UDC identifier 631.348

SRAYING WITH ROsá CENTRIFUGAL ATOMIZERS

(This article was originally published in the Ukrainian journal "Техніка і технології АПК" – /Engineering and Technologies in Agribusiness/, No. 2, February, 2012)

V.P. Koval, Dr. Sci. in Engineering; O.I. Melezhyk, Ph.D. in Engineering, LLC «Agromodul»

Part 4. Pesticide losses in spraying

A pesticide application rate is governed by the amount of an active ingredient concentrate in cells, which is necessary for destruction or suppression of weeds and pests (a lethal dose). Actual pesticide application rates in spraying are often excessive because of losses encountered due to non-uniformity of pesticide distribution in the working fluid, non-uniformity of the fluid flow along the boom length, evaporation losses, and also because of droplet splashing or bouncing off and slipping on the ground.

The distribution of pesticide in the working fluid depends on the quality of a mixture preparation for spraying, i.e. mixing and blending the pesticide with water, while the distribution of the working fluid along the boom length depends on the nozzle performance. European Standard EN 12761-2 sets the limits for non-uniformity of the working fluid distribution as ± 15 % in the tank and ± 9 % along the length of the boom; and in order to minimize the drift of droplets in spraying, the amount of droplets less than 115 μm in size should not exceed 10 % in the total volume [1].

Dirceu Gassen and Flavio Gassen [2] have estimated that only as little as 5 % of a total insecticide amount effectively reaches target plants in spraying. Accordingly, 95 % of the pesticides is wasted and pollutes the environment. The losses of pesticides will be reducedб provided a larger share of droplets is deposited and retained on plants.

The list of pesticides and agrochemicals permitted for use in Ukraine [3] specifies minimum and maximum application rates per hectare for all kinds of spray mixtures. These standard rates are envisaged for spraying operations performed with slit-type nozzles. For example, to protect corn and sunflower against annual grass and dicotyledonous weeds, the herbicide of the brand name "Harness" can be used at a flow rate from 1.5 to 3.0 L/ha. In view of the fact that these recommendations on chemical dosage are usually given as a certain range, users generally select an average or a maximum application rate, which results in higher production costs and soil pollution.

Using the mathematical model developed for the jet in the ROsá centrifugal atomizer and also taking into account the experimental data for droplet velocities and distribution in the jet, let us estimate the losses due to evaporation, splashing and slipping of droplets.

1. Droplet losses due to evaporation.

In fine-droplet spraying, evaporation losses constitute the main share in the total pesticide wastage. All the droplets which evaporate before deposition will be lost. The key factors in evaporation are wind, humidity and air temperature, and also the temperature of the working fluid.

<u>Wind.</u> In accordance with physical representations, fine droplets are blown out downwind from the jet. Under such conditions, the time of droplets deposition increases and, as a result, greater evaporation losses of the working fluid occur, while the number of deposited droplets decreases. According to the sanitary standards [4], spraying operations with boom sprayers are considered appropriate when a wind velocity is less than 3 m/s (for fine droplet spraying) or 4 m/s (for large droplet spraying).

It is known that wind velocities can be slowed down due to irregularities in the terrain surface and the wind velocity fluctuations with height above the ground are governed by the logarithmic law:

$$\frac{U_z}{u_*} = \frac{1}{\chi} \ln \frac{z}{z_0},$$

where U_z is the wind velocity in a given height z above the ground; $u_* = \sqrt{\frac{\tau_0}{\rho}}$ is a wind dynamic velocity, $\chi = 0.4$ is the Kármán's constant; and z_0 is the terrain roughness parameter.

The kinematic stress is

$$\frac{\tau_0}{\rho} = C_z \cdot U_z^2,$$

where C_z is the wind-drag coefficient.

In accordance with the experimental data [5], when the wind velocity measured at the height of 10 m above the ground is U_{10}, then $C_z = (1.3 \pm 0.3) \cdot 10^{-3}$.

From the above-mentioned, we obtain the following equation for the wind velocity distribution over the rough surface:

$$\frac{U_z}{U_{10}} = 0{,}09 \ln \frac{z}{z_0},$$

which will be further used in the calculations of the motion of droplets.

As it is recommended in GOST 20915, the wind velocity should be measured at a height of 1.5 m from the ground. For example, if the wind velocity is $U_{1.5}$ = 3.0 m/s and z_0 = 0.03 m, the wind velocity at the height of z = 10 m will be U_{10} = 8.5 m/s, while at the height of z = 0.6 m, i.e. at the level of location of an atomizer, the wind velocity is $U_{0.6}$ = 2.3 m/s. In other words, in the wind of $U_{1.5}$ = 3.0 m/s, the spray jet is exposed to the influence of the wind velocity, which decreases from $U_{0.6}$ = 2.3 m/s at the height of z = 0.6 m to zero near the surface being treated.

Fig. 1 represents the temperatures and the droplet mass losses due to evaporation for the ROsá atomizer at a flow rate of 1.0 L/min, the sprayer travel speed of 12 km/h in the presence of the wind velocity of 9 m/s, with both the ambient air and the working fluid temperatures being equal to 20 °C, and under relative humidity conditions of 50 %. The droplets smaller than 150 μm in size evaporated completely. The share of such drops constituted 2.73 % of the total volume.

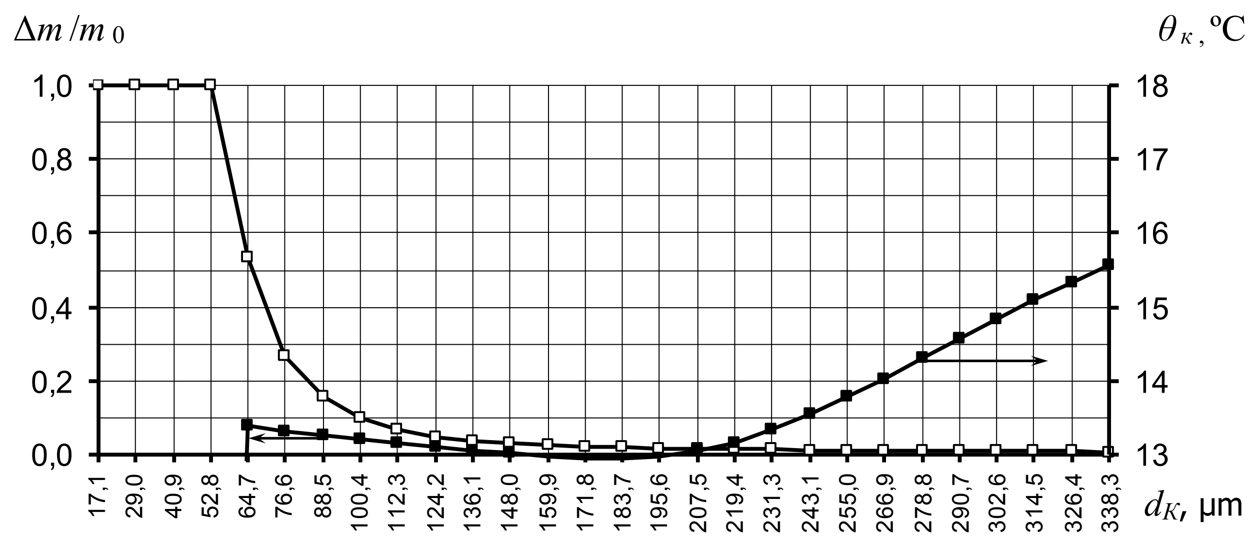
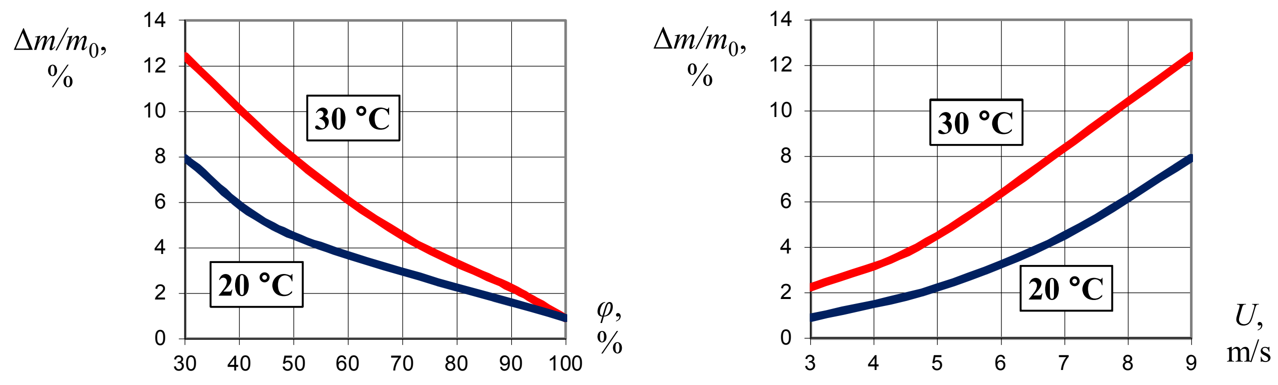


Fig. 1. Droplet mass losses versus temperature.

While evaporating, droplets get gradually cooled and their temperature reaches the value of $\theta_{К}$. As droplet diameters decrease, cooling of droplets proceeds more rapidly. For the atomizer ROsá, at a flow rate of 0.6 L/min, the volume shares of evaporating droplets will be 0.9 %, 4.5 % and 7.9 % under conditions of the wind velocities of 3 m/s, 7 m/s and 9 m/s, respectively, and with both the water and air temperatures of 20°C.

Humidity and air temperature. The atmospheric air represents a gaseous mixture of dry air and water vapor. The ratio of the partial vapor pressure to the saturated vapor pressure at a given air temperature is called as relative humidity, denoted by φ and expressed in percentage. It is generally known that the partial pressure of water vapor depends on a water temperature. Prior to reaching the saturation stage, vapor is considered to be an ideal gas; and the water vapor density is determined as $\rho_{\Pi} = P_{\Pi}/R_{\Pi}T$, based on the relative humidity calculated as $\rho_{\text{В}\Pi} = \rho_{\Pi}\varphi/100$. Evaporation of droplets during their deposition depends on the difference between the water vapor density near the surface of a droplet and that in the atmosphere. When the water vapor density in the surrounding air exceeds the water vapor density near the droplet, the evaporation ceases.

The results of calculations of the volumes of evaporated droplets at the ambient temperature of 20 °C and 30 °C as a function of a variable relative humidity and at the wind velocity of 7 m/s are illustrated in Fig. 2, a; and the effect of variable wind velocities on the estimated volumes of evaporating droplets at a 30 % relative humidity is shown in Fig. 2, b.



a b

Fig. 2. Calculated volumes of evaporated droplets as the functions of:
a - variable relative humidity of air; b - variable wind velocity.

2. Droplet losses in splashing and slipping off

Only those pesticide-containing droplets of the working fluid, which are deposited on a target surface and retained on it, are considered to be effective. The presence and distribution of pesticide in a droplet depends on the working fluid preparation technique used prior to spraying, while deposition efficacy of droplets depends on the droplet velocity at the moment of its impingement upon the target surface.

Droplet splashing. Any droplet having a greater kinetic energy than the surface kinetic energy will splash during its impingement upon the surface.

The ROsá centrifugal atomizer operating at a flow rate of 0.6 L/min deposits the droplets of less than 200 μm in size on the leaves, at a droplet critical velocity of 2.1 m/s.

A slot-type injector nozzle at a flow rate of 0.6 L/min is capable to deposit on the leaves the droplets less than 97 μm in size, whereat the critical velocity of droplets is 2.95 m/s.

Using the well-known integral characteristics of droplet distribution according to their volume median diameters, we have determined the volume of droplets deposited by the ROsá atomizer as 82.0 % and that deposited by the slot-type injector nozzle as 8.3 %. The measurements [7] have shown that the high velocities of droplets are characteristic of other slot-type nozzles as well, for example, LU120-03, XR11003, IDK120-03, AI11003VS models.

In the slot-type nozzles, the maximal droplet velocity of up to 15 m/s at a pressure of 0.3 MPa exceeds the boundary velocity of ≈ 9 m/s of raindrops. At such a velocity, the leaves of field crops are at risk of damage with droplets.

Spraying with slot-type nozzles envisages wetting of leaves, which can be achieved at the fluid flow rates from 200 L/ha to 300 L/ha. In such cases, the application rates for chemicals are excessive because as much as 91.7% of droplets are not deposited on the leaves but fall on the ground. It is a common practice around the world is to perform chemical crop protection by pesticide spraying of plants with the use of slit-type nozzles, though this equipment is capable to deposit as less as ≈ 8 % of a total droplet volume of the atomized liquid sprayed on the leaves, and that leads to a total contamination of soil with pesticides.

Slipping of droplets. A droplet slips off the surface during its impingement on the surface in case when a kinetic energy component in the direction of the droplet motion, i.e.

$$E_K = \frac{m(V_0 \cos\alpha)^2}{2},$$

is greater than the work of adhesion:

$$W_a = \sigma(1 + \cos\theta)\pi r_0^2,$$

where $m = \frac{1}{6}\pi d^3 \rho$ is the droplet mass, V_0 is the velocity at the moment of impingement, α is the angle of impingement on the surface, d is the droplet diameter, ρ is the density of the working fluid, σ is the surface tension, θ is the equilibrium contact angle, $r_0 = d f(\theta)\sin\theta$ is the radius of the contact area under the deposited droplet; and $f(\theta)$ is the function of wetting.

From the equation $E_K = W_a$ we obtain the critical Weber number of droplet slipping:

$$We^{**} = We^{*}\frac{F(\theta)}{\cos^2\alpha},$$

where $We = \frac{\rho \square_0^2}{\sigma}$ is the Weber number; We^{*} = 12 is the critical Weber number for droplet splashing; and $F(\theta) = (1 + \cos\theta) f^2(\theta)\sin^2\theta$ is the function of droplet slipping (Fig. 3).

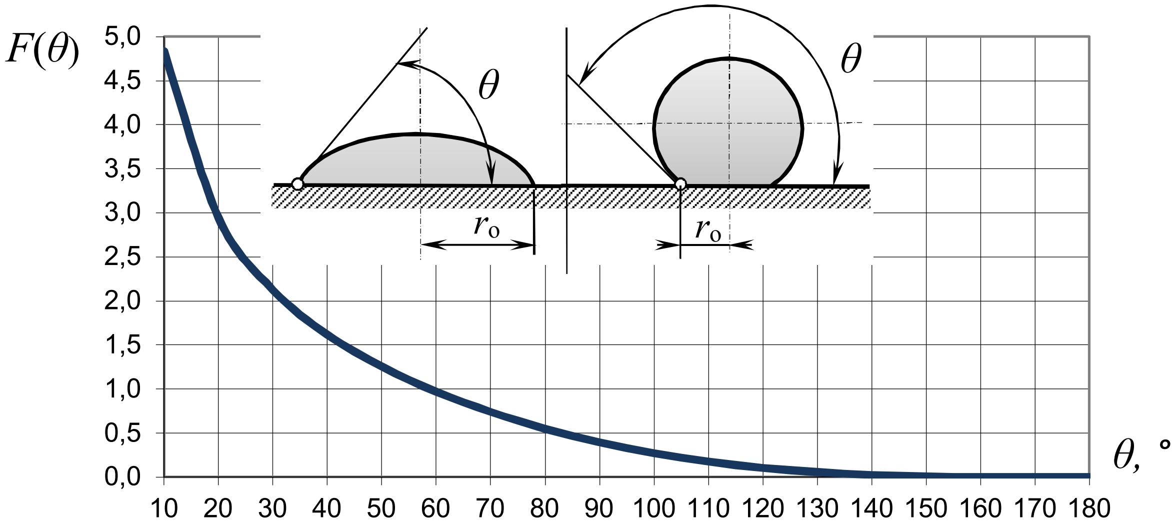


Fig. 3. The function of droplet slipping.

At the moment of a droplet impingement on the solid surface, the droplet which has $We > W$▯* splashes and forms water mist, but when $We >$ ▯ **, the droplet slips off the surface.

Since $\cos\alpha \leq 1$, then with $F(\theta) \geq 1$ $(\theta < 60°)$, $We^{**} > W$▯* is the critical number for slipping. With the ROsá atomizer, the droplets less than 200 μm in size, at a wetting contact angle of $\theta < 60°$, are retained on the leaf surface at any angle of impingement. For non-wettable field crops, for example, spring barley or spring wheat, which have θ ≈ 166° and, $F(\theta)$ = 0.015 and at α < 15 °, the critical number for slipping is We^{**} = 0.18. For the droplets of 20 μm in size and travelling at a velocity of 2.9 m/s, we obtain the Weber number of We = 2.4. Thus, all the droplets will slip off the non-wettable leaves, and therefore, the cultivated crops do not present any obstacle to the pesticide spraying of weeds through the field crops.

Conclusions:

1. When spraying pesticides with slit-type injector nozzles, the amount of droplets deposited on the plants represent only ≈ 8% of the total volume of sprayed liquid, while the rest of the droplets splash and pollute the soil.
2. The ROsá centrifugal atomizer ensures an increase of up to 82 % in the volume of droplets deposited on the plants, or it is a 10 times greater volume than that attained with a slit-type injector nozzle. This is an adequate reserve for minimization of application rates in spraying pesticides.
3. Pesticide losses in spraying depend on the environmental conditions wherein the spraying operations are performed. Pesticide application rates have to be increased as consisted with the losses, which do not exceed 12 % under the conditions of a wind velocity up to 9 m/s and a relative humidity of 30 %.
4. The performance parameters of efficacy, durability and reliability achieved with the ROsá atomizers give reason to believe the time of slit-type nozzle application is expiring and the future of chemical plant protection belongs to centrifugal atomizers.

References:

1. EN 12761-2:2004 Agricultural and forestry machinery – Sprayers and liquid fertilizer distributors – Environmental protection – Part 2: Field crop sprayers [Effective in Ukraine since 01.01.2006]. - Kyiv: State Committee of Ukraine for Technical Regulation and Consumer Policy, 2005. – P. 12.

2. D. Gassen. The Art of Pesticide Application / J. Gassin, F. Gassin / / Jl. "Zerno" ("Grain") - 2007. - № 10. - P. 55 - 61.
3. The list of pesticides and agrochemicals permitted for use in Ukraine / [Contributors: B. W. Yaschuk, D.V. Ivanov, A. Kaplin, M. Tkachuk, A.P. Koretsky] – Kyiv, Univest Media Publishing House, 2010. – P. 544.
4. Transportation, storage and use of pesticides in the national economy (of Ukraine): DSP 8.8.1.2.001-98 – Kyiv, 1998. – P. 70.
5. E.B. Kraus. Atmosphere-Ocean Interaction (tr. from English, ed. By A.S. Dubova and E. K. Butner.) Leningrad, USSR: Gidrometeoizdat Publishing House, 1976. – P. 295.
6. Paul C. H. Miller. Measurements of the droplet velocities in sprays produced by different designs of agricultural spray nozzle / Miller Paul C. H., Tuck Clive R., Murphy Seamus, Ferreira Marcelo da Costa – Como Lake, Italy, 2008. – P. 8.