Thermal conditions of storing seed grain in a hermetic container with a regulated air environment

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Abstract. Grain production largely determines the level of development of the country, its food security and the standard of living of the population. Currently, about 70,000 enterprises and organizations in all agricultural regions of the country are engaged in grain production in the Russian Federation, of which more than half are peasant farms that do not have an adequate base for storing seed grain and scientifically based storage technologies, in particular. The choice of the storage method is determined by many conditions. It is necessary to consider climatic features of the area where grain will be stored, types and capacities of granaries, etc. The cheapest and easiest way to store grain is storage in metal silos, but it does not protect seeds from thermal processes occurring in the grain bulk under the influence of external climatic factors and therefore it is unsuitable for their storage.

1. Introduction
Grain temperature and moisture are the keys to safe seed storage. When grain moisture increases, it begins to breathe intensively, releasing a large portion of heat into the environment. Therefore, the temperature of the grain mass is a natural accurate indicator of the quality of grain storage.

When the ambient temperature changes in the grain mound, moisture and heat are transferred from warmer layers to colder ones.

Heat \( Q \) supplied to a metal silo installed in an open space from the environment and spent on changing its temperature consists of heat from solar radiation \( Q_E \), heat resulting from convective heat exchange of the silo surface with the environment \( Q_S \) and heat from atmospheric precipitation in the form of rain, snow, dew \( Q_A \). It can be defined by the following expression [5]

\[
Q = Q_E + Q_S + Q_A
\]  

The amount of heat supplied to the metal silo is variable, so heat balance conditions for time interval \( dt \) are determined by the following expression [5]:

\[
g_A dt + g_E dt + g_S dt - \gamma G dT = 0
\]  

Where \( g_A \) is the amount of heat supplied to the metal silo with atmospheric precipitation per unit of time, W/s; \( g_E \) is the amount of heat supplied to the silo from the action of solar radiation per unit of time, W/s; \( g_S \) is the amount of heat supplied to the silo as a result of convective heat exchange of the silo surface with the environment, W/s; \( \gamma \) is the coefficient of thermal conductivity of a silo with grain,
W/(kg·°K); \( G \) is the weight of metal silo with grain, kg; \( \Delta T \) is the temperature difference between the silo surface and the environment, °K.

The intensity of heat transfer leads to a change in temperature in different layers of the grain and the occurrence of the phenomenon of movement of the air mixture and moisture transfer [3-4].

In the process of moisture transfer inside the metal silo, conditions may arise for the formation of moisture condensate from the air mixture located in the intergranular space. It can be partially reduced by rarefying the air mixture inside the metal silo.

To prevent moisture condensation in the near-wall layers of a metal silo, the following condition must be honored:

\[
\theta = T_3 - T_c < T_3 - T_{dp}
\]  

Where \( T_c \) is the metal silo wall temperature, °K; \( T_{dp} \) is the dew point temperature, °K.

According to the research results of V.P. Brovenko and V.F. Sorochinskiy to improve the storage conditions of seed grain in a sealed metal container, it is necessary to reduce the heat exchange of the near-wall layer of grain with the environment through the use of a heat-shielding coating [6-7].

Representing the near-wall layer of a grain in a sealed container with a heat-shielding coating as a multilayer wall, the thermal resistance of which will be equal to:

\[
R = R_c + R_{ins} + R_{out} = \frac{\delta_c}{\lambda_c} + \frac{\delta_{ins}}{\lambda_{ins}} + \frac{\delta_{out}}{\lambda_{out}}
\]  

Where \( R_c \) is the thermal resistance of the metal wall of the container, (m²·°K) / W; \( R_{ins} \) is the thermal resistance of the layer of thermal insulation material, (m²·°K) / W; \( R_{out} \) is the thermal resistance of the outer lining of the thermal insulation material, (m²·°K) / W; \( \delta_c, \delta_{ins}, \delta_{out} \) are the thickness of the metal wall of the silo, thermal protection and external lining of the thermal insulation, m; \( \lambda_c, \lambda_{ins}, \lambda_{out} \) are coefficients of thermal conductivity of the metal wall of the silo, thermal insulation and external lining, W / m²°C.

A heat-insulating material of IZOKOM FS brand can be used as a heat-shielding coating. It consists of polyethylene foam on one side, and is coated with aluminum foil on the other side, with an adhesive composition that is not sensitive to the moisture of the protected surface [1-2].

After evaluating the influence of individual layers of a multilayer wall on the overall process of heat exchange between the grain and the environment, carried out using Biot criterion, the required thickness of the heat-shielding layer can be determined by the following formula:

\[
\delta_{ins} = \frac{\lambda_{ins}}{R} \{ R - (1/\alpha_{out}) \}
\]  

Where \( R \) is the total thermal resistance of the heat-shielding flat design, (m²·°K)/W; \( \delta_{ins} \) is the thickness of the thermal insulation layer, m; \( \lambda_{ins} \) is the coefficient of thermal conductivity of the selected type of insulation, W/m²·°K, \( \alpha_{out, env} \) is the heat transfer coefficient from the side of the outer enclosure, W/m²·°K.

In accordance with building codes and regulations, the total thermal resistance of a heat-shielding flat structure located in the open air, necessary to prevent condensation of moisture from the air mixture located in the intergranular space inside the container, can be determined by the following formula:

\[
R = \frac{(T_3 - T_{oc})}{\alpha_{out}(T_3 - T_{dp})}
\]  

Where \( T_{dp} \) is the dew point temperature, °K and can be set from the expression.

The calculation carried out according to formula 6 showed that the thickness of the heat-shielding layer of a hermetic metal container should be at least 5 mm to be sufficient to prevent the formation of moisture condensation in the near-wall layers of a grain embankment.
2. Materials and methods
To confirm the scientific hypothesis and the results of theoretical studies, laboratory studies were carried out on the possibility of storing seed grain in a hermetic metal container with a controlled air environment. The studies were carried out using a model of a hermetic container (figure 1).

![Figure 1. A model of a hermetic container for storing seed grain in a controlled air environment.](image)

To implement the method of storing grain in a container with a rarefied air environment, the container was filled through the neck with seeds of spring wheat "KVS Akvilon". Then the lid was hermetically sealed and the model was installed in artificial climate chamber KOMEG KMHW - 6, which during the experiments maintained relative moisture of 90 % and created a temperature difference according to the plan of the experiment.

In the course of laboratory studies, an experiment was carried out according to the second-order Box-Benkin plan. As an optimization parameter, the laboratory germination of seed grain was taken. Determining factors included the rarefaction of the air in the working volume of the container, the volume of the container, the moisture of the grain stored and the thickness of the heat-shielding coating.

At the end of the experimental storage period, grain seeds were tested for germination, in accordance with the requirements of GOST 12038-84 (Seeds of agricultural crops. Methods for determining germination). Field studies of the storage conditions of seed grain in metal containers with a rarefied air environment were carried out at the production base of peasant farms in Ryazan region.

The study was subject to two options for storing seed grain in a hermetic container with a rarefied air environment:

- Storage in an open area under a canopy.
- Storage in a closed, unheated granary.

For each method, two groups of containers were installed. The first group included hermetic containers with a heat-shielding coating and the second group included the ones without any heat-shielding coating. To obtain the results of observations with an error of no more than 1 %, each group included five containers with a working volume of 1.2 m³.

Seeds for storage were weighed and had a moisture content of not more than 15.2 %, a temperature of 20-22° C and purity of at least 98 %.

To record the temperature and moisture of the air mixture in the working volume of the hermetic container and the environment, air moisture and temperature recorders model DT-171 were used. Three recorders were fixed inside each container to control air moisture and temperature in the grain embankment at a depth of 50 cm from the sealed cover. The first container was at a distance of 25 mm from the vertical wall of the second one in the center of the grain embankment. The recorders were also installed inside the granary and in the open area and were used to control the temperature and
relative moisture of the air in the environment. All recorders were connected to a personal computer. Measurements were taken every 6 hours. The entire period of seasonal storage of seed grain in hermetic metal containers was divided by months.

An analysis of the storage conditions of seed grain in hermetic metal containers with rarefied air was carried out for the month with the highest indicator of technical climate rigidity, which was calculated using a simplified mathematical model based on the obtained data on changes in external climatic conditions for seasonal storage of seed grain [11-12].

3. Results and Discussion
It was found in the course of laboratory studies that rational technological indicators under which seed grain can be stored were:

- The working volume of the hermetic container of 1-1.2 m$^3$.
- The working pressure of the air mixture in the container of 64-66 kPa.
- The limiting content of oxygen in the air mixture inside the container, at which it is necessary to carry out aeration of the grain embankment of 14 %.
- Grain for storage must have a moisture content of about 14.5-15 %, a temperature of 20-22°C, a frequency of at least 95 %.

The analysis of the results of field tests was carried out on the example of October, which has the highest indicator of technical climate rigidity [8-10] and its results are presented in figures 2 and 3.

![Figure 2](image-url)

**Figure 2.** Changes in the temperature of the air mixture inside hermetic metal containers in October 2021: 1 - average daily air temperature in the open area; 2 - temperature in the peripheral layer of the grain embankment in a container without a heat-shielding coating; 3 - temperature in the center of the grain embankment in a container without a heat-shielding coating; 4 - temperature in the peripheral layer of the grain embankment in a container with a heat-shielding coating; 5 - temperature in the center of the grain embankment in a container with a heat-shielding coating.
The use of a container under a canopy will reduce the cost, the canopy will protect the grain from sunlight and precipitation.

The research results indicated that solar radiation during seasonal storage of grain in hermetic containers placed in an open space under a canopy did not significantly affect the temperature regime of the grain embankment. The temperature difference between the walls and lids of the containers was observed only in spring months and was no more than 0.8°C (the difference was observed in the morning and evening hours, when the sun was close to the horizon and did not show much radiation activity). There were also no changes in the surface temperature of the containers due to heat from precipitation.

![Figure 3. Changes in the relative moisture of the air in the environment and the air mixture in the grain embankment inside metal containers in October 2021: 1 - average daily relative moisture in an open area; 2 - average daily relative moisture in the peripheral layer of the grain embankment in a container without a heat-shielding coating; 3 - average daily relative moisture in the center of the grain embankment in a container without a heat-shielding coating; 4 - average daily relative moisture in the peripheral layer of the grain embankment in a container with a heat-shielding coating; 5 - average daily relative moisture in the center of the grain embankment in a container with a heat-shielding coating.]

When seeds were stored in a metal container without a thermal protective coating, installed in an open area under a canopy, changes in the state of the air mixture were observed at the beginning of the month and at the very end of the month. The temperature of the air mixture in the peripheral layer of the grain embankment was lower than the temperature in the central layer by 3.5-8°C, which caused an increase in the relative moisture of the air in the peripheral layer up to 94-100%.

The temperature difference between the peripheral and central layers in a hermetic metal container with thermal protection, installed in an open area under a canopy was only 1-1.6°C, which led to an increase in the relative moisture of the air in the peripheral layer up to 70-76%.

With such parameters of atmospheric air, the process of moisture transfer of seed in a metal container was not observed, which indicated the efficiency of using a heat-shielding coating.
4. Conclusion
The results obtained in the course of the research allow to conclude that the storage of seed grain in metal containers without a heat-shielding coating is permissible only indoors in a granary. To store seeds in an open area under a canopy, it is necessary to use metal containers with a heat-protective coating made of ISOKOM FS material 5 mm thick.

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