World Bulletin of Social Sciences (WBSS)
Available Online at: https://www.scholarexpress.net
Vol. 34, May 2024
ISSN: 2749-361X

INVESTIGATION OF THE PROCESS OF IRRIGATING AGRICULTURAL LANDS UNDER ARTIFICIAL IRRIGATION

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Article history:
Received: 26th February 2024
Accepted: 11th March 2024

Abstract:
It is necessary to optimize the parameters of artificial irrigation devices considering climatic conditions. In the article, the process of irrigation and the trajectory of movement of the water jet, as well as the influence of variable environmental factors on it, have been investigated. A mathematical model of the water jet movement has been obtained. The mathematical model of the water jet takes into account the distance and time of irrigation, as well as the direction and speed of the wind.

Keywords: Water jet, irrigation distance, irrigation time, trajectory, wind speed, influencing forces, mathematical model

INTRODUCTION. The trajectory of the water jet has been studied by several researchers. In the dissertation work of G.P. Nadejkin, the irrigation trajectory was determined taking into account the wind speed, and the mathematical model of the irrigation trajectory was developed [1]. However, during the creation of the process model, the internal pressure of the water jet and the upward Archimedean force were not considered. Similarly, in the scientific paper of A.G. Vinogradov and O.M. Yakhnov, this process was studied in detail [2]. In their scientific work, the mathematical model of the water jet coming out of the deflector nozzle was developed based on the law of energy conservation and the principles of fluid dynamics. In the study, not only the movement of water but also the gas movement in the air environment was examined. Therefore, the mathematical model obtained does not fully describe the process of artificial irrigation. The movement trajectory of the water jet through the mathematical model allows investigating various parameters such as the irrigation time, irrigation distance, height of the jet above the ground, distribution on the surface, and intensity of irrigation.

MATERIAL AND METHODS. The coordinates of the water jet at any given time are determined by the following formula [3]:

$$x(t_{i+1}) = x(t_i) + \vartheta_x(t_i)\Delta t; \quad (1)$$

$$y(t_{i+1}) = y(t_i) + \vartheta_y(t_i)\Delta t \ . \quad (2)$$

Let's consider calculating the trajectory of the water jet using formulas (1) and (2) provided.

Assume the initial condition of the water jet is given by equilibrium. Here, h is the height of irrigation (the height from the nozzle to the ground level).

$$X(0) = 0; \quad (3)$$

$$Y(0) = h \quad (4)$$

The initial velocity $\vec{\vartheta}(o)$ of the water jet at the deflector B point in the α direction mentioned in the previous paragraph is determined by calculating the absolute value of $|\vec{\vartheta}_B|$ with the following formula:

$$\vartheta_x(0) = |\vec{\vartheta}_B| \cos\alpha \ ; \quad (5)$$

$$\vartheta_y(0) = |\vec{\vartheta}_B| sin\alpha \ . \quad (6)$$

The initial data also include values specifying the parameters of air and environment. The mathematical model of the water jet's movement (1), (2) determines the trajectory of the water jet $y{=}x(t)$, $y{=}x(t)$ its characteristics $x(t_i)$, $y(t_i), \vartheta_x(t_i), \vartheta_y(t_i)$, $K(t)$, the irrigation distance L, and t_i - the diameter of the water jet at the moment of irrigation, the initial velocity $\vartheta_o(t)$, the deflection angle α of the deflector, and the height h of the nozzle.

RESULTS. The dependence of the initial velocity $\vartheta_o(t)$ of the water jet on its trajectory is illustrated in Fig. 1. Through the graphs, an analysis is conducted concerning various initial velocities of the water jet, deflection angles, and the trajectory of the water jet at different irrigation heights.

The analysis of the obtained data indicates that when the initial velocity $\vartheta_o(t)$ of the water jet is large, both the distance traveled along the X-axis (the irrigation distance L) and the height along the Y-axis (the height of the trajectory above the ground h) increase. For instance, with a deflection angle α=25°, a diameter d_s =2 mm, and a nozzle height h=0.7 m, as the initial velocity of the water jet increases from 6 m/s to 12 m/s, the irrigation distance L increases from 3.6 meters to 6.7 meters. The maximum increase in the trajectory

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height above the ground h due to the deflection angle α=25° and the nozzle height h=0.7 m forms a trajectory that reaches a height of $h+\Delta h$=2.60 meters (refer to Fig. 1.

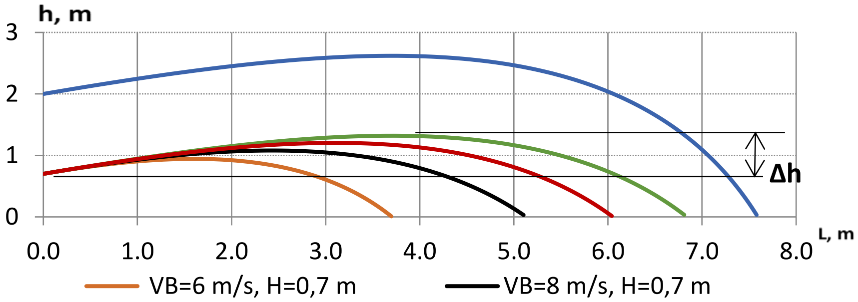
When ϑ_B>[ϑ_{Bsh}], where $\vartheta_B = 8\ m/s$ is anticipated, the condition L=5.1 meters, $h+\Delta h$=1.18 meters corresponds to a decrease in the irrigation distance by 30-32% relative to existing machines, and an increase in the distance from the nozzle to the ground by more than 2 times. This positively affects the reduction of water loss due to evaporation and wind drift during irrigation.

With an increase in the trajectory height due to increased irrigation height, the irrigation distance also increases. For instance, with h=0.7 m, L=5.1 meters, and with h=2,0 meters, L=6.1 meters. During the irrigation process, small-sized water jets are raised above the ground from the irrigation point due to environmental factors, leading to water losses caused by wind drift and evaporation.

Based on the obtained values, it was found that reducing the irrigation height from h=2,0 to h=0,7 m has a significant effect on not increasing the maximum elevation above the ground from the irrigation point, mainly affecting the irrigation distance (from L=5,1 meters to L=6,1 meters).

When the deflection angle α of the water jet with the ground surface is β=45°, there is a sharp increase in the pressure directed towards the soil surface. To optimize the technological process and minimize damage to the soil structure from the impact of the water jet, the angle of contact with the ground surface and the velocity at the time of contact were determined, and graphs were constructedee Fig. 2).

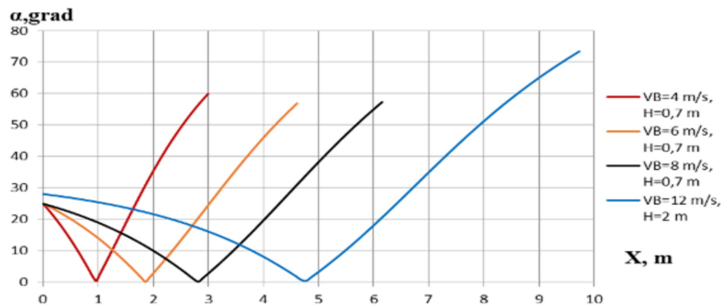
The water jet exiting the deflector moves at an angle α relative to the ground surface. Since the forces acting on the water jet are variable, the value of the angle α also varies (refer to Fig. 3).



1-Figure. The irrigation distance of the water jet depends on the initial velocity of the water jet.

When α = 25°, the angle α becomes equal to α=0° when Δh reaches its maximum value, meaning the water jet continues its motion parallel to the ground surface for a certain distance. Then, the water jet starts moving downwards, and the value of the angle α starts increasing. The maximum value of the angle α is reached at the point of contact between the water jet and the ground surface.

When a water jet with a diameter d_s=1,5 mm and an initial velocity ϑ_B =4 m/s is deflected, the angle of contact with the ground surface is formed at α = 58.6°. For initial velocities ϑ_B =6; 8; 12 m/s, the angles α are approximately equal to =55,42°; 55,96° and 71.46°, respectively. All obtained values in all modes satisfy the condition α ≠ 45°.



3-Fig: Graphs depicting the trajectory of the water jet and the variation in the angle between the jet and the surface

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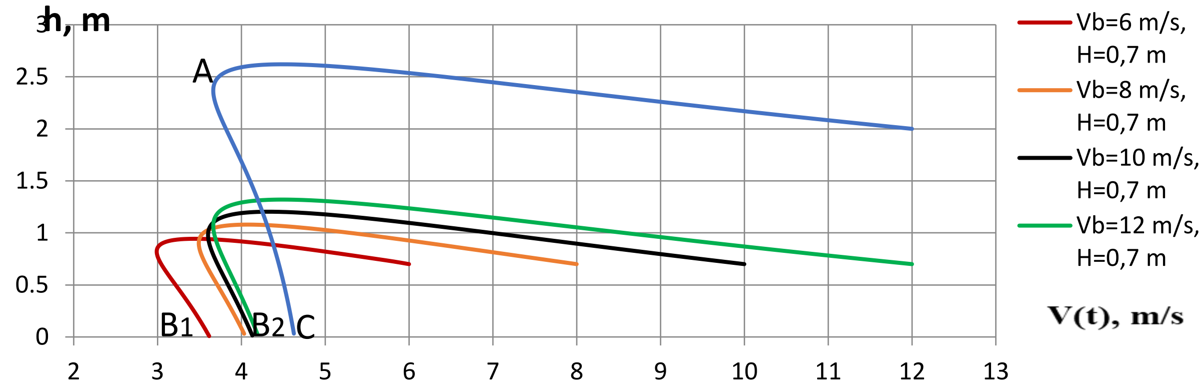
The pressure exerted by the water jet on the surface it contacts depends on the speed of the jet at the moment of impact with the soil.

The angle at which the water jet contacts the surface, β=45°, is found to correspond to the maximum force affecting the soil structure.

DISCUSSION. Graphs based on equations (1) and (2) illustrate the water jet's characteristics, dependent on the nozzle's design parameters, and analyze their technological impact (refer to fig. 4). The absolute velocity of the water jet varies, changing in two stages. In the first stage, the speed of the water jet decreases until it reaches its maximum range from the irrigation height (marked as point A on the graph). At the end of this stage, when $\vartheta_y(t_i) = 0$, the absolute velocity of the water jet becomes equal to $\vartheta_B = \vartheta_x(t_i)$. Then, the second stage begins, during which the water jet starts to descend, and the vertical component of its velocity, $\vartheta_y(t_i)$ increases due to the gravitational force, leading to an increase in the absolute velocity of the water jet. From the graph, it is possible to determine that the velocity of the water jet at the moment of impact with the soil surface (point B_1 B_2) is approximately 3.54...4.15 m/s relative to the initial velocity of the jet. M.S. Zverkov determined that a velocity range of 6.3...6.9 m/s at the moment of impact during irrigation ensures sufficient pressure to disrupt the soil structure.



4-Fig. Graphs depicting the water jet's velocity V(t) as a function of initial velocity

When the water jet nozzle is designed with a diameter of 1-2 mm (according to the requirements of GOST ISO 8224-1-2004), an irrigation height of *h*=0.7 m, an initial velocity of ϑ_B =8 m/s, and an initial angle of α=25°, the velocity of the water jet at the moment of impact with the soil is $\vartheta_x(t_i)$= 1.87 m/s, $\vartheta_y(t_i)$= -3.57 m/s, and the absolute velocity is $\vartheta(t_i)$= 4.13 m/s. The obtained results demonstrate the suitability of accepting an initial velocity of $\vartheta_B(t)$= 8 m/s for the water jet and indicate a decrease in the velocity from that produced by irrigation machines ($\vartheta(t_i)$ 4.63 m/s, marked as point S on the graph).

The investigation aimed to analyze the effect of wind speed on the water jet's characteristics based on the nozzle's structural dimensions using the mathematical model of the trajectory of the water jet during the irrigation process. The objective of the research was to determine the influence of wind speed on the characteristics of the water jet.

The variable coefficient of the environment under the influence of wind can be expressed as follows:

$$K_1(t) = -\left(\frac{18\mu}{\rho_c d^2} + \frac{\rho_m c_x\left(\sqrt{\vartheta_x^2(t)+\vartheta_y^2(t)}-\vartheta_{sh}\sin\theta\right)}{4\rho_s d}\right), \quad (7)$$

In this context: ϑ_{sh}-represents the wind speed, measured in m/s; θ denotes the angle between the water jet trajectory line and the direction of the wind, measured in degrees; ρ_m stands for the ambient density, where at ambient temperature t=20°Ct=20°C, the air density is ρ_m=1.2754kg/m3; μ signifies the viscosity coefficient of the environment: $\mu=1{,}8\cdot10^{-5}$ Pa for air and $\mu=10^{-5}$ Pa for water; d_s- represents the diameter of the water je; $\vec{\vartheta}(t)$indicates the absolute value of the velocity vector.

Taking into account the influence of wind speed on the water jet's velocity, we express equation (1) in the following form:

$$\vartheta_x(0) = |\vec{\vartheta}(o)|\cos\alpha - \vartheta_{sh}\sin\theta \ ;$$
$$\vartheta_u(0) = |\vec{\vartheta}(o)|\sin\alpha \ . \quad (8)$$

In this case, the mathematical model of the water jet's trajectory (1) and (2) equations) can be represented as follows [5]:

$$x(t_{i+1}) = (1 + K_1(t_i)\Delta t)\vartheta_x(t_i); \quad (9)$$

$$y(t_{i+1}) = (\frac{p_c}{p_t}-1)\cdot 9{,}81\cdot\Delta t + (1 + \ K_1(t_i)\cdot\Delta t\cdot\vartheta_y(t_i). \quad (10)$$

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During the variable environmental conditions in the irrigation process, the trajectory of the water jet changes were obtained using equations (1) and (2) in a numerical method and discretization approach. The obtained values are depicted in the graph presented in Fig 4.

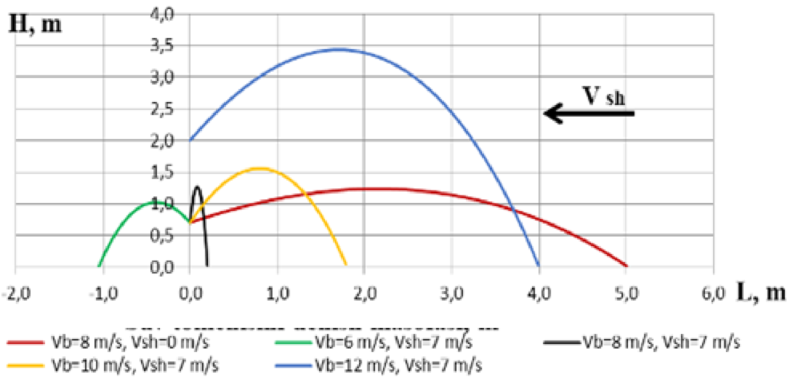

Fig 4. Variation of the water jet trajectories in a variable environment

Graphs were constructed for the water jet trajectories under wind speeds of ϑ_{sh}= 0 m/s, and ϑ_{sh}= 5 m/s, blowing in the opposite direction of the water jet. Initial data for the calculations were: water jet diameter d_s=2 mm, jet angle 25 degrees, and irrigation height h=0.7 m. With an initial velocity of ϑ_B=8 m/s, the water jet reaches a distance L=5.1 m under no wind conditions (see Fig 4). As the wind speed increases, deformation of the water jet trajectory begins. The results indicate the necessity of satisfying the condition $\vartheta_B > \vartheta_{sh}$ to mitigate the influence of wind and prevent water jet deflection.

CONCLUSION: Under zero wind speed $\vartheta sh=0\vartheta s$ h=0 m/s, the water jet is distributed in an elliptical shape towards the soil surface. With increasing wind speed, a sharp deflection along the wind direction is observed in the trajectory distribution. The calculations also demonstrate variations in the irrigation time under the influence of wind speed. It should be emphasized that the segments where the highest water jet velocities are located lie within the range of 45-60 degrees. The effect of the deflector is evident in the deformation of the water jet velocity in the first half-segments.

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