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THE EFFECT OF A LATERAL AIRFLOW CREATED ON NOZZLE TIP ON THE SPRAY DROPLETS DEPOSITION

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ABSTRACT. Improved application efficacy of a plant protection products by using a pneumatic device to change the dispersion of spray droplets is depended on the intensity of crosswind. The laboratory investigations of the spraying process of plants by means of the nozzles of a pneumatic system determined the quality indicators of pressure in the injection process of 0.4 MPa – the droplet coating density of 19–46 pcs $cm^{2\,-1}$ for the weighted mean droplet diameters (WMD) in the other experimental variants was within 304–543 μm. These indicators were compared with those for the standard, anti-drift and air injection nozzle types in which the droplet coating density was 23–59 pcs $cm^{2\,-1}$ and the weighted mean droplet diameters (WMD) were in the range of 350 to 485 μm. An analytical dependence was obtained of the influence of the lateral airflow and air pressure in the pneumatic system upon the amount of the deposited spray liquid.

Introduction

To increase the yield in agricultural crops, it is important to controlling pests (weeds, pests and diseases) (Directive 2009; Arvidsson *et al*., 2011; Hanafi *et al*., 2016; Ivanovs *et al*., 2018; Pascuzzi *et al*., 2020). Unless appropriate means of protection are taken in due time, the crop losses (based on FAO), can reach up to 30% of the potential crop, and the grown products lose their quality and cannot be used for the purpose they are intended (IYPN, 2020).

Intensification of agricultural production and wide-spread introduction of mechanized technologies for growing field crops require use application of the plant protection means. Such increase poses an acute problem how to reduce their impact upon the ecology of the environment and contamination of the food products with the residual amount of pesticides. The process of applying pesticides is accompanied by losses, in particular, the drift of droplets of the working fluid by the wind outside the processing zone. Particularly urgent is the problem of the drift of the preparation during its application under unfavorable weather conditions, caused by windy weather, as a result of which the efficiency of plant protection with the preparations decreases, and the load on the ecology of the environment increases (Fritz, 2006; Wang *et al*., 2015; Fornasiero *et al*., 2017). One of such technical solutions is applying a sprayer equipped with a pneumatic device to force the droplet to move downward, leading a better deposition of the working fluid of which corresponds to the spraying of standard, anti-drift and air injection nozzles, which makes it essentially universal (Felsot *et al*., 2011; Yuan *et al*., 2013).

Based on the literature (Jasinskas *et al*., 2015; Aliverdi, Zarei, 2020; Biocca *et al*., 2021), there have been determined the main trends in the development of technical means of plant protection, aimed at improving the assimilation of chemical preparations by the plant. To solve this problem, the European manufacturers use devices with air supply to the nozzle. The TeeJet has developed the AirJet nozzle (Fig. 1) and the AirMatic controller for the implementation of pneumatic spraying (Kravchuk *et al*., 2004; TeeJet Technologies, 2014).

The advantage of pneumatic spraying is that the droplet size is adjusted during operation. Even with the same droplet size, in contrast to the conventional atomizers, we can get a lesser drift at windy conditions. The principle of operation of this nozzle is that air and the working fluid are fed into the mixing chamber, where emulsion is formed, which reaches the plant through a deflector sprayer. To study the pneumatic spraying process, a prototype of a pneumatic nozzle is shown in Figure 2. A pneumatic system of a sprayer with AirJet nozzles is shown in Figure 3.

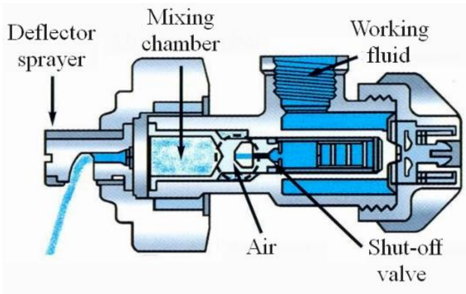
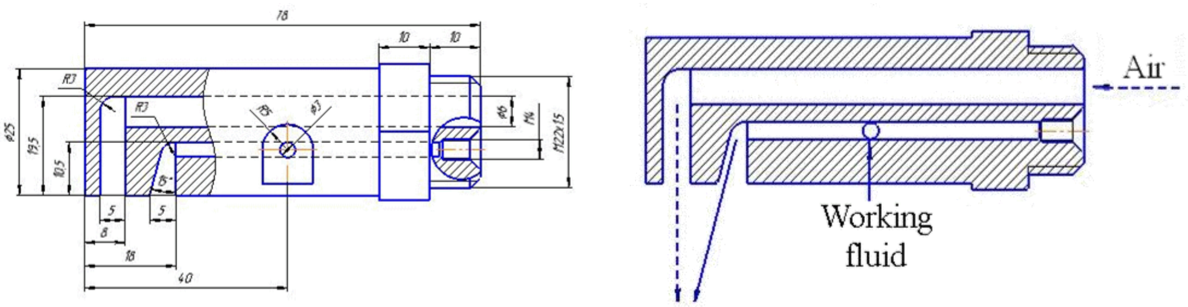


Figure 1. Hydropneumatic deflector AirJet nozzle (TeeJet Technologies)



a) b)

Figure 2. A scheme (a) and cross-section (b) of the pneumatic hydraulic nozzle

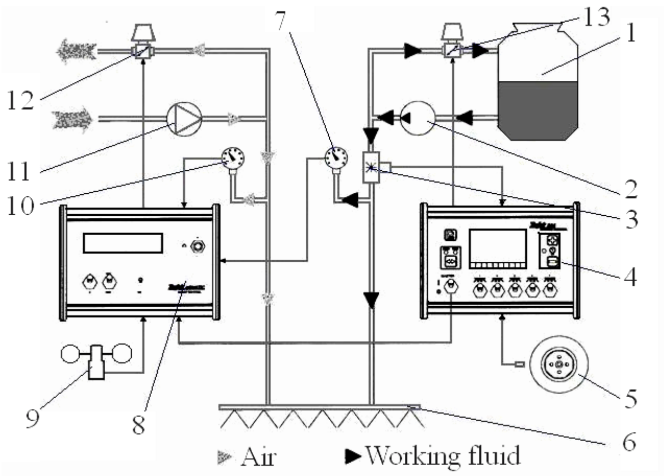


Figure 3. The pneumatic system of a sprayer with the Airjet nozzles (TeeJet Technologies): 1 – a tank for the working fluid; 2 – a membrane-piston pump; 3 – a flow meter; 4 – a liquid flow control console; 5 – a touch sensor of the wheel movement; 6 – a manifold with the pneumatic sprayers; 7 – a pressure sensor; 8 – an airflow control panel; 9 – a wind speed sensor; 10 – a pressure sensor 2.5 – bar; 11 – an oil-free compressor; 12 – a control valve (for air); 13 – a control valve (for the liquid)

In this pneumatic system, the airflow pressure is always adjusted to the variable fluid pressure in the system. The fluid pressure, in its turn, is adjusts to the change in the wind speed in the processed area of the field. These two systems work as a whole. The main task that these systems perform is to maintain the required constant dispersion of the droplet spraying, depending on the cultivated crop, the speed of the lateral airflow at the present time at a stable rate of application of the working fluid per hectare. This system operates in four modes of operation depending on the air pressure in the pneumatic system. The pressure of the liquid and air are interconnected through the graphical dependences of the droplet size on the three modes of the wind speed programmed in the system.

The purpose of the work was to study the possibilities how to increase the efficacy of the use of the plant protection means, by using a pneumatic device to change the spraying dispersion of the droplets, depending on the intensity of the lateral wind.

Materials and Methods

The laboratory investigations were carried out on an experimental setup, a general view of which is shown in Figure 4.

a)

b)

Figure 4. A general view of the experimental setup and the spraying process: a) pumping device and adjuster; b) customized laboratory equipment.

The experimental setup was a pneumatic fluid sprayer, installed directly into the manifold. A voltage piston-diaphragm pump, using hoses, from a 100 L tank, supplied the working fluid. Air was supplied from a cylinder by air, compressed up to 5.5 MPa, through a reducer located directly on the cylinder. A valve adjusted the air pressure, and the pressure of the working fluid and pressure gauges adjusted air.

The liquid supply and spraying system contained a liquid tank with a filter, a membrane pump 8000-543-138 SHURflo with a high-pressure filter (up to 0.68 MPa) from the HYPRO Company, which was connected to a laboratory DC source of the LIPS-35 device with a voltage of 12 V (Fig. 4). The prototype of the pneumatic sprayer, installed directly into the manifold, the sleeves, and the adjusting valve with a pressure gauge were fixed directly on the manifold holder. The working pressure of the fluid in the manifold was regulated by means of a valve and monitored by a pressure gauge. The studies were performed at the height of installation of the sprayer, 60 cm above the corrugated surface.

The device for creating a lateral airflow is driven by a centrifugal fan. The airflow rate was adjusted by changing the amount of the air entering the fan due to blocking its inlet.

The setup for collecting liquid contains was a corrugated surface, installed with a slope for water drainage, with a depression pitch of 48 mm. The liquid, settled from the sprayer, was collected into containers, installed under these depressions.

The objective of the experimental study was to optimize the processes of deposition of the sprayed liquid on the corrugated surface. The variable factors were the lateral airflow velocity and the air pressure in the pneumatic system.

During the deposition process of the liquid, sprayed onto the corrugated surface, the following indicators were determined: the liquid flow rate through the sprayer, the speed of the lateral airflow created by the centrifugal fan, the air pressure in the pneumatic system, and the mass of the liquid collected in the container. The liquid flow rate through the sprayers at a constant pressure of 0.4 MPa was determined in accordance with Standard ISO 22866:2005 for one minute with an accuracy of 0.1 g by weighing these containers on an electronic balance CERTUS BALANCE. The value of the working pressure was set according to the EN 837-1 standard using a WIKAI manometer, installed in the manifold with a sprayer, the measurement range being 0–2.5 MPa, the measurement accuracy of the manometer – 0.01 MPa.

The speed of the airflow, created by the centrifugal fan at the location of the prototype sprayer, was determined using a SKYWATCH ATMOS digital anemometer with a measurement range from 2 to 42 m s^{-1}; the anemometer measurement accuracy was ± 3%. The pressure in the compressed air supply system was measured using pressure gauges, installed on the reducer.

Influence of various factors upon the value of drift and deposition of the sprayed liquid was assessed by the method of planning a two-factor experiment.

Before conducting the research, the corrugated surface was moistened with water and kept in a wet state during the research. The investigations were performed at a constant pressure of the liquid of 0.4 MPa and the air pressure from 0 to 0.3 MPa, and the sprayer height above the corrugated surface of 60 cm. In addition, the sprayer was located above the thirteenth depression of the corrugated surface, counting from the manifold holder with the pneumatic sprayer. The sprayer was installed so that the spraying pattern was perpendicular to the direction of the depressions of the corrugated surface.

Investigation of the drift of the drops was carried out at the lateral airflow rates: 0; 3.0 and 6.0 m s^{-1}. The collection time of the liquid, sprayed on the corrugated surface, was 1 min. After the end of each spraying cycle, we waited up to 5 minutes for all the liquid to drain into the container, and then measured these containers with the liquid in it on the measuring glass.

Processing of the research results made on a personal computer using the methods of mathematical statistics. Data processing was used to determine the distribution of liquid by weight along the entire length of the corrugated surface of the laboratory setup. As the optimization criterion there was taken the mass of the liquid collected in the container under the corrugated surface, within the actual area of action of the pneumatic sprayer from 0 to 158.4 cm.

Setting of the dispersion parameters of spraying took place due to the control of the drops, trapped on the distribution pattern, depending on the intensity of the lateral wind, artificially created by an axial fan. The purpose of the laboratory investigations was also to establish the value of the drift of the drops from the actual zone of spraying of the liquid by the pneumatic sprayer at different speeds of the lateral wind and variable parameters of the air pressure in the pneumatic liquid spraying system. The amount of liquid that settled along the operating width of the sprayer at different distances from it was determined in accordance with Standard ISO 22866:2005 and Standard of Ukraine 74.3-37-266:2005.

During the study of the performance indicators of the pneumatic sprayer there was a comparison made of the spraying dispersion of droplets of the prototype sample with the dispersion of the injection IDK-120-04, anti-drift AD-120-04 and standard ST-110-04 nozzles. Comparison of these research results was performed at a working fluid pressure of 0.4 MPa, an air pressure in the pneumatic system of 0.1; 0.2; 0.3 MPa, but without the action of the artificially created lateral airflow.

Results

Processing of the results of the conducted laboratory investigations in order to determine the efficiency of application of the pneumatic sprayers for spraying a liquid revealed an improvement in the quality of the spraying process and savings of the plant protection means.

Diagrams of the droplet distribution by the prototype pneumatic sprayer are shown in Figures 6 and 7 at a fluid pressure in the system of 0.4 MPa.

By microscopic analysis of the cards there was established the value of the density of the droplet deposition on the treated surface and their weighted mean diameter (WMD) and mass-median-diameter (MMD), which at a pressure in the injection communication of 0.4 MPa are, respectively: 19–46 pcs $cm^{2\,-1}$ and 304–543 µm for a pneumatic sprayer; 23–59 pcs $cm^{2\,-1}$ and 350–485 µm for standard, anti-drift and injection nozzles. As evident from Table 1, the spray by one «universal» pneumatic sprayer corresponds to the total spray of three different types of sprayers, and it is this circumstance that makes it universal.

These investigations confirmed the possibility to influence the dispersion of the droplet spraying by changing the air pressure in the pneumatic system depending on the change in the intensity of the lateral airflow.

The results of microscopic processing of the distribution pattern are listed in Table 1.

Impact of factors upon the amount of the collected sprayed liquid

Factors, their code designation and levels during the two-factor experiment in order to establish the impact of factors (the lateral airflow velocity and air pressure in the pneumatic system) are shown in Table 2.

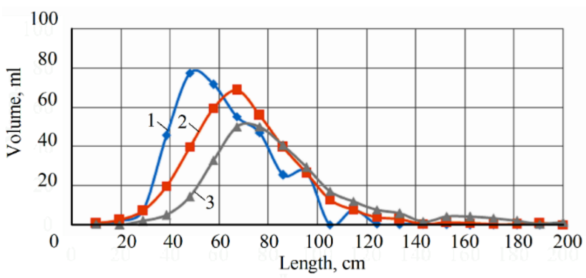


Figure 6. Distribution of the sprayed liquid over the corrugated surface at a speed of the lateral airflow of 0–6 m s^{-1} and air pressure in the pneumatic system to 0.15 MPa: 1 – V = 0 m s^{-1}; 2 – V = 3 m s^{-1}; 3 – V = 6 m s^{-1}

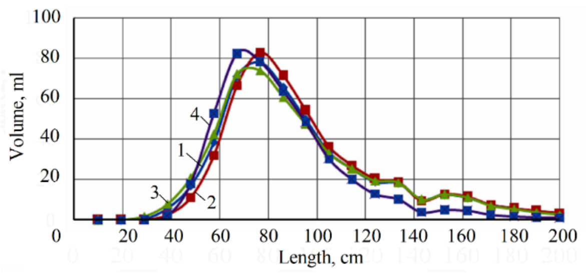


Figure 7. Distribution of the liquid over the corrugated surface depending on the air pressure in the pneumatic system 0–0.15 MPa at speed of a lateral air stream of 6 m s^{-1}: 1 – P_p = 0 MPa; 2 – P_p = 0.05 MPa; 3 – P_p = 0.10 MPa; 3 – P_p = 0.15 Mpa

Table 1. Microscopic processing of the distribution pattern at a fluid pressure of 0.4 Mpa

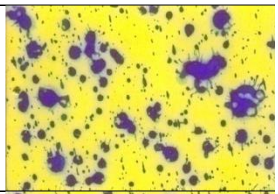
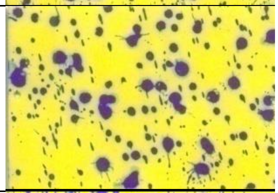
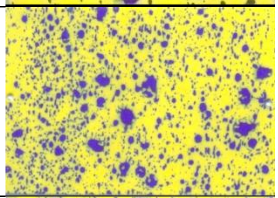
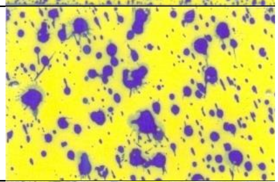
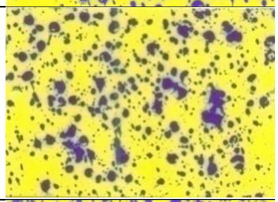
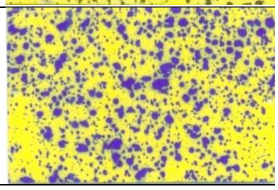
Number of drops, pcs cm^{2-1}	WMD, µm	Air pressure, MPa	Nozzles	MMD, µm	Polydispersity coefficient, µm	Distribution pattern
19	543	0.1	Pneumatic	1 125	3.73	
29	393	0.2		515	3.36	
46	304	0.3		495	4.50	
23	485	0	IDK-120-04 	860	2.24	
43	410	0	AD-120-04 	574	3.67	
59	350	0	ST-110-04 	488	4.19	

Table 2. Levels of the laboratory research factors of a prototype model of the pneumatic setup

Name of the factor	Designation	Variation levels of factors			Variation interval
		upper (1)	Zero (0)	Lower (-1)	
The airflow velocity V, m s^{-1}	X_1	6	3	0	3
The working air pressure in system P_p, MPa	X_2	0.2	0.1	0	0.1

Table 3. The results of the implementation the matrix of a two-factor experiment of the prototype model of the pneumatic setup

No.	V, m s^{-1}	P_p, MPa	Collected liquid (Q), kg
1	0	0.00	1.041
2	0	0.15	1.001
3	0	0.20	0.880
4	3	0.00	1.018
5	3	0.10	0.971
6	3	0.15	0.865
7	6	0.00	0.974
8	6	0.05	0.974
9	6	0.10	0.960

But the mass of the liquid, sprayed by the prototype model of the pneumatic sprayer, that has settled within the actual coverage of the corrugated surface by the sprayer flow, which in this case is already 295 cm, is shown in Table 3.

All the investigations were carried out at a constant fluid pressure in the pneumatic system of 0.4 MPa, the height of the sprayer above the corrugated surface of 0.6 m, the collection time of one minute at a relative atmospheric humidity of 57% and an air temperature of 22 °C.

Analysis of the data in Table 3 showed that the amount of the liquid sprayed by the prototype model of the pneumatic sprayer at the air pressure of up to 0.1 MPa has little effect upon the dispersion of the droplet spraying since a small amount of liquid is carried away by a lateral airflow, and this indicates that in the fraction of small droplets there is a fairly small number of them. But at an air pressure of more than 0.12 MPa, it is observed that the airflow begins to affect more the dispersion of the droplets.

According to the conducted studies of the deposition process of the droplets, sprayed under the impact of the lateral airflow and the air pressure in the pneumatic system of the prototype of the pneumatic sprayer above the corrugated surface, the obtained analytical dependence is:

$$Q = -4.39P_p^2 - 0.13V + 1.06, \qquad (1)$$

where Q – the amount of liquid that has passed through the sprayer, l min^{-1};
P_p – the air pressure in the pneumatic system, MPa;
V – velocity of the lateral airflow, m s^{-1}.

This equation is adequate for the probability $\rho = 0.9$. The obtained analytical dependence makes it possible to determine the amount of the deposited sprayed liquid at the corresponding values of the variable factors.

Conclusions

1. Trends in the development of the technical means of chemical plant protection have been determined: application of pneumatic sprayers that are capable to change the spraying dispersion of the droplets depending on the intensity of the lateral airflow, which allows the operator to work in a wider range of the wind speeds (up to 9 m s^{-1}) and the movement of the aggregate (up to 25 km h^{-1}). To improve the quality of the spraying, devices with the air supply into the nozzles are used to regulate the spraying dispersion depending on the intensity of the lateral wind while maintaining a pre-set rate of application of the working fluid per hectare.
2. As a result of investigations, there was revealed a possibility to influence the air pressure upon the spraying dispersion of the droplets. It has been experimentally established that with an increase in the air pressure in the pneumatic system, starting from 0.12 MPa, a decrease in the diameter of the sprayed drops is observed, and after an increase in the air pressure of more than 0.25 MPa, spraying takes place that is equivalent to a standard fine-dispersed slot sprayer.

Conflict of interest

The author declares that there is no conflict of interest regarding the publication of this paper.

Author contributions

VB, JO, VA – study conception and design;
VB, JO – drafting of the manuscript;
VB, VA, JO, SP – analysis and interpretation of data;
JG, SI, SP, YI – acquisition of data.
JO – critical revision and approval of the final manuscript.
All authors have read and agreed to the published version of manuscripts.

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