Deflector nozzles of rain irrigation machines

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Abstract. The paper is devoted to the study of deflector nozzles of rain irrigation machines. The selection of the parameters of the deflector nozzle of artificial sprinkler irrigation machines on a scientific and practical basis allows for the correct organization of ecologically safe irrigation. The article presents the results of the scientific research of the parameters of a short-distance irrigation nozzle with a deflector.

1 Introduction

Artificial sprinkler irrigation is widely used as a cost-effective irrigation technology in the world. For example, sprinkler irrigation in the US is 10 million. 900 thousand hectares, or 56% of the total cultivated area, 3 mln. Artificial irrigation is used on 500,000 hectares, 78.2% of the total cultivated area, 177,000 hectares in Israel, or 99.8% of the cultivated area, 716,000 hectares in Saudi Arabia, respectively 78.1% of the cultivated land (1). It is known that this method of irrigation has been introduced to small areas in our country, and a number of government decisions have been made to introduce it widely [1-36].

Short-distance sprinkler nozzles with deflectors are widely used in sprinkler irrigation. Analysis of the parameters of such nozzles, theoretical justification of the technological process is among the current problems of application in irrigation devices [1-6].

2 Research object and methods

Figure 1 shows the flow of water coming out of the deflector nozzle.

The jet of water ejected from the nozzle at the initial speed ϑ_1 from the cross-sectional surface S_1 with a pressure p_1 moves along the deflector wall and creates a speed ϑ_2 a cross-sectional surface S_2, and a pressure p_2 at the point of air release.

To justify the technological dimensions of the deflector nozzle, the work done by all the forces acting on the body A_i is equal to the change in kinetic energy ΔE_k, i.e

$$\sum A_i = \Delta E_k \tag{1}$$

The work done by the forces generated during the flow is as follows:

The work done by the forces generated in the 1st section of the nasadka:

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$$A_{p1} = F_1 \Delta l_1 cos\alpha \quad (2)$$

$\alpha -$ the angle between the force and fluid flow directions, $\alpha = 0^o$.

So,

$$A_{p1} = F_1 \Delta l_1 cos\alpha = p_1 S_1 \Delta l_1 (1) = p_1 V_1 \quad (3)$$

The work done by the forces generated in area 2:

$$A_{p2} = F_2 \Delta l_2 cos\alpha = p_2 S_2 \Delta l_2 (-1) = -p_2 V_2; \quad (4)$$

$$p_2 = p_1 - \Delta p$$

In hydraulic systems, the hydrodynamic loss of fluid flow due to friction is determined by the Darcy-Weissbach formula and has the following form:

$$\Delta \mathrm{P} = \gamma \frac{L}{D} \frac{\vartheta^2}{2} \rho_c \quad (5)$$

Here γ - longitudinal friction loss coefficient (Darcy coefficient), $\gamma = \frac{68}{Re}$;

L- hydraulic system length; D - hydraulic system diameter; $\rho_c -$ liquid density. ϑ- the velocity of the water flow, we take it to be equal to the velocity of the water flowing out of the nozzle.

It is known that this formula is relevant for non-bendable pipes. The flow of water coming out of the deflector nozzle is affected by the deflector wall on the one hand, and the air layer at atmospheric pressure on the other. In order for the water droplet to regularly interact with the deflector wall, we tentatively accept the following condition:

$$\overrightarrow{F_{jq}} > \vec{G}, \quad (6)$$

this $\overrightarrow{F_{jq}}$ the resistance force that ensures the impact of the water droplet with the deflector wall, $\vec{G}$ – gravity.

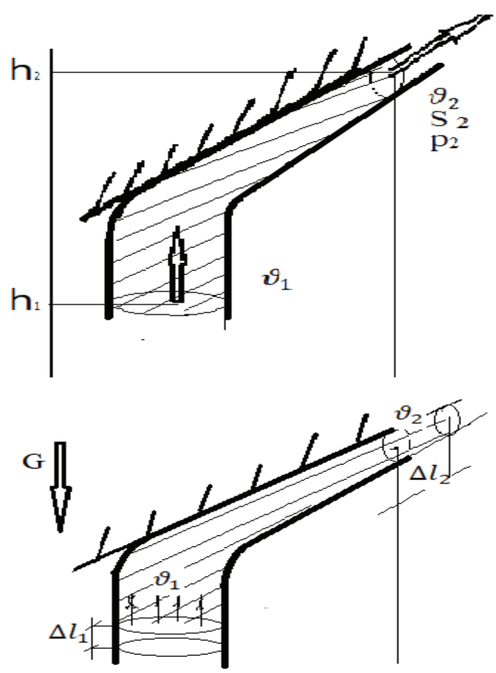

Fig. 1. Scheme for determining the velocity of the water flow coming out of the deflector nozzle.

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According to the condition, a droplet of water interacts with the deflector wall within a unit of time and is suspended in the air. If the forces F_{jq} acting on the water droplet are greater than the force of gravity G, it will stick to the wall of the deflector, otherwise it will break off from the wall as a result of its own weight.

We find the water velocity and diameter satisfying the above condition using Figure 2.

We write the equation (1.6) in the following form:

$$\vec{\boldsymbol{F}}_{qq} > m\vec{g}, \tag{7}$$

Here m – mass of water droplet; $\vec{g}$- free fall acceleration.

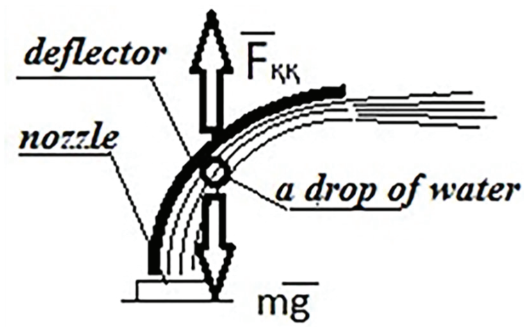

Fig. 2. Scheme for determining the velocity of a drop of water using the Darcy-Weissbach formula.

When the water flow is turbulent, the resistance force of the medium acting on the water droplet is determined as follows:

$$\vec{\boldsymbol{F}}_{ҚҚ}(\boldsymbol{t}) = \frac{\boldsymbol{C_x \rho_m \vartheta^2 S}}{\boldsymbol{2}}$$

Here C_x − aerodynamic drag coefficient for spherical bodies C_x =0,5; ρ_m − density of the medium, ambient temperature t=20°S air density at ρ_m = 1,2754 kg/m³; ϑ- the speed of the body; S – the medelevoy surface in the direction of motion of the body.

$m = \rho_c V_c$, expression taking into account that the water droplet is spherical

$V_c = \frac{4}{3}\pi r^3 = \frac{\pi}{6}d^3$ we write in the form. From this $m = \frac{\pi}{6}\rho_c d^3$ originates.

The expression (7) becomes:

$$\frac{\boldsymbol{C_x \rho_m \vartheta^2}}{\boldsymbol{2}}\frac{\pi d^2}{\boldsymbol{4}} = \frac{\pi}{6}\rho_c d^3 g.$$

Or

$$\vartheta > \sqrt{\frac{2\boldsymbol{\rho_c d g}}{3\boldsymbol{C_x \rho_m}}}. \tag{8}$$

In Eq ρ_c, C_x, ρ_m quantities have a fixed value.

The calculation of the fulfillment of the condition (6) at different values of the water drop ***d*** in the equation (1.8) is presented in the graph in Figure 3.

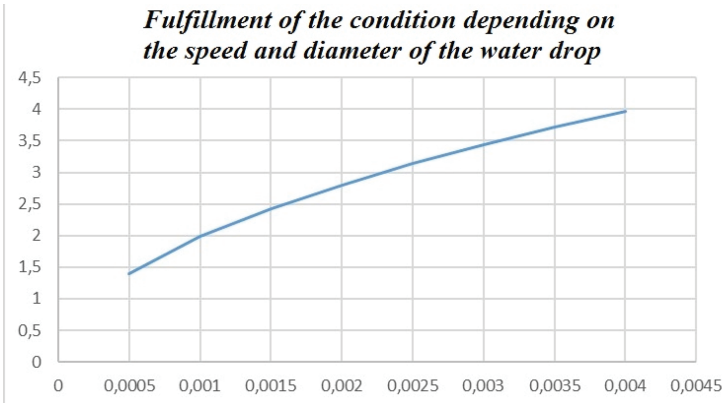

Fig. 3. (6) is a graph of the change in speed of the water roof according to its diameter.

Given the fulfillment of the above condition:

$$p_2 = p_1 - \gamma \frac{L}{D}\frac{\vartheta^2}{2}\rho_c$$

In that case

$$A_{p1} = p_1 V; \tag{9}$$

$$A_{p2} = (p_1 - \gamma \frac{L}{D}\frac{\vartheta^2}{2}\rho_c) V. \tag{10}$$

The work done by gravity is represented by the change in potential energy ΔEp:

$$A_{mg} = -\Delta E_n = -(m_2 g h_2 - m_1 g h_1) = m_1 g h_1 - m_2 g h_2 = \rho V g h_1 - \rho V g h_2. \tag{11}$$

Due to the fact that the speed of the water flow does not change for each section of the deflector surface of the nozzle, the change in potential energy looks like this:

$$\Delta E_n = \frac{1}{2} m_1 \vartheta_2^2 - \frac{1}{2} m_1 \vartheta_1^2 = \frac{1}{2}\rho V \vartheta_2^2 - \frac{1}{2}\rho V \vartheta_1^2 ; \tag{12}$$

Substituting expressions (9), (10), (11) and (12) into (1):

$$p_1 V - (p_1 - \gamma \frac{L}{D}\frac{\vartheta^2}{2}\rho_c) V + \rho V g h_1 - \rho V g h_2 = \frac{1}{2}\rho V \vartheta_2^2 - \frac{1}{2}\rho V \vartheta_1^2 \tag{13}$$

By summarizing the expression (13), it is possible to find the water flow rate in section 2:

$$-\gamma \frac{L}{D}\frac{\vartheta_1^2}{2}\rho_c + \rho g h_1 - \rho g h_2 = \frac{1}{2}\rho\vartheta_2^2 - \frac{1}{2}\rho\vartheta_1^2;$$

Or

$$\frac{1}{2}\rho\vartheta_2^2 = \frac{1}{2}\rho\vartheta_1^2 - \gamma \frac{L}{D}\frac{\vartheta^2}{2}\rho_c + \rho g h_1 - \rho g h_2. \tag{14}$$

From this

$$\vartheta_2 = \sqrt{\vartheta_1^2 - 2g(h_2 - h_1) - \gamma \frac{L}{\rho D}\vartheta_1^2 \rho_c)} \tag{15}$$

In order to find the speed of the water flow coming out of the deflector nozzle using the equation (15), it is necessary to first determine the length of the L-hydraulic system and the diameter of the D-hydraulic system. For this, we use the scheme in Figure 4. Figure 4a shows the axionometry of the deflector nozzle, in which the length of the L-hydraulic system, the angle of inclination a of the deflector, and the height of the deflector λ are shown on the n-n line. Figure 4b shows the calculation scheme of the deflector surface.

From the scheme $sin\alpha = \frac{\lambda}{L}$ or $L = \frac{\lambda}{sin\alpha}$.

Let the point of contact of the deflector with the surface of the cylinder be at the point F_2 . Then the length L of the deflector (in our case, the length of the hydraulic system) is equal to the apofocus distance r_a of the ellipse.

The surface of the deflector

$$S_{def}=S_1-S_2 \tag{16}$$

can be calculated from Eq. Where S_1 is the surface of the ellipse,

$$S_{tul} = \pi ab \tag{17}$$

is calculated by the formula.

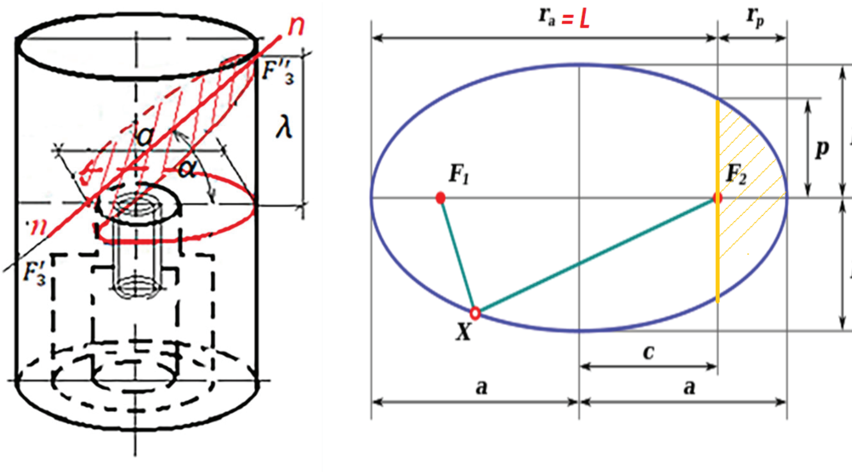

Fig. 4. Scheme for calculating the value of quantities L and D in the Darcy-Weisbach formula (5): a). Axionometry of the deflector nozzle; b). The surface of the ellipse deflector. a – large half axis; b- small half axis; c- focal length; p- focal parameter; r_p – focal length; r_a - apofocal distance; α- the slope angle of the deflector; λ- the height of the deflector [1-6].

From Figure 4a, we find the semimajor axis of the ellipse. *n-n* if we continue in a straight line, it is with the cylinder wall F_3' or F_3'' meet at points. F_3' or F_3'' the distance between the points is equal to 2a. F_3' or F_3'' the distance between the points is:

$$a = \frac{|F_3' F_3''|}{2} = \frac{D}{2cos\alpha}\ . \tag{18}$$

Here, D - is the outer diameter of the cylinder (in our case, the nozzle).

It follows from the drawing that b = $\frac{D}{2}$

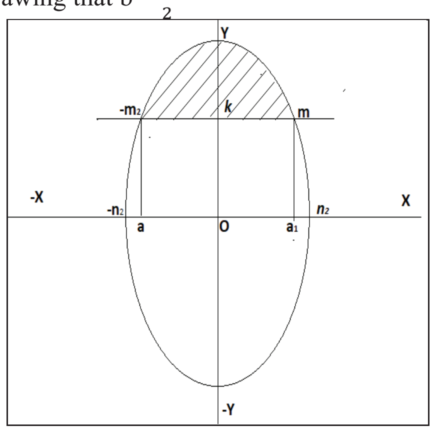

Fig. 5. Scheme for determining the surface of the deflector.

The surface of a figure bounded by lines given by some functions is determined by the following formula:

$$S = \int_{\beta}^{\alpha} y(t)x'(t)dt. \tag{19}$$

Ellipse surface of the deflector

$$\begin{cases} x = n_2 cost, \\ y = n_1 sint \end{cases} \tag{20}$$

let the equations be determined by the system. Here n_1 and n_2 are the major and minor semi-axes of the ellipse. Let the ellipse surface of the deflector intersect at a distance K from the axis of the cylinder (nozzle). In that case, the surface of the desired figure is bounded by the following lines with $t \in [0; 2\pi]$, y=k (y$\geq k$):

$$\begin{cases} x = n_2 cost, \\ y = n_1 sint, \\ y = k. \end{cases} => \begin{cases} x = n_2 cost, \\ k = n_1 sint, \\ y = k. \end{cases} => \begin{cases} x = n_2 cost, \\ sint = \frac{k}{n_1}, \\ y = k. \end{cases} \tag{21}$$

The sine function has two areas of detection in this interval. Taking this into account, the system of equations (2) is shown below

$$\left[\begin{array}{l} \begin{cases} x = n_2 \cos\left(arcsin\frac{k}{n_1}\right), \\ t = arcsin\frac{k}{n_1}, \\ y = k. \end{cases} \\ \begin{cases} x = n_2 \cos\left(-arcsin\frac{k}{n_1}\right), \\ t = \pi - arcsin\frac{k}{n_1}, \\ y = k. \end{cases} \end{array} \right. \tag{22}$$

we create. We find the desired surface using the formula (1) by introducing the designations $a = arcsin\frac{k}{n_1}$ and $a_1 = \pi - arcsin\frac{k}{n_1}$:

$$S_{\cap} = \int_{a_1}^{a} n_1 sint\,(n_2 cost)'\,dt = \int_{a_1}^{a} -n_1 sint\, n_2 sint\,\,dt = \int_{a}^{a_1} n_1 n_2 sin^2 t\,dt =$$

$$= \left(\frac{n_1 n_2 t}{2} + \frac{n_1 n_2 t}{4} sin2t\right)\Big|_{a}^{a_1} = \frac{n_1 n_2}{2}(a - a_1) + \frac{n_1 n_2}{4}\sin(2a - 2a_1) \tag{23}$$

(4) looks like this:

$$S_{\cap} = \frac{n_1 n_2}{2}\left\{(a - a_1) + \frac{\sin(2a - 2a_1)}{2}\right\}. \tag{24}$$

The resulting formula represents the sum of the hatched segment and a(-m$_2$)ma$_1$ rectangular surface. The hatched surface of the ellipse above the point K is equal to the surface area of $S_{\cap}$ divided by the area $S_{\blacksquare}$. In turn, it is equal to $S_{\blacksquare} = k\,(a_1 - a)$.

Therefore, the surface of the deflector is equal to:

$$S_{деф} = S_{tul} - S_{\cap} - S_{\blacksquare} = \pi n_1 n_2 - \frac{n_1 n_2}{2}\left\{(a - a_1) - \frac{\sin(2a - 2a_1)}{2}\right\} - -k\,(a_1 - a). \tag{25}$$

The graph of the dependence of the surface of the deflector calculated by the obtained equation on the angle of inclination of the deflector α and the diameter of the nozzle is presented in Figure 6.

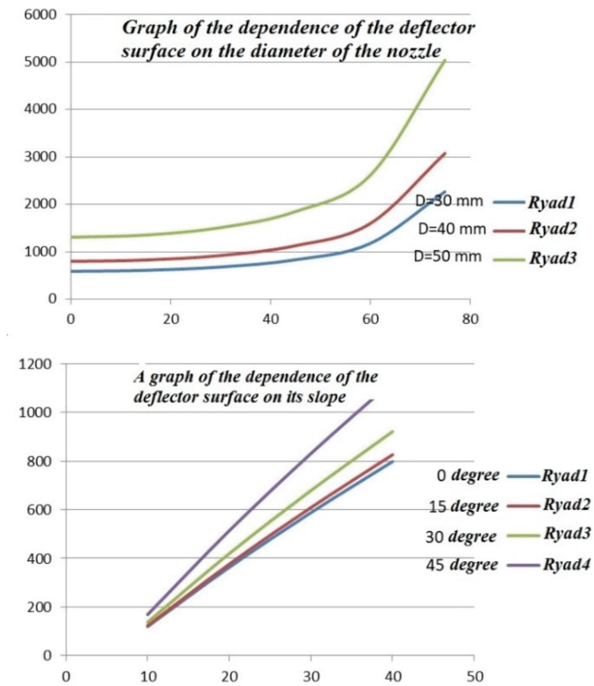

Fig. 6. The graph of the dependence of the angle of inclination of the deflector surface α and the diameter of the nozzle.

If we divide the surface of the deflector S_{def} by its length L the conditional l_{ayl}= πD_{sh} of the circle is derived:

$\pi D_{sh} = \frac{S_{def}}{L}$

Or

$$D_{Ш} = \frac{S_{def}}{\pi L}. \quad (26)$$

$$L = \frac{D+2k}{2cos\alpha}. \quad (27)$$

Taking into account the expression (27), we write the work generated by the movement of a drop of water in 2 sections:

$$A_{p2} = (p_1 - \gamma \frac{\pi(D+2k)^2 \vartheta^2}{8 S_{def} cos^2\alpha} \rho_c) V. \quad (28)$$

3 Results and discussion

Taking into account that the water droplet diameter d =0,5-3 mm in order to fulfill the condition (6) from the graph in Figure 3, its speed should be ϑ=2-3,5 m/s, the friction loss coefficient along the length is $\gamma = \frac{68}{\text{Re}}$ we count.

Reynolds number to characterize fluid flow

$$Re = \frac{\vartheta d\, \rho_c}{\mu_c} \quad (29)$$

uses.

Where ϑ – is the velocity of the fluid, m/s; d – quantity characterizing the size of the liquid, m; ρ_c - density of liquid or gas, ρ_c = 998,2 kg/m^3 for water at a temperature of

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20°S; μ_c- viscosity of the environment, the viscosity of air at an ambient temperature of 20°S is equal to μ_c= 1,78·10^{-5} Pa·s.

If the fluid is flowing through a pipe, turbulent flow occurs when the condition Re>2000 is met. Laminar flow is formed when Re<2000 [1-6].

When watering crops by raining on the surface, the diameter of the water droplet is d=0,5-3 mm, and the flight speed is ϑ=5 m/s. For this case (ρ_m = 1,2754 kg/m³; μ_c = 1,78·10^{-5} Pa·s) the Reynolds criterion is Re=56067 So, in this regime, the water flow flows turbulently, and the resistance force is determined according to the aerodynamic law. As a result of certain calculations, the coefficient of frictional loss along the length is equal to γ =0,0001213.

Based on the theoretical formulas and the analysis, it is possible to calculate the values of equations (7) and (15) obtained above. The calculation results are presented in the graph in Figure 6.

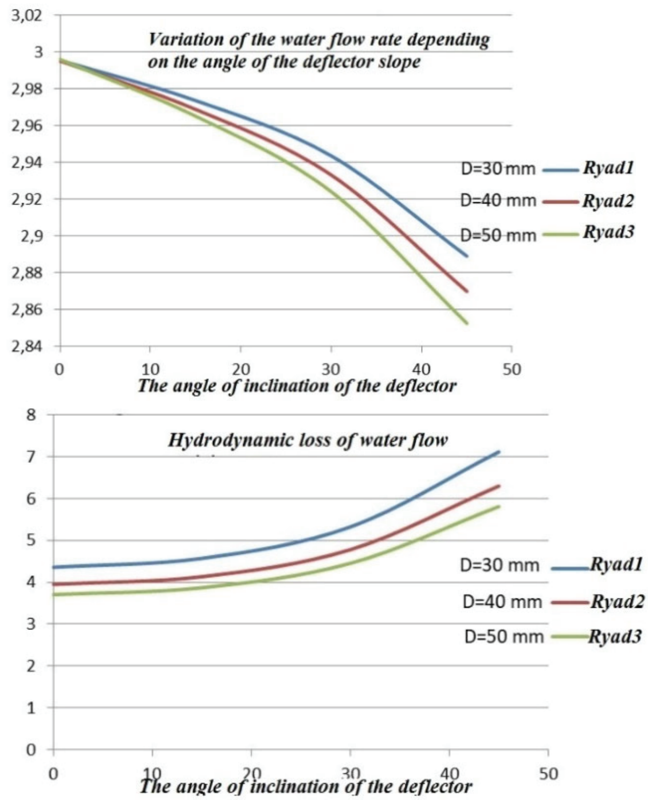

Fig. 7. Variation of water flow velocity and hydrodynamic loss (according to Darcy-Weisbach) in site 2 depending on the angle of the deflector slope

4 Conclusion

The equations obtained make it possible to determine the work performed by the water flow coming out of the deflector nozzle, the pressure change in it, as well as the speed of the water droplet coming out of the nozzle. It is known that the flight of a water droplet in the air depends on its initial speed (in our case, the speed of the water flow in the 2nd section of the deflector), the slope of the flight. From this point of view, the obtained equations serve to justify the main parameters of sprinkler nozzles with deflectors.

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