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Experimental Studies of Parameters of Pneumatic Slot Sprayer

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ABSTRACT

This article describes the trends of application of protecting and stimulating agents aiming at increase in agricultural crop yield. A promising method to use protecting and stimulating agents is their simultaneous application and soil processing by disk harrow. This article proposes engineering flowchart of disk harrow equipped with atomizers with pneumatic slot sprayers. The description of design and operation of the proposed flowchart includes engineering features and possible adjustments of the proposed solutions. Aiming at efficient application of the proposed pneumatic slot sprayers, the article presents experimental results of studies of axial jet velocity of operating fluid depending on nozzle shape, air pressure and distance from the sprayer. As a result of this research, it is recommended to use jet generator with bulbous nozzle or Vitoshinsky nozzle. In addition, the analysis of sprayer capacity is described depending on position of surge drum, air pressure, and inclination angle of feeding tube. Based on experimental results, the regression equation is derived allowing to determine the sprayer variables required for application of preset flow rates of operating fluid.

Key words: pneumatic slot sprayer, protecting and stimulating agents, capacity, axial jet velocity, disk harrow.

1. INTRODUCTION

Modern conditions of global agrarian sector demonstrate not only its necessity for each single region but also its high cost efficiency stipulated by innovative technologies and tools required for individual procedures. Agricultural production can be intensified by energy saving technologies based on development and operation of integrated assemblies which can combine various procedures [1-7]. Based on the versatile analysis of advanced agricultural technologies, it can be concluded that the increase in agricultural crop yield is mainly determined by the use chemicals [8-14]. Therefore, it is required to develop new technologies and tools for combined use of individual procedures with simultaneous application of protecting and stimulating agents.

2. METHODS

A promising variant of integrated solution to the formulated problem is combined application of protecting and stimulating agents by spraying with simultaneous soil cultivation (ploughing, harrowing, cultivation, etc.) [2, 15-18]. In addition to major fertilizers and pesticides, the protecting and stimulating agents are comprised of microfertilizers, biological products, efficient microorganisms, and other biologically active substances characterized by fungicide and immune stimulating action. Their application would allow to decrease pesticide consumption by 20–30%, to increase crop yield and to improve sanitary hygienic situation of environment.

2.1 Formulation of requirements to the problem solution

However, equipment used for application of protecting and stimulating agents with simultaneous soil cultivation is structurally cumbersome and should be manufactured individually for each certain machine. This decreases its applicability upon various procedures, that is, it is required to operate several units of such equipment accompanied by deterioration of their amortization period. Therefore, a new approach to development of integrated units should be developed aiming at simultaneous soil cultivation and application of protecting and stimulating agents (PSA), oriented mainly at development of rapid change tools.

2.2 Overview of previous results

The engineering flowchart was presented [19-23] with pneumatic slot sprayers developed by KubGAU for application of PSA onto soil with simultaneous processing by disk harrow or integrated soil processing machinery.

A peculiar feature of this device is generation of finely-dispersed air-droplet jet feeding working fluid at sufficient velocity preventing its drift and providing uniform distribution over processed surface. In addition, the proposed flowchart makes it possible to vary the sizes of working fluid droplets in wide range.

The air-droplet jet is generated by jet generator with replaceable slot nozzle with the following sizes: 0.6×5; 0.3×5; 1.0×5 mm, and feeding pipe which supplies the working fluid to air jet from the nozzle with the diameter of 2–5 mm.

The assembly for application of PSA onto soil (Fig. 1) with their simultaneous embedding is comprised of the disk harrow 7 with the reservoir 1 for working fluid installed on its frame. In order to maintain the required static pressure after the reservoir 1, the surge tank 2 is installed from which, via the feeding pipelines 3, the working fluid is supplied to the pneumatic slot sprayers 4. In addition to the working fluid, the compressed air from the tractor compressor 8 is fed to the sprayers 4 via pneumatic pipelines 6. The air flow pressure can be monitored and adjusted by the pressure meter 9 with the valve 10 installed on the pneumatic pipeline.

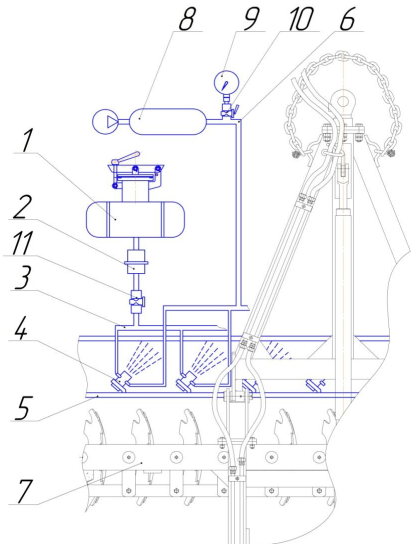

Figure 1: Assembly for addition of protecting and stimulating liquids into soil: 1 – reservoir; 2 – surge tank; 3 – feeding pipeline; 4 – pneumatic slot sprayer; 5 – apron; 6 – pneumatic pipeline; 7 – disk harrow; 8 – compressor; 9 – pressure meter; 10 – valve; 11 – shutoff device.

The pneumatic sprayers 4 are installed on the frame of the disk harrow 7 between the two aprons 5 which minimize contact between PSA and working elements. The projecting aprons 5 are required since the working fluid upon its application onto soil not only deposits on it but also is partially repelled, and movement of disk harrow results in generation of air resistance which also results in drifting of working fluid leading to contact between PSA with working elements, thus causing failure of the design [24-27]. In order to prevent PSA spillage upon idle run of the unit or upon its transportation, the working fluid supply is terminated by means of the shutoff device 11.

To widen the scope of functional capabilities of the unit, the two-jet sprayer is applied. The pneumatic slot sprayer (Fig. 2) is comprised of the body 3 where the confusor 4 is installed increasing air flow rate, and the diffusor 5 is installed on the opposite side decreasing the rate of dispersed working fluid 5 [19].

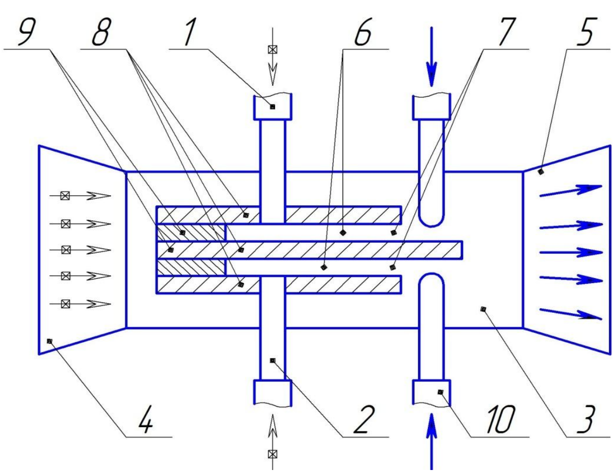

Figure 2: Pneumatic slot sprayer: 1 – air line; 2 – air pipe; 3 – body; 4 – confusor; 5 – diffusor; 6 – jet generator; 7 – nozzle; 8 – plate; 9 – gasket; 10 – feeding pipe.

In addition, three plates 8 are installed in the body with the gaskets 9 between them with continuous profile along the edges and cutouts inside. Due to the cutouts in internal parts of the gaskets 9 and the plates 8 above and below with regard to the middle plate, the jet generators 6 are formed, the outlet from which is made in the form of the nozzle 7. Compressed air is supplied via the air pipe 2 with the air line 1, and the working fluid is fed to the spraying area by means of the feeding pipes 10. Two jet generators 6 with two air nozzles 7 and two feeding pipes 10 increase the functional and engineering capabilities of the device due to increase in its capacity, jet density, and uniformity of its distribution.

The sprayer operates as follows. The working fluid by gravity is supplied from the reservoir 1 (Fig. 1) via the surge tank 2, the shutoff device 11 and the feeding pipelines 3 to the feeding pipes 10 (Fig. 2). Then, the working fluid contacts with the air jets from the upper and the lower nozzle 7 of the jet generators 6. Due to the confusor 5 and the body 7, the air jets are ejected and the obtained mixed air jets are injected and disperse the working fluid which is applied onto soil via the diffusor 5. Then, the disk harrows mix the working fluid with soil. In such operation mode the parameters of disk milling units can be remained unchanged [28-30].
The fluid flow rate is adjusted by selection of feeding pipes with predetermined diameter of outlet orifice and position of surge tank which maintains steady pressure (head) of the working fluid from the reservoir. Uniform distribution of the working fluid and density of soil covering are adjusted by the number of applied sprayers and the angle of their positions overlapped with regard to soil surface and direction of unit movement.

This design not only increases the sprayer capacity while retaining the required droplet sizes (mass median diameter) of 100–300 μm but also saturates soil with various substances, including biological products and microorganisms. It should be mentioned that some products should not be mixed or be exerted to excessive pressure upon jet generation, which is provided by pneumatic slot sprayers operating according to the proposed variant.

3. RESULTS AND DISCUSSION

The velocity of air-droplet jet provided by pneumatic slot sprayer depends on parameters of nozzle of slot jet generator, feeding pipes, and, respectively, sprayer capacity, which determines interdependence of the mentioned parameters. In addition, spraying can be performed via pneumatic slot with various shapes of slot nozzles of jet generators, namely: bulbous, Vitoshinsky, and straight [31-33].

Theoretical definition of working parameters of the sprayer is not unique and cannot be based only on analytical predictions, thus, it should be supported by experimental results. In order to perform experimental studies of air-droplet jet velocity, it is required first of all to determine the initial engineering parameters of pneumatic slot sprayer and experimental conditions.

Selection of the nozzle shapes is stipulated by generation of air-droplet jet characterized by the properties meeting the agrotechnical requirements to processing of agricultural objects with PSA. In this regard such air-droplet jet should be generated where mass median diameter off droplets is in the range of 80–300 µm and the covering density is at least 10 droplets/cm^2 upon ultra-low covering and at least 30 droplets/cm^2 upon low capacity covering. The diameter of outlet orifices of feeding pipes is from 2 to 5 mm. In its turn, this determined selection of the nozzle width of jet generator equaling to 5 mm aimed at flowing round and efficient action on working fluid jet from the feeder.

The selected nozzle thickness (0.3; 0.6; 1.0 mm) is stipulated by generation of air jet using the minimum air flow rate from compressor, that is, as a method of energy saving. This is important when energy is supplied from tractor compressor. Hence, arrangement of air duct from power source to sprayers is simplified and does not require for additional compressors, assemblies, units, etc.

The issue of working pressure is solved in a similar way. Compressors of 80–90 HP tractors and their analogs generate the maximum pressure up to 0.8 MPa. In this regard the studies were performed with the minimum pressure of 0.05 MPa sufficient for generation of droplet jet up to the maximum pressure of 0.3 MPa. Selection of working pressure depends on the number sprayers processing a given object.

The studies were aimed at determination of qualitative indices of soil spraying as well as of vegetables, arable and commercial crops upon various vegetation stages planted at various steps (norms, rates) and different width of row spacing; these factors determined the coverage density of working fluid droplets [34-38]. Therefore, the axial flow velocity of working fluid was detected by means of anemometer at the distance L equaling to 0.3; 0.6; 0.9; 1.2; and 1.5 m. The obtained initial parameters of the considered pneumatic slot sprayer as well as the measurement points of axial flow velocity are summarized in Table 1.

Table 1: Sprayer specifications and operation modes

Nozzle shape	Nozzle thickness, (*a*) mm	Nozzle width, (*b*) mm	Air pressure, (*P*) MPa	Distance from sprayer, (*L*) m
Bulbous Vitoshinsky Straight	0.3; 0.6; 1.0	5 mm	0.05; 0.1; 0.15; 0.2; 0.25; 0.3	0.3; 0.6; 0.9; 1.2; 1.5

Based on the experimental results, aiming at convenience and visualization of the obtained data, graphical dependences of axial flow velocity were plotted at various engineering parameters (Figs. 3, 4, and 5).

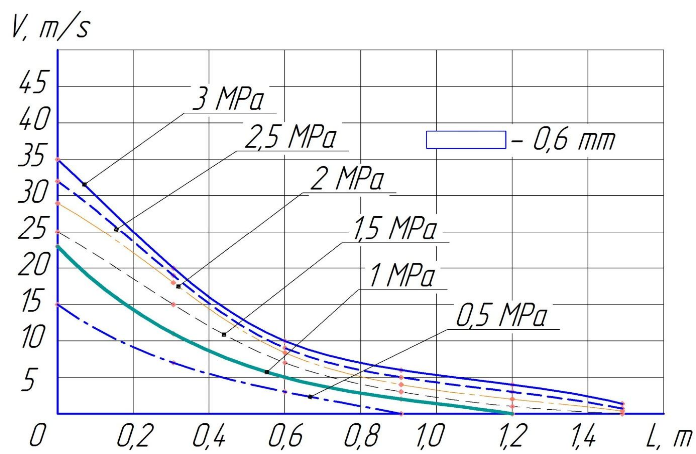

Figure 3: Axial flow velocity as a function of passed distance at the nozzle thickness a = 0.6 mm and straight shape.

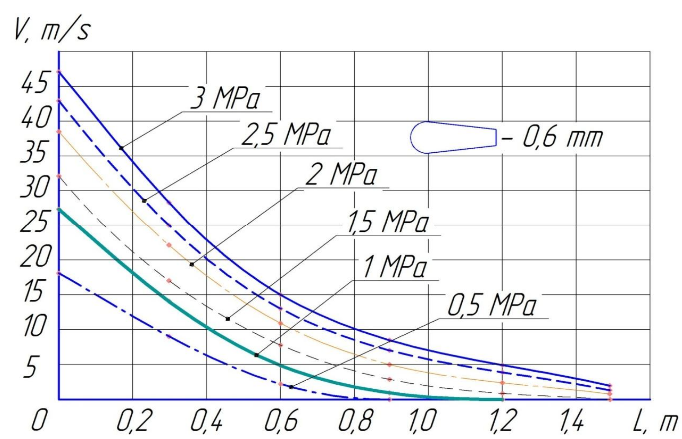

Figure 4: Axial flow velocity as a function of passed distance at the nozzle thickness a = 0.6 mm and bulbous shape.

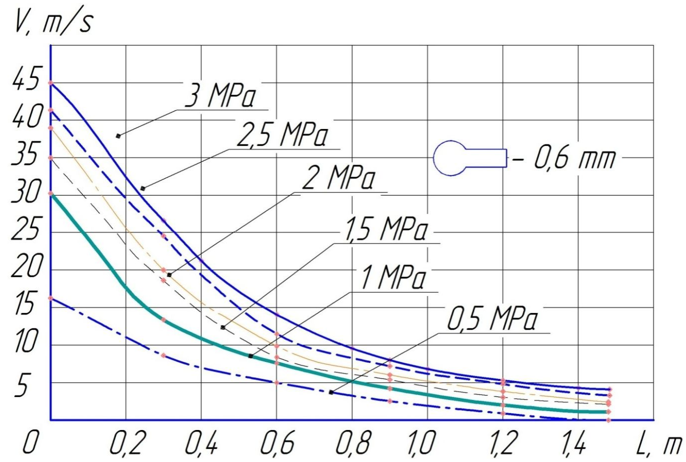

Figure 5: Axial flow velocity as a function of passed distance at the nozzle thickness a = 0.6 mm and Vitoshinsky shape.

The obtained plots demonstrate that the velocities varied according to logarithmic law. Herewith, the highest difference of the axial velocity of air jet as a function of air pressure at inlet of jet generator is at the distance up to L = 0.6-0.9 m from the sprayer, then the velocities with all nozzle shapes and pressures are relatively stable. The maximum axial velocity V_{max} = 45 m/s is for the jet generator with the Vitoshinsky nozzle, herewith, the jet propagates to the distance up to L = 1.5 m. The minimum velocity at nozzle output is V_{min} = 15 m/s at minimum pressure equaling to P = 0.5 MPa according to experiment design. The velocities as a function of pressure are varied with successive variation of operation parameters. Even at the minimum pressure, the action of air jet is finished at the distance of at least 0.8 m.

While considering the velocities of jet generator with bulbous nozzle, the observed maximum axial velocity at P = 3.0 MPa is V_{max} = 35-37 m/s, the minimum velocity is V_{min} = 15 m/s at P = 0,5 m/s, decrease to zero occurs at the distance of about L = 0.6 m.

For the jet generator with straight nozzle, the maximum velocity is V_{max} = 30 m/s and the minimum velocity is V_{min} = 12 m/s. The jet distance at P = 0.3 MPa is L = 1.2 m.

On the basis of the obtained data, it is possible to conclude that the most optimum and efficient processing can be achieved by the jet generator with bulbous nozzle or Vitoshinsky nozzle.

In addition to the axial jet velocity which effects the precipitation rate of working fluid, another important operation performance of pneumatic slot sprayer is its capacity which also depends on a set of factors [34]. The capacity of pneumatic slot sprayer was studied using central rotatable composite design [31]. The influence of active factors was studied. The factors are summarized in Table 2 with their variation intervals.

Table 2: Factors, intervals, and levels of variations

Factors	Coded notation of factors	Variation interval	Factor levels				
			-1.682	-1	0	+1	+1.682
Position of surge tank (h), cm	x_1	5	-8.41	-5	0	+5	+8.41
Air pressure (P), MPa	x_2	0.05	0.066	0.1	0.15	0.2	0.236
Inclination angle of feeding pipe (α), deg.	x_3	18	30	42	60	78	90

The levels and intervals of factor variation were selected from the following considerations. Preliminary studies of the maximum and minimum positions of the surge tank demonstrated that aiming at uninterrupted sprayer operation, the surge tank position should be in the limits of ±10 cm. This fact, upon its imposition on the experimental design, makes it possible to conclude that the surge tank position should be varied in the limits of ±5 cm, which would retain variations of the parameters in the star points without leaving the area of factor determination. Therefore, the level of working fluid corresponding to the position of surge tank is identical to output orifice of feeding pipe, it is the zero point of the factor x_1. In addition, no spontaneous efflux of working fluid from the feeding pipe occurred upon sprayer shutoff. The working fluid was supplied in the zero point without injecting, thus proving possibility of its application [17, 22, 37].

In the case of simultaneously operating sprayers in the amount of n = 8 pieces, the air supply from tractor compressor at the pressure of P = 0.2 MPa is sufficient. This pressure was set as maximum for the second factor. The pressure below P = 0.1 MPa for sprayer operation was considered as inefficient due to low sprayer capacity. Thus, this variation interval was adopted for variation of the second factor x_2 in the experiment design. In addition, in order to obtain more complete data on the influence of pressure on the capacity of pneumatic slot sprayer, the star points of the experiment will be outside of this interval.

Regarding the third factor, the inclination angles of feeding pipe were set to 30º and 90º accounting for the sprayer operability. These values were selected as the star points, thus allowing to select zero level of the third factor x_3 as well as the interval of its variation.

The experiments were carried out according to standard procedure based on the matrix of experiment design. The experiments were carried out in random order. The average values of optimization parameters were determined.

Based on the experimental results after their statistical processing, the response surface was determined described as follows:

$$y_{cap} = 130.949 + 61.93x_1 + 5.582x_3 + 19.125x_1x_2 + 1.598x_1^2 + 0.891x_3^2, \quad (1)$$

where y_{cap} was the sprayer capacity, l/min; x_1 was the surge tank position, cm; x_2 was the air pressure, MPa; x_3 was the feeding pipe inclination angle, deg.

The response surface plotted by the experimental results is hyperbolic paraboloid. Let us analyze the response surface (Fig. 6) upon fixed optimum position of the second factor. It is possible to conclude that the capacity can be increased significantly.

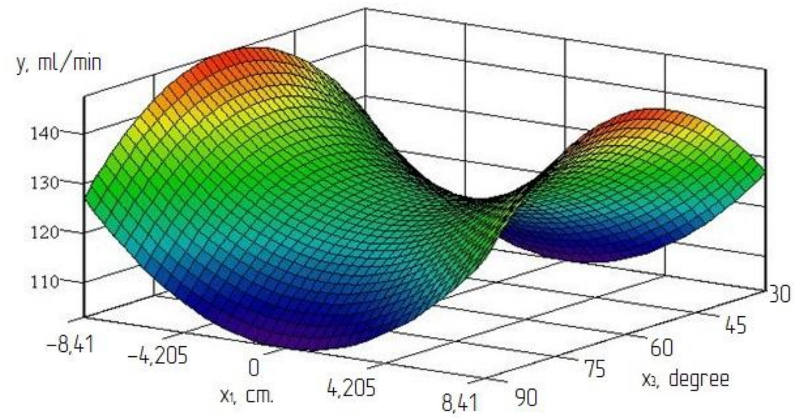

Figure 6: Response surface of sprayer capacity at air pressure P = 0.111 MPa.

With the aim of convenience and visualization of the influence of each factor on the optimization criterion, the obtained regression equation was reduced to regular canonic form and truncated by 2D cross section (Fig. 7).

The system of isolines plotted according to canonic equation demonstrates that the sprayer capacity strongly depends on variation of surge tank height h and the minimum angles of feeding pipe α.

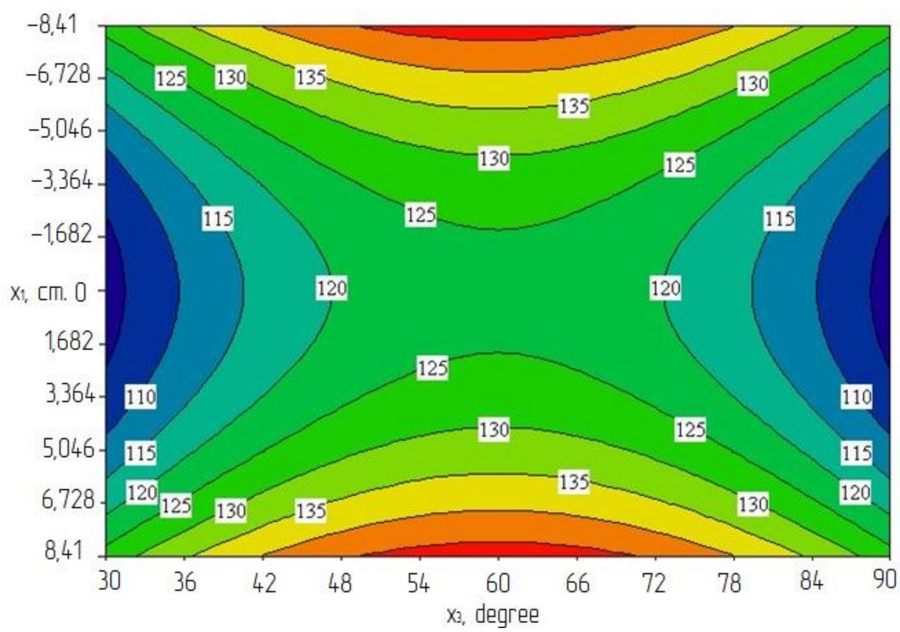

Figure 7: 2D section of response surface.

The limits of the sprayer capacity were determined varying in the range from 0.06 to 0.95 l/min, confirming wide possibilities of practical application of pneumatic slot sprayers.

5. CONCLUSION

A promising approach to improve agricultural crop yield is more efficient application of PSA. In order to apply PSA simultaneously with soil cultivation, the engineering flowchart has been proposed comprised of disk harrow and atomizer with pneumatic slot sprayers. On the basis of experimental studies of axial jet velocity of pneumatic slot sprayer, it is recommended to apply jet generator with bulbous nozzle or Vitoshinsky nozzle. Based on analysis of the influence of position of surge tank, air pressure, and inclination angle of feed pipe on the sprayer capacity, the regression equation has been derived allowing to determine the sprayer variables required for application of preset flow rates of operating fluid.

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