

*One of the most responsible operations in the cultivation of vegetables includes seeding. Its timing and quality largely determine the quality of sprouts, yield and crop morbidity. The emergence of sprouts can be accelerated and their uniformity can be improved by using hydraulic seeding of germinated seeds. The operation of hydraulic seeders can be divided into main stages: agitation of seeds in a liquid, selection, and dosage of seeds, seeding in the seedbed.*

*The process of seed agitation in a liquid, that is, obtaining a fluidized bed with required seed concentration in the intake chamber of the hydropneumatic precision seeder was considered. The process of seed agitation in the liquid is performed in different ways: bubbling or the use of mechanical stirrers. Each of them requires the use of energy-intensive actuators.*

*A method of seed agitation in a liquid was proposed. It makes it possible to reduce energy consumption by means of agitation, not the entire volume but just the part that is in the zone of seed intake to the seed duct.*

*According to the results of theoretical studies, it has been established that to ensure reliable and accurate seeding, the seed concentration should be in the range of 0.2–0.65 pcs/ml. Under such conditions, the charging process takes place without clogging the seed duct and at an acceptable speed of the seeder.*

*The main factors influencing the formation of a set seed concentration were established: seed diameter, the height of the fluidized bed, flow speed in the intake chamber, the angle between walls of the intake chamber, fluid flow rate.*

*According to the results of theoretical studies of the process of formation of a set seed concentration, limits of existence of the fluidized bed ( $h_2=0.014$  m,  $h_1=0.07$  m) and height of the seed duct ( $h_H=0.015$ – $0.02$  m) which will ensure reliable and prompt taking of seeds from the intake chamber for their further dosage and seeding.*

*The main provisions of theoretical studies of the agitation process and formation of a set seed concentration were confirmed by experimental studies in a laboratory*

**Keywords:** *germinated seeds, hydroseeder, precision seeding, fluidized bed, seed concentration, porosity*

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# STUDY OF SEED AGITATION IN THE FLUID OF A HYDROPNEUMATIC PRECISION SEEDER

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## 1. Introduction

Seeding is one of the most responsible operations in the process of growing vegetables. Its timing and quality largely determine sprout quality, yield and morbidity of crops.

Seeding should be carried out in a short time determined by properties of plants and concrete climatic conditions, with the required accuracy of seed depth and intercropping.

Seeding accuracy has always been one of the most important criteria for the seeder quality and conventional technologies should ensure optimal crop density, ability to carry out subsequent operations of plant care and harvesting. The coefficient of variation of seed distribution in a row which directly depends on the coordinated and reliable operation of all major components of the seeder is one of the qualitative indicators for assessing the performance of precision seeders. Field germination of seeds is another important non-standard indicator, which clearly depends on the quality of the seed grain.

The power of seed germination in the field is one of the important indicators on which gross harvest depends. The main factors influencing the field germination of seeds include: mechanical (damage during harvesting, storage, and seeding), physical (humidity, temperature, gas exchange, soil density), biological (microorganisms) and chemical (herbicides). Moisture which accelerates the process of seed germination is one of the key factors. Taking into account the biological properties of vegetable seeds, the process of their germination occurs under conditions of relative soil moisture not less than 60 % [1, 2]. In the absence of normal moisture, seed germination is uneven, some seeds germinate in more humid areas of the field and others are waiting for precipitations. All this negatively affects the future harvest. Seed germination can be accelerated and uniformity of germination can be ensured by using hydraulic seeding. Hydraulic seeders make it possible to sow germinated seeds at one time with the required amount of liquid, means of protection, and growth stimulation.

Seed agitation in liquid and maintaining the set concentration is one of the key processes that affect seeding accuracy. Therefore, it will be important to conduct theoretical and practical studies in this area.

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## 2. Literature review and problem statement

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Soaking of seeds up to their germination was used in the past before seeding to ensure simultaneous and early sprouting. Seeds were sown manually which resulted in low productivity of the process. The first attempts to increase productivity were implemented by using classic seeding machines for seeding germinated seeds. Before sow, seeds were dried a little, loaded into hoppers, and sown [2]. The disadvantage of this approach to sowing germinated seeds relates to a decrease in field germination as a result of injury to germs and lack of starting moisture for the initial sprouting process which was compensated by increasing the seeding rate. In the 40s of the last century, American scientists proposed technology and later hydraulic seeders for cross-country landscaping (roadsides, hills, mountain dumps) [3]. At present, hydraulic seeders are widely used as it was 50 years ago, only in road building and landscape areas. The use of hydraulic seeders in agriculture has not yet become widespread because of the complexity of the preparatory and technological processes of seeding germinated seeds, namely, before seeding, the seeds must undergo a germination process followed by rejection of substandard seeds [4]. The technological process of seeding is carried out under the condition of intensive agitation of seeds in liquid which increases the energy component of the process.

Studies [5–7] address the issue of realization of precision seeding and improvement of the process of seeding germinated seeds of agricultural crops.

An SGO-4.2 seeder that makes it possible to carry out seeding of germinated vegetable seeds simultaneously with pouring a liquid is presented in [8, 9]. The results of field studies with seeding celery confirmed the effectiveness of hydraulic seeding. Disadvantages of this seeder include the inability to perform dotted seeding at a given interval which relates to a probable nature of seed distribution in the seeding liquid.

A hydraulic seeder of the unorthodox design was presented in [10, 11]. The process of agitation of seeds with liquid was realized by means of compressed air (bubbling) to reduce the injury of seed germs. Air enters the working tanks through their perforated bottoms and lifts seeds to traps connected to seed ducts and colters. The seeding process is carried out by pouring the liquid together with seeds. Variation of air pressure from 0.5 to 2 atm and flow rate in the throttle valve enables the required seeding rate.

According to the developers, the proposed seeder is especially effective when used in backyard and country areas, in greenhouses for growing vegetables and medicinal herbs.

Hydraulic seeders were studied in [4, 12]. To determine the effect of hydroseeding on the field sprouting of seeds, a seeder design was developed [4]. The study was carried out on three seeding options: hydraulic seeding with the use of ordinary water, hydraulic seeding with the use of electro-activated water, and control seeding without the use of liquid. According to the results of field studies [12], it was found that the best sprouting was observed on plots where electro-activated water was used which had a positive effect on the yield growth: about 30–40 %.

The advantage of hydraulic seeding, which accelerates the emergence of sprouts and ensures their simultaneous growth,

was confirmed in [13]. This indicates the topicality of the development and implementation of hydraulic seeders. The study was conducted with corn crops. It was found that time of seed soaking does not significantly affect the rate of sprouting but the sown seeds germinate earlier when the optimal supply of moisture sufficient for its germination is provided. A mathematical model of the rate of fluid pouring depending on soil moisture has been constructed. Seeds were agitated by means of mechanical activators. Distribution of seeds in a line has probable character at the preservation of the seeding rate.

Experimental studies of the process of seed agitation in water were carried out in [14] by bubbling in the agitation chamber under conditions of varied air pressure and water level in the chamber. Uniformity of seeding depending on the number of seeds in the agitation chamber and speed of seed lifting depending on their dimensional characteristics were determined.

When analyzing the principle of operation of existing and proposed seeders, their operation can be divided into the following main stages: agitation of seeds in the liquid, selection and dosing of seeds, seeding in the seedbed.

Agitation of seeds with liquid in tanks of the considered hydro seeders is carried out in entire volume using gas or paddle activators. This increases energy consumption for the agitation process. The use of such components is only justified in a case of the permissibility of low seeding accuracy and when energy-intensive tractors are used.

The problem of reducing energy consumption for the agitation process can be solved by agitating seeds locally in the zone where seeds are taken for the seed duct of the precision hydropneumatic seeder. For this purpose, a fundamentally new design of a seeder has been developed with an intake chamber in which seeds are mixed locally using the fluidization principle.

According to the search results, no information was found on the theoretical study of the process of seed agitation by a fluid flow locally in the area of seed intake to the seed duct. This encourages the theoretical and experimental study of this issue.

According to the study results, a scientific result can be obtained in the form of a description of the process of mixing liquid with seeds by fluidization which is interesting from a theoretical point of view. From a practical point of view, the mechanism of mixing the liquid with seeds discovered in such a study will make it possible to determine an optimal value of seed concentration in liquid in the technology of precision hydraulic seeding. Thus, an applied aspect of the application of the obtained scientific result consists in the possibility of improving the technology of precision hydraulic seeding.

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## 3. The aim and objectives of the study

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The study objective consists in establishing an optimal value of seed concentration in the intake chamber to improve the seeding accuracy of the hydraulic seeder.

To achieve this objective, the following tasks were set:

- to theoretically describe the process of forming a fluidized bed of seeds and liquid in the intake chamber of the hydraulic seeder;
- to conduct a theoretical study of the influence of the main design and technological parameters of the hydropneumatic seeder on the process of seed agitation in the liquid of the intake chamber;
- to experimentally substantiate the value of seed concentration in the intake chamber of the hydropneumatic seeder.

#### 4. Materials and methods used in the study of the process of seed agitation in liquid

The Dnipro State Agrarian and Economic University is working on the development and implementation of a precision hydropneumatic seeder (Fig. 1) [7, 15, 16], which will eliminate the shortcomings inherent in existing hydraulic seeders. Seeds are mixed with liquid locally only in intake chamber 12 for their further taking for seeding. The dispensing part of the seeder makes it possible to realize precision seeding using optical sensor 11 and pneumatic ejection of seeds together with liquid reducing the seeding time.

The hydropneumatic seeder works as follows. After filling tank 1 with seeds and working fluid from tank 7 through open hydraulic valve 8, the air is removed from the tank through drain valve 19 and then the drain channel is closed. This prevents spontaneous leakage of working fluid with seeds through open seed duct 3 and nozzle 2.

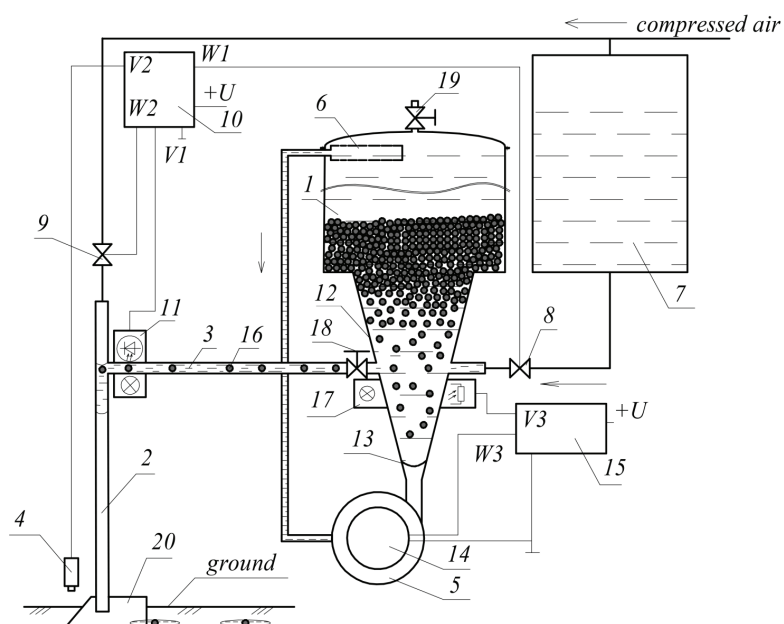


Fig. 1. Diagram of a hydropneumatic seeder of precision seeding: tank (1); nozzle (2); seed duct (3); sensor for monitoring the seeder movement (4); pump (5); mesh strainer of the bypass line (6); liquid tank (7); solenoid valve (8, 9); seeder control unit (10); optical sensor for monitoring seed passage (11); intake chamber (12); protective mesh (13); electric drive of the pump (14); seed concentration control unit (15); seeds (16); optical sensor for monitoring optical density of seeds (17); cock of the seed duct (18); cock of the drainage channel (19); colter (20)

Circulation pump 5 is actuated by adjustable electric drive 14 and creates a circulation of the working fluid taking it through filter 6 from the top part of tank 1 and feeding into the bottom part of intake chamber 12 through protective mesh 13 to meet the seeds that sink in the working fluid. The liquid flow picks up the seeds and transports them up the volume of the intake chamber of a wedge shape. Dimensions of the intake chamber are taken so that a fluidized bed (FB) with the required seed concentration is formed in the zone of seed intake to seed duct 3.

The set concentration of seeds in the zone of intake to a seed duct is maintained by means of change of the liquid flow rate by the circulating pump. Its operation is controlled by block 15.

In the first stroke, control unit 10 supplies current to solenoid valve 8, which opens and passes the working fluid under

pressure from tank 7 into tank 1. The working fluid brings seeds from the intake chamber to the seed duct. The seed continues to move and when passing by sensor 11 causes a pulse to enter the first input V1 of the control unit, solenoid valve 8 is turned off and the seed with the liquid stops in the nozzle.

In the second cycle, in a predetermined position of the seeder relative to the ground, position sensor 4 generates a signal that is fed to the second input V2 of the control unit. A short current pulse opens solenoid valve 9 to supply air from the receiver to nozzle 2. The air in the nozzle expands and pushes seeds with the liquid toward the ground.

At the end of the current pulse on solenoid valve 9, the current is supplied to solenoid valve 8, and the cycle is repeated.

To fulfill the set tasks, a laboratory simulator of a hydropneumatic precision seeder has been developed. The main parts of the seeder were made of transparent materials. This design has provided visual observation of workflows. To control seeding accuracy, the VKR-1 measuring and recording unit with optical sensors was used. Operating parameters for pressure were determined using manometers MP-63 with measuring limits 0...0.1 MPa and 0...1.0 MPa. A spirometer was used to determine the airflow rate and a measuring cup was used to determine the liquid flow rate. The working fluid flow speed was determined using a rotameter with a measurement range of 0 to 2 l/min.

Studies of the process of agitation of seeds in the liquid were carried out according to generally accepted methods.

#### 5. The results of studies of the process of seed agitation in the liquid of a hydropneumatic precision seeder

##### 5.1. Theoretical studies into the formation of a fluidized bed in the intake chamber

The study subject: the process of mixing seeds with liquid (fluidization) to ensure the required concentration of seeds in the zone of its intake from the intake chamber.

In previous studies [7, 15], the process of fluidized bed formation in the intake chamber of the seeder was considered in detail. The issue of the dependence of seed concentration on structural and technological factors of the hydropneumatic seeder and the size of the mixed seed itself remains unsolved.

Taking into account the previously conducted theoretical studies [7, 15, 17, 18] on fluidized bed formation, let us take shape of the intake chamber as a triangular prism placed on its edge with a variable cross-section along its entire length (Fig. 2, a).

The proposed design solution will provide the formation of a fluidized bed (FB) from seeds at a height  $H$  of the intake chamber due to the varied value of the upflow speed  $v_{ho}$ :

$$H = (h_1 - h_2), \quad (1)$$

where  $H$  is the height of existence of FB, m;  $h_1$  and  $h_2$  are higher and lower heights of FB existence, m.

The fluid flow is directed from the narrowed lower part and expands and loses speed when rising.

Expansion of the layer in a fluidized state is characterized by a change in porosity  $\varepsilon$  which is defined as a ratio of the volume of cavities  $V_p$  in the seed layer to the volume of the entire layer  $V_c$ :

$$\varepsilon = \frac{V_p}{V_c} = \frac{(V_p - V)}{V_c} = 1 - \frac{V_H}{V_c}, \quad (2)$$

where  $V_H$  is the volume of seeds in the layer,  $\text{m}^3$ ;  $V_c$  is the total volume of the layer,  $\text{m}^3$ .

It is known that the porosity of the still layer  $\varepsilon_0$  of solid particles is 0.4 [19].

With increasing height  $h$  from the minimum value  $h_0$  (the inlet level) cross-sectional area  $S_h$ ,  $m_2$  increases linearly as:

$$S_h = a_n \cdot B_n = 2 \cdot B_n \cdot h \cdot \text{tg} \left( \frac{\alpha}{2} \right) = k \cdot h, \quad (3)$$

$$k = 2 \cdot B_n \cdot \text{tg} \left( \frac{\alpha}{2} \right) = \text{const}, \quad (4)$$

where  $a_n$  is the length of the intake chamber,  $a_n = 2 \cdot h \cdot \text{tg}(\alpha/2)$ , m;  $\alpha$  is the angle between planes of the intake chamber, deg;  $B_n$  is the width of the intake chamber, m.

If the flow rate at the input is equal to  $v_o$ , then average flow rate  $v_{ho}$  will change with an increase in height  $h$  according to dependence:

$$v_{ho} = v_o \cdot \left( \frac{S_{h_0}}{S_h} \right) = v_o \cdot \left( \frac{h_0}{h} \right), \quad (5)$$

where  $S_{h_0}$  is the cross-section area of the intake chamber at a height  $h_0$ ,  $\text{m}^2$ ;  $S_h$  is the cross-section area of the intake chamber at a height  $h$ ,  $\text{m}^2$ .

An increase in height of the flow is accompanied by a decrease in its speed.

This means that if the input flow speed  $v_o$  exceeds the particle removal speed  $v_o > v_{K2}$ , then at some level  $h$  it will decrease to the value  $v_{K1} < v_{ho} < v_{K2}$  at which a fluidized bed exists, and still higher, the rate will decrease to the filtration speed  $v_{ho} < v_{K1}$ .

The height of the zone of the existence of the fluidized bed  $H$  should depend on the intensity of speed change, i.e., on the angle  $\alpha$  between the prism faces: when this angle decreases, the FB zone expands. In addition, according to experimental data [15], porosity decreases almost linearly in proportion to the decrease in speed which leads to a change in seed concentration (Fig. 2, b).

Therefore, porosity will decrease linearly along the intake chamber height from  $\varepsilon = 1$  at  $v_{ho} > v_{K2}$  and  $h < h_{II}$  to  $\varepsilon = \varepsilon_0 = 0.4$  at  $v_{ho} > v_{K1}$  and  $h < h_1$ .

$$\varepsilon = h \cdot (1 - 0.4) / (h_1 - h_2) = 0.6 \cdot h / (h_1 - h_2), \quad (6)$$

where  $h$  is the current height when  $h_2 < h < h_1$ .

Seed concentration  $k_H$  in the FB can be defined as the number of seeds  $n_1$  per unit volume of the FB, pcs/ $\text{m}^3$ :

$$k_H = \frac{n_1}{V_c}. \quad (7)$$

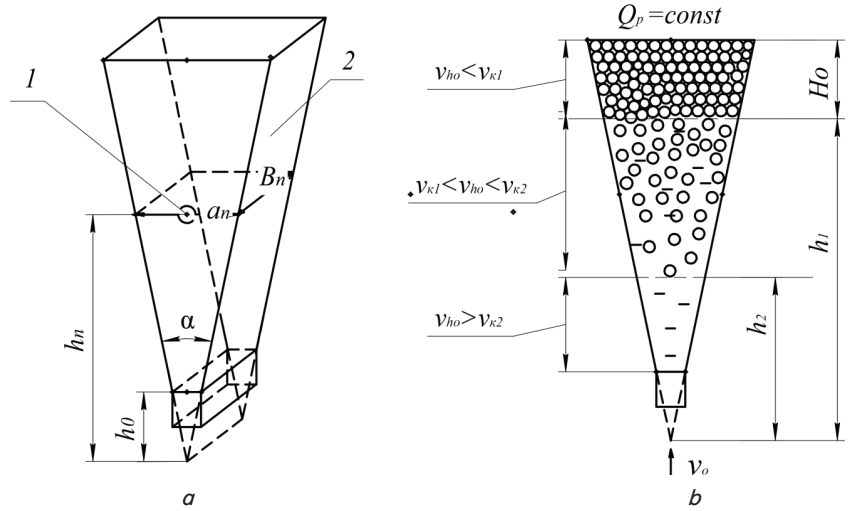


Fig. 2. Intake chamber of hydropneumatic seeder: geometrical ratios of the intake chamber (a); seed distribution (b); entrance to the seed duct (1); intake chamber of the seeder (2)

The change in concentration of seeds  $k_H$  in the FB along the height of the intake chamber is determined as follows. Let us single out a fluidized bed of height  $\Delta h$  which is equal to the seed diameter  $d_H$  (note that  $\Delta h \ll h_1 - h_{II}$ ). The volume of this layer  $V_c$  depends on the height  $h$  in the intake chamber:

$$V_c = S_h \cdot \Delta h = 2 \cdot B_n \cdot h \cdot \text{tg} \left( \frac{\alpha}{2} \right) \cdot d_H. \quad (8)$$

The volume of seeds  $V_H$  contained in the singled-out layer  $V_c$  is as follows:

$$V_H = (1 - \varepsilon) \cdot V_c. \quad (9)$$

Given that a seed shape is close to the shape of a sphere with diameter  $d_H$  and volume of one seed is  $V_{HC} = \pi \cdot (d_H)^3 / 6$ , the number of seeds in the singled-out layer, pcs. will be as follows:

$$n_1 = \frac{(1 - \varepsilon) \cdot V_c}{\pi \cdot (d_H)^3 / 6}, \quad (10)$$

where  $d_H$  is the seed diameter, m.

Then the concentration of seeds in the volume of the singled-out layer is determined from the equation:

$$k_H = \frac{n_1}{V_c} = \left( \frac{(1 - \varepsilon) \cdot V_c}{\pi \cdot (d_H)^3 / 6} \right) / V_c = \frac{(1 - \varepsilon)}{\pi \cdot (d_H)^3 / 6} \text{ pcs}/\text{m}^3. \quad (11)$$

Within the FB, under the condition of linear change in velocity and porosity in the FB height, concentration  $k_H$  changes as follows:

$$k_H = \frac{0.6 \cdot (h - h_2) / (h_1 - h_2)}{\pi \cdot (d_H)^3 / 6}. \quad (12)$$

Seeds are absent ( $k_H \leq 0$ ) at the height  $h \leq h_{II}$ , fill the singled-out layer to a maximum at  $h \leq h_{II}$  with a porosity of 0.4 and leave the FB at  $h > h_1$  and  $h < h_{II}$ .

Maintenance of the flow rate  $v_o$  within the first and the second critical speeds  $v_{K1}$  and  $v_{K2}$  of FB existence is the main



factor of FB existence and maintenance of the set seed concentration. According to previously conducted theoretical studies [7, 15], values of critical speeds should be within  $v_{K1} \approx 0.002-0.02$  m/s,  $v_{K2} \approx 0.057-0.162$  m/s for seeds with a diameter of 1 to 5 mm.

Taking into account theoretical provisions of [19], an equation of intermediate velocity value  $v_p$ , m/s will be obtained under the condition of the FB porosity in the range from  $\varepsilon=0.4$  to  $\varepsilon=1$ :

$$v_p = \frac{A_r \cdot \mu_l \cdot \varepsilon^{4.75}}{d_H \cdot \rho_p \cdot (18 + 0.61 \sqrt{A_r} \cdot \varepsilon^{4.75})}, \quad (13)$$

where  $\mu_l$  is the dynamic coefficient of liquid viscosity, Pa·s;  $A_r$  is Archimedes' criterion;  $\rho_p$  is the liquid density, kg/m<sup>3</sup>.

After transforming equation (13), the intermediate value of seed porosity is determined:

$$\varepsilon = \left( \frac{18 \cdot \left( \frac{v_p \cdot d_H \cdot \rho_p}{\mu_l} \right) + 0.36 \cdot \left( \frac{v_p \cdot d_H \cdot \rho_p}{\mu_l} \right)^2}{A_r} \right)^{0.21}. \quad (14)$$

The obtained mathematical dependences of the process of seed agitation in the intake chamber make it possible to determine the limit values of the design and technological parameters of the hydropneumatic seeder.

## 5.2. Theoretical study into the influence of main design and technological parameters of the hydropneumatic seeder on the process of seed agitation in the liquid of the intake chamber

Taking into account the peculiarities of the process of FB formation, the main factors influencing seed concentration in the intake chamber can be determined. The main factors include the height of the fluidized bed  $H$ , seed diameter  $dH$ , flow speed at the entrance to the chamber  $v_o$ , the angle  $\alpha$  between the intake chamber walls. The angle  $\alpha$  specifies the intensity of change in the cross-sectional area  $S_h$  of the chamber and, accordingly, the flow rate  $v_{ho}$ .

According to the results of previous studies [7, 15], it was found that reliable charge of the seed duct occurs at porosity in a range from  $\varepsilon=0.8$  to 0.98. When porosity decreases ( $\varepsilon < 0.8$ ), the seed duct gets clogged and when porosity  $\varepsilon > 0.98$ , the seeder charging time  $t$  increases.

Taking into account the previously performed calculations of critical speeds and porosity [15], cross-sectional

values of the intake chamber at the lower and upper levels ( $h_2$  and  $h_1$ , respectively) of the fluidized bed are determined (Fig. 2, b). The value of the cross-section for our case is determined from the following equation under the condition of constant fluid flow rate  $Q_p$ :

$$Q_p = v_o \cdot S_h, \text{ m}^3/\text{s}. \quad (14)$$

To perform calculations, take the following initial data: average seed diameter  $d_{Hcp} = 3$  mm, flow speed  $v_{h1o} = 0.03$  m/s and  $v_{h2o} = 0.15$  m/s at heights  $h_1$  and  $h_2$ , respectively, fluid consumption  $Q_p = 1 \cdot 10^{-5}$  m<sup>3</sup>/s, the cross-sectional width of the intake chamber  $B_n = 15$  mm, angle between the intake chamber walls  $\alpha = 15^\circ$ .

According to the calculation results, graphical dependence was constructed (Fig. 3).

Height  $H$  of the existence of the fluidized bed at levels  $h_1$  and  $h_2$  is determined from the condition of maintaining critical speeds  $v_{K1}$ ,  $v_{K2}$  and seed porosity  $\varepsilon$  within 0.8–0.98 which directly depend on the cross-section of the intake chamber using equations (3):

$$h_1 = \frac{S_{h1}}{2 \cdot B_n \cdot \text{tg}(\alpha/2)}, \quad (15)$$

$$h_2 = \frac{S_{h2}}{2 \cdot B_n \cdot \text{tg}(\alpha/2)}, \quad (16)$$

where  $S_{h1}$ ,  $S_{h2}$  are the cross-sections, m<sup>2</sup>, of the intake chamber respectively at higher and lower levels of existence of the fluidized bed.

According to the calculations, the lower level of the FB will be at a height  $h_2 = 0.014$  m and the upper level at a height  $h_1 = 0.07$  m, the height of the fluidized bed  $H = 0.056$  m according to equation (1).

Taking into account the obtained value of the height of the existence of the fluidized bed, determine seed concentration in it according to equation (12).

According to the calculation results, the graphical dependence of seed concentration on seed diameter and the current value of the height  $h$  is presented in Fig. 4.

Analyzing the obtained results of theoretical studies of seed concentration, the following conclusions can be made taking into account fulfillment of the condition  $0.8 \leq \varepsilon \leq 0.98$  and seed concentration  $0.15 \leq kH \leq 0.65$ , respectively. Seed intake to the seed duct should be carried out at a height  $h_n \approx 0.015-0.02$  m which will ensure a reliable supply of seeds to the nozzle of the hydropneumatic precision seeder.

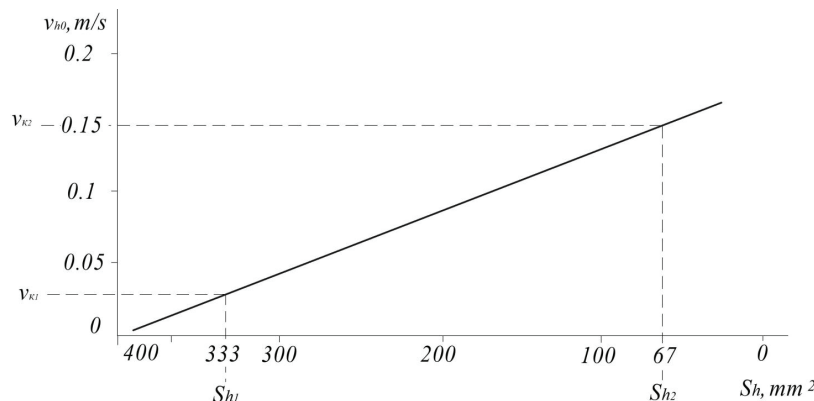
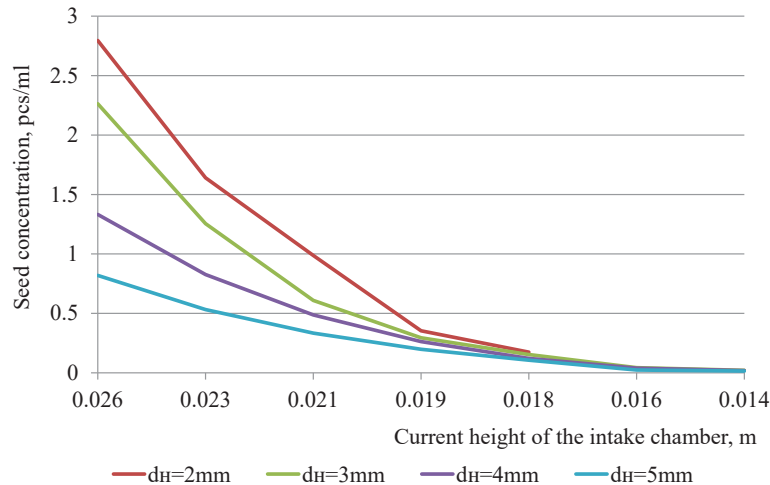


Fig. 3. Dependence of flow speed  $v_{ho}$  on cross section  $S_h$  of the intake chamber

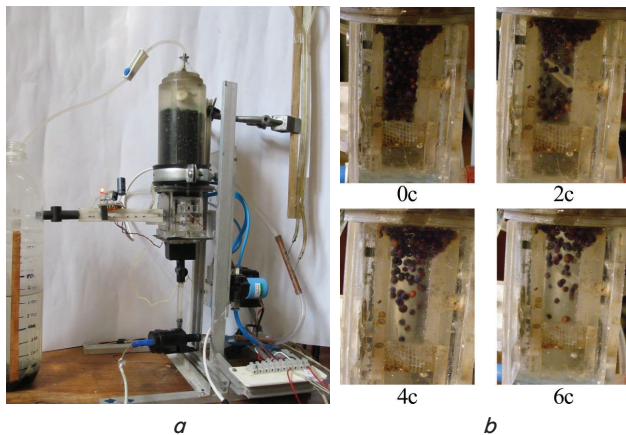
Fig. 4. Dependence of seed concentration  $k_H$  on the current height  $h$ 

### 5. 3. Experimental substantiation of value of seed concentration in the intake chamber of the hydropneumatic seeder

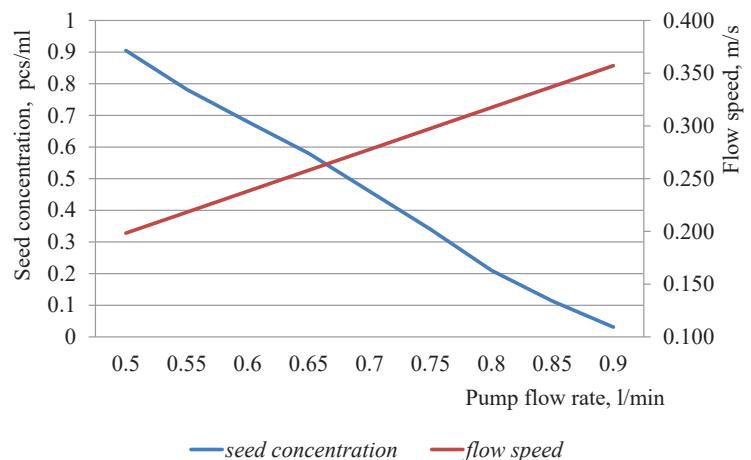
Flow speed in the intake chamber which depends on the geometric dimensions of the chamber and flow rate of the pump of the hydropneumatic precision seeder are the main indicators of the formation of required concentration and porosity of the seed.

Taking into account theoretical provisions of the process of formation of the fluidized bed in the intake chamber, laboratory studies of this process were performed on a laboratory simulator of the hydropneumatic precision seeder (Fig. 5). The study was conducted in two stages.

At the first study stage, the influence of the pump flow rate  $Q_p$  on seed concentration in the intake chamber was determined (Fig. 5, *b*).

Fig. 5. Laboratory simulator of the hydropneumatic precision seeder: general view (*a*); study of seed concentration (*b*)

According to theoretical studies of the fluidized bed formation, the cross-section was taken  $S_{h2min}=67 \text{ mm}^2$  in the lower part of the intake chamber,  $S_{h1max}=333 \text{ mm}^2$  in the upper part, and  $S_A=125 \text{ mm}^2$  in the zone of the seed duct. The study was carried out under the condition of maximum filling of the tank with seeds. According to the study results, graphical dependences are presented in Fig. 6.

Fig. 6. Results of studies of seed concentration  $k_H$  in the intake chamber

Visual observations of the process of formation of the fluidized bed have allowed us to determine the limit values of seed concentration in the intake chamber of the hydropneumatic seeder.

For example, seed concentration should not exceed  $k_{Hmax}=0.65 \text{ pcs/ml}$  for the process of seed entry into the seed duct without blockage at its entrance. The minimum value of seed concentration at which the process of charging the seed duct with seeds was still continuous was  $k_{Hmin}=0.2 \text{ pcs/ml}$ , however, this value significantly reduces the productivity of the hydropneumatic seeder. Reliable and accurate operation of the seeder occurs at a seed concentration in the range of 0.3–0.4 pcs/ml.

In the second stage of the study, the influence of the level of filling the tank with seeds on seed concentration in the intake chamber was determined. The study was performed for two cases: without and with the use of a pump controller. The pump supply without controller was maintained at  $Q_p=0.75 \text{ l/min}$ .

According to the study results, a graphical dependence (Fig. 7) of seed concentration on seed level in the tank was obtained for two cases: with the use of the pump flow controller and without it.

Analyzing the graphical dependence, the following conclusion can be made. The use of the pump controller makes it possible to maintain the set seed concentration with a slight deviation, regardless of the seeds level in the tank. The

operation of the pump without the controller is accompanied by a change in the seed concentration in the intake chamber depending on the seed level in the tank which negatively affects the productivity and reliability of the seeder.

Fig. 8 shows the characteristics of change in the supply voltage of the electric pump drive of the hydropneumatic precision seeder.

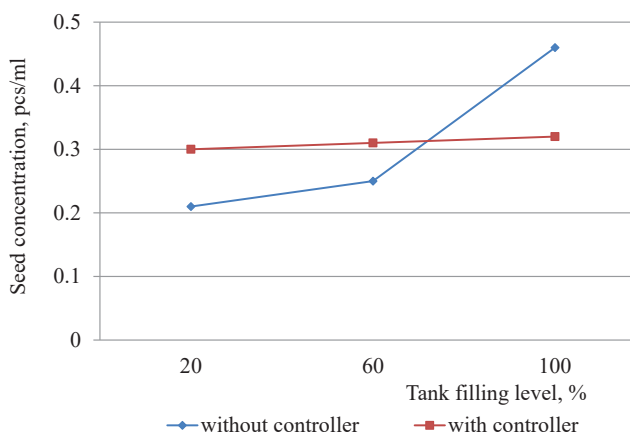


Fig. 7. Graph of the dependence of seed concentration in pulp on the level of tank filling with seeds

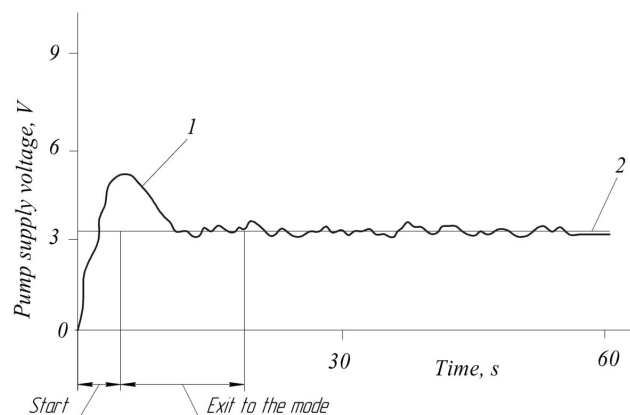


Fig. 8. Characteristics of change of supply voltage  $U$  of the electric pump drive: with the controller (1); without the controller (2)

At the initial stage of seed lifting, the pump must provide maximum flow speed for lifting the compacted seeds on the bottom of the wedge and then switch to the operation mode. Without the controller, the operator must perform this function manually which degrades the seeder performance.

## 6. Discussion of the results obtained in the study of the process of seed agitation in the intake chamber of the hydropneumatic precision seeder

In the studies devoted to the process of seed agitation by fluidization (bubbling) [9, 14, 19], cylindrical agitation chambers were used provided that the entire volume of liquid is mixed with seeds. This leads to additional energy consumption and injury to the seed germs. The proposed design of the intake chamber in a form of a prism placed on its edge makes it possible to solve the existing problems by local partial agitation of seeds in the liquid of the hydraulic precision seeder.

The obtained mathematical model of the process of seed agitation in the liquid has allowed us to analytically determine the influence of main design and technological parameters on the concentration and porosity of seeds in the intake chamber of the seeder.

According to the results of theoretical and experimental studies, it was found that to ensure reliable and accurate seeding, the seed concentration should be in the range of 0.2–0.65 pcs/ml. Under such conditions, the charging process takes place without clogging the seed duct and at an acceptable speed of the seeder. According to the obtained values of seed concentration, limits of existence of the fluidized bed in the intake chamber are  $h_2=0.014$  m,  $h_1=0.07$  m, and height of the fluidized bed  $H=0.056$  m provided that the fluid flow rate  $Q_p=0.75$  l/min.

The developed laboratory simulator of the hydropneumatic precision seeder makes it possible to carry out studies of technological processes with the use of the measuring equipment and conduct visual supervision of all processes occurring in the device operation.

The disadvantages of the hydraulic seeder include the dependence of seed concentration on the level of the tank filling with seeds (Fig. 7, the pump operation without the flow controller). For example, as seed quantity in the tank decreases, the seed concentration decreases which affects the seeder charging time and, accordingly, its productivity.

This problem can be solved by using the feedback between the seed concentration in the intake chamber and the pump flow rate that supports it (Fig. 7, the pump operation with the flow controller). According to the study results, the flow controller maintains the set seed concentration  $k_H=0.32$  pcs/ml in the intake chamber with a minimal deviation.

Experimental studies have shown that seed agitation is chaotic because of the turbulent vortices occurring during the fluidization of seeds in the intake chamber. Therefore, theoretical studies have allowed us to describe the process of seed agitation close to actual conditions. This is sufficient to determine acceptable values of seed concentration and establish limits of variation of main factors influencing it.

The complexity of the process of seed agitation in the liquid volume does not allow to determine desired values of main operational and technological indicators by analytical means. Further studies will use a numerical calculation method with the help of the mathematical modeling package STAR-CCM+. The package will make it possible to more accurately describe the fluidization process in the intake chamber and optimize the basic qualitative indicators of the precision seeder (seeding accuracy, reliability, and productivity).

The practical significance of the studies conducted and the results obtained will solve the problems associated with energy consumption and the reliability of precision hydraulic seeders. Namely, due to local agitation in the intake chamber and the obtained values of optimal seed concentration and maintaining it within the specified limits. Thus, the possibility of improving the technology of precision hydraulic seeding is the applied aspect of the application of the obtained scientific result.

## 7. Conclusions

1. Based on the results of theoretical studies of the process of forming a fluidized bed in the intake chamber of the seeder, the shape of the intake chamber in a form of a prism placed on its edge was selected and a mathematical model of the process of liquid and seed agitation was obtained. The

obtained equations make it possible to determine the influence of fluid flow speed, seed diameter, the cross-sectional area of the intake chamber on concentration and porosity of seeds in the intake chamber applying the analytical method.

2. According to the results of the theoretical study of the influence of the main design and technological parameters of the hydropneumatic precision seeder on the process of seed and liquid agitation in the intake chamber, limit values of seed concentration in the intake chamber was  $k_H=0.15-0.65$ . Limits of the fluidized bed existence in the intake chamber ( $h_2=0.014$  m,  $h_1=0.07$  m) and the height of the fluidized bed existence ( $H=0.056$  m) were determined.

3. Taking into account the obtained value of the fluidized bed height  $H$ , laboratory experimental studies have confirmed that reliable and accurate operation of the seeder is possible at seed concentration in the intake chamber in a range of  $k_H=0.15-0.65$  pcs/ml. Seed intake to the seed duct should be carried out at a height  $h_H\approx 0.015-0.02$  m.

Experimental studies have shown that the proposed pump flow controller makes it possible to maintain seed concentration in the intake chamber with just a slight deviation from the set value. This will ensure the uninterrupted and productive operation of the seeder.

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