Original Research

The Influence of Wind Speed and Atomization Degree on Distribution of Liquid Fall under the Nozzle

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Abstract

The aim of this research was to determine the influence of atomization degree change on distribution of atomized liquid fall taking place under conditions of airflow of varied speed, and define liquid fall characteristics for different nozzles in variable parameters and conditions such as airflow speed, liquid pressure, and atomization height. The research was done in laboratory conditions in a wind tunnel. The results showed that within the range of the accepted work conditions of the selected nozzles, the greater degree of atomization does not impair the distribution of liquid fall over the atomized area.

Keywords: airflow, atomizer, atomized liquid fall

Introduction

Liquid atomization as a classical unit operation can be applied in various fields of man's economic activity. Among other things, it has significant influence on agriculture, especially in terms of chemical protection of plants. The main goal of this process is to increase the surface of interfacial contact in the atomized system determined by the sum of surfaces of single drops within this system. Nozzles, which can be divided considering the type of energy required for liquid dissolution, serve the purpose of liquid atomization. It can come from the liquid's internal pressure (as in the case of pressure nozzles), it can be delivered by, another medium (as in the case of pneumatic nozzles), or it can be delivered by mechanical energy (rotational nozzles). Pressure nozzles are most often used for protection of arable crops, since they are the least complicated and the cheapest, and thus they require the least atomization energy [1]. Their principle of operation is based on injecting liquid under pressure by the sprayer's nozzle. In such a case potential energy is turned into the kinetic energy of the liquid. Liquid preparations available as water, oil, or water-oil solutions of various concentrations, the influence of which is different throughout the atomization process, are used for plant protection. However, pure water can also be used for scientific research and the results can be treated as a comparison with those which would be obtained from the use of liquids characterized by various, most often very little concentration. The atomized liquid should then be treated as the Newtonian fluid [2]. The proper functioning of a nozzle is evaluated above all through the level and uniformity of drift as well as the appropriate degree of the sprayed object's coverage [3]. One of the criteria that is most often used for the evaluation of the quality of the sprayers' work is the lateral distribution variability index, the degree of atomized surface coverage, the number of drops per square centimeter, and the drift of the spray liquid measured in micrograms per square centimeter [4, 5].

The important parameter is the angle of atomization that determines the height of the beam's setting over

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the sprayed area. As Nowakowski and Chlebowski [6] demonstrate, the angle of atomization changes together with the change of pressure although it is described by the constructor as one that is constant for the particular construction of a nozzle. The greater the pressure, the wider the angle but such variation applies more to standard slotted nozzles rather than electrode ones. In the case of pressure atomizers the degree of atomization depends on the working pressure applied according to the rule stating that the greater the pressure the wider the angle of atomization. The size of drops of the sprayed liquid and their dose per square meter are related to the degree of sprayed objects' coverage which, among other things, determines the operation's efficiency. The greatest difficulty during the process of atomization is the large heterogeneity of the drops' size. The smallest drops evaporate very quickly and are easily drifted by the wind. Counteraction to such a situation requires the use of various atomization techniques that are adjusted to the type of operation as well as weather conditions. The most important parameter that is used to adjust the degree of atomization to the occurring conditions is the liquid's pressure. The pressure is closely related to the liquid's distribution, which in turn affects covering the sprayed objects with liquid and determines the drift of plant pesticides as well as the operation's efficiency [7]. Another factor that allows the adjustment of proper atomization to occurring conditions and the kind of operation is the type of sprayer. The change of droplet spectrum in pressure sprayers is unfortunately connected with the change of the liquid's intensity of the outflow, which in turn complicates the course of the operation. In order to avoid the change of the nozzle stream's droplet spectrum and the simultaneous change of the intensity of the outflow, which is common for sprayers of traditional construction, an attempt (with relatively good results) was made to apply a special device allowing the liquid stream's buzz [8].

These actions however, still remain at the stage of experimentation. As it was also stated, the degree of the liquid's atomization is closely connected with the drift phenomenon in case of unfavorable weather conditions, especially strong wind. The research on this phenomenon in natural conditions is expensive, difficult, and labour-consuming. It is easier to carry out research that checks the influence of the atomization's conditions and parameters on the drift inside a wind tunnel, which saves both time and expense. For many researchers such results are sufficient [9, 10]. It was confirmed by the research on drift conducted at Silsoe Research Institute, where wind tunnel research was compared to one in the field and the results in both cases were similar [11, 12]. Agüera and others [13], while using the mathematical modeling based on geometrical features of hydraulic nozzles, have also received results of the simulated atomization spectrum that were compatible with the actual results. Other researchers using artificial neuron networks received high correlation between the modeling results and the experimental research [14]. In many quoted publications the authors dealt with the influence of atomization degree on liquid drift while paying less attention to the influence of degree of atomization on distribution of liquid over the area located directly under the nozzle, which is clearly connected with the degree of coverage of sprayed plants and thus with spraying efficiency.

The efficiency of the spray can't be the sole purpose for the use of pesticides. The spraying must take into account all aspects of plant protection in the assessment of the potential environmental risks of pesticides resulting from the use of pesticides and continuous monitoring of pesticide residues in agricultural plants [15, 16].

The aim of the conducted research was to determine the influence of degree of atomization change on the distribution of a sprayed liquid's fall over the area located directly under the sprayer and the characteristics of liquid fall for selected sprayers in changing conditions and parameters of spraying.

Experimental Procedures

The following parameters of nozzles' work were used for the research:

- the height of the nozzle's setting h = 0.4; 0.5; 0.6; 0.7 m
- liquid's pressure p = 0.1; 0.2; 0.3; 0.4; 0.5; 0.6 MPa
- air flow speed v_w = 0; 1.5; 3.0; 4.5 $m{\cdot}s^{-1}$

The subjects of the research were ejector AI 11003 VS and universal XR 11003 VP TeeJet brand nozzles. Table 1 contains characteristics of the stream sprayed by both selected nozzles obtained with the use of liquid pressure used in measurement. The values determining the degree of atomization such as VMD- volumetric median and NMD- numerical median were particularly important. On the basis of this data it was possible to determine the degree of liquid atomization which, according to BCPC, in the case of universal nozzle (XR 11003) allowed to obtain medium drops, whereas in the case of the ejector nozzle (AI11003) the atomization gave very thick drops [17]. Such a big difference in the degree of atomization

Table 1. Characteristics of the sprayed stream chosen for testing the nozzles [17].

Nozzle type	Intensity of the outflow from the nozzle q [l min^{-1}]	Liquid pressure p [MPa]	Degree of liquid atomization parameters [μm]	
			VMD	NMD
XR 11003 VP	0,73	0,10	262,5	154,1
XR 11003 VP	0,96	0,20	229,4	133,3
XR 11003 VP	1,17	0,30	248,8	114,7
AI 11003 VS	1,18	0,30	495,0	221,2
AI 11003 VS	1,36	0,40	475,3	231,0
AI 11003 VS	1,49	0.50	443,3	221,3
AI 11003 VS	1,61	0,60	418,8	208,3

should result in significantly different behaviour of the sprayed stream during atomization.

In order to understand the behaviour of drops creating the sprayed stream during atomization when the drops are affected by the air flow with the speed resulting from the calculus of vectors of the initial velocity of the drops that are leaving the nozzle and the resultant velocity of the so-called apparent wind resulting from the sprayer's movement and the atmospheric wind. Fig. 1 presents the theoretical outline of the track, which can be made by a sprayed stream after the drop fall on the sprayed area in windless conditions a) and during the wind (b). In the case of the wind affecting the sprayed stream, the outline of the sprayed liquid's fall depends on the wind speed and the degree of atomization. The liquid's distribution under the nozzle is also affected by the initial velocity of the sprayed drops, which is connected with the applied liquid pressure.

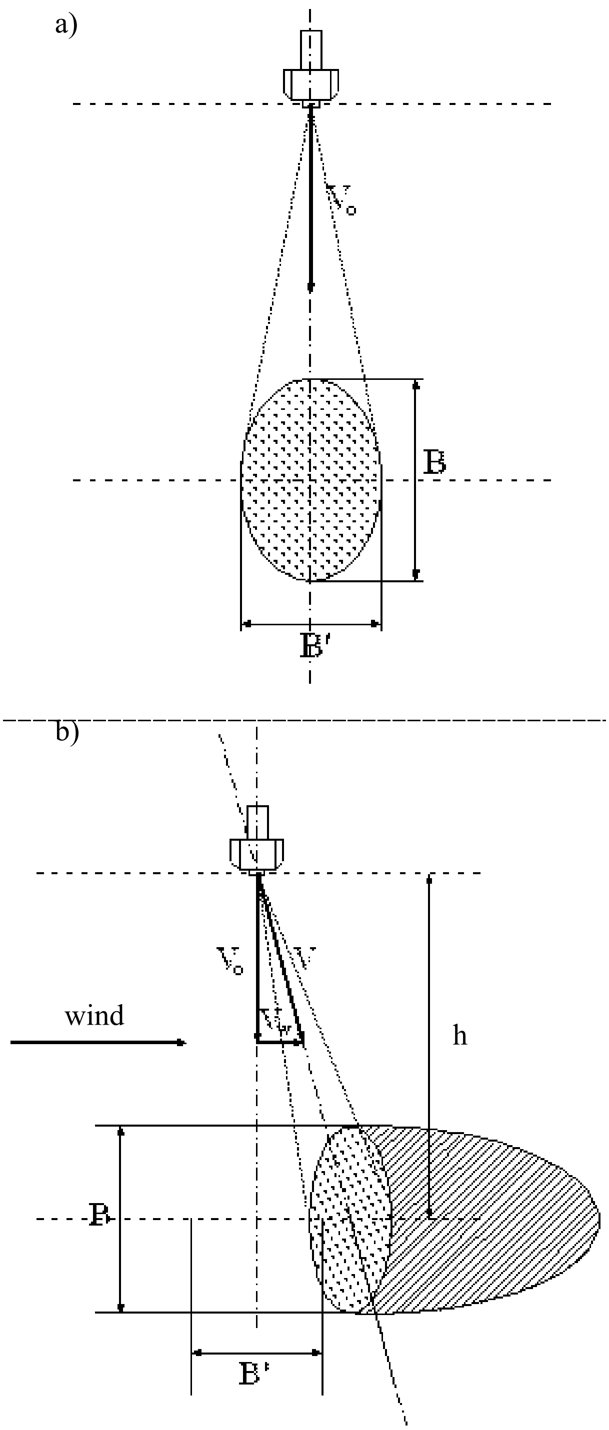

Fig. 1. Theoretical distribution of the sprayed liquid: a) windless b) with wind

The research on the sprayed liquid distribution was conducted at the post presented in Fig. 2. A fan (3) and a system of diaphragms (2) allowing the change of the air flow speed (1) were placed inside the wind tunnel (8). The sprayed surface was a groove table (7), over which the tested nozzle was mounted (6). A straightened tube (4) was used for air flow uniformity [18].

The intervals in the scheme designated as "b" (negative) and "c" (positive) determine the zones of atomization of the groove table's surface that result from the theoretical division, the nozzle's symmetry plane, the whole sprayed surface on the windward part in relation to the sprayed stream, and the leeward part.

The characteristics of the sprayed liquid's fall was made on the basis of the accepted liquid fall index W_{sor} defined by the formula:

$$W_{sor} = \frac{\sum V_{i(B')}}{V_c} \cdot 100\% \tag{1}$$

...where:

V_c – liquid's total volume used for measurement [ml]

$\Sigma Vi_{(B')}$ – liquid's volume measured under the nozzle on the length of the groove table designated as B′ in Fig. 1

Length B′ encloses the range of the sprayed surface located symmetrically to the nozzle's symmetry plane that was determined by tracks created by the theoretical fall of the sprayed stream on the sprayed surface.

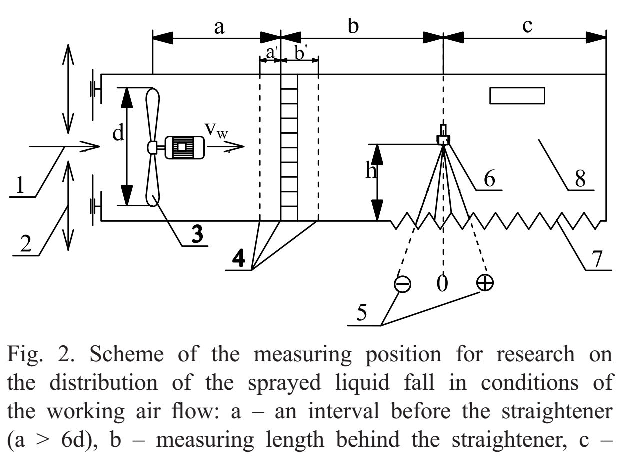

Fig. 2. Scheme of the measuring position for research on the distribution of the sprayed liquid fall in conditions of the working air flow: a – an interval before the straightener (a > 6d), b – measuring length behind the straightener, c – measuring length behind the sprayer, d – blowing fan's rotor diameter, h – the height of the sprayer setting, 1 – air intake, 2 – the direction of the air intake diaphragms' movement, 3 – axial flow fan, 4 – tube straightener with a system of networks homogenizing the air flow, 5 – designation of the sprayed surface, 6 – sprayer's mounting, 7 – groove table, 8 – aerial tunnel.
Source: [18]

Results and Discussion

The obtained results of measurements served to elaborate curves illustrating the oblong distribution of liquid and diagrams showing the liquid fall index value W_{sor} determined for the accepted atomization degrees. In accordance with the explanation concerning the measuring post, the division of the "x" axis into positive and negative parts in Figs. 3-6 resulted from dividing the groove table into a part designated as negative, located on the windward side in relation to the vertical plane going through the nozzle and a positive one located on the leeward side of the nozzle.

In order to be able to compare the distribution of liquid for nozzles characterized by different flow rate values (q) obtained with the use of different liquid pressures, relative values of the liquid fall on the sprayed surface resulting from the dependance V_i/V_c where: V_c – total liquid volume used for measurement [ml] and V_i – liquid volume noted in particular measuring cells[ml] were used. Because of the limited volume the only cases that were used to present the results of the sprayed liquid fall were those that involved the work of wind speed of 4.5 m s^{-1}, as they are representative for the scientific problem that was discussed. The choice to analyze the cases of liquid fall distribution involving the wind speed of 4.5 m s^{-1} results from the fact that the permissible wind speed, in accordance with the Plant protection act [19] is 3.0 m s^{-1}, and the speed that is most often used for spraying in practice ranges between 5 and 7 km h^{-1}.

By analyzing the courses shown in Figs. 3-6 we can see that the air flow causes the displacement of the sprayed liquid fall's volume in accordance with the direction of the flow, as it was initially assumed, showing the theoretical distribution of the fall in Fig. 1. The tendency is similar in the case of both nozzles used in our research. We can see that the greater height causes the phenomenon to be clearer. Figs 3 and 4 display characteristics of the liquid fall depending on the degree of distribution for the universal nozzle placed at atomization height 0.5 and 0.6 m. By comparing the distribution of liquid fall obtained with different pressure, it can be stated that they are characterized by different degrees of atomization. It can be seen that in spite of the common conviction, the liquid with greater degree of atomization does not move more powerfully in the direction compatible with the air flow

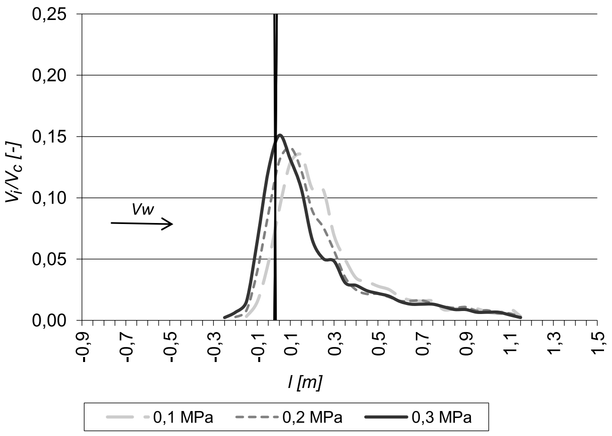

Fig. 3. Distribution of the sprayed liquid fall in conditions of working air flow at 4.5 m·s-1 with changeable liquid pressure and height of atomizaton h = 0.5 m, for the universal nozzle XR.

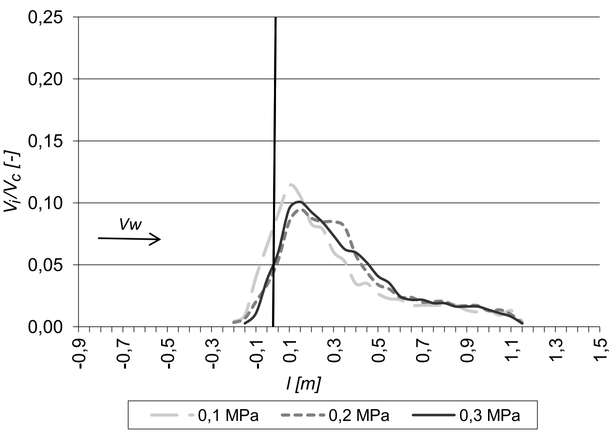

Fig. 4. Distribution of the sprayed liquid fall in conditions of working air flow at 4.5 m·s^{-1} with changeable liquid pressure and height of atomization h = 0.6 m, for the universal nozzle XR.

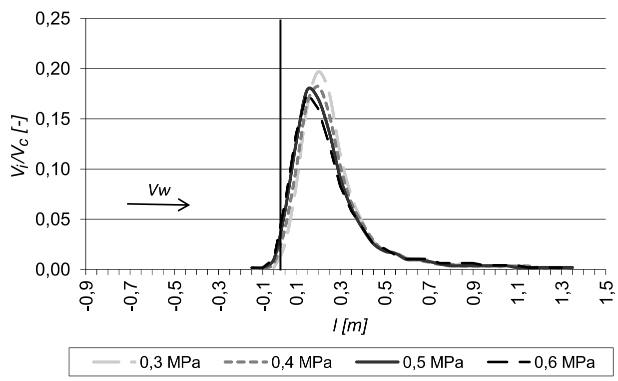

Fig. 5. Distribution of the sprayed liquid fall in conditions of working air flow at 4.5 m·s^{-1} with changeable liquid pressure and height of atomization h = 0.5 m, for the ejector nozzle AI.

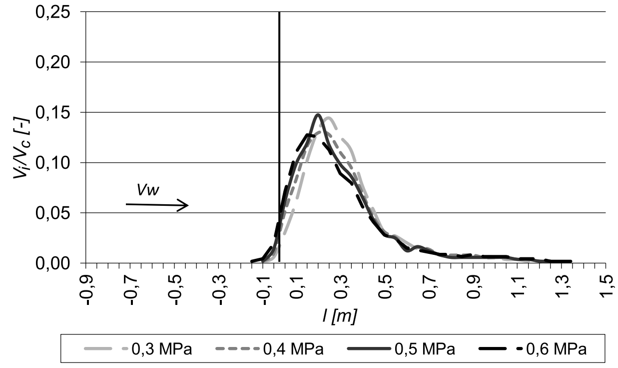

Fig. 6. Distribution of the sprayed liquid fall in conditions of working air flow at 4.5 m·s^{-1} with changeable liquid pressure and height of atomization h = 0.6 m, for the ejector nozzle AI.

than the sprayed stream containing bigger drops. This apparent contraction can be explained by the fact that during greater atomization liquid drops, despite their smaller size, have greater initial velocities v_o (Fig. 1). The behavior of the sprayed stream was more distinct in the case of the ejector nozzle that produces drops that are much bigger than those produced by the universal nozzle, and it spatters them with much greater initial velocity. In this way, its crucial feature as an anti-drifting nozzle becomes apparent.

The characteristics of the liquid fall on the surface directly below the nozzle is shown in Fig. 7 for the universal nozzle and in Fig. 8 for the ejector nozzle. The "y" axis contains W_{sor} index value calculated in accordance with dependence (1), while the "x" axis contains parameters of the nozzles' work; atomization height and liquid pressure responding to the given degree of atomization. Both of the figures show similar dependence. The analysis of W_{sor} index value in both diagrams confirms the conclusion that could be drawn from the evaluation of the diagrams displaying the courses of the sprayed liquid's fall.

It can be noticed that the relative value of the liquid's volume that falls directly under the nozzle grows together with the increasing liquid pressure. And so the value of the W_{sor} index with the liquid pressure 0.1 MPa and the

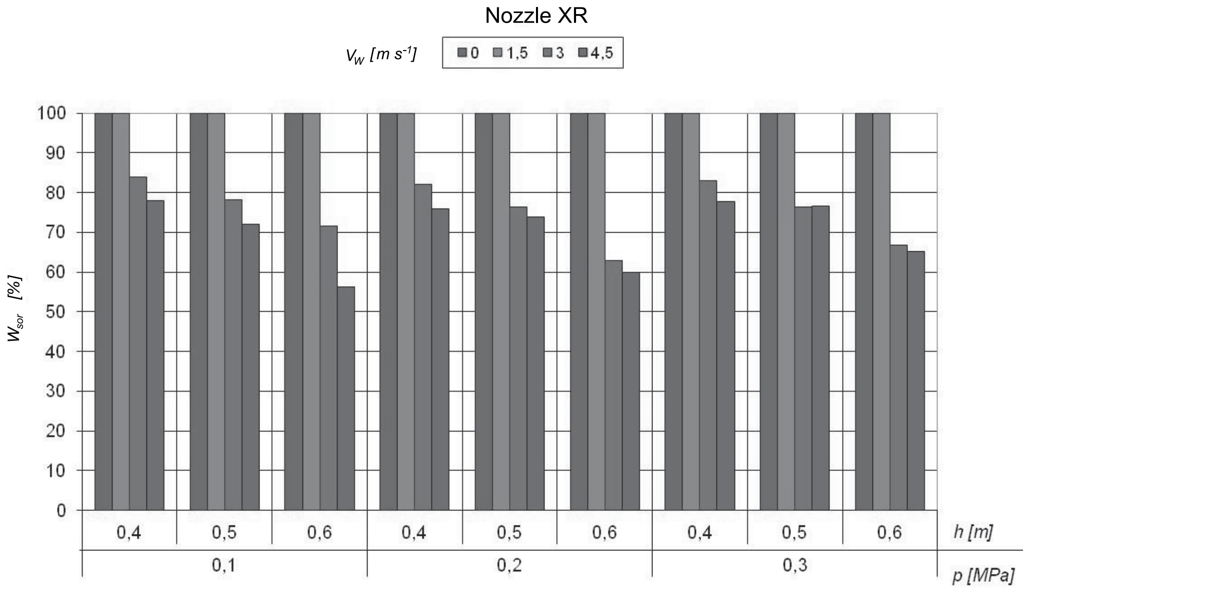

Fig. 7. Values for the W_{sor} fall index for the universal nozzle obtained from various wind speeds v_w, atomization height *h*, and liquid pressure *p*.

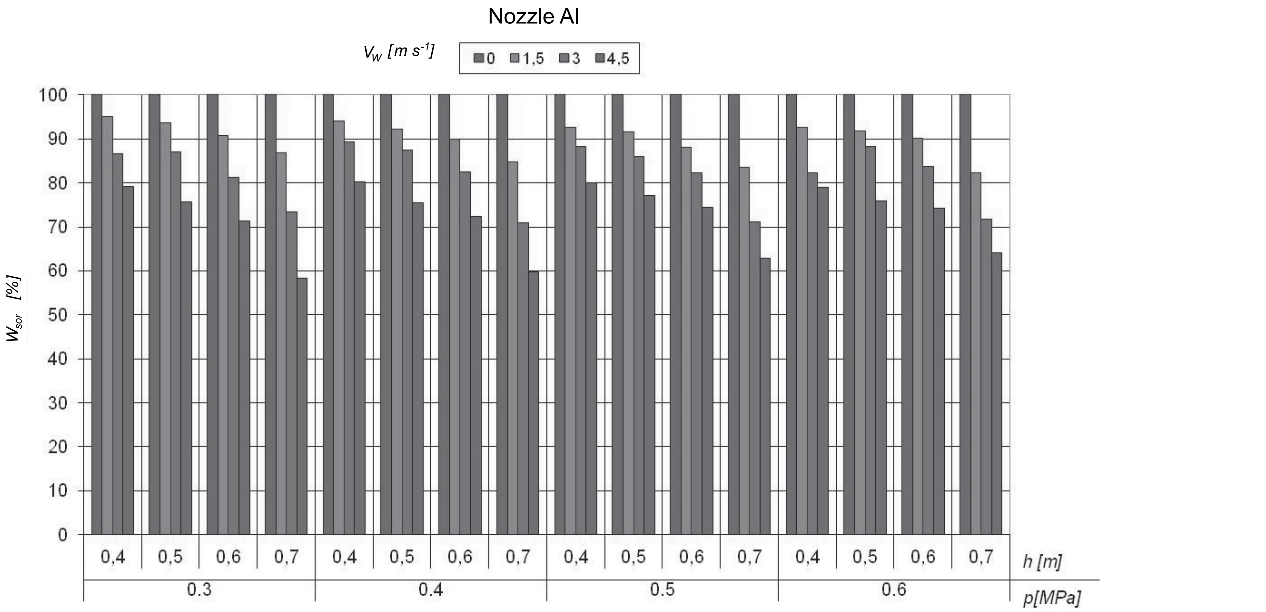

Fig. 8. Values for the W_{sor} fall index for the ejector nozzle obtained from various wind speeds v_w, atomization height *h*, and liquid pressure *p*.

height of atomization 0.6 m was about 55%, whereas with the pressure 0.3 MPa and the same height it was 65% w in the case of universal nozzle and wind speed 4.5 m·s^{-1} .

For the ejector nozzle the value W_{sor}, with the liquid pressure 0.3 MPa and the atomization height 0.7 m, was about 58%, for the speed 4.5 m·s^{-1}, while with the pressure 0.6 MPa and the same atomization height and the wind speed it was about 65%. As we can see, the differences between those values are significantly smaller. The data confirms that drops produced by the ejector nozzle are more resistant to drift.

Conclusion

1. The analysis of the research has shown that in the scope of accepted parameters of a nozzle's work, the sprayed stream of greater atomization degree does not undergo greater displacement under the influence of the air flow than the drops of the stream that was sprayed with the lesser atomization degree. It results from the fact that with the greater pressure the smaller drops of the sprayed stream have greater initial velocity and reach their destination (the object of spraying) faster.
2. As a result, air flow influencing the changes of the fall index W_{sor} under the nozzle turned out to be much greater in the case of the medium liquid drops produced by the universal nozzle than in the case of index changes concerning the stream consisting of thick drops produced by the ejector nozzle.
3. On the basis of the obtained results of the liquid fall distribution and the fall index value, it can be stated with certainty that, in the range of the accepted working parameters of the nozzles' setting as well as the conditions of spraying, the increase of atomization degree does not impair the distribution of liquid fall. On the contrary, the characteristics of these parameters turned out to be clearly better.

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