Global Journal of Food Sciences and Nutrition

Research Article

doi: 10.39127/2475-2368/GJFSN:1000116
Kechkin IA, et al. Gl J Food Sci Nutri: GJFSN-116

# Ventilation of Grain in Metal Silos of Large Capacity in The South of Russia

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**Citation:** Kechkin IA, Ermolaev VA, Slavyanskiy AA, Gurkovskaya EA, Bronnikova VV (2020) Ventilation of Grain in Metal Silos of Large Capacity in The South of Russia. Gl J Foo Sci Nutri: GJFSN:116.

**Received Date:** 03 December 2020; **Accepted Date:** 21 December 2020; **Published Date:** 30 December 2020

***Abstract***

*The peculiarity of grain storage in the South is that it is required to supply a standard air volume of at least 10 m3*h/t to a silo filled with a formed batch of grain during ventilation. It is not possible to meet this requirement under the existing condition of the silos. The silos are not equipped with air flow control devices, they are equipped with ventilators with different characteristics, that have different designs and sizes of devices for air movement. There are cases of ventilation with minimal volumes of air supply, which contribute to the development of storage molds that degrade the quality of the grain.*

## Introduction

Grain is ventilated to cool it for the following technological tasks:
- ensuring the preservation of quality during storage;
- elimination and prevention of self-heating centers;
- cooling after drying;
- slowing down of pests' vital activity in grain stocks.

Ventilation without cooling is used for finishing grain drying, accelerating the processes of post-harvest ripening of seeds and solving other technological problems [1,2]. In this work, a procedure is being developed to fulfill one technological task- to ensure the preservation of grain quality during storage in a metal silo in the conditions of the South of Russia.

Inside the silo, changes in temperature and relative humidity in the over-grain space are observed during the day. Temperature and relative humidity in the intergranular space of the surface layer of the grain practically do not change during the day. The relative humidity of the air in the space above the grain decreases with increasing temperature above the grain and increases with decreasing temperature [3,4]. The moisture content per one-unit volume of air in the surface layer of the grain and above the grain practically does not change during the day. The moisture content of the air in the grain is greater than the moisture content in the air above the grain.

When storing grain, condensation over the grain mass is unacceptable [5,6]. To prevent the formation of condensation, forced ventilation of the above-grain space (under the roof) is required. Ventilation should be turned on when the temperature above the grain (under the roof) rises above the outside temperature by more than 10 °C. The ventilation should be stopped when the temperature is equal inside and outside the silo [7,8].

## Materials and methods

To ensure the supply of a standard volume of air into the grain layer in any silo, regardless of the configuration and design features, some recommendations have been developed [9,10]. These can be performed after additional equipping of the silo with a device for measuring the air pressure drop [11,12]. The device is installed outside the silo and connected by tubes with two fittings screwed into special bolts. These bolts are installed in place of the fastening bolts located in the vertical wall of the silo and used to connect the metal plates. The diagram of the device installation is shown in Fig. 1.

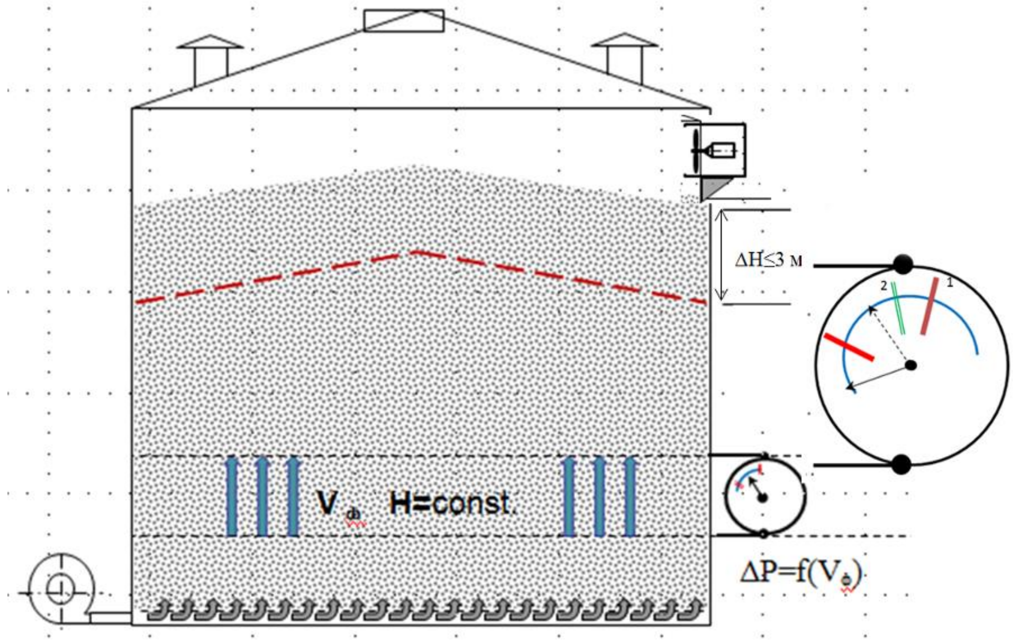


**Figure 1:** Installation diagram of the device for measuring the air pressure drop in the grain layer in a metal silo

The sequence of actions for grain ventilation in a large-capacity metal silo can be divided into several main stages. When preparing a large-capacity metal silo, two fittings are made for each of the silos for taking air pressure, Fig. 1, and two bolts for connecting the fittings, Fig. 2 and Fig. 3, fastening to a device (differential pressure gauge) for measuring the pressure drop.

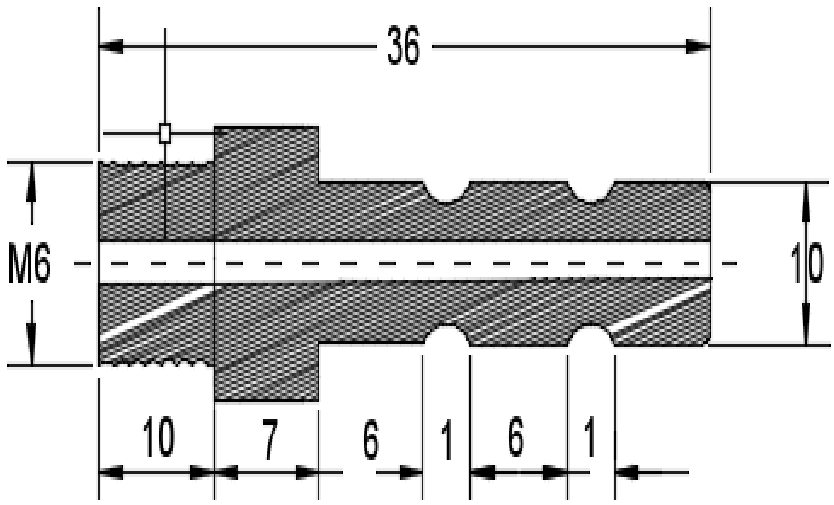


**Figure 2:** Sketch of the air pressure fitting

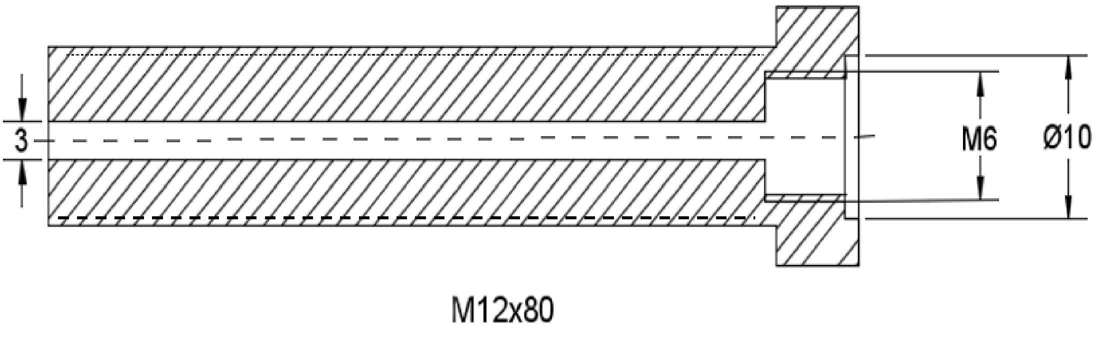


**Figure 3:** Sketch of a bolt for connecting a fitting.

Then the bolts on the vertical silo wall are replaced. The lower bolt is installed at a height of at least 1 m from the air distribution grille. The upper one is installed at a distance of 3 m vertically from the lower bolt with an error of not more than 5 mm. The fittings are screwed into the installed bolts.

A device for measuring the air pressure difference is installed outside the silo and the fittings on the silo and the device are connected with flexible tubes, for example, silicone, rubber, etc. The lower fitting on the silo is connected to the fitting that is marked on the device with a (+) sign, and the upper one with a (-) sign. The device is installed in a place convenient for visual inspection. Differential pressure gauges DNMP-100-M1 with an upper limit of overpressure measurement of 600 Pa or 1000 Pa with an accuracy class of 2.5 in the performance of UZ (moderate climate) or TZ (enclosed self-cooled space) can be used as such devices.

Ventilation of grain in a metal silo in order to cool it is carried out with atmospheric air, the temperature of which must be at least 5 0C lower than the grain temperature [13,14].

Determine the relative humidity (φ) and temperature (t) of atmospheric air. It is allowed to use household meteorological stations to measure atmospheric air parameters. Air sampling sensors are installed near the fan, protected from the sun's rays.

Determine the equilibrium grain moisture (Wp) for the air parameters φ and t, taking into account the measurement error of these parameters: φ - 5%, t - 2 °C.

Ventilation is allowed if the value of the initial moisture content of the grain (Wg), laid in the silo, is equal or exceeded over its equilibrium moisture content. Otherwise, the grain mass will be moistened, which will reduce the grain storage resistance and deteriorate its quality. In this case, ventilation should be postponed until the weather conditions change, under which the required condition Wp ≤ Wз is fulfilled. The moisture content should be compared taking into account the error in its determination in the original grain mass of 0.5%

## Results

The air consumption required for ventilation of grain in the silo at a standard specific flow of 10 m3*h/t is determined by the following formula:

$$Q = 2{,}78 \cdot 10\text{-}3 \cdot M, \text{ where} \quad (1)$$

Q– air consumption, m3/sec;
M – mass of grain in the silo, ton.

To determine the value of the pressure, drop (ΔP) in a grain layer of 3000 mm thickness at the required air flow rate for ventilation there was used the formula:

$$\Delta P = 29430 \cdot A \cdot (Q/F)n \text{ , where} \quad (2)$$

F – cross-section area of the silo, m2.

| *Grain crop* | *A* | *n* | *Grain crop* | *A* | *n* |
|---|---|---|---|---|---|
| Wheat | 1,41 | 1,43 | Corn | 0,67 | 1,55 |
| Rye | 1,76 | 1,41 | Peas | 0,82 | 1,51 |
| Oats | 1,64 | 1,42 | Buckwheat | 1,76 | 1,41 |
| Barley | 1,44 | 1,43 | Panicum | 2,34 | 1,38 |

**Table 1:** Constant coefficients A and n, depending on the grain crop.

The obtained value of the pressure drop is applied on the dial of the device. At the stage of ventilation, the ventilator is switched on and the pressure drop in the grain layer is determined. If the arrow of the device is below the mark on the dial, then part of the grain is unloaded from the silo until the arrow on the device matches or exceeds the mark. The unloaded grain is weighed and the mass (Mg) remaining in the silo for ventilation is determined. The power consumption is measured by the electric motors of the ventilators serving the metal silo. In the process of ventilation, at least 1 time per shift (8 hours), the relative humidity (φ) and temperature (t) of the outside air are measured [15,16]. If the relative humidity of the air exceeds the equilibrium humidity of the grain, ventilation is stopped until the weather conditions change.

After that, the grain is cooled to a temperature calculated by the following formula:

$$Tf = 0{,}3Ti + 0{,}7\, To.a \text{ , where} \quad (3)$$

Tf– final grain temperature after cooling, °C;
Ti – initial temperature of the grain filled into the silo, °C;
To.a– outdoor air temperature, °C.

The ventilator is turned off when all (without exception) sensors in the thermal suspensions show a temperature equal to or less than Tf.

After ventilation is completed, the grain is returned to a large-capacity metal silo. The grain temperature is monitored at least once every 3 days. The specific energy consumption is calculated per a ton of grain.

$$\Delta g = N/M \quad (4)$$

According to this indicator, the silos are subsequently compared with each other. A silo, in which the specific energy consumption is less than in others, is more acceptable in operation.

Fulfillment of the recommendations and installation of additional equipment on a large-capacity metal silo allows for the supply of the standard volume of air to the grain layer in any silo, regardless of the configuration and design features and thermos-physical parameters of the air inside the large-capacity metal silo.

## Discussion

When storing grain, the formation of condensation over the grain mass is unacceptable [17]. To prevent the formation of condensation, forced ventilation of the over-grain space (under the roof) is required [18]. Ventilation should be turned on when the temperature above the grain (under the roof) rises above the outside temperature by more than 10 °C. The ventilation should be stopped when the temperature is equal inside and outside the silo.

When the air parameters inside the silo change, active ventilation of the grain throughout the entire ventilation period and an increase in the values of relative humidity and air temperature in the intergranular space of the upper grain layer and in the over-granular space occur, the ventilation must be stopped. An increase in the values of relative humidity and temperature in the upper layer of the grain and in the above-grain space occurs due to the transfer of heat and moisture from the deep layers to the upper part of the silo.

An increase in the relative air humidity in the over-grain space and reaching a critical level of 95% or more during the entire ventilation period indicates the impossibility of continuing ventilation, as this would lead to moistening of the upper layer and a decrease in grain storage resistance.

## Conclusion

Experimental data indicate that during ventilation, conditions can be obtained that worsen the preservation of grain quality. Therefore, before performing this technological operation, it is necessary to assess the degree of its risk. To prevent the formation of condensation, the grain should be ventilated with air having parameters at which the equilibrium moisture content is equal to or less than the actual moisture content of the grain poured into a metal silo for storage.

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