GRAIN AUGER CONVEYOR-DISTRIBUTOR / ШНЕКОВЫЙ ТРАНСПОРТЕР-РАСПРЕДЕЛИТЕЛЬ ЗЕРНА

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ABSTRACT

The construction of a solar dryer-grain storage facility is described in this paper. The design of a grain auger conveyor-distributor for its loading is made. The dependence of the width of the discharge opening in the casing of the auger conveyor-distributor on its length is obtained. The results of laboratory tests of the grain auger conveyor-distributor are presented. It is established that the minimum initial width of the drain opening for wheat grain should be not less than 9 mm. The conditions of grain uniform distribution grain by the auger conveyor-distributor are justified: the filling factor of the auger inter-turn space in its loading zone – 0.35; the length of the discharge opening of the charging hopper should be equal to the doubled value of the auger pitch size. In this case, the uneven distribution of grain along the discharge opening will be no more than 5%.

РЕЗЮМЕ

Описана конструкция гелиосушилки-зернохранилища. Предложена конструкция шнекового транспортера-распределителя зерна для ее загрузки. Получена зависимость ширины высыпного отверстия в кожухе шнекового транспортера-распределителя от его длины. Представлены результаты лабораторных испытаний шнекового транспортера-распределителя зерна. Установлено, что минимальная начальная ширина высыпного отверстия для зерна пшеницы должна составлять не менее 9 мм. Обоснованы условия равномерного распределения зерна шнековым транспортером-распределителем: коэффициент заполнения межвиткового пространства шнека в зоне его загрузки – 0.35; длина выходного отверстия загрузочного бункера должна быть равна удвоенному значению величины шага шнека. При этом, неравномерность распределения зерна вдоль высыпного отверстия составит не более 5%.

INTRODUCTION

Drying of freshly harvested grain is a necessary and energy-consuming operation, since the used drying installations consume on average 10 kg of liquid fuel per ton of grain while reducing its moisture content by one percent. The usage of high-capacity dryers for small amounts of grain production is especially inefficient, as the share of depreciation deductions from the cost of the drying unit, included in the grain cost, in this case significantly increases it. It is possible to reduce energy costs by using drying installations with non-traditional energy sources. We have conducted research on post-harvest drying of grain during its storage in a solar dryer-grain storehouse (fig. 1).

As a result of the experiment, the grain was dried to condition moisture content of 14% and stored well – no self-heating sources were observed. In spring, the crops had high germination rates *(Kupreenko et al., 2011)*. However, the disadvantage of the experimental solar dryer-grain storage facility is the lack of mechanized loading and unloading of grain. Therefore, we have developed a design of mechanized solar dryer-grain storage facility. The main equipment for grain moving are auger conveyors *(Pezo et al., 2015; Shimizu and Cundall, 2001; Orefice and Khinast, 2017; Rohatynskyi et al., 2019)*. Therefore, the usage of an auger conveyor was proposed to mechanize grain processing in the solar dryer-grain storage facility.

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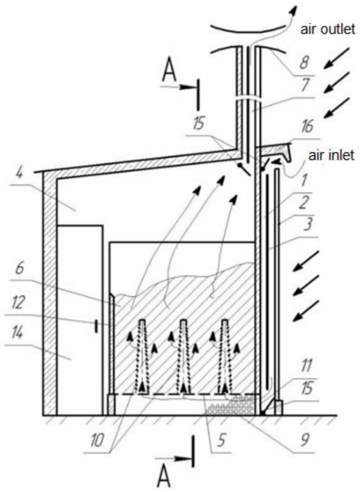
A number of works regard the study of auger conveyors operating modes *(Hou et al., 2014; Tian et al., 2018; Hevko et al., 2019; Trokhaniak et al., 2020; Arkhangel'skii, 2019; Mashkov et al., 2018)*. At the same time, some scientists have also studied the process of grain outflow through various discharge openings *(Han et al., 2017; Arkhangel'skii, 2019)*. However, they do not provide a uniform grain discharge along the length of the conveyor in its stationary position.



a) ***b)***

Fig. 1 - Scheme *(a)* and general view of the solar dryer-grain storage facility *(b)*
1 - vertical solar collector; 2 - translucent coating; 3 - light-absorbing surface; 4 - drying chamber; 5 - perforated deck; 6 - dried grain; 7 - ventilation pipe; 8 - deflector; 9 - gravel accumulator; 10 - perforated air-distributing channels; 11 - openings in the grain storage facility walls; 12 - longitudinal partition; 13 - transverse partition; 14 - door; 15 - flaps; 16 - roof ridge

The purpose of the study is to justify the design of the grain auger conveyor-distributor, allowing to ensure uniform distribution of grain mass along the length of its discharge opening when loading rectangular tanks with a horizontal or sloping location of the bottom.

MATERIALS AND METHODS

The new design of the mechanized solar dryer-grain storage facility is shown in fig. 2. The usage of an auger conveyor-distributor was proposed to load grain on the perforated rectangular air-distributing trays, located in the drying chamber of the solar dryer-grain storage facility *(Chashchinov et al., 2016)*.

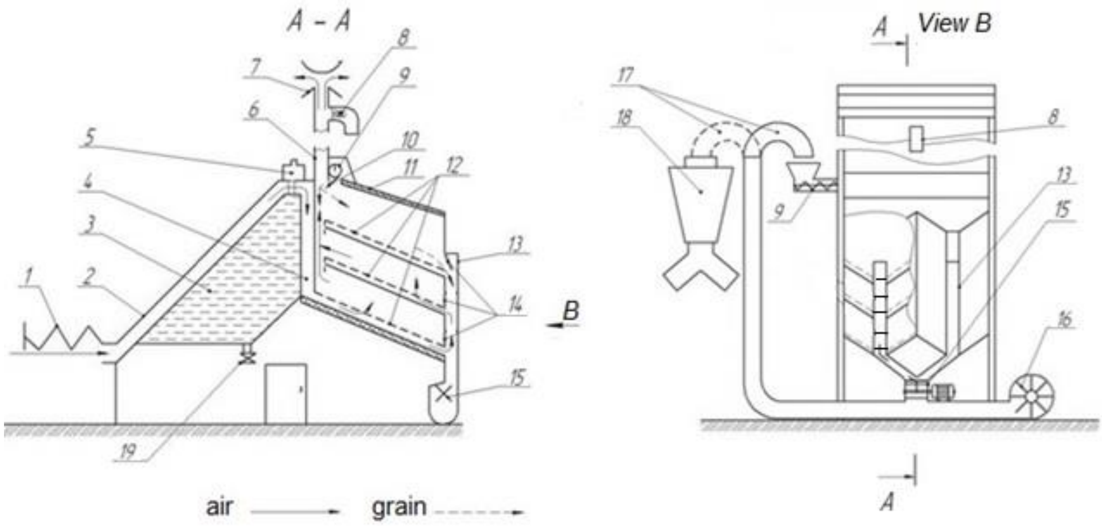


Fig. 2 - Mechanized solar dryer-grain storage facility
1, 2 - retractable film and inclined solar collectors; 3 - water heat accumulator; 4 - main air channel; 5 - expansion tank; 6 - ventilation pipe; 7 - deflector; 8 - exhaust fan; 9 - loading auger conveyor-distributor; 10 - guide tray; 11 - drying chamber; 12 - perforated air-distributing trays; 13 - discharge channels; 14 - flaps; 15 - lock gate; 16 - pneumatic conveyor; 17 - rotary deflector; 18 - cyclone; 19 - drain cock

The design feature is the presence of a longitudinal slot (discharge opening) in the lower part of the auger conveyor-distributor casing. Through it the grain is discharged along the entire length of the casing (fig. 3) *(Kupreenko et al., 2017)*.

A grain auger conveyor-distributor (fig. 3) works in the following way. Grain from the charging hopper 1 enters the casing 3 and auger 2 moves along the casing 3. Passing over the discharge opening 4, the grain begins to pour out of the auger casing. Due to the special shape of the discharge opening 4, the grain is discharged evenly along the entire length of the casing. There is a uniform loading of grain along the entire length of the hopper. The height of the grain layer along the length of the discharge opening decreases to zero at its end.

It was assumed that to ensure uniform grain distribution, the shape of the discharge opening in the auger casing should be as in fig. 3.

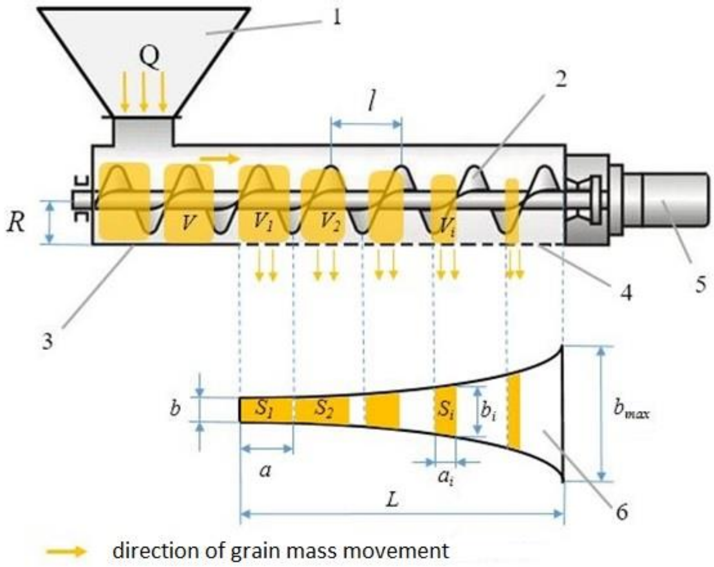


Fig. 3 - Construction and technological scheme of grain auger conveyor-distributor
1 - loading hopper; 2 - auger; 3 - auger casing; 4 - discharge opening; 5 - electric engine; 6 - type of discharge opening

Let's assume that within the auger inter-turn space, the discharge opening is rectangular in shape. The grain moves above the discharge opening in the auger casing. At any time it spills in the auger inter-turn space through the area $S = ab$, where a – the length of the area of the discharge opening, loaded with grain, b – the width of the discharge opening. In order to ensure a constant discharge volume V, it is necessary that the area S should be constant at each section of the discharge opening. As the grain moves along the auger casing, the grain volume in the auger inter-turn space decreases, which reduces the length a. Therefore, the width b must increase, so that the discharge area is constant.

During the time dt the inter-turn discharge opening will shift to $dx = v\,dt$, where v is the grain velocity within the auger casing. At the same time some grain volume will spill through the discharge opening in the inter-turn space. It will spill through the opening with the area:

$$S = a(x) \cdot b(x) \quad [\mathrm{m}^2] \tag{1}$$

where: $a(x)$ and $b(x)$ depend on the value of the path traveled by the grain for the time t.

In this case, the grain outflow rate through the discharge opening in the inter-turn space will be:

$$q = k \cdot S \cdot v_{outflow} \quad [\mathrm{m}^3/\mathrm{s}] \tag{2}$$

where: k – coefficient of grain outflow through the opening;

$v_{outflow}$ – velocity of grain outflow through the discharge opening, [m/s].

Then in time dt the outflow rate through the discharge opening in the inter-turn space at the velocity of grain outflow from the auger casing $v_{outflow}$ with regard to expression (1) will be equal to:

$$q = k \cdot a(x) \cdot b(x) \cdot v_{outflow} \tag{3}$$

From expression (3), the specific grain outflow rate over time dt, per unit length of discharge opening $a(x)$, is:

$$\frac{q}{a(x)} = k \cdot b(x) \cdot v_{outflow} \tag{4}$$

The specific outflow rate of the grain mass at each section of the length of the discharge opening in the inter-turn space must be constant, i.e.

$$\frac{q}{a(x)} = const. \tag{5}$$

Then, from the expression (4)

$$b(x) = \frac{q}{k \cdot a(x) \cdot v_{outflow}} = \frac{Q}{k \cdot n_s \cdot a(x) \cdot v_{outflow}} \text{ [m]} \tag{6}$$

where: Q – conveyor-distributor capacity, [m^3/s];

n_s – the number of auger inter-turn spaces over the entire length of the discharge opening.

The outflow coefficient depends linearly on the width of the discharge opening. Then, the dependence of the grain outflow velocity through the opening on its width can be represented as:

$$v_{outflow} = b \cdot C_1 + C_2 \tag{7}$$

where: C_1 and C_2 linear equation constants determined empirically (C_1 = 0.0144; C_2 = - 0.0621).

Let us find the dependence of the discharge opening width b on its length. We consider the specific mass outflow rate Q_m:

$$Q_m = \rho \frac{Q}{L} \text{ [kg/m·s]} \tag{8}$$

where: ρ – grain loading density, [kg/m^3];

L – discharge opening length, [m].

Capacity Q is calculated as the product of the cross-sectional area of the spilling grain flow by the grain outflow velocity:

$$Q = S \cdot n_s \cdot v_{outflow} \tag{9}$$

Accordingly, the specific mass outflow rate with regard to expression (9) will be:

$$Q_m = \frac{\rho \cdot S \cdot n_s \cdot v_{outflow}}{L} = \frac{\rho \cdot a \cdot b \cdot v_{outflow}}{l} \tag{10}$$

where: l – grain loading density, [m].

Since the specific mass outflow rate is a constant, we find the dependence $b(a)$ from (10):

$$b = \frac{Q_m l}{(\rho \cdot a \cdot v_{outflow})} \tag{11}$$

Or considering expression (8):

$$b = \frac{Q_m l}{\rho \cdot a (b \cdot C_1 + C_2)} \tag{12}$$

After transforming expression (12) we obtain the equation:

$$C_1 \cdot b^2 + C_2 \cdot b - \frac{Q_m l}{\rho \cdot a} = 0 \tag{13}$$

The solution of equation (13) is:

$$b = \frac{-C_2 + \sqrt{C_2^2 + \frac{4C_1 \cdot Q_m l}{\rho \cdot a}}}{2C_1} \tag{14}$$

The value of the specific mass outflow Q_m through the construction-mode parameters of the auger conveyor-distributor is calculated by the formula:

$$Q_m = \frac{\rho \cdot f \cdot \pi \cdot R^2 \cdot l^2 \cdot n}{60 L^2} \tag{15}$$

where:

f – filling factor of the auger inter-turn space;

R – auger radius, [m];

n – auger rotation frequency, [s^{-1}].

Let's substitute expression (15) into formula (14). We obtain the equation to find the discharge opening width at each of its sections:

$$b = \frac{-C_2 + \sqrt{C_2^2 + 4C_1 \cdot \frac{f \cdot \pi \cdot R^2 \cdot l^3 \cdot n}{60\, aL^2}}}{2C_1} \text{ [mm]} \tag{16}$$

RESULTS

To determine the construction and technological parameters of the auger conveyor-distributor, a laboratory installation was made (fig. 4.).

The installation has the following construction features. In the lower part of the casing *8* along its entire length there is the discharge opening (fig. 4b). Its width is regulated by plates *4*. Adjustment of the width of the discharge opening is carried out by adjusting screws *6*. Under the discharge opening there is a collecting tank *7*, divided into equal compartments.

The experimental installation has the following geometrical dimensions, parameters and possible modes of operation: auger length – 1000 mm; auger pitch l – 65 mm; auger radius R – 55 mm; length of discharge opening L – 800 mm; width of discharge opening b varies from 10 mm to 24 mm along the length of the discharge opening; auger rotation frequency n – 309 and 364 min^{-1}.

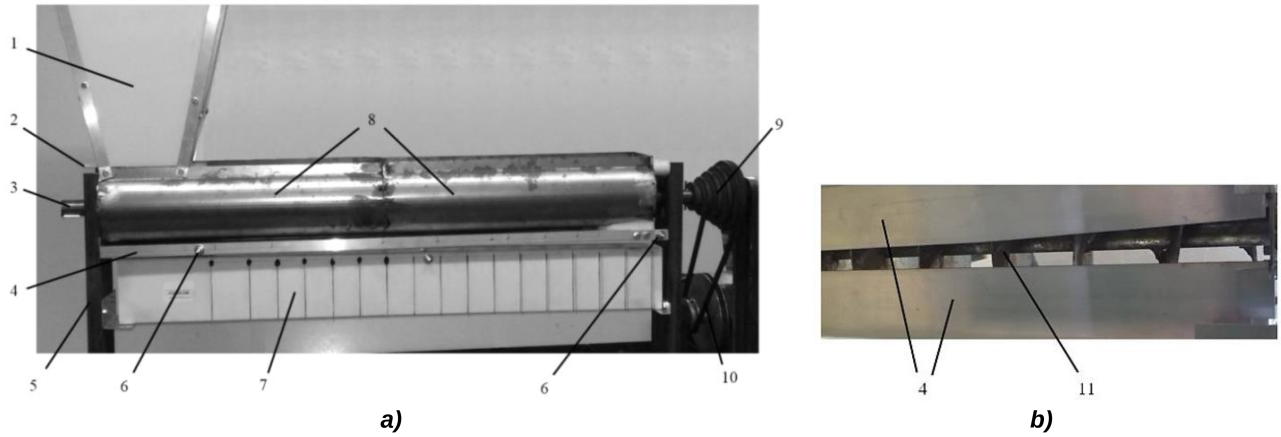


Fig. 4 - General view of the laboratory installation of the grain auger conveyor-distributor *(a)* and loading opening view from the bottom *(b)*

1 - loading hopper; 2 - flap; 3 - auger shaft; 4 - plates of discharge opening width adjustment;
5 - installation frame; 6 - adjustment screws of the discharge opening; 7 - collecting tank; 8 - auger casing;
9 - reducer; 10 - electric engine; 11 - auger

Grain of wheat variety "Moscow 39" (Russia) with the following characteristics: grain moisture – 12-18%; bulk density of grain – 750-760 kg/m^3 was used as a bulk material. Studies have shown that changes in grain moisture within these limits do not affect the work of the auger conveyor-distributor.

The material was tested for compliance with the requirements for moisture and grain size distribution. In accordance with these requirements, the fractions of the studied material of class 3-2 mm should not exceed 5%, and the fractions of class 4-3 mm should not exceed 1% of the total mass of the aggregate of all fractions.

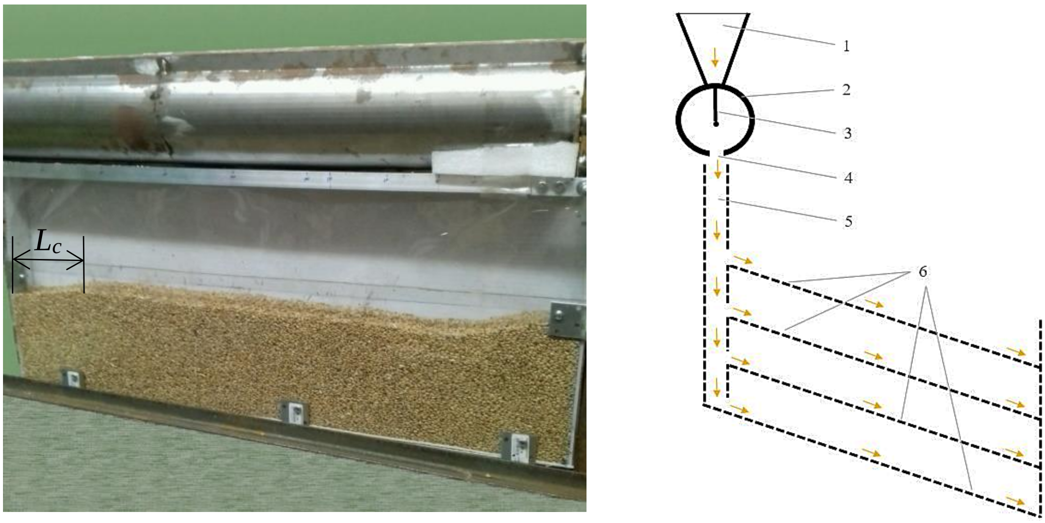
Studies have shown that with a constant area of the discharge opening, there is no effect of the layer height h above the discharge opening on the time and on the grain outflow velocity $v_{outflow}$ through the discharge opening accordingly.

During the experiment, it was found that the process of grain discharge stops when the width of the discharge openings $b \leq 7$ mm, and in the range of values b from 7 to 9 mm the process of grain outflow through the openings is unstable because of the presence of different impurities in the grain mass.

When the width of the discharge opening b ≥ 9 mm, there is a linear character of the grain outflow process. Grain in free fall moves along parabolic trajectory. This gives uneven distribution of grain at the beginning and end of the rectangular tank (fig. 5a).

For uniform loading, the tank should be shifted relative to the beginning of the discharge opening towards its end by the value L_c. For example, in the case of loading height h = 1 m at the auger rotation frequency n = 309 min $^{-1}$ L_c = 130 mm; at n = 364 min^{-1}, L_c = 156 mm.

If the inclination of the loaded tank bottom to the angle of the horizon is equal to the angle of natural slope, then the tank will be filled with a uniform grain layer over the entire area of the bottom of the tank. Fig. 5b shows the scheme of loading air distributing trays of solar dryer-grain storage, located at an angle of natural slope of the grain to the horizon.



a) *b)*

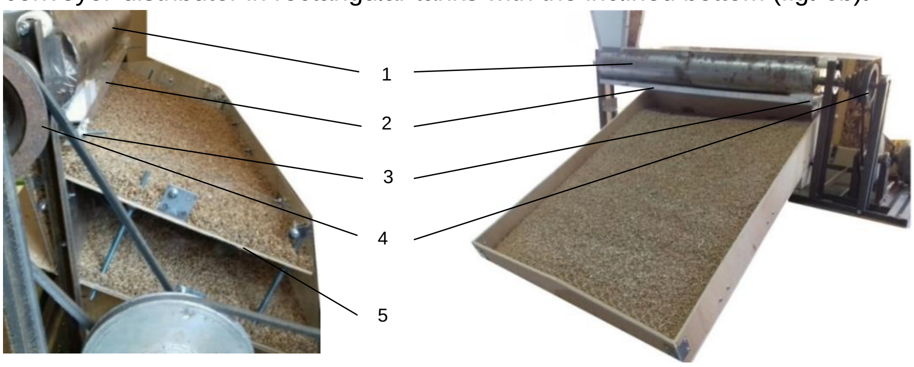
Fig. 5 - Example of loading a rectangular tank (*a*) and scheme of air-distributing trays of solar dryer-grain storage facility (*b*)

1 - loading hopper of auger conveyor-distributor; 2 - auger casing; 3 - auger; 4 - discharge opening; 5 - grain movement channel with perforated walls; 6 - perforated air-distributing trays

From the loading hopper *1* grain enters the casing *2* of auger *3*. The auger *3* moves the grain to the discharge opening *4*. First, the grain fills the bottom tray in an even layer – the layer thickness is limited by the gap between the wall of the vertical channel of grain movement *5* at the beginning of the tray and the bottom of the tray. Then, after filling the channel *5* between the lower and upper trays with grain, the second tray is filled similarly, and so on. The movement direction of grain mass in the scheme is shown by arrows.

In the laboratory installation a tank – analog of perforated air-distributing trays of solar dryer-grain storage facility was installed. Their angle to the horizon is equal to the angle of wheat grain natural slope – 30^0 (fig. 6a).

The studies confirmed the theoretical provisions. They showed the possibility of forming a uniform grain layer by the auger conveyor-distributor in rectangular tanks with the inclined bottom (fig. 6b).



a) *b)*

Fig. 6 - Layout loading: *a)* - perforated air-distributing channels of solar dryer-grain storage facilities; *b)* - inclined rectangular tank

1 - auger conveyor-distributor; 2 - plates, which set shaping of the discharge opening; 3 - screws for adjustment of discharge opening width; 4 - auger conveyor-distributor drive; 5 - perforated air-distributing channel

Additional conditions for uniform distribution of grain by the auger conveyor-distributor were determined: the filling factor of the auger inter-turn space in the loading area – 0.35; the length of the discharge opening of the hopper should be equal to the doubled value of the auger pitch size. In this case, the uneven grain distribution along the discharge opening was not more than 5%.

During the research, a nomogram for determining the parameters and modes of operation of the grain auger conveyor-distributor was obtained (fig. 7).

So when the auger rotation frequency n = 400 min^{-1} and auger diameter D = 200 mm, the length of the discharge opening L = 4 m, for D = 250 mm, L = 6 m.

To preserve grain quality when loading by auger conveyor-distributor one should use the rotation frequency n = 300 min^{-1}. Under this condition, it is possible to load tanks up to 11 m wide.

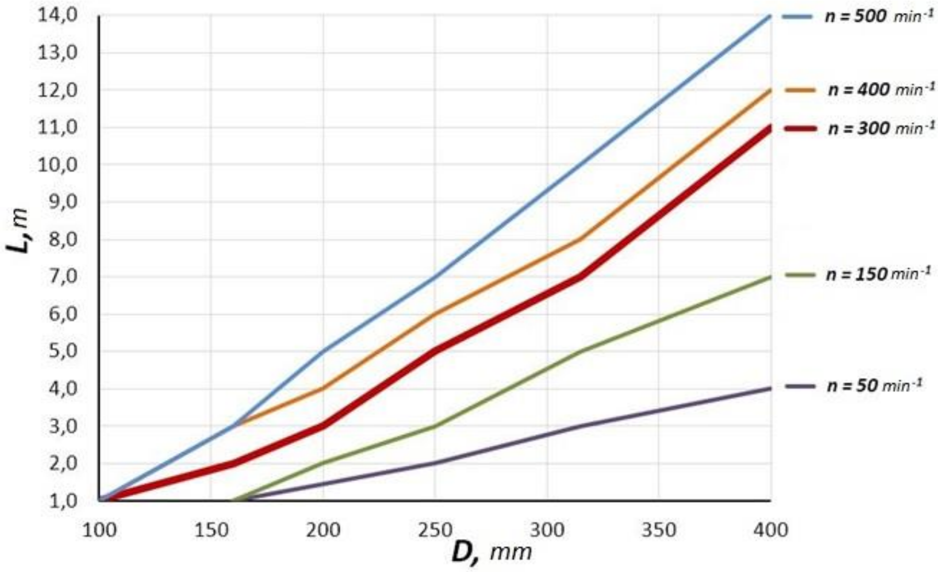


Fig. 7 - Nomogram for determining the parameters and modes of operation of the grain auger conveyor-distributor

CONCLUSIONS

The proposed auger conveyor-distributor provides mechanized loading of perforated air-distributing trays of solar dryer-grain storage facility with grain. The laboratory tests confirmed the adequacy of theoretical dependence (16) of the width of the discharge opening in the auger conveyor-distributor casing on its length. In the experimental studies, uniform distribution of grain mass over the entire surface in the rectangular tanks with horizontal and inclined position of the bottom was obtained. The above nomogram is convenient for practical use when choosing parameters and operating modes of auger conveyor-distributor taking into account the overall dimensions of the loaded tank.

In the future it is necessary to study the performance of the auger conveyor-distributor when loading the grain of small-seeded crops, as well as the grain with moisture above 18% and determine the appropriate dependency factor (16) to calculate the width of the discharge opening.

In addition, it is necessary to automate the adjustment of the discharge opening width for different production conditions.

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