To justification of parameters of ultra-low-volume spraying with pneumatic slot sprayers

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Abstract. Intensive potato production technology provides for improving the process of planting tubers with a potato planter with simultaneous treatment with protective and stimulating liquids. To this end, the design of the device was developed, and the parameters of pneumatic slot sprayers recommended for treated tubers with working fluids were optimized.

The main task of plant protection is the rational use of existing technologies to achieve high economic potential and ensure environmental protection.

Reducing the consumption of pesticides is associated with the improvement of technology and equipment.

The use of low-volume and ultra-low-volume spraying will significantly reduce the consumption rate of the preparation.

We have developed a design of an ultra-low-volume sprayer that uses pneumatic slot sprayers.

The working fluid flows from the tank mounted on the tractor hitch through the equalizing tank for regulating the flow of the working fluid.

The sprayers create an air-drop jet directed at the soil, for which compressed air and working fluid are supplied to the cylindrical sprayer.

A special feature of this sprayer is the non-pump supply of working fluid through the discharge line to sprayers and the regulation of the dose rate by changing the static pressure, by using an equalizing tank, and most importantly, that the working fluid is sprayed by pneumatic slot sprayers of the Kuban State Agrarian University design.

Air from the tractor compressor is supplied with overpressure through the receiver and pressure regulator into the jet-forming nozzle. The high-speed jet ejects the working fluid coming from the tank into the feed tube of the sprayer. An essential feature of pneumatic slot sprayers is the creation of air-drop jets that allow the working fluid to be fed through the outlet openings of feed tubes of 3-6 mm to prevent clogging.

The special features of pneumatic-slot sprayers are the creation of high-speed jets capable of delivering the working fluid in directed jets without losses outside the treatment area. In addition, when operating the sprayers, it is possible to use the absorption principle, when the working fluid enters the feed tube of the sprayer by injecting a high-speed air jet flowing from the slot nozzle (Figure 1).

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At the same time, it is possible to use the inflow principle when the working fluid enters from a container located at a higher level relative to the jet nozzle (Figure 1).

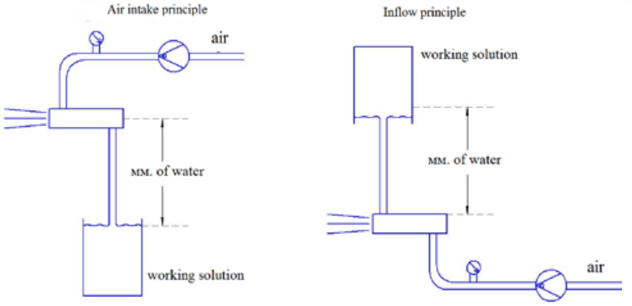

Fig. 1. Principles of operation of pneumatic slot sprayers: a-the principle of absorption; b - the principle of inflow

The use of these methods allows to create a more economical scheme of the technological process of forming an air-drop jet that treats plants, since there is no need to use sufficiently complex technical means, in the form of pumping devices and controlling and regulating units

A special feature of the pneumatic slot sprayer design is the creation of air jets by using slot nozzles of different designs.

For the formation of air jets in a jet generator, a pear-shaped nozzle or a "Vitoshinsky" type nozzle with different geometric parameters and operating in different modes are used, thanks to which the certain shape of the jet from the nozzle, the size of the spray torch, the size of drops on the surface of plants and the coating density of the treated objects are provided.

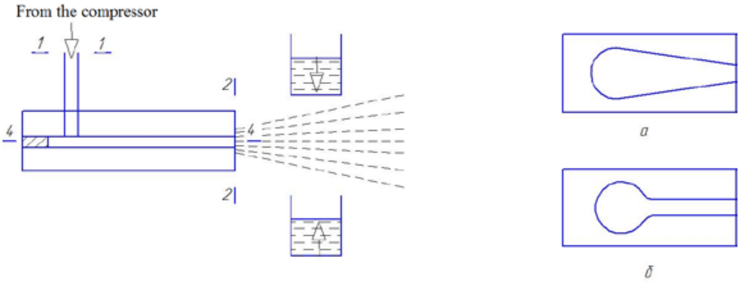

Fig. 2. Scheme of the pneumatic slot sprayer work: a – the pear-shaped nozzle; б – the nozzle "Vitoshinsky"

The technological process of the sprayer with a pneumatic slot sprayer is shown in Figure 3.

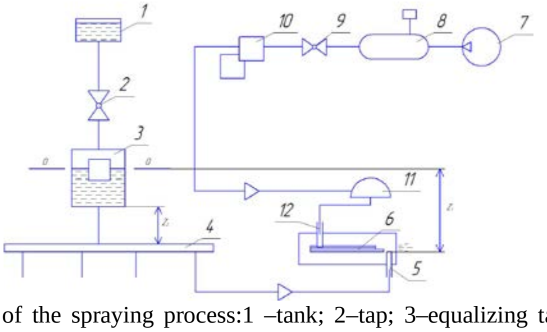

Fig. 3. Flow diagram of the spraying process:1 –tank; 2–tap; 3–equalizing tank; 4–distributor; 5–supplying tube; 6–sprayer; 7–compressor; 8–receiver; 9–tap; 10–pressure regulator; 11–air collector; 12–compressed air supply tube

To determine the parameters of a pneumatic slot sprayer, we use the Bernoulli equation, which is the equation of operation, that is, energy, where each of its items characterizes air energy, attributed to a unit of mass (J/kg) or specific energy.

The Bernoulli equation is the following:

$$\frac{R}{R-1}\frac{P_1}{p}+\frac{U_1^2}{2}=\frac{R}{R-1}\frac{P_2}{p}+\frac{U_2^2}{2}+\sum h, \qquad (1)$$

where $\frac{P}{p}$ – specific energy of pressure;

$\frac{U^2}{2}$ – specific kinematic energy;

$\sum h$ – energy losses under movement in a jet-forming slot sprayer;

$$\sum h = h' + h'',$$

h' – at turn energy losses occur at the transition of air jet from the inlet tube into the pear-shaped slot nozzle under the angle 0º, in our case under the angle 90º;

h'' – energy losses under the movement in a confuser;

$$h' = \frac{P_p}{p}. \qquad (2)$$

where P_p – pressure losses at turn defined from the equation:

$$P_p = \frac{p(U_1^2+U_2'^2-2U_1'^2\cdot U_2^2\cdot \cos\theta)}{2}, \qquad (3)$$

This dependence is obtained by considering the solution of a right triangle (Figure 4).

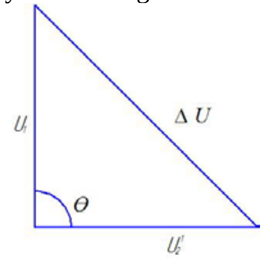

Fig. 4. Speed of the air jet after turning (U_2')

Getting into the pear-shaped nozzle, the jet loses speed as a result of movement in the confuser (Figure 5).

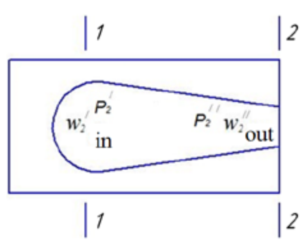

Fig. 5. Parameters of the slot nozzle of the jet generator

Pressure losses during movement in the confuser:

$$P_c = R_c\cdot\frac{pU_2^2}{2}(1-n), \qquad (4)$$

where $n=\frac{w_2''}{w_2'}=\frac{U_2'}{U_2''}$ (at Θ/2=30º).

After the transformation, the regression equation takes the form:

$$\frac{R}{R-1}\frac{P_1}{P}+\frac{U_1^2}{2}=\frac{R}{R-1}\frac{P_2}{p}+\frac{p_2}{p}+\frac{U_2^2}{2}+\frac{p(U_1^2+U_2^{;2}-2U_1^{;2}\cdot U_2^2\cdot cos\theta)}{2}+R_c\cdot\frac{pU_2^2}{2}(1-n). \quad (5)$$

Pressure generated by the air jet:

$$H=\frac{p_1}{p}-\frac{p_2}{p}, \quad (6)$$

where p_1 – air pressure in the inlet, in the nozzle;
p_2 – air pressure in the outlet from the nozzle;
p – air density плотность.

Solving together expressions (3), (4), (5), we get an expression for determining the pressure:

$$H=\frac{R-1}{R}\left\{\frac{U_2^2}{2}-\frac{U_1^2}{2}+\frac{U_1^2+U_2^{;2}-2U_1^{;2}\cdot U_2^2\cdot cos\theta}{2}+R_c\cdot\frac{pU_2^2}{2}(1-n)\right\}. \quad (7)$$

Substituting in the expression (7), according to the law of mass conservation:

$$U_1=\frac{Q}{w_1};U_2=\frac{Q}{w_2}$$

where *Q* – air consumption entering the jet nozzle, we get under pressure:

$$H=f(Q,w_1;w_2;w_2^{/};w_2^{//}). \quad (8)$$

Thus, the coefficient of resistance for the air flow when moving in the jet generator will be:

$$\xi_g=\xi_p+\xi_c,$$

$$\xi_g=0{,}23+0{,}2=0{,}43. \quad (9)$$

The coefficient at the outlet of the flow into the atmosphere depends, respectively, on the dynamic pressure at the inlet to the nozzle and the narrow cross-section of the confuser:

$$\xi_o=p\frac{w_{2o}^2}{2}, \quad (10)$$

where p – air compaction.
Since, according to the design features $w^{/}{}_{2_{in}}=a\cdot b$,

where $w^{/}{}_{2_{in}}$ – nozzle cross-sectional area at the inlet;
a – inlet nozzle thickness;
b – inlet nozzle width.

So, $w_{2вх}^{/}=25\cdot 0{,}3=7{,}5$ мм^2.

Outlet nozzle cross-sectional area:

$$w_{2o}^{//} = a \cdot b\,, \tag{11}$$

where *a*=0,3 mm, *в*=5 mm, respectively:

$$w_{2o}^{//} = 0{,}3 \cdot 5 = 1{,}5 \text{ мм}^2$$

Consequently, ξ_o = 0,04.

So, the resistance coefficient of the jet-forming nozzle:

$$\xi_g = \xi_p + \xi_c + \xi_o = 0{,}23 + 0{,}2 + 0{,}04 = 0{,}47. \tag{12}$$

The general formula of the gas mass flow rate is the following:

$$M = \mu w \sqrt{p_o p_o}, \tag{13}$$

where $\mu = \varphi\varepsilon\psi$ – the flow consumption coefficient for the case of the compressible liquid flow, where $\psi_{кр} = 0{,}68$ for air;
ε – the compression ratio;
φ – the velocity ratio which can be determined by the following dependence:

$$\varphi = \frac{1}{\sqrt{L_2 + \xi}}, \tag{14}$$

wherte L_2 – the Carliolis coefficient;
ξ – the resistance ratio.

Taking $L_2 = 1$; $\xi = 0{,}47$ (12) for our case, we have $\varphi = \frac{1}{\sqrt{1+0{,}47}} = 0{,}83$, and the coefficient of the consumption is $\mu = 0{,}83 \cdot 0{,}74 \cdot 0{,}68 = 0{,}41$.

Along with theoretical studies, experimental studies of air flow by pneumatic slot sprayers were carried out.

The sprayer was connected to a pneumatic line, into which air was supplied from the compressor, and a flow meter was installed before entering the slot nozzle to determine the air flow through the slot nozzle of the jet generator, which has a size of 0.3 mm × 5 mm at the outlet.

The pressure regulator sets the pressure from 0.05 to 0.3 MPa with an interval of 0.05 MPa. The flow meter showed the air flow rate in m^3/h.

The results of the studies were entered in the table, analyzing the flow parameters using sprayers with different slot nozzle shapes (one nozzle had a pear-shaped shape, the second “Vitoshinsky” nozzle with a mleniscate conjugation of generators), Figure 6.

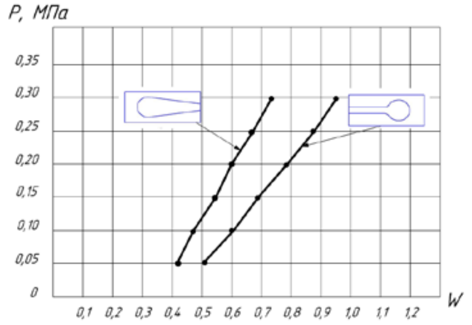

Fig. 6. Air flow consumption of the pneumatic slot sprayer

The following results were obtained: the maximum flow rate of the “Vitoshinsky” nozzle was 1.0 l/min, and from the pear-shaped nozzle 0.700 l/min at air pressure in the system of 0.3 MPa, and respectively 0.500 and 0.400 l/min at pressure of 0.05 MPa (Figure 6). This is due to the speed characteristics of nozzles. Higher values are typical for the “Vitoshinsky” nozzle, which determines the selection of the nozzle type for corresponding object processing tasks.

To reduce the energy consumption pneumatic slot sprayers, aggregated by tractors, and simplification of the design, it is recommended to use a compressor of a tractor to create air-drop jets of working fluids. The air consumption of the MTZ-80 type tractor compressors is 110-145 l/min.

It is possible to provide air from 6 to 12 pneumatic slot sprayers, depending on the shape of the air nozzles of the jet generators taking into account the losses of the working pressure created by the tractor's compressor when moving in pneumatic ducts and other elements of the sprayer.

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