

Вивчені конструкції існуючого обладнання для післязбиральної обробки не дозволяє проводити дбайливий прийом і сушку високоволого насіння сої, що призводить до зниження якості і втрати врожаю. Для вирішення даної проблеми було розроблено і виготовлено мобільний пристрій для прийому і сушки за один пропуск високовологої куни сої – тканинний аерожолоб. Розроблений пристрій з низькою металоємністю конструкції забезпечує прийом, сушіння і транспортування високовологого насіння. Зазначені переваги досягнуті шляхом застосування в конструкції додаткових повітронідводячих каналів і використання тканих матеріалів, в тому числі зі збільшенням до 46 % коефіцієнтом живого перетину – тканинних сит.

У зволоженої зоні найбільш відповідальна операція – сушка вологого матеріалу. Використання існуючих приймальних відділень і пристроїв для сушіння і вентилявання насіння зернобобових культур не забезпечує якості і зниження собівартості сушіння високовологого насіння в зонах підвищеного зволоження.

Використання додаткових каналів підведення повітря з тканинних сит в конструкції тканинного аерожолоби дозволяє додатково збільшити подачу агента сушіння в шар куни на 60 %. Конструкція сушильної камери забезпечує високу рівномірність сушіння з відхиленням відносно вологості насіння сої не більше 1,2 % і збільшення їх схожості до 4,5 %.

Застосування розробленого тканинного аерожолоби дозволяє приймати і якісно без травмування за один пропуск сушити високоволого насіння сипучих культур різних за масою партій – від 2 до 10 тонн з найменшими енерговитратами. Особливості конструкції відкривають можливість його використання в зонах підвищеного зволоження на підприємствах з різними обсягами виробленої продукції

Ключові слова: сушарка, сушка насіння сої, тканинний аерожолобами, тканинні сита, післязбиральної обробки

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DESIGN AND STUDY OF EQUIPMENT FOR ACCEPTING AND DRYING SOYA SEEDS WITH HIGH MOISTURE CONTENT

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1. Introduction

Soya is increasingly conquering global agriculture due to its high yields and content of cheap protein (up to 50 %) [1]. Combination of biologically active protein and presence of crude oil (18–22 %) in seeds makes soya a multifunctional crop. Soya is used in production of foods, fodder, technical products and pharmaceuticals [2]. It is the most preemptive of all export-oriented crops. Over the past 10 years, world soya production has grown almost 1.6 times and is close to 350 million tons [1].

Soya is cultivated in more than 60 countries and is confidently moving into zones of humid climate where moisture content in its seeds may reach 30 % at the time of harvest which brings about additional difficulties for the post-harvest treatment. Under unfavorable conditions such as high dockage and moisture content, soya deteriorates rapidly because of high hygroscopicity of seeds and high protein and fat content [2]. Even dry seeds get self-heated in the presence of wet dockage.

As a rule, intake pits are used to accept damp soya piles from harvesters. This renders impossible blowdown of piles waiting for their further treatment. By means of norias, soya

is taken from the intake pit and moved for cleaning and drying. With this technology, damp material is subjected to repeated mechanical stresses and, as a result, increased injury.

Accepting compartments with air-slide conveyors are widely used in areas of high dampness for taking highly damp piles from harvesters, their temporary storage and pre-drying [3]. However, the accepting compartments with air-slide conveyors have drawbacks: they are highly metal-intensive, do not ensure even distribution of the air flow in the volume of a damp soya pile and their use for treatment of very damp soya piles is not well known.

Soya seeds differ significantly from grain in terms of drying. They give off less moisture, dry unevenly and have abrasive properties which contribute to shell cracking when processing in dryers and cause intensive wear of equipment working parts. The difference in approaches is enormous: some producers of soya seeds generally try to avoid the drying step. Failure to comply with temperature conditions and their overshoot by just 17 °C can result in a 50–90 % cracking and a 20–70 % splitting of seeds [4].

High-temperature dryers of shaft, drum or column design are used mainly for drying soya seeds with moisture content not more than 20 % in animal husbandry and industrial

processing. Drying soya seeds in these dryers is accompanied by friction, both between seeds and between seeds and hard metal surfaces which results in injury of the protective shell and formation of seeds dust. High thermal conductivity of steel ducts, walls and gratings causes burns on the bean surface, denaturation of the embryo protein and significant drying irregularities. When drying a high-moisture material, multiple passages through the drying chamber are required.

Drying of seeds on belt and conveyor type grain dryers has a series of advantages as compared to drying in shaft and drum dryers. They include the possibility of drying various materials including low-loose materials, ease of productivity regulation, possibility of differentiated supply of the drying agent and mixing of material layers in the drying process. Such designs of grain dryers enable visual observation and control over movement and drying of materials and the working bodies are easily accessible for maintenance. The main drawback of conveyor and belt dryers is their bulkiness. Presence of a relatively large number of moving parts and components imposes increased requirements on the structure strength, reduces operational reliability. Universal dryers are considered as an additional means of grain and seed drying.

For drying soybeans for seeds, low-temperature dryers of the dense layer such as bins, aerating platforms are used worldwide. Disadvantages of these dryers include high pressure of the upper layers on the lower layers which causes compaction and injury of seeds, especially high-moisture seeds, deterioration of their quality, high non-uniformity of drying and increased aerodynamic resistance of the entire system. Also, condensate forms on the metal dryer surfaces at sudden changes of ambient temperature.

Thus, post-harvest processing of high-moisture soya seeds with known accepting and drying devices requires multiple passages of seeds through the drying chamber which complicates organization of the technological process. The use of high-temperature dryers with metal working surfaces leads to superficial burns of seeds, denaturation of embryo protein and significant drying non-uniformity. Besides, when moving high-moisture seeds on numerous working surfaces of transporting devices, significant deformation, micro and macro injury of seeds (up to 95 %), worsening of their quality and germination take place (up to 93 %). Therefore, the use of existing equipment for post-harvest processing of high-moisture soya seeds inevitably leads to a decrease in quality and yield loss which hinders soya advancement to highly humid areas.

2. Literature review and problem statement

Soya belongs to easily injured crops in which seeds are large, consist of two cotyledons and have abrasive properties. Even with a minor impact, the shell is injured and the grain is split to cotyledons. It is known [5] that the seeds are injured during the harvesting period and post-harvesting processing. Harvesting injures up to 20–30 % of grain and drying and sorting of seeds injure them up to 60–70 %. Especially high injures (90–95 %) get corn and legume seeds with high moisture content. Nature of soya injury depends on moisture content. When relative moisture content in seeds is 18–50.6 %, seeds get micro injures, are deformed and their shells peel off. At small moisture content, the seeds are injured and they are crushed at the macro level. There are more micro injures than macro injures at high moisture content in seeds and vice

versa when moisture content is small. Violation of integrity of the seed-vessel promotes development of microorganisms on it including microscopic fungi whose vigorous activity significantly deteriorates quality of grain during storage. Uninjured seeds are affected by fungi by 15 % and those with injured shells by 45 %. At the same time, seed germination can be reduced to 93 % [5]. For these reasons, it is especially dangerous to pre-clean high-moisture seeds since virtually any movement of them results in micro injures and significant reduction of yield.

Currently, post-harvest processing of soya seeds is carried out at elevators and grain cleaning and drying stations. As a rule, dump pits (metal or concrete bins) are used for accepting wet piles of soya seeds from combines, their accumulation and delivery for post-harvest processing. When dump pits are loaded, seeds strike on the metal and concrete surfaces of walls. Norias take soya from the dump pits and move it first for cleaning and then for drying. With this technology, damp material is subjected to repeated mechanical stresses and, as a result, increased injuries (up to 60...70 %). In soya cultivation, it is necessary to exclude use of any mechanisms with speed of movement of their working bodies more than 1.5 m/s and the angle of inclination of gravity pipes must be less than 30° [5]. Application of this technology in highly damp areas is difficult because there is no possibility of active ventilation and drying of high-moisture piles when they are waiting for further processing.

In highly damp areas, accepting compartments with air-slide conveyors are widely used for accepting high-moisture piles from harvesters, their temporary storage and drying [3].

A device for ventilation and transportation of high-moisture grain piles [6] contains an air distribution duct and a duct formed by two perforated inclined walls mounted above it. The duct is made with perforated slots in the lateral walls with their exits directed down and parallel to the walls and with a perforated base along its length. Disadvantage of this design is that the central part of the grain pile is subjected to active ventilation but stagnant zones may form at the lateral walls of the unit which contributes to uneven drying. High labor input will be required when operating the device of such a complex design in production conditions.

Paper [7] describes design of a cloth air-slide conveyor for temporary storage and ventilation of high-moisture grain. It consists of a metal frame and a cloth air-slide conveyor fixed to the frame. Damp material moves through this air-slide conveyor. The cloth element of the air-slide conveyor consists of outer and inner layers. The outer layer is made as a duct of an airtight cloth. The internal air distribution layer of the cloth air-slide conveyor is made of a nylon bolting cloth. Disadvantages include the fact that the device cannot transport even dry grain when it is unloaded for the following reasons. At exposure of the lateral walls of cloth screens (with a large coefficient of open space and area significantly larger than the load-carrying partition), air will escape through them along the path of least resistance, that is, without affecting the grain. The cloth does not provide directional effect of airflow on the seeds. To displace seeds under the action of gravity, it will be necessary to install the cloth load-carrying partition at a very large angle to the horizon. This will drastically increase dimensions of the air-slide conveyor and reduce its working volume.

The above devices for accepting high-moisture piles from harvesters on the basis of air-slide conveyors have common drawbacks: highly uneven distribution of the air flow in the

volume of a damp grain pile and their use for processing a high-moisture soya piles is not well understood.

High-temperature dryers are used at all grain elevators. However, when drying soya, temperature of the drying agent is reduced to 54–60 °C for commercial (commodity) batches and 35–44 °C for seed batches. As a rule, these are gravity-type grain dryers of shaft and column types. Drum dryers are much less commonly used. The seed retention time in the heating section of the dryers is less than 30 minutes. When drying seeds, moisture removal should be no more than 3 % per pass [8]. Friction occurs during drying of soya seeds in these dryers both between the material particles and between the material and hard metal surfaces which leads to injury of surface of the material particles. This especially applies to shaft grain dryers. Disadvantages of these dryers include high thermal conductivity of steel ducts and walls. Contact of grain with these ducts and walls causes local grain overheating and denaturation of the embryo protein. Speed of grain movement down the duct near the walls is much less than speed of the grain flow between the ducts and the walls which leads to a growth of drying non-uniformity. At relative moisture content in soya within 30...35 %, number of passes through the dryer will be 6 to 8 which will inevitably lead to additional injury of seeds. For the purpose of moisture leveling in pericarp and in the entire volume of seed, hours of keeping in a special tank are necessary with active ventilation after shaft drying.

Today, soya bean producers are greatly interested in the technology of drying and storing seeds at their enterprises using low-temperature dryers. In this case, producers can start harvesting crops at earlier stages of ripening and at a higher than usual content of moisture. This allows them to reduce likelihood of crop losses and get higher quality, higher than the market average. In the case of sending it to the elevator where all batches are mixed together in depersonalized storage, the advantage in quality and, consequently, money from its sale is lost. In-house storage of soya provides marketing flexibility and benefits in the crop sale process.

For low-temperature drying of soya seeds, aerated bins are widely used worldwide in which height of the seed layer reaches 7 meters or more beginning with a thickness of 0.6 m. That is why one of the main drawbacks of bin dryers is high pressure from upper layers producing compaction of the bottom layer, especially when seeds are damp. Other shortcomings consist in increased aerodynamic resistance of the system, drying time, consumption of thermal and electrical energy, reduced product quality and possibility of condensation nearby metal structures when sudden changes of air temperature take place.

Drying in two stages on a new line of post-harvest grain processing by means of a mobile shaft dryer for corn was studied in [9]. During testing of this technology, the authors have found that there was a problem with cooling seeds after drying. Therefore, seeds were ventilated alternately in several silos. Shortcoming of this technology consists in increase in the number of operations and transporting devices which can lead to significant injury to leguminous seeds.

A device for storing soya and corn seeds is known as a bin-dryer-aerator complex consisting of a chamber with four independent dryers [10]. Disadvantages of this design include complexity of organization of the technological process, high metal consumption, compaction and injury of seeds in the lower layers.

In [11], during drying of soya seeds, a system was used consisting of a stationary drying bin with capacity of 10 tons.

It had a perforated central cylinder with radial distribution of the air flow and an air conditioning unit consisting of six compressors and a centrifugal fan. In addition to the known drawbacks of bin dryers, design complexity, presence of a large number of moving parts, increased consumption of electrical energy should be mentioned.

Soya seeds are often dried on platforms of active ventilation [2] making breaks for 4–6 hours every 4–6 hours with the heating unit shut off. Under these operating conditions, seeds dry out in 8–16 hours depending on the initial moisture content. When drying high-moisture (up to 35 %) seeds, more than one drying and cooling periods are required. Manual agitation of seeds is used in such dryers which also results in an increase in time and cost of seed processing and downtimes of the entire process line.

A low-temperature seed dryer using a desiccant and recirculation of air flow [12] is known. It comprises an air conditioning control unit and a chamber for drying seeds. The dryer capacity is up to 0.33 kg/h. It works with the use of dried air in two modes: seed drying and desiccant regeneration. Its main disadvantages include low productivity, design complexity and impossibility of operation in real production conditions.

Effect of microwave drying in a fluidized bed on quality, energy consumption and kinetics of drying soya seeds was studied in [13] using an experimental setup of a microwave oven and a cylindrical drying chamber built into it. The use of microwave drying in a fluidized bed makes it possible to intensify the process while efficiency of the magnetron can reach 80 %. However, power plants having efficiency around 40 % are required for generation of electric power of which 10 % is lost in its transfer (losses in urban networks measure 5 to 10 %). Thus, overall efficiency of the system does not exceed 43 %. Microwave heating is characterized by a small depth of heat penetration (1.5 to 2.5 cm) as well as heating heterogeneity in the space of standing waves. Also, the high cost of equipment and likelihood of negative effects of microwaves on staff slows down spread of this technology.

Thus, the known technologies and devices for grain reception and drying cannot be effectively used for post-harvest processing of high-moisture soya seeds in highly damp areas. This is caused by a high degree of seed injury, the need for multiple passes of the material through the dryer and complexity of organization of the technological process.

There is a need to improve quality of post-harvest processing of high-moisture soya seeds through the use of new technologies, working bodies mitigating effects of their surfaces on grain, elimination of repeated drying and cooling operations and reduction of the degree of impact from transporting devices.

3. The aim and objectives of the study

The study objective is to develop and justify design of a mobile device that combines technological operations of accepting and drying soya piles with the use of woven materials. This will enable drying high-moisture soya seeds without their injury in one pass and reduction of energy consumption for drying.

To achieve this objective, the following tasks were set:

– substantiate scheme of a mobile device for one-pass accepting and drying high-moisture soya piles based on an air-slide conveyor providing high specific air supply and uniform drying of the material;

- conduct laboratory studies to determine rational design indicators of a central air distributing air-slide conveyor and simulate the process of soya drying in the developed device for accepting and drying high-moisture soya piles;
- carry out production tests of the developed device to determine its technological parameters when drying high-moisture soya piles.

4. Materials and methods used to study a device for accepting and drying soya seeds

A design diagram of a mobile device for accepting and drying in one pass high-moisture soya piles based on an air-slide conveyor with the use of woven materials [14] (a cloth air-slide conveyor) has been developed. The device consists of a fan 1 connected to the central 4 and lateral 5 air distribution ducts by means of an air supply pipe 2 with butterfly valves 3 (Fig. 1).

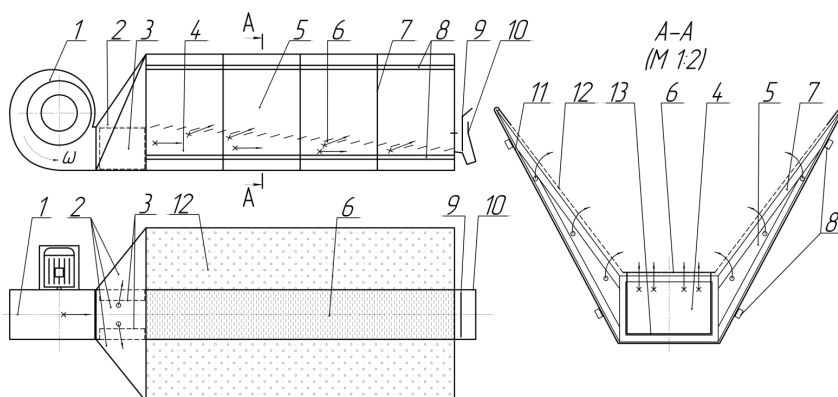


Fig. 1. Design diagram of the mobile device for reception and drying of soya piles (the cloth air-slide conveyor), heat generation unit is conventionally not shown: $\times \rightarrow$ is the air flow from the central air distribution duct; $\circ \rightarrow$ is the air flow from the lateral air distribution duct; fan (1); air supply pipe (2); butterfly valves (3); central air distribution duct (4), lateral air distribution ducts (5); load-carrying air distribution partition (6); metal frame (7); longitudinal beams (8); gate valve (9); discharge chute (10); airtight walls (11, 13); cloth screens (12)

The central air distribution duct 4 is formed by a rigid load carrying air distribution partition 6 and airtight walls 13. The lateral air distribution ducts 5 are made of air tight walls 11 and cloth screens 12. The rigid load carrying air distribution partition 6 is inclined to ensure grain flow. To ensure rigidity of the air-slide conveyor structure, the cloth and the rigid perforated load-carrying partition are secured on a metal frame consisting of vertical links 7 and longitudinal metal beams 8. The device is equipped with an outlet tray 10 with a gate valve 9 for unloading.

The device works as follows (Fig. 1): the material is loaded from the side with a loading device onto the load-carrying air distribution partition 6 and the lateral walls from cloth screens 12 until the entire volume is filled.

Then the fan 1 is turned on and the butterfly valves 3 of the air supply pipe 2 open. The drying agent from the heat generator enters the fan 1 and uniformly introduced into the layer of high-moisture seeds through the load-carrying perforated partition 6 and cloth screens 12 with a high coefficient of open space. At the same time, seeds are uniformly heated, the drying agent takes away the moisture evaporated from

them and escapes to the atmosphere through the top surface of the layer [14].

At the end of the process of drying the pile of high-moisture seeds, the heat generator is turned off and the gate valve 9 of the discharge chute 10 is opened. The butterfly valves 3 of the air supply pipe 2 are closed, and the entire air flow from the fan is directed into the central air distribution duct 4 under the load-carrying air distribution partition 6. This increases speed of the air jets released at an acute angle from the slots of the load-carrying air-distribution partition 6 which ensures careful and reliable displacement of the dry seed pile along the air-slide conveyor to the unloading device [14].

To substantiate design parameters of the central air-distribution duct, studies were conducted on uneven distribution of the drying agent by the load-carrying air-distribution partition among sections, Q_i .

The main factors were as follows: angle of inclination, α , of the load-carrying air distribution partition, supply of the drying agent, Q , at the entrance to the central air distribution duct and the coefficient of open space, k , of the load-carrying air distribution partition.

To identify nature of influence of these factors on uniformity of release of the drying agent from the load-carrying air distribution partition as well as determine rational design parameters, a full three-factor, two-level experiment (1) was conducted.

$$V=f(k; Q; \alpha). \quad (1)$$

Uniformity of release of the drying agent from the load-carrying air distribution partition was evaluated by the coefficient of air flow variation along the length of the partition and determined by relationship (2):

$$V=(\sigma/Q_{av}) \cdot 100, \quad (2)$$

where V is the coefficient of air flow variation, %; σ is the mean square deviation of air flow along the length of the load-carrying air distribution partition, m^3/s ; Q_{av} is the arithmetic average value of air flow along the length of the load-carrying air distribution partition, m^3/s .

Coding and levels of variation of the factors are presented in Table 1.

Flow rate of the drying agent in sections A, B, C, D (Fig. 2) was determined by dynamic pressure in the holes located on the axis of the load-carrying air-distribution partition taking into consideration changing environmental parameters. The flow rate of the drying agent was established and controlled by the dynamic pressure at the inlet to the air supply pipe 2 (Fig. 1, 2).

Repetition of the experiments was changed from 3 to 7 so that the relative guarantee error of the experiment did not exceed 10 %.

Production tests were conducted to determine rational design and technological parameters of the developed device when drying in it high-moisture piles of soya of Svetlaya variety. An installation with dimensions of

6,000×2,200×3,000 mm was manufactured and equipped for testing with all necessary instruments and systems in accordance with generally accepted methods.

Table 1

Coding and factor variation levels

Factor and unit of measurement	Symbol	Natural levels of variation	
		upper	low
Coefficient of open space, %	k	8	4
Supply of drying agent underneath the load-carrying partition, m ³ /s	Q	1.5	0.5
Angle of inclination of the load-carrying partition, deg.	α	4	0

Distribution of air flows was studied simultaneously depending on position of the butterfly valves 3 in the distributing air supply pipe 2 and the degree of closure of the cloth screens of the lateral air distribution ducts 5 in the test sample (Fig. 1, 2).

The following main factors were taken (Fig. 3): position of the butterfly valves X was adjusted by points I^* (the valves are completely closed, the drying agent enters only beneath the load-carrying air distribution partition), II^* (the valves are half open, the drying agent enters the central and lateral air distribution ducts) and III^* (the valves are fully open, most of the flow of the drying agent goes to the lateral air distribution ducts) as well as the degree of closure of the cloth screens of the lateral air distribution ducts L , mm. The right side was closed in 600 mm from the upper edge of the lateral air distribution ducts and the left side was closed in 300 mm from the upper edge of the lateral air distribution ducts (Fig. 2).

Temperature of the drying agent at the fan outlet, T_1 , °C, was set at 60 °C.

The output values were as follows: average temperature of the drying agent inside the soya layer, t_a , °C; flow rate of the spent drying agent, Q_2 , m³/h and temperature of the spent drying agent T_2 , °C. Material moisture content during drying ω_2 ,%; seed temperature during drying, t_2 , °C; fuel consumption q , kg/h; electric power consumption N , kW·h.

The controlled factors were as follows: atmospheric air pressure P , Pa; initial moisture content of the received batch of soya seed ω_1 , %; initial seed temperature t_1 , °C; outdoor temperature t , °C. Relative air moisture ϕ , %; flow rate of the drying agent at the entrance to the distributing air supply pipe, Q_1 , m³/h.

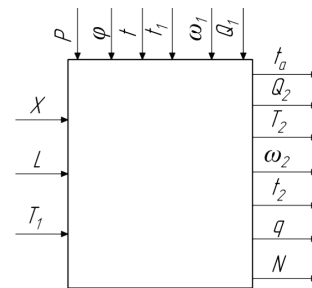


Fig. 3. Simulation of the process of soya drying in the device for accepting and drying of high-moisture soya piles:

X is position of the butterfly valves; L is the degree of closure of the cloth screens of the lateral air distribution ducts; T_1 is temperature of the drying agent at the outlet of the fan, °C; P is atmospheric air pressure, Pa; ϕ is relative air moisture, %; t is the outdoor temperature, °C; t_1 is initial temperature of seeds, °C; ω_1 is initial moisture of the received batch of soya seeds, %; Q_1 is flow rate of the drying agent at the inlet to the distribution pipe, m³/h; t_a is average temperature of the drying agent inside the soya layer, °C; Q_2 is the flow rate of the spent drying agent, m³/h; T_2 is temperature of the spent drying agent, °C; ω_2 is moisture content in the material during drying, %; t_2 is seed temperature during drying, °C; q is fuel consumption, kg/h; N is electric power consumption, kW·h

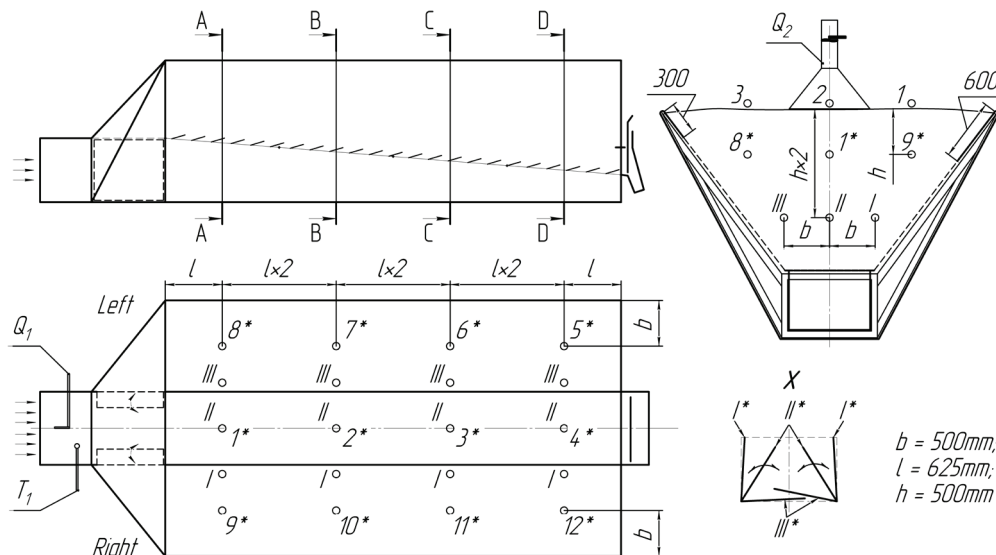


Fig. 2. Layout of the measuring equipment when determining parameters of the cloth air-slide conveyor operation as a mobile device for accepting and drying high-moisture soya piles: A, B, C, D are the measurement sections;

$1, 2, 3$ are points of measurement of seed moisture, flow of discharged drying agent and its temperature on the pile surface in sections A, B, C, D ; $1^*... 12^*$ are the points of measurement of soya temperature; I, II, III are the points of measurement of temperature of the drying agent and the moisture content of seeds inside the layer in sections A, B, C, D

The tests were conducted as follows. Fan 1 (Fig. 1, 2) and the heat generator (not shown in the figures) were started to supply the drying agent to the fully loaded device. After entering the mode, flow rate of the drying agent at the inlet to the distribution air inlet pipe 2 was measured. Then required position of the butterfly valves in the distribution air inlet pipe 2 was set according to the diagram in Fig. 2. The first position *I**: the butterfly valves are completely closed; the drying agent is supplied only beneath the load carrying air distribution partition 6 (transportation mode). The second position *II**: the butterfly valves are half open, the drying agent is distributed between the central air distribution duct 4 and the lateral air distribution ducts 5 (ventilation mode). The third position *III**: the butterfly valves are fully open, the largest part of the drying agent flow is directed to the lateral air distribution ducts 5 and the rest agent flow is directed to the central air distribution duct 4 (drying mode).

To determine flow rate of the spent drying agent on the pile surface at points 1, 2, 3, a confuser with an electronic anemometer was installed in sections *A, B, C, D* (Fig. 2).

To determine uniformity of heating of the soya pile at points 1*...12* of sections *A, B, C, D* according to the diagram (Fig. 2), temperature of soya seeds was measured with electronic pyrometric sensors and transmitted to a computer. At points I, II, III, 1, 2, 3 of sections *A, B, C, D*, temperature of the drying agent and the relative moisture of soya seeds were measured (Fig. 2).

Measurements were done every 3 hours with a fivefold repetition. Average values of the results were calculated on completion of the experiments.

5. Results obtained in the studies of a mobile device for accepting and drying soya piles

Correlation analysis was conducted according to the results obtained in laboratory experiments on substantiation of the design parameters of the central air distribution duct to identify meaningful relationships between the input and output parameters and assess the level of meaningfulness of these relationships. The coefficients of pair correlation of the coefficient of variation of the drying agent flow through the load-carrying partition, *V*, and the coefficient of the open space of the partition, *k*, %; the angle of inclination of the partition, α , deg., and supply of the drying agent beneath the load carrying air distribution partition, *Q*, m/s, are meaningful (the level of meaningfulness of relations less than 0.5). It should be noted that the coefficient of variation of the drying agent flow from the load-carrying partition is least affected by the angle of inclination and air flow (the level of meaningfulness is $p=0.58$ and 0.58 , respectively). The greatest influence is exerted by the coefficient of the open space ($p=0.0064$).

To predict change of the coefficient of variation of the flow rate of the drying agent in the load-carrying partition depending on combination of the selected factors, a multi-dimensional regression analysis was performed. As a result, a mathematical model (3) was obtained:

$$V = 8.8 + 30.1 \cdot \alpha + 0.7 \cdot k + 16.0 \cdot Q - 3.2 \cdot \alpha \cdot k - 18.2 \cdot \alpha \cdot Q + 1.1 \cdot \alpha \cdot k \cdot Q \quad (3)$$

It was established in the course of the regression analysis that the obtained model is informationally capable since the coefficient of determination of the parameter *V* is $R^2 = 81.7\%$.

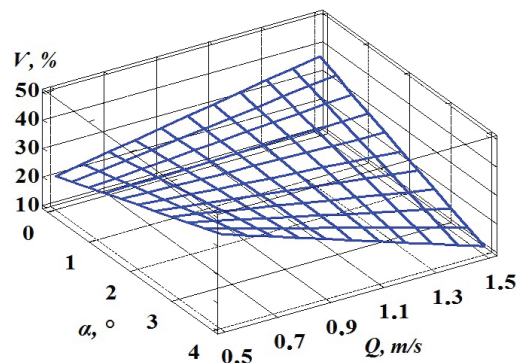


Fig. 4. Effect of the flow of a drying agent and the angle of inclination of the load carrying air distribution partition on uniformity of distribution

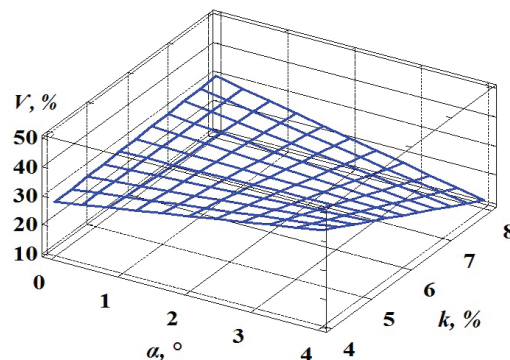


Fig. 5. Effect of the coefficient of the open space and the angle of inclination of the load carrying air distribution partition on uniformity of distribution of the air flow along the duct length

The best distribution of the air flow across the area of the load-carrying air distribution partition is achieved with the following design parameters. The ratio of the open space of the partition is 8 %, the scales should be directed downwards. The angle of the scaly partition to the horizon: 4°; the partition width: 600 mm.

In the course of production tests of the developed device (Fig. 6), in order to determine the technological parameters of its operation when drying high-moisture soya piles, the outside air temperature *t* was from -2 to 2.1 °C. Relative air humidity, ϕ was 92 %; air flow rate at the inlet to the distributing air supply pipe, *Q*₁, was on average 10,957 m³/h. Initial relative moisture of soya seeds ω_1 was 23 %; initial seed temperature *t*₁ was 2.4 °C; atmospheric air pressure *P* was 101.9 kPa. The pile surface area was 15 m².

Average temperature of the drying agent in the soya layer, *t*₀, was 44.8 °C, average temperature of the spent drying agent, *T*₂ was 32.8 °C. The seed heating temperature during drying, *t*₂, was within 40±5 °C.

As a result of the studies, it was found that the use of an additional air supply unit (fully open butterfly valves *III**) and the cloth screens with a coefficient of open space of 46 % increased air supply to the seed layer by 60 %. Specific flow rate of the drying agent was 0.3 m³/s·t at thickness of the purged layer of soya seeds of 1.5 m.

The maximum value of the coefficient of variation of flow of the spent drying agent along the length on the surface of the soya pile at fully open butterfly valves during drying was 16 %. The greatest amount of air (Fig. 7, 8) entered at

the initial sections *A* and *B* and on the left side of the drying chamber of the cloth air-slide conveyor in which the side screen was closed by 300 mm from the surface of the soybean layer. Closure of the cloth screens in the upper part of the lateral air distribution ducts by 600 mm reduced flow of air into the layer of soya pile by 26.2 % (Fig. 8).



Fig. 6. A device for accepting and drying high-moisture soya piles under production conditions (air-slide conveyor): fan (1), cloth air-slide conveyor (2); scraper conveyor (3); pneumatic separator (4); storage bin (5); conveyor (6); fractional pneumatic separator (7)

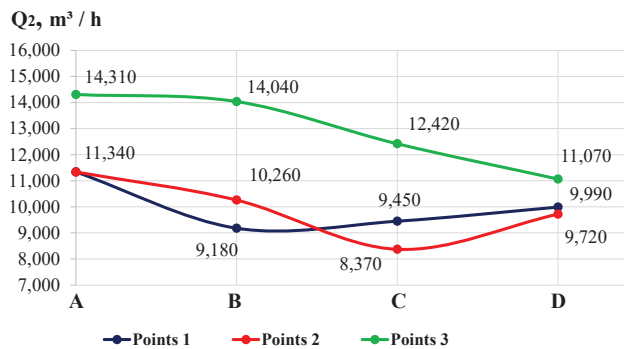


Fig. 7. Change in the flow rate of used drying agent along the length on the surface of the soya pile when the butterfly valves are open during drying at points 1, 2, 3, sections *A, B, C, D* (Fig. 2)

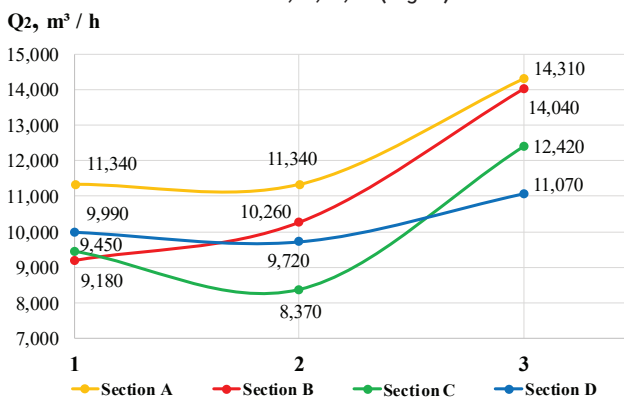


Fig. 8. Change in the flow rate of used drying agent over width of the soya pile surface when the butterfly valves are open during drying at points 1, 2, 3, sections *A, B, C, D* (Fig. 2)

Maximum value of the coefficient of variation of flow rate of the spent drying agent over the width on the soya pile surface at fully open butterfly valves during drying was 11.2 %.

Deviation of seed moisture (Fig. 9, 10) in the entire volume of the drying chamber on completion of drying did

not exceed 1.2 %. The seed quality at combination of technological operations of reception and drying has improved: seed germination after drying and the period of post-harvest ripening increased by 4.5 % from 75.5 to 80 %.

Fig. 7–9 demonstrate intersection of the grain layer curves and as a result of stochastic distribution of air flow over the volume of the drying chamber. This is explained by the fact that parameters of the pile coming from a combine (moisture, density, dockage) are of a stochastic character because of the lack of pre-treatment which was not performed to reduce injury of high-moisture seeds.

Compared with the known batch-type dryers [15], the reduced heat consumption for drying has decreased by 0.2 MJ/kg_{evap.m ev.moist}, specific metal content was 181 kg/t less compared to the SAU-6 dryer with an air-slide conveyor [16].

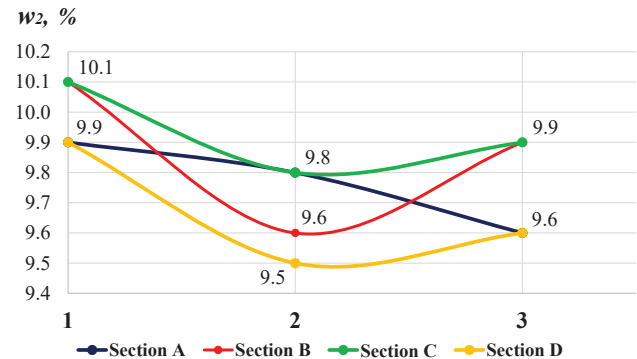


Fig. 9. Change in the moisture content in soya seeds at the surface of the layer over its width at the end of drying at points 1, 2, 3, sections *A, B, C, D* (Fig. 2)

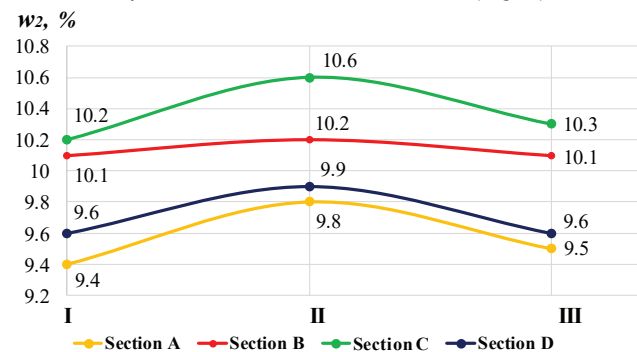


Fig. 10. Change in the moisture content in soya seeds inside the layer over its width at the end of drying at points I, II, III, sections *A, B, C, D* (Fig. 2)

6. Discussion of results obtained in the study of the device for accepting and drying soya seeds

Owing to the use of a new technology combining two technological operations, that is accepting and drying of high-moisture soya piles, the scope of adverse effects from transporting devices on the seeds leading to their injury was reduced. The

use of the developed dryer based on an air-slide conveyor with woven working bodies softens effect of the working body surface on the seeds preserving quality of the latter. The use of woven screens with a high coefficient of open space provides an additional uniform introduction of air flow into the material layer, eliminates the need for agitation of the damp piles and repeated drying and cooling operations.

Advantages of this study include the device design which has a small specific metal content, is easy in manufacture and assembly and can be transported by widely used vehicles. The low cost of materials used in manufacture of the air-slide conveyor made from woven screens provides for a high competitive ability and, as a result, a reduction in costs of post-harvest processing of high-moisture seeds. The specified drying capacity can be easily changed by using other number of woven air-slide conveyors in-parallel installed in the process line.

Disadvantages of using the developed device include the fact that when combining the technological operations of accepting and drying of high-moisture material, the specific energy consumption increases since litter is also dried along with the high-moisture seeds.

The use of the developed woven air-slide conveyor makes it possible to take high-moisture loose material in batches of various weights (2 to 10 tons) and dry them in one pass with the least energy consumption at a high quality and without injuries. Features of the design open up the possibility of its use in highly damp areas at enterprises with various product outputs. The air-slide conveyor made with the use of woven materials can be operated as a main unit of mobile grain cleaning and drying stations to ensure preservation of high-moisture seeds without building expensive specialized departments for post-harvest processing of crops.

The study results are a continuation of development of a new grain drying equipment [17]. In the future, it is possible to use these results in substantiation and building mobile facilities for post-harvest processing of grain and grass seeds.

7. Conclusions

1. An air-slide conveyor made of woven materials has been developed. It is a mobile device with a low specific

metal content (50 kg/t) for a simultaneous high-quality execution of two technological operations: reception and drying in one pass of high-moisture loose materials. The device contains an air-slide conveyor divided by a load-carrying perforated partition into air supply and transport parts. The air-slide conveyor is made of a frame covered with a woven material. The outer walls of the air-slide conveyor are made of an air-tight and water-repellent cloth and the inner lateral walls are made of a bolting cloth. The lateral air supply cavities were separated from the central air distribution duct by walls of air-tight water-repellent cloth. Studies have shown that the use of additional ducts for supplying air from the woven screens with a coefficient of open space of 46 % has made it possible to further increase supply of the drying agent to the seed layer by 60 %. Design of the air-slide conveyor made with the use of bolting cloth provides high uniformity of drying high-moisture soya seeds. Deviation of relative moisture of seeds throughout the entire drying chamber volume did not exceed 1.2 % with an increase in seed germination by 4.5 %.

2. Rational design parameters of the central air distribution duct were established. The best distribution of the air flow over the area of the scaly load-carrying air-distribution partition with a width of 600 mm was achieved at a coefficient of open space of 8 %. The angle of inclination of the partition to horizon should be 4°. The partition scales should be directed downwards, against the flow of the drying agent.

3. Technological parameters of the cloth air-slide conveyor during drying of soya seeds at its full loading were established. Specific flow rate of the drying agent was 0.3 m³/s·t, temperature of the drying agent at the inlet to the cloth air-slide conveyor was 60 °C. The bolting cloth screens of the lateral air distribution ducts during drying must be closed at 300 mm from the surface of the layer being dried. Air flow is only delivered to the air distribution duct of the air-slide conveyor in the mode of loading and unloading of seeds and is additionally delivered to the side cavities in the mode of drying while all butterfly valves should be fully open. The integral energy consumption for drying was 7.8 MJ/kg_{evap.m} of ev.moist.

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