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Editorial

The National Institute of Research-Development for Machines and Installations designed to Agriculture and Food Industry - INMA Bucharest has the oldest and most prestigious research activity in the field of agricultural machinery and mechanizing technologies in Romania.

Short History

- In 1927, the first research **Center for Agricultural Machinery** in Agricultural Research Institute of Romania - ICAR (Establishing Law was published in O.D. no. 97/05.05.1927) was established;
- In 1930, was founded **The Testing Department of Agricultural Machinery and Tools** by transforming Agricultural Research Centre of ICAR - that founded the science of methodologies and experimental techniques in the field (Decision no. 2000/1930 of ICAR Manager - GHEORGHE IONESCU ŞIŞEŞTI);
- In 1952, was established the Research Institute for Mechanization and Electrification of Agriculture - ICMA Băneasa, by transforming the Department of Agricultural Machines and Tools Testing;
- In 1979, the Research Institute of Scientific and Technological Engineering for Agricultural Machinery and Tools – ICSITMUA was founded - subordinated to Ministry of Machine Building Industry - MICM, by unifying ICMA subordinated to MAA with ICPMA subordinated to MICM;
- In 1996 the National Institute of Research-Development for Machines and Installations designed to Agriculture and Food Industry – INMA was founded – according to G.D. no.1308/25.11.1996, by reorganizing ICSITMUA, G.D no. 1308/1996 coordinated by the Ministry of Education and Research G.D. no. 823/2004;
- In 2008 INMA has been accredited to carry out research and developing activities financed from public funds under G.D. no. 551/2007, Decision of the National Authority for Scientific Research - ANCSno. 9634/2008.

As a result of widening the spectrum of communication, dissemination and implementation of scientific research results, in 2000 was founded the institute magazine, issued under the name of SCIENTIFIC PAPERS **(INMATEH)**, ISSN 1583 – 1019.

Starting with volume 30, no. 1/2010, the magazine changed its name to ***INMATEH - Agricultural Engineering***, appearing both in print format (ISSN 2068 - 4215), and online (ISSN online: 2068 - 2239). The magazine is bilingual, being published in Romanian and English, with a rhythm of three issues / year: January-April, May-August, September-December and is recognized by CNCSIS – with B^{+} category. Published articles are from the field of AGRICULTURAL ENGINEERING: technologies and technical equipment for agriculture and food industry, ecological agriculture, renewable energy, machinery testing, environment, transport in agriculture etc. and are evaluated by specialists inside the country and abroad, in mentioned domains.

Technical level and performance processes, technology and machinery for agriculture and food industry increasing, according to national requirements and European and international regulations , as well as exploitation of renewable resources in terms of efficiency, life, health and environment protection represent referential elements for the magazine „***INMATEH - Agricultural Engineering***".

We are thankful to all readers, publishers and assessors.

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CONTENT

THEORETICAL RESEARCHES ON COOLING PROCESS REGULARITY OF THE GRAIN MATERIAL IN THE LAYER
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ТЕОРЕТИЧНІ ДОСЛІДЖЕННЯ ЗАКОНОМІРНОСТЕЙ ПРОЦЕСУ ОХОЛОДЖЕННЯ ЗЕРНОВОГО МАТЕРІАЛУ В ШАРІ

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Keywords: *grain material, cooling, air, heat and mass transfer, venting*

ABSTRACT

The mathematical description of the cooling process dynamics of seed material in a layer, as a method of temporary preservation of grain with cold, before further processing is given.

РЕЗЮМЕ

Наведено математичний опис динаміки процесу охолодження насіннєвого матеріалу в шарі, як способу тимчасової консервації зерна холодом, перед подальшою обробкою.

INTRODUCTION

The urgency to apply artificial cold at the storage of grain materials (food and fodder grain) is defined by different factors. Use of high-efficiency combine harvesters considerably reduces the period of harvesting and makes strict the requirements of processing acceleration and preparation of a grain material for storage. Thus, increasing the amount of units and power capacities for intensive drying, clearing and sorting of grain in most cases is not profitable *(Khmelniuk M.H., et. al., 2014)*. The most widespread practice, a method of reduction of grain material humidity in a conditioned state is drying. It is one of the most power-intensive processes in grain production *(Gaponjuk O.I., et.al, 2014)*. The essential factor of reduced price of this process is the add-on of drying machines seasonal loading. As it is known *(Voblikov E.M., 2010),* the longer the process of grain material drying lasts the more profitable it is. It explains the tendency to extend the drying period in dryers and the use of low-temperature modes *(Kotov B., et.al. 2016)*. Increase in the work period of the machine for drying *(Kurhanskyi O. and Kotov B., 2016)* is, first of all, a problem of extending the period of safe storage *(Paleliulko M.I., 2015)*. Cooling of the grain mass *(Verkholantseva V.O., 2016; Yalpachyk V.F., et.al., 2014)* proved to be the most effective method of wet grain time conservation treatment. Conservation treatment of wet grain by cooling supposes the presence of an engineering system which allows to keep it until it is processed and put to constant storage *(Kiurchev S.V. and Verkholantseva V.O., 2015; Petrunia B., 2004)*. Fodder grain can be stored in periodically chilled condition for the entire period of its use. It is possible to use special refrigerating compressor-condenser assemblies *(Kozin B., 2014)* to cool the grain material during the harvest period at the factories in different grain-cultivated climatic zones. Application efficiency of grain material cooling should be defined *(Yalpachyk V.F., et.al., 2014).* For this purpose, it is necessary to investigate the cooling process of wet grain by air in stationary volume and to justify the equipment parameters.

Advantages of grain cooling in an embankment or grain tank by artificially cooled air are proved in different works *(Petrunia B., 2004; Verkholantseva V.O., 2016)* and the limits of grain cooling *(Kiurchev S.V. and Verkholantseva V.O., 2015)* providing the maximum safety of quality indicators are defined. Perspective use of analytical methods of processes modeling, namely: thermal, biochemical and microbiological at refrigerating storage, is presented by the latest scientific works *(Yalpachyk V.F., et.al., 2015, 2016)*. Many researchers *(Kiurchev S.V. and Verkholantseva V.O., 2015; Paleliulko M.I., et.al., 2015; Petrunia B., 2004; Verkholantseva V.O., 2016; Yalpachyk V.F. et.al., 2014)* investigated the process of grain cooling during storage. It is possible, by means of mathematical modeling and computer technics, to define cooling process rational parameters and refrigerating storage and the operating conditions of the equipment for its implementation.

The purpose of this work is to create mathematical models for the analysis of grain cooling processes, and to define working process-related parameters.

MATERIALS AND METHODS

The stationary model of the grain material layer, blown through by air (from below-upwards) is object of modelling and research. Air arrives from an air cooler of the refrigerating machine with a constant mass flow rate and constant parameters. To study the object under consideration, we select the analytical method of investigation. For this purpose, we compose the equations of material and energy balance, the conditions for the exchange of heat and the mass of the product with air. This fact makes it possible not to take into account the specific characteristics of the storage, the type of grain material and the equipment parameters.

Let`s consider the physical model of the process and the simplifying assumptions for its formalization. Through a layer of dispersed material arranged on a grid, with a thickness H, with the initial grain parameters: humidity u, temperature θ, the air is blown through with parameters constant at the entrance to the layer – temperature t and moisture content d, mass flow G (speed v). The scheme of the process is shown in Fig. 1.

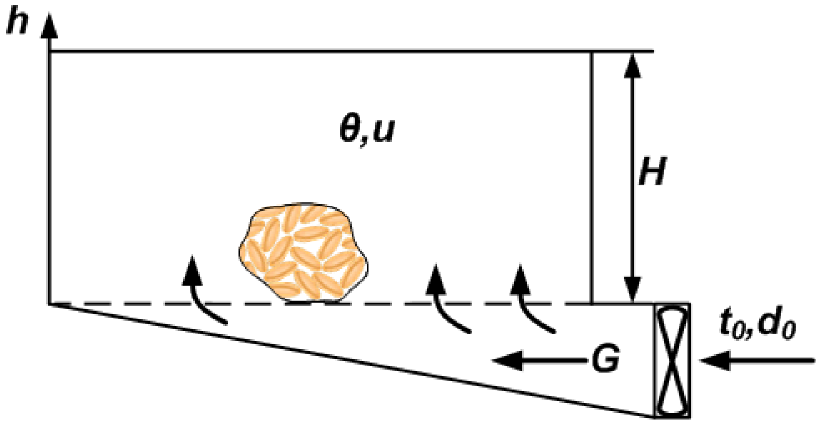

Fig. 1 - The scheme of cooling the grain material in a stack of layers

For a simplified analysis of this process, we made assumptions idealizing the process without distorting the general physical scheme: the thermophysical properties of grain material and air do not depend on temperature; the transfer of heat and mass is convective; other types of heat transfer and mass transfer are accounted for by the coefficients; there are no losses spread to the environment; air movement is unidirectional from the bottom up; the distribution of the temperature and humidity fields is one-dimensional; change in temperature and moisture content of individual grains - without a gradient; contact (conductive) transfer of heat and mass are not taken into account; the coefficients of heat and mass transfer from temperature and humidity are independent and equal to the average values for the process. Heat transfer is carried out according to Newton's law, and mass transfer is described by Merkel's equation.

RESULTS

Let's describe the process of cooling the grain in a layer by differential equations of thermal and a material balance; according to the adopted scheme and the physical model, we introduce the following notation:

$q_h = q/H$ - specific allocation of biological warmth per unit layer altitudes, W/m;

θ, t - temperature of grain material and air, °C;

u, d - moisture content of grain material and air, kg/kg$_{dm}$ and kg/kg$_{da}$;

m_z, m_a - weight of grain and air in layer volume, kg;

c_z, c_a - grain and air specific heat, J/(kg°C);

H - height of a material layer, m;

f, f' - the general surface of grain and transpiration surface, m^2;

α, β - heat exchange and mass transfer coefficient, W/(m^2°C) and m/s;

$d''_н(\theta)$ - saturated air moisture content at temperature of a material surface, kg/kg$_{dm}$;

ρ_z, ρ_{z0} - density of wet and absolutely dry grain, kg/m^3;

ρ_a - air density, kg/m^3;

F_z, F - the square of cross-section of a grain material and air in layer volume, m^2;

h - coordinate on layer altitude;

τ - time, s.

Let's write down the differential equations thermal and a material balance for grain and filtrated air.

The equation of thermal balance for an element of disperse material layer in altitude dh which presents change of grain temperature will look like:

$$r_0 F_z \rho_{z0} dhdu + c_z F_z \rho_z dhd\theta = q_h dhd\tau - \frac{\alpha f}{H}(\theta - t)dhd\tau \tag{1}$$

The equation of the thermal balance, temperatures of air presenting change for the same element dh like in next equation:

$$\rho_a c_a F dhdt = \frac{\alpha f}{H}(\theta - t)dhd\tau \tag{2}$$

The equation of a material balance presenting change of grain moisture content at surface evaporation for an element dh:

$$-\rho_{z0} F_z dhdu = \frac{\beta f'}{H}\left(d''_н(\theta) - d\right)dhd\tau \,. \tag{3}$$

The equation of material balance describing the change in the moisture content of air absorbing the moisture evaporating from the grain, for an element dh will become:

$$\rho_a F dhdd = \frac{\beta f'}{H}\left(d''_н(\theta) - d\right)dhd\tau \,. \tag{4}$$

Opening total differentials of variable quantities $d\theta$, dt, du, dd: $dT = \frac{\partial T}{\partial \tau}d\tau + \frac{\partial T}{\partial h}dh$ (T - the conditional generalized variable) and considering that $\frac{dh}{d\tau} = v$ - speed, m/s; $m_z = F_z \rho_z H$ - weight of grain, kg; $m_a = F\rho_a H$ - weight of air in a layer, and also using an obvious relationship $F\rho = \frac{G}{v}$, kg/m we convert the equations (1) - (4) and become:

$$m_z c_z \frac{\partial \theta}{\partial \tau} - m_0 r_0 \frac{\partial u}{\partial \tau} = -\alpha f(\theta - t) - q_h \tag{5}$$

$$m_a c_a \frac{\partial t}{\partial \tau} + c_a GH \frac{\partial t}{\partial h} = \alpha f(\theta - t) \tag{6}$$

$$-m_0 \frac{\partial u}{\partial \tau} = \beta f'\left(d''_н(\theta) - d\right)\rho_a \tag{7}$$

$$m_a \frac{\partial d}{\partial \tau} + GH \frac{\partial d}{\partial h} = -m_0 \frac{\partial u}{\partial \tau} \tag{8}$$

The system of the hyperbolic differential equations in a partial derivative (5-8) with sufficient accuracy presents dynamics of processes of a heat and weight exchange at grain layer cooling.

Definition of values θ, u, t, d, as coordinate and time functions is reduced to the following: for any $0 \le h \le H$ and $0 < \tau < \infty$ to find the solution of system (5-8) at boundary and entry conditions: $u(h,0) = u_0$; $\theta(h,0) = \theta_0$; $t(0,\tau) = t_0$; $d(0,\tau) = d_0$. The accurate solution of the system can be obtained by numerical methods of calculation. To obtain the approached analytical dependences, we shall make simplifying transformations. Using the definition of Rebinder measure $Rb = \frac{c_z d\theta}{r_0 du}$ *(Kotov B., Kalinichenko R., Spirin A., 2015)*, we get the equation:

$$-\frac{\partial u}{\partial \tau} = \frac{c_z}{r_0 Rb}\frac{\partial \theta}{\partial \tau} \tag{9}$$

Substituting (9) in (5) we will have:

$$m_z c_z' \frac{\partial \theta}{\partial \tau} + q_h = \alpha f (t - \theta) \tag{10}$$

where:

$$c_z' = c_z\left(1 + \frac{1}{r_0 Rb}\right).$$

Rates of derivatives $dt/d\tau$ and $dd/d\tau$ are small enough in comparison with other terms of the equations and they can be neglected. After simple transformations of the equations (6) and (10) we will come to their kind of system:

$$\begin{cases} t - \theta = \frac{1}{B}\frac{\partial \theta}{\partial \tau} - \varepsilon \\ \theta - t = \frac{1}{A}\frac{\partial t}{\partial h} \end{cases} \tag{11, 12}$$

where:

$$A = \frac{\alpha f}{HGc_a};\; B = \frac{\alpha f}{m_z c_z};\; \varepsilon = \frac{q_h}{\alpha f}.$$

Approximate solution of the system (11-12) (under conditions $\varepsilon = 0$ or $\varepsilon = \varepsilon_0(\theta - t)$ where ε_0 - coefficient of linear approximation of a function $q = f(\theta, t)$) is *(Kotov et.al., 2015)*:

$$\theta = \theta_0 - (\theta_0 - t_0)Be^{-Ah}\int_0^{\tau} e^{-B\tau} J_0\left(2\sqrt{ABh\tau}\right)d\tau \tag{13}$$

$$t = \theta_0 + (t_0 - \theta_0)e^{-Ah}\left(e^{-B\tau} J_0\left(2\sqrt{ABh\tau}\right)\right) + B\int_0^{\tau} e^{-B\tau} J_0\left(2\sqrt{ABh\tau}\right)d\tau \tag{14}$$

where:

J_0 - Bessel function of a zero order from imaginary argument.

For the simplified accounts, it is possible to spread out Bessel function abreast and it will be limited to the one first member (solution error less 10%):

$$\theta \approx \theta_0 - (\theta_0 - t_0)e^{-Ah}\left(1 - e^{-B\tau}\right) \tag{15}$$

$$t = \theta_0 + (t_0 - \theta_0)e^{-Ah} \tag{16}$$

To determine the humidity reduction rate at cooling, we approximate function $d''_н(\theta)$ by linear dependence:

$$d''_н(\theta) = a\theta + b \tag{17}$$

where

a, b - constant factors, and substituting the solution (15) in the equation (7) taking into account (8) we obtain:

$$T_d \frac{dd}{dh} + d = c' + De^{-Ah} \tag{18}$$

where

$$T_d = \frac{GH}{\beta f \rho_a};\ c' = b + a\theta_0;\ D = a(t_0 - \theta_0)\left(1 - e^{-B\tau}\right).$$

The solution of the equation (18) under the condition: $h = 0$; $d = d_0$ looks like:

$$d(h,\tau) = (d_0 - c'T_d)e^{-\frac{1}{T_d}h} + c'T_d + \frac{e^{-Ah} - e^{-\frac{1}{T_d}h}}{A_1 - A}\left(a(t_0 - \theta_0)\left(1 - e^{-B\tau}\right)\right) \tag{19}$$

From the equations (7) and (8) it is obtained:

$$m_a \frac{\partial d}{\partial \tau} + GH\frac{\partial d}{\partial h} = \beta f'\left(d''_н(\theta) - d\right)\rho_a. \tag{20}$$

Taking differential from (19) and substituting the expression obtained in the equation (20) we have:

$$-\frac{m_0}{GH}\frac{du}{d\tau} = \left(\frac{1}{T_d(AT_d - 1)}e^{-\frac{h}{T_d}} - \frac{A}{AT_d - 1}e^{-Ah}\right)D + \frac{d_0 - c'}{T_d}e^{-\frac{h}{T_d}} \tag{21}$$

The solution of the equation (21) under entry conditions: $h = 0$; $u = u_0$ will have the expression:

$$u(\tau,h) = u_0 + \frac{1}{T_u T_d (At_d - 1)B}\left(\begin{array}{l}\left(AT_d(\theta_0 - t_0)e^{-Ah} + (t_0 - \theta_0)e^{-\frac{h}{T_d}}\right)e^{-B\tau} + \\ \left(ABT_d t(\theta_0 - t_0) + AT_d(t_0 - \theta_0)\right)e^{-Ah} + \\ \left(ABT_d(c't - d_0 t) - Bt(\theta_0 + c' - d_0 - t_0) + \theta_0 - t_0\right)e^{-\frac{h}{T_d}}\end{array}\right) \tag{22}$$

Fig. 2-4 show the examples of calculated graphs of grain temperature change (Fig. 2), cooling air (Fig. 3) and grain moisture content (Fig. 4) in terms of time and height.

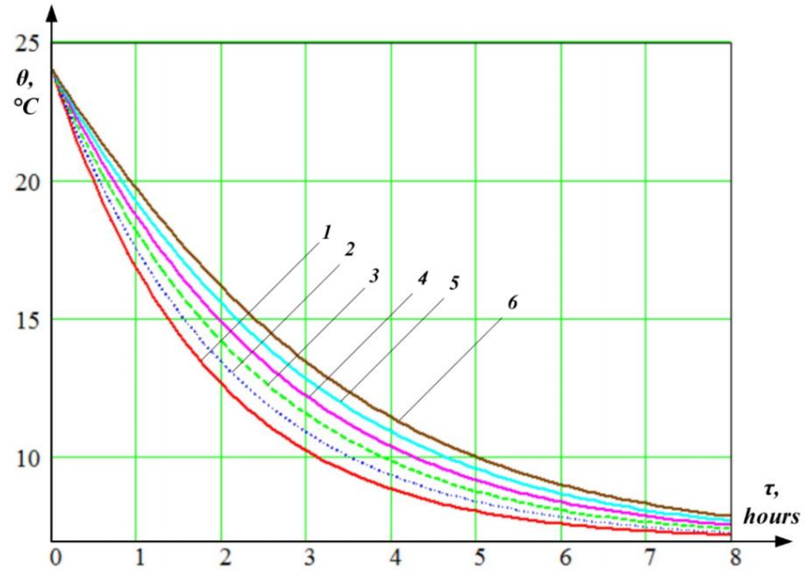

Fig. 2 - Example of graphs of grain temperature variation in time and height (G=0.205 kg/s; t_0=7 °C; u_0= 20 %): 1 – h=0.2 m; 2 – h=0.4 m; 3 – h=0.6 m; 4 – h=0.8 m; 5 – h=1 m; 6 – h=1.2 m

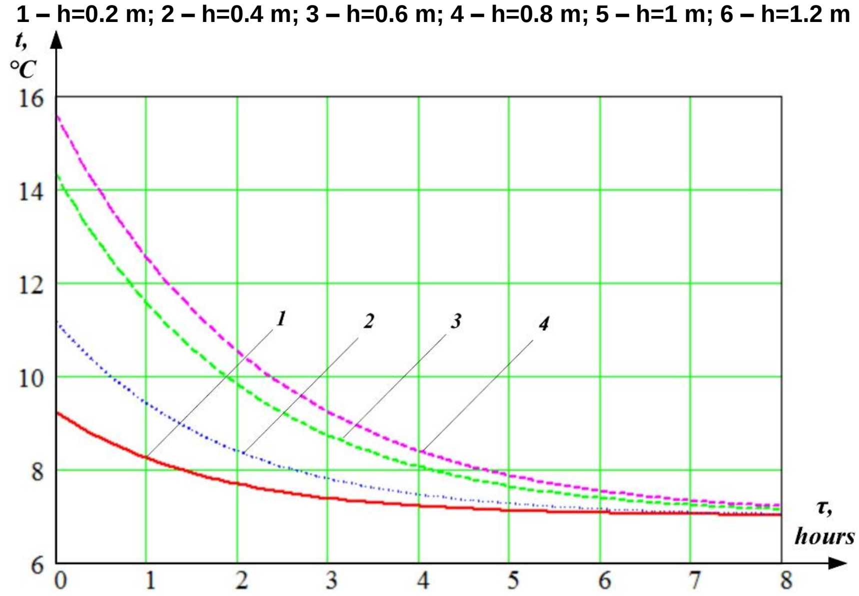

Fig. 3 - Calculated graph of the cooling air temperature in terms of time and height (G=0.205 kg/s; t_0=7 °C; u_0= 20 %): 1 – h=0.2 m; 2 – h=0.4 m; 3 – h=0.8 m; 4 – h=1 m

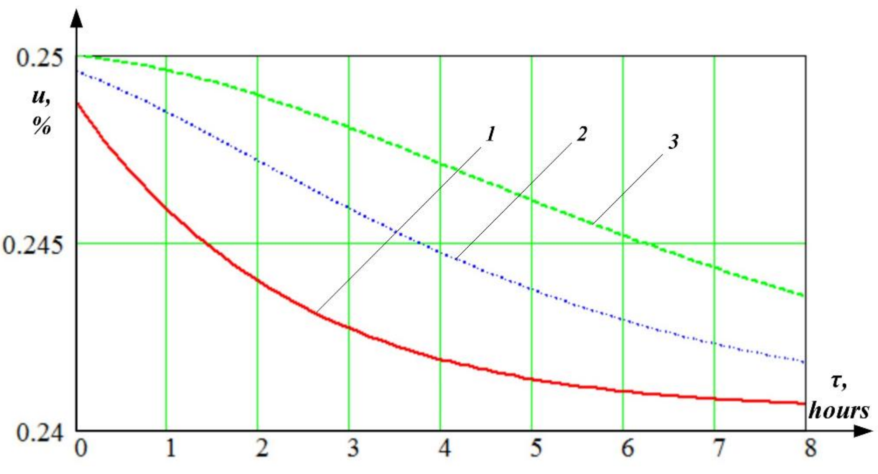

Fig. 4 - Graph of changes in grain moisture content in terms of time and height (G=0.205 kg/s; t_0=7 °C; u_0= 20 %): 1 – h=0.6 m; 2 – h=2.6 m; 3 – h=4.6 m

Fig. 5 shows the graphs of temperature changes in barley seeds when cooled in field storage.

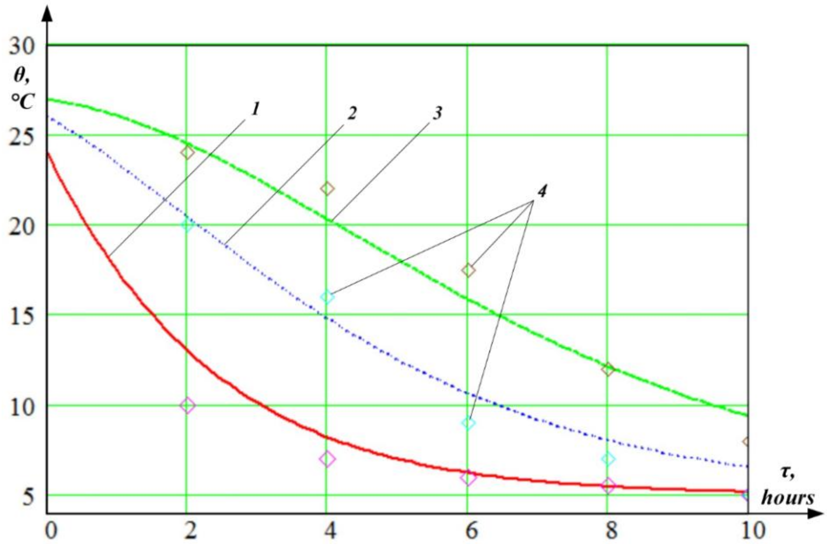

Fig. 5 - Curves of grain temperature changes during cooling in the storage with parameters (G=0.103 kg/s; t_0=5 °C; u_0= 20.1 %): 1 – h=0.6 m; 2 – h=2.6 m; 3 – h=4.6 m; 4 – experiment data (for 0.6, 2.6, 4.6 m)

To compare the data obtained theoretically (formula 13) and direct measurements of the grain mass temperature at an altitude (0.6, 2.6, 4.6 m) with the fan turned off, experiments were carried out on the actual object - the grain embankment in the storage (storage section).

CONCLUSIONS

Thus, the gained analytical dependences (13) - (14) and (19) - (22) allow counting change of grain material parameters and chilling air on altitude of a layer at any moment of time; it also allowed defining a cooling time at specified values of the charge of air and its temperature.

The dependence of the cooling duration on the speed of air penetrating the grain layer is in good agreement with the results of the study of heat transfer in a layer of granular materials.

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