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DROPLET SIZE ANALYSIS OF SPRAY NOZZLES

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Abstract

In this paper we present laboratory equipment for illustrating the operation of spraying nozzles. It is also suitable for studying the basic processes of spraying and for measuring and evaluating the methods used in the control of sprayers. The equipment allows the monitoring of the spray film formed by the nozzles, measuring the yield of the nozzle and determining the size of the droplets formed. In the dissertation, we explore the factors influencing the droplet size. We compare the average diameter of droplets formed by the three hydraulic principle nozzles. Based on the average droplet diameters, the operation of the spray nozzles is analyzed and conclusions are drawn.

Keywords*: plant protection, nozzles, droplet size, water-sensitive paper.*

1. Introduction

Crop protection spray nozzles are used to break down the spray liquid into drops.

The droplets are distinguished by their aver-age diameter: spraying, 80% of the droplets are between 150-750 µm; pulverizing, 80% of the droplets are between 50-150 µm; atomizing, the droplets are between 0.5-50 µm. [1]

The drop formation can be hydraulic, pneumatic, mechanical or thermal[1].

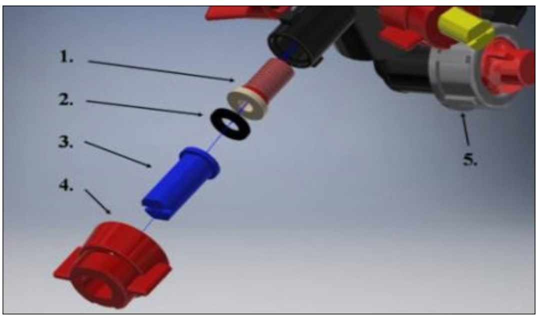

Figure 1. *Parts of the nozzle holder*

Sprayers generally deliver hydraulically formed drops to the vegetation. The droplets are formed by means of spray nozzles. A spray nozzle and its fittings can be seen in **Figure 1.**: 1 nozzle strainer, 2 gasket, 3 spray nozzle, 4 bayonet cap, 5 diaphragm check valve.

1.1. Theoretical fundamentals of the hydraulic drop formatting

During hydraulic drop formation, the spray liquid is decomposed by the forces exerted on the fluid flowing through the nozzle orifice under pressure. Hydraulic drop formation can occur by swirling or impacting.

Droplets formed by swirling pass through a circular cross section nozzle orifice and form a cone spray. (**Figure 2.**)

Droplets formed with the impact of liquid-solid, or liquid-liquid interface, passing through the orifice of nozzle, form a flat membrane. These nozzles are used the most. They are also known as flat spray nozzles. (**Figure 2.**)

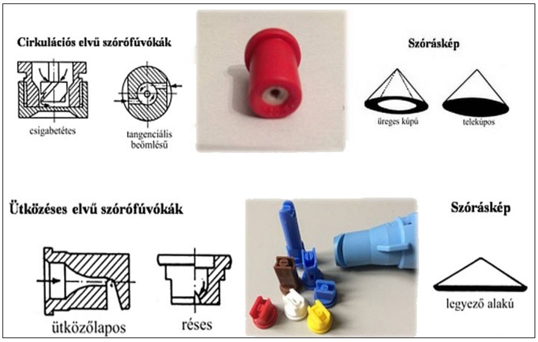

Figure 2. *Hydraulic drop spray nozzle structure, orifice, spray pattern* [1]

1.1.1. Fluid mechanics relationships

The relationship between the average diameters of droplets formed by hydraulic drop forming nozzles:

$$d_{csepp} = \frac{8 \cdot \sigma_f}{\rho_{leveg ő} \cdot v^2 \cdot \alpha_k} \quad [m] \tag{1}$$

where:

σ_f - the surface tension of the spray liquid, [N/m],

$\rho_{levegő}$ - the density of air, [kg/m^3];

v - the liquid exit velocity, [m/s];

α_k - the air resistance coefficient.

The velocity of the liquid stream exiting the nozzle

$$v = \mu \cdot \sqrt{\frac{2 \cdot \Delta p}{\rho_{permetl é}}} \quad \left[\frac{m}{s}\right], \tag{2}$$

where:

μ - the reduction factor,[-],

Δp - the droplet formation pressure difference, [Pa];

$\rho_{permetlé}$ - the density of the spray liquid, [kg/m^3].

The reduction factor is the ratio of the liquid jet diameter to the nozzle orifice diameter:

$$\mu = \frac{d_{sug ár}}{d} \quad [-], \tag{3}$$

where:

$d_{sugár}$ - is the diameter of the liquid jet exiting the nozzle, [m];

d - the nozzle orifice diameter, [m].

Summarizing relationships (1), (2) and (3):

$$d_{csepp} = \frac{8 \cdot \sigma_f}{\rho_{leveg ő} \cdot \left(\mu \cdot \sqrt{\frac{2 \cdot \Delta p}{\rho_{permetl é}}}\right)^2 \cdot \alpha_k} \quad [m], \tag{4}$$

$$d_{csepp} = \frac{4 \cdot \sigma_f \cdot \rho_{permetl é} \cdot d^2}{\rho_{leveg ő} \cdot {d_{sug ár}}^2 \cdot \Delta p \cdot \alpha_k} \quad [m]. \tag{5}$$

Equation (5) reveals the relationship between physical quantities affecting the average drop diameter of hydraulically formed droplets. The average droplet diameter is influenced by the surface tension of the spray liquid, the droplet formation pressure difference, the density of the spray liquid and the orifice diameter of the nozzle.

The drop formation can be at low pressure to 5 bar, at medium pressure, between 5-15 bar, and at high pressure, above 15 bar. [1]

The aim is to reduce the drop diameter, since a larger surface can be covered with a given volume of spray liquid. The relationship with the surface that can be covered:

$$A = 1{,}5 \cdot V_f \cdot \beta^2 \cdot d_{csepp}^{-1} \quad [m^2] \tag{6}$$

where

V_f - the fluid volume, [m^3];

β - spreading factor, [-].

The small droplets drift easily, which means a loss and increased environmental load. To eliminate this, air-injector flat spray nozzles and compact air-injector flat spray nozzles are used to create air bubbles in the spray liquid. The spray jet with air bubble wraps into larger droplets arrive to the plant surface, it explodes due to atmospheric pressure and provides good coverage (**Figure 3.**). For large droplets, the orifice diameters of air-injector flat spray nozzles are larger than those of the standard nozzle of the same designation.

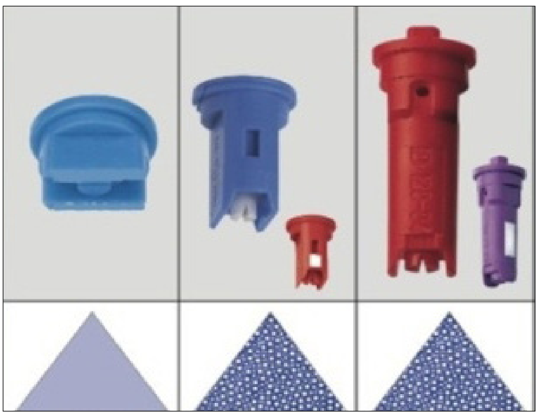

Figure 3. *Spray pattern of standard and air-injector flat spray nozzles*

2. Droplet size testing options

In this paper we intend to study the droplets size formed by flat spray nozzles. The droplet size can be determined with:
- camera;
- water-sensitive paper.

Determination by camera is very costly; therefore, we utilize water-sensitive paper to study the flat spray nozzle droplet size.

Water-sensitive paper is a 26x76 mm2 rigid paper with a special yellow coating. In contact with water it turns to a blue color. This method has been developed for use in the field. The paper is placed in the area to be sprayed and after spraying, the dried paper is collected. Results may be evaluated by:
- comparison with reference samples;
- counting and measuring droplets using a magnifier;
- computer image processing [2].

Water-sensitive paper is suitable for control-ling spray distribution, droplet density and size [3].

2.1. Experimental equipment

We have created a laboratory equipment to simulate spraying. The equipment allows monitoring of droplet formation and spray jet. In order to study the basic processes of plant protection, pressure measurement and yield measurement are carried out on the equipment. The drop pressure is created by a centrifugal pump. Equipment parts: 1 tank, 2 pipeline, 3 nozzle holder, 4nozzles. The mounted nozzle holder is capable of receiving four nozzles. The system is equipped with 5flow sensor, 6a pressure measuring sensor, 7 analog pressure gauge. The drainage of the water was solved with a drain (Figure 4.).

Data is collected using an Arduino Mega 2560 microcontroller.

2.2. The method of testing

A dolgozatban laboratóriumi körülmények között történő cseppképzést vizsgáltunk, vízérzékeny papíron megjelenő vízfolt méretének meghatározása alapján.

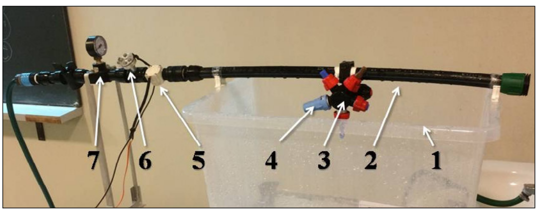

Figure 4. *The experimental equipment*

In this dissertation we investigated the droplet formation in laboratory conditions by de-termining the size of the water spot on water-sensitive paper.

The drop formation was investigated at a lower and a higher drop formation pressure. 8 pressure data points per measurement were recorded, averaged and plotted in Figures 7–9. and Tables 1–2.

The study was performed on three spray nozzles (Figure 5.):
- Lechler SC-110-03 standard flat spray nozzle;
- Lechler IDK-120-03 air-injector flat spray compact nozzle IDK;
- Lechler ID-120-03 air-injector flat spray nozzle IDK.

Group number 03 suggests the size of the resulting droplets, illustrated by the standard blue color of the nozzles.

During the laboratory spraying, the nozzle was manually moved over the water-sensitive paper at a height of 50 centimeters, since such a height is used during real-time operation [4]. The movement was done quickly so that few drops would settle on the paper. Water-sensitive paper is always placed in the vertical symmetry axis of the nozzle spray film, perpendicular to the axis. Absorbent paper was placed under the water-sensitive paper so that droplets bouncing off the solid surface did not affect the accuracy of the measurement. (Figure 6.)

The spray-treated papers were glued to a hard substrate after drying to perform measurements with a tool microscope. (Figure 7.)

Figure 5. *Examined spray nozzles*

Figure 6. *Water-sensitive paper before and after treatment*

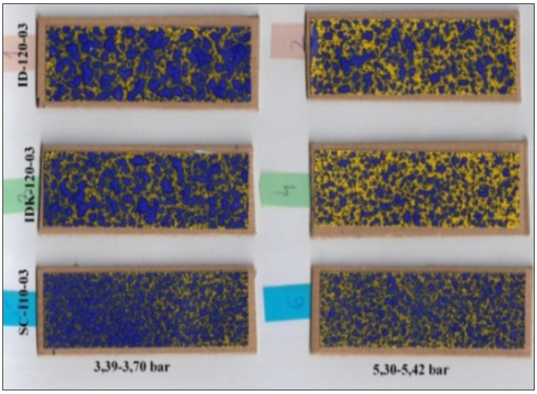

Figure 7. *Spray-treated water-sensitive papers*

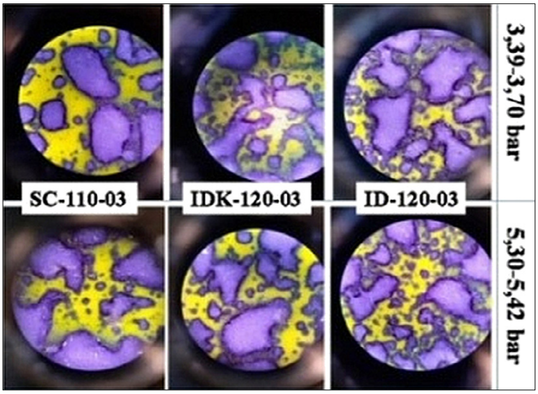

Figure 8. *Determination of spot dimensions*

Table 1. *Measured and calculated data*

	SC-110-03				IDK-120-03				ID-120-03			
p [bar]	3.39		5.3		3.77		5.42		3.66		5.37	
d [mm]	dfolt	dcsepp	dfolt	dcsepp	dfolt	dcsepp	dfolt	dcsepp	dfolt	dcsepp	dfolt	dcsepp
1	0.274	0.168	0.410	0.251	0.447	0.274	0.280	0.171	0.465	0.284	0.353	0.216
2	0.411	0.252	0.574	0.351	0.354	0.217	0.397	0.243	0.262	0.160	0.248	0.152
3	0.341	0.209	0.534	0.327	0.282	0.173	0.410	0.251	0.284	0.174	0.317	0.194
4	0.722	0.442	0.516	0.316	0.335	0.205	0.362	0.222	0.337	0.206	0.332	0.203
5	0.647	0.396	0.400	0.245	0.458	0.280	0.295	0.180	0.324	0.199	0.329	0.201
6	0.943	0.577	0.429	0.262	0.408	0.250	0.334	0.205	0.323	0.197	0.359	0.220
7	0.335	0.205	0.234	0.143	0.323	0.198	0.344	0.210	0.308	0.188	0.331	0.202
8	0.319	0.196	0.384	0.235	0.363	0.222	0.238	0.146	0.303	0.185	0.284	0.174
9	1.104	0.675	0.276	0.169	0.302	0.185	0.342	0.209	0.535	0.328	0.332	0.203
10	2.123	1.299	0.388	0.238	0.357	0.219	0.298	0.182	0.267	0.163	0.344	0.211
átlag [mm]		0.442		0.254		0.222		0.202		0.209		0.198
szórás [mm]		0.121		0.004		0.001		0.001		0.003		0.000

2.3. Collection and processing of data

A total of 10 water spots were determined on each sheet using a tool microscope. Measurements were made using a Carl Zeiss tool micro-scope with a universal head.

Spots that had a regular circular shape and a darker, defined outline were measured. The other spots are thought to have been formed by the merging of several drops, and their size is not relevant to this study. The outline is important for accurately positioning the cross of the tool microscope (**Figure 8.**).

Three positions were identified on the outline of the spots selected for measurement. From the three point positions, d_{folt} spot diameter was calculated using the AUTOCAD program.

Drop diameter was calculated using the spot size. In determining the droplet diameter, we have taken into account that the droplets spread over the

Table 2. *Droplet size guaranteed by the manufacturer* **[5], [6]**

p [bar]	d_{csepp} [mm]		
	SC-110-03	IDK-120-03	ID-120-03
3.39-3.70	0.200-0.250	0.400-0.450	0.500-0.550
5.30-5.42	0.190-0.200	0.300-0.350	0.450-0.500

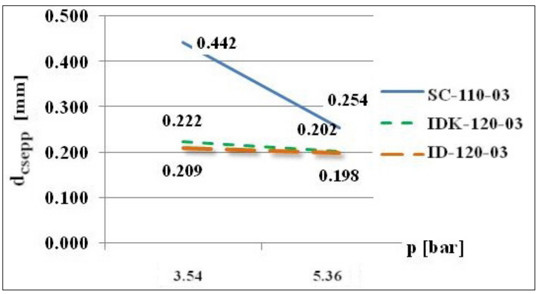

Figure 9. *The size of the droplets captured on the water-sensitive paper during the experiment*

surface, so the β spreading factor is required for analysis. The spreading factor is used to correct the difference between spot size and d_{csepp} droplet size. The spreading factor is determined by the manufacturer for spot size intervals. The values of the water spray spreading factor at 20 °C, 40% RH and sedimentation rate lead to the following regression relation **[3]**:

$$\beta = 0{,}000857 \cdot d_{folt} + 1{,}633333 \quad (7)$$

Relationship between droplet size determinations:

$$d_{csepp} = \frac{d_{folt}}{\beta} \quad [mm]. \quad (8)$$

The measured and calculated data were tabulated in **Table 1.**

The results were then compared with data provided by the manufacturer . **Table 2.** contains the guaranteed droplet size for the spray nozzles tested.

Finally, the data is displayed (**Figure 9**).

3. Conclusions

Droplet formation is a very complex process.

According to the theory of droplet formation, smaller droplets are formed near the smaller orifice. In the case of our observation this has not been proven. The standard flat spray nozzle SC-110-03 is the nozzle with the smallest orifice. The maximum droplet size was determined on the water-sensitive paper handled. This is because the manufacturer recommends this nozzle to be used below 2 bar pressure. It is likely that the very small droplets formed at higher pressures merged during sedimentation to form larger spots.

Changes in droplet size as a function of pressure was confirmed for each of the three nozzles. On higher pressure are formed smaller sized droplets.

The IDK-110-03 and ID-110-03 nozzles create droplets of approximately the same size. These droplet sizes are smaller than those guaranteed by the manufacturer. The phenomenon can also be explained by the fact that the droplets we measured are the results of the subsequent drop explosion.

The experiment explains the processes described in the literature, but it does not illustrate the air inclusions, only their presence can be inferred.

The implemented equipment is suitable for monitoring of spraying in laboratory conditions, for studying the relationships between nozzle type and droplet size and for monitoring the spray jet, however, the determination of droplet size using water-sensitive paper and microscope can lead to inaccuracy.

Further research is suggested to clarify the measurement method.

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