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Control and management scheme of air flows in inner space of steel silo during grain storage

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Abstract. The design of steel silo does not provide for constant monitoring of the air amount circulating inside the silo. Silos are not equipped with measuring equipment to control air flow. The height of the grain layer near the vertical wall corresponded to 15 meters and 20 meters at the same pressure of 3000 Pa in the lower part of the layer. At a higher layer height, the lower filtration rates and lower air flow are performed. Near the silo wall, the air rate depends on the height of the layer and is the same for silos of different diameters at the same pressure in the lower part. The silo with a large diameter has a greater variation in the values of the filtration rates along the surface of the grain mass. A typical technological scheme for storing grain in large-capacity steel silo was proposed and tested, taking into account the control and management system for air flows in the inner space of the grain mass.

1. Introduction

The most unfavorable storage conditions inside a metal silo develop in the upper part of the bulk-grain. If the relative humidity of the air in the silo is higher than the relative humidity of the outside air, it is recommended to provide ventilation of the grain space [1].

At low air filtration rates, moisture desorbed from the grain settles on the surface of the grain mass, which leads to its humidification [2].

In order to avoid moisture sedimentation on the surface of the grain mass, it is necessary to ventilate it at filtration rates ensuring the removal of moisture outside the silo [3].

2. Research results

It was proposed to regulate the amount of forced air by changing the mass of the ventilated grain. This method does not require capital expenditures, but requires some knowledge of air flow control. The smaller the mass of grain is, the greater the air flow is needed. A volume of air is calculated to provide a critical filtration rate in the most loaded central part of the silo [4]. Critical speed is understood as its minimum value that ensures the removal of moisture outside the granary.

The air moves unevenly inside the grain mass. Near the walls of the silo, the air has a higher speed comparing to the central part. This is justified by the difference in the height of the grain layer: in the center the layer is higher than that near the walls. The height difference occurs due to the loading of the silo through one hole in the center of the roof, a conical bulk-grain is formed in the silo. The plot of air velocities at the boundary of exit from the grain mass from the center to the wall can be described by the following formula:

$$\bar{V}_{\Phi} = R^{-1} \int V_x(x)dx \tag{1}$$

$$V_{\Phi} = exp\left(\frac{ln\Delta P - lnA - 2{,}28 - \ln{(H_1 + (R - x)tg\alpha)}}{n}\right) \tag{2}$$

where, v_x – is the air filtration rate at the exit of the grain mass at a distance x from the center of the silo, m/sec;

P – is the air pressure in the lower part of the bulk-grain, Pa;

h – is the height of the grain layer near the vertical wall of the silo, mm;

R – s the radius of the silo, mm;

x – s a variable value of the distance from the center of the silo to its wall, mm;

α – is the slope repose angle of the grain, degree;

A and n – are empirical coefficients shown in table 3.

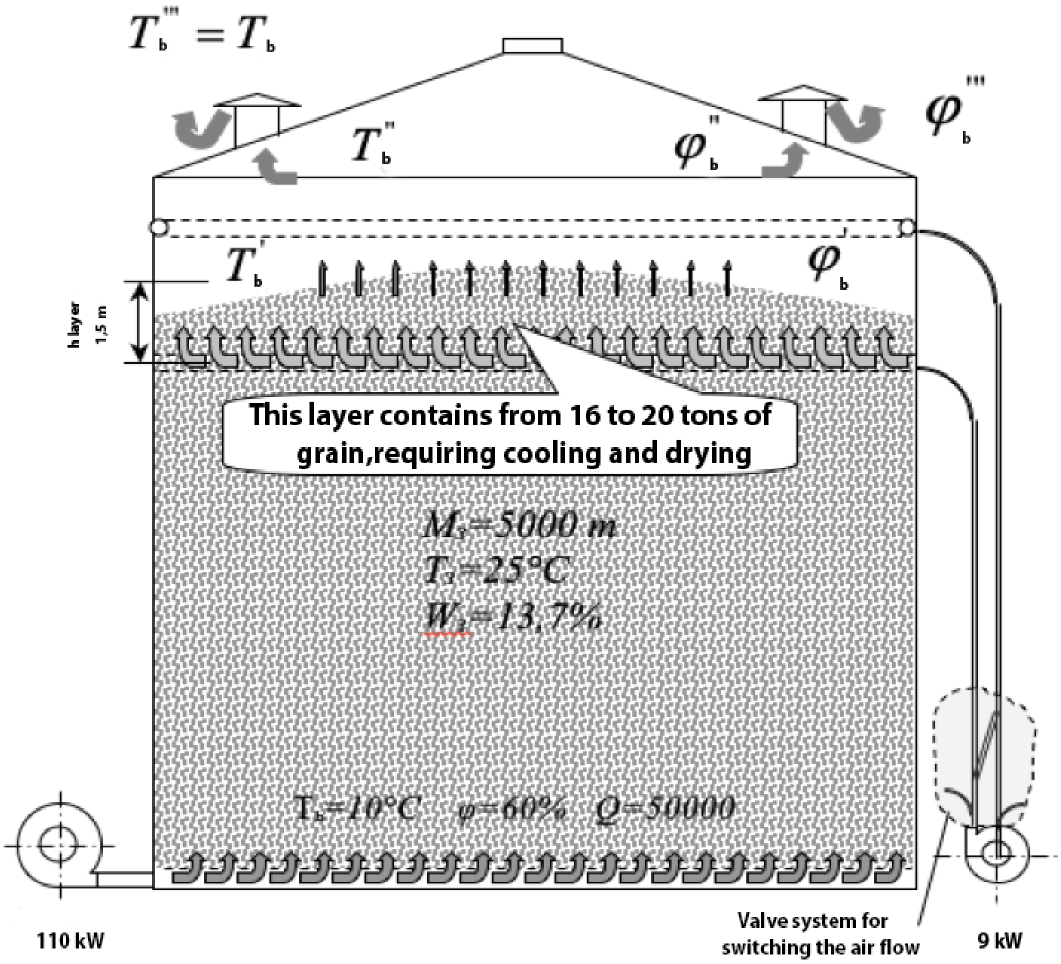

Figure 1. Technological diagram of a large-capacity steel silo for grain storage with air flow control and management in its inner space

Figure 2 shows plots of air filtration rates from the center to the wall in two silos with a diameter of 12.5 meters (R = 6.25 m) with a capacity of 2000 tons and a diameter of 28.3 meters (R = 14.15 m) with a capacity of 10,000 tons respectively. For example, a silo with a diameter of 12.5 m shows the air rate in the center of 0.039 m/s, and near the wall of 0.046 m/s, the difference is 0.007 m/s. While a silo with a diameter of 28.3 m has the air rate in the center of 0.034 m/s, the same speed near the wall of 0.046 m/s, the difference is 0.012 m/s. For a silo with a diameter of 12.5 m, the filtration rate of 0.007 m/s corresponds to the air flow of 3000 m^3/h. For a silo with a diameter of 28.3 m, the filtration rate of 0.012 m/s corresponds to the air flow rate over 27000 m^3/h. To compensate uneven air distribution, additional energy costs are required.

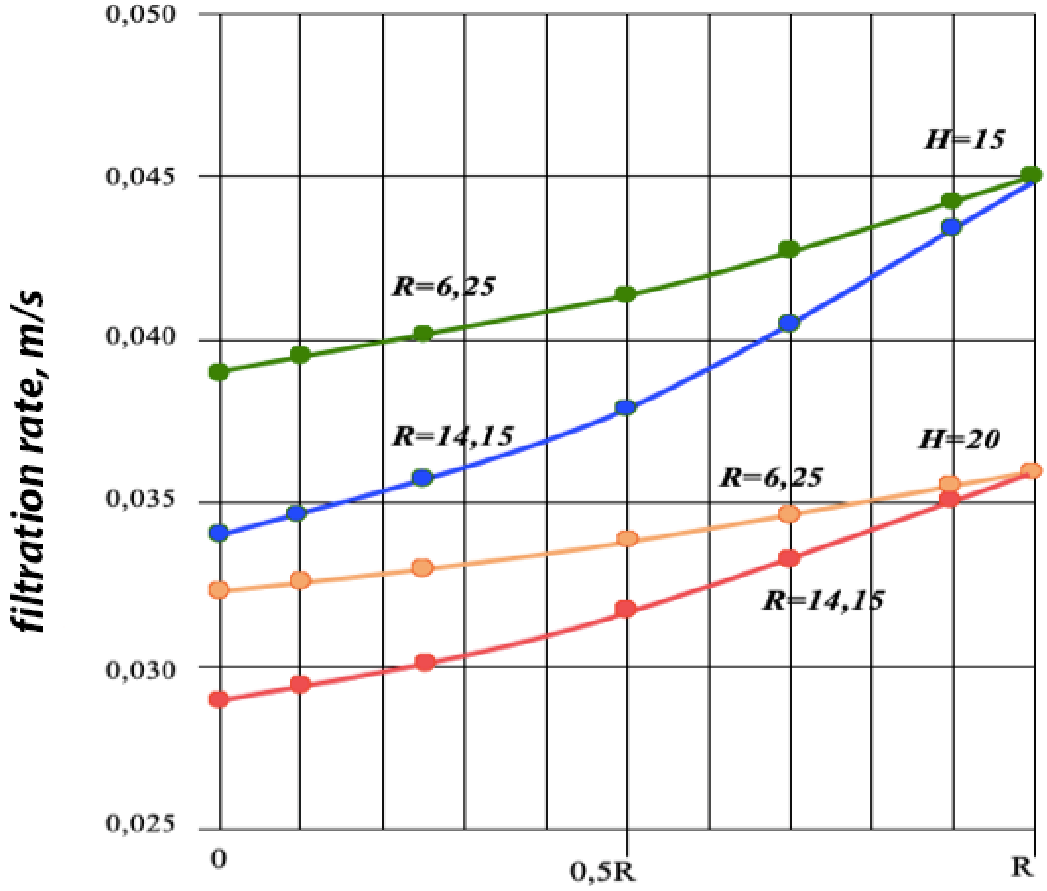

Figure 2. Plots of air velocities on the surface of the grain mass in silos with a diameter of 12.5 m and 28.3 m with a height of the bulk-grain near the walls of 15 m and 20 m, air pressure in the lower part of the bulk-grain is 3000 Pa.

The required critical filtration rate in the center of the silo is ensured by supplying air in a volume corresponding to the value of the average weighted rate and at a bottom pressure, corresponding to the critical rate in the center [5]. The maximum air pressure in the lower part of the grain is calculated by the formula:

$$P = 9{,}81 \times A \times (H + R \cdot \tan\alpha) \times V^n \qquad (3)$$

where, H – is the height of the vertical wall of the silo, mm;

υ – is the critical filtration rate, m/s.

Substituting expression (3) into formula (2), we obtain the following dependence for calculating the average weighted filtration rate.

$$\bar{\upsilon} = \exp(n^{-1}) \tag{4}$$

$$\bar{\upsilon} = R^{-1}\int_0^R \upsilon(\mathrm{x})\mathrm{dx} \tag{5}$$

where, x – is the coordinate of the average weighted filtration rate, mm.

The coordinate of the average weighted filtration rate was calculated using formulas (4) and (5) for large-capacity steel silo (LCSS) with a diameter of 8–40 meters with equal heights of the grain layer and the silo wall of 15–20 meters. The coordinate does not practically depend on the height of the wall; it changes in silos of various diameters [6]. The values of the coordinate obtained by the calculation for LCSS with different diameters are presented in table 1.

Table 1. Coordinate values of the average weighted air filtration rate in silos of various diameters.

Coordinate	Silo diameter, m			
X	to 10	from 10 to 20	from 20 to 30	over 30
	0,50R	0,55R	0,60R	0,65R

In order to prevent the development of the grain self-heating process, it is recommended to equip the inside space of the grain mass by the temperature monitoring system with an alarm or a device for automatically turning on fans when the temperature rises above 7 °C for 2 to 3 days with two or more sensors [7]. If there is a risk of self-heating of the grain mass, its ventilation is carried out under any weather conditions [8].

3. Conclusion

The technology of safe active ventilation of grain in steel silos is as follows:

1. The LCSS is equipped with an air pressure measuring instrument. A diffonometer is installed outside to measure the pressure drop of the air in the grain layer with a thickness of 2.5 to 3.5 meters. The lower pressure take-off point is at least 1 meter from the air distribution grill of the silo.

2. In LCSS, grain storage with a moisture content of not more than 14% is allowed. Ventilation is allowed with outside parameters excluding additional moisture of the grain. The outside temperature should be lower than the grain temperature by at least 5 °C.

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