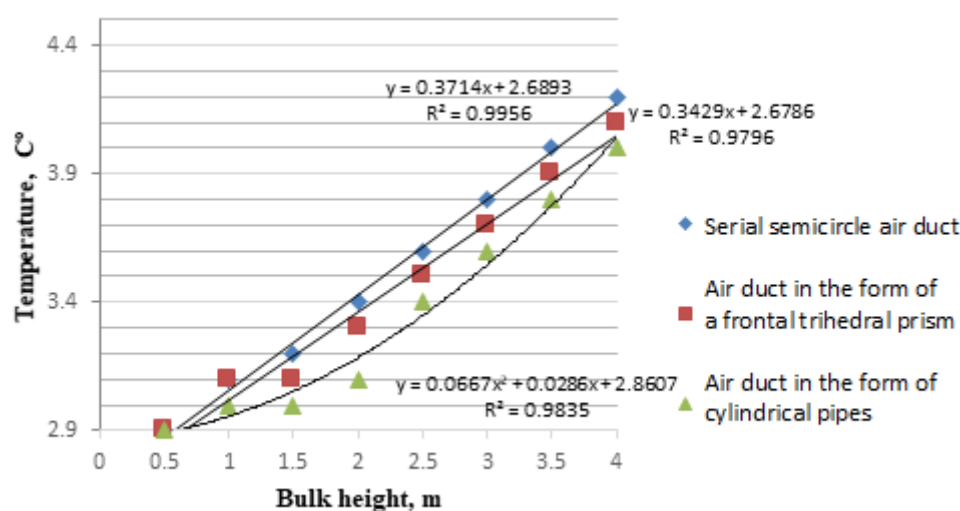


Figure 4. Temperature change along the height of the bulk relative to three geometric shapes of the duct

Table 2. Results of economic tests of the floor ducts of the potato storage in Ryazan region in 2018-2019

Parameter	Potato loss for 5 months of storage, %				Energy consumption by sections for 5 months of storage, kWh
	Total	mass loss	including technical waste	absolute rot	
Economic tests from 27/9/2018 to 26/2/2019					
Serial semicircle air duct	8.09	5.88	1.62	0.59	13,275
Air duct in the form of a frontal trihedral prism	6.51	4.7	1.3	0.51	12,451
Air duct in the form of cylindrical pipes	6.44	4.66	1.29	0.49	11,698

4. Conclusion

The study of the temperature in the potato bulk ventilated by cooling air made it possible to clarify the optimal microclimate parameters (temperature, humidity, flow rate) as applied to the conditions of the Central Federal District of the Russian Federation. The obtained research results show that the microclimate (temperature and humidity) in different parts of the bulk will depend on the shape of the floor air duct, ventilation gaps on its sides and the speed of the air flow entering the bulk due to the design of the air ducts. It was also found that the preservation of potatoes of Gala variety amounted to

6.44%, 8.09% and 6.51% respectively relative to the use of an air duct in the form of cylindrical pipes, a serial air duct and an air duct in the form of a frontal trihedral prism [6].

The energy consumption of the potato storage ventilation systems in the indicated period in three sections amounted to:

- 11,698 kW in section “A” with an air duct in the form of cylindrical pipes;
- 12,451 kW in section “B” with an air duct in the form of a frontal trihedral prism;
- 13,275 kW in section “C” with a serial air duct.

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