Mathematic Modelization of the Absorption of Water Drop by Wind in the Rainbowing Irrigation of Agricultural Crops

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Keywords: Rain Irrigation, Water Drop Trajectory, Wind Influence.

Abstract: The article takes a mathematical model of the process of blowing a drop of water under the influence of the wind when raining and watering agricultural crops. Graphs of the movement trajectory of a water drop in a changing environment are built, the influence of wind speed and direction on the process is analyzed. To improve the raining process, methods have been developed to increase the effective irrigation coefficient, on which the technological and structural parameters of raining machines are based.

1 INTRODUCTION

Due to the change in the size of the artificial water drop formed by rainmaking machines in the range of 0.8-3.5 mm, due to the rise of water particles from the ground level to 4-4.5 meters,evaporation of the water drop and wind blowing increase, on windy days, the effective irrigation coefficient decreases from 0.76-0.80 to 0.45-0.5. Waste of Water Resources in rainfall can reach 22-24 percent, in some cases up to 40 percent (Sevryugin, 1998; Zhelyazko et al., 2015; Khudayorov, 2022; Khudayorov et al., 2023a). It is relevant to reduce the waste of Water Resources, develop the scientific and technical basis of the energy-efficient rain irrigation process, improve the quality indicators of rain irrigation, improve rainmaking machines and devices, introduce into design and mechanical engineering practices (Voronin, 1988; Vinogradov, 2015; Akpasov, 2018; Khudayorov, 2024a; Khudayorov, 2024b).

2 MATERIALS AND METHODS

The sum of the forces acting on a drop of rainwater is expressed by the formula on it (Khudayorov et al., 2023b):

$$m\vec{a}\,(t) = m\vec{g} - p_m V_{ch}\vec{g} - 3\pi d_s \mu \vec{\vartheta}\,(t) - \frac{1}{2} C_x\, \rho_m\; S_T\, \left|\vec{\vartheta}\,(t)\right| \vec{\vartheta}\,(t). \quad (1)$$

where m- is the mass of the drop of water; $\vec{a}\,(t)$- is the vector of acceleration of the drop of water; g - is the acceleration of free fall; ρ_m -is the density of the environment, ambient temperature at t=20 °C is the air density ρ_m = 1,2754 kg/m³; V_{ch} - is the volume of the drop of water, m³; μ–coefficient stickness of the environment: air for μ=1,8·10^{-5} Pa, water for μ=10^{-3} Pa; d_s -the diameter of the water drop, $\vec{\vartheta}\,(t)$ -the absolute value of the vector of the speed of a body, m/s; π – sharing coefficient and its value depends on the form of a body which is about equal to 0.4 in the form of solids; S_T – direction transverse incisions of the movement of solids (midelevoy) surface,

$$S_T = \frac{\pi d_s^{\,2}}{4};$$

C_x - aerodynamic resistance coefficient, sferik in the form of solids C_x =0.5 in.

To represent $\vec{a}\,(t)$ projections of water drop acceleration in flight

$$K(t) = -\left(\frac{18\mu}{\rho_s\, d_s^{\,2}} + \frac{3\,\rho_m C_x \sqrt{\vartheta_x^{\,2}\,(t) + \vartheta_y^{\,2}(t)}}{4\rho_s d_s}\right) \quad (2)$$

by introducing a variable coefficient, we get the following expressions for its projection on the X and Y axes:

$$a_x(t) = K(t)\vartheta_x(t); \quad (3)$$

$$a_y(t) = \left(\frac{\rho_m}{\rho_s} - 1\right) g + K(t)\,\vartheta_y(t)\;. \quad (4)$$

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Khudayorov, Z.
Mathematic Modelization of the Absorption of Water Drop by Wind in the Rainbowing Irrigation of Agricultural Crops.
DOI: 10.5220/0014225000004738

In *Proceedings of the 4th International Conference on Research of Agricultural and Food Technologies (I-CRAFT 2024)*, pages 172-175
ISBN: 978-989-758-773-3; ISSN: 3051-7710

To calculate the resulting equations, we use the method of time discretization.

Let the speed and acceleration of the rainwater drop between selected times. If the values of the velocity vector and acceleration projections within the time unit t_i are denoted by $\vartheta_x(t_i), \vartheta_y(t_i), a_x(t_i), a_y(t_i)$ respectively, then the projections of the velocity vector t_{i+1} at the same time are equal to:

$$\vartheta_x(t_{i+1}) = (1 + K(t_i)\Delta t)\vartheta_x(t_i); \quad (5)$$

$$\vartheta_y(t_{i+1}) = \left(\frac{\rho_m}{\rho_s} - 1\right) g \cdot \Delta t + K(t_i) \cdot \Delta t \cdot \vartheta_y(t_i), \quad (6)$$

The coordinates of the water drop at any time are determined by the formula:

$$x(t_{i+1}) = x(t_i) + \vartheta_x(t_i)\Delta t; \quad (7)$$

$$y(t_{i+1}) = y(t_i) + \vartheta_y(t_i)\Delta t \,. \quad (8)$$

To determine the wind effect on an artificial water drop in flight, let's consider the obtained equations (7) and (8) in a variable environment. The resistance force of the environment under the influence of wind has the following appearance:

$$\vec{F}_{qk\ t}(t) = \frac{C_x \rho_m S}{2} \vartheta^2 = \frac{C_x \rho_m S}{2} \left(\sqrt{\vartheta_x^{\,2}(t) + \vartheta_y^{\,2}(t)} - \vartheta_{sh} \sin\theta \right), \quad (9)$$

where ϑ_{sh} is the wind speed, m/s; θ is the angle between the water flow line and the wind direction, °.

Given the wind Effect (2) the variable coefficient of the environment expressed by the formula can be written as:

$$K_1(t) = -\left(\frac{18\mu}{\rho_c d^2} + \frac{\rho_m C_x \left(\sqrt{\vartheta_x^{\,2}(t) + \vartheta_y^{\,2}(t)} - \vartheta_{sh} \sin\theta \right)}{4\rho_s d} \right) \quad (10)$$

Taking into account the effect of wind speed on the speed at which the water drop flies ,we represent the equation (5) and (6) in the following way:

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

$$\vartheta_u(0) = |\vec{\vartheta}(o)| \sin\alpha \,. \quad (11)$$

Then the mathematical model of the motion trajectory of a water drop (7) and (8) come to the following view:

$$x(t_{i+1}) = (1 + K_1(t_i)\Delta t)\vartheta_x(t_i); \quad (12)$$

$$y(t_{i+1}) = \left(\frac{p_c}{p_t} - 1\right) \cdot 9{,}81 \cdot \Delta t + (1 + \ K_1(t_i) \cdot \Delta t \cdot \vartheta_y(t_i) \quad (13)$$

3 RESULTS AND DISCUSSION

In the process of rainmaking in a changing environment, the water drop trajectory changes (12), (13) formulas were solved numerically by time discretization, and the obtained values are given in the graphs in Figure 1.

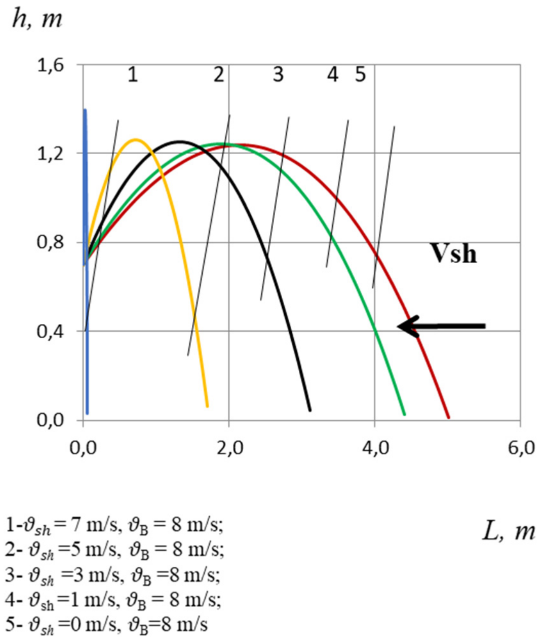


Figure 1: Change of water droplet flight trajectories in changing environments.

The graphs are constructed for the state in which the wind blows in the opposite direction to the water flow line at ϑ_{sh} = 0 m/s, ϑ_{sh} = 3 m/s, ϑ_{sh} = 5 m/s, and ϑ_{sh} = 7 m/s. Initial data in calculations: water drop diameter d_s =2 mm, takeoff angle 25 degrees, rainfall height h=0.7 m. The initial ϑ_B = 8 M/S makes a drop of flying water with a wind speed of ϑ_{sh} = 0 m/s with a takeoff distance of L = 5.1 m (Figure 1a). As the wind speed increases, the water drop begins to deform the flight trajectory. At wind speed ϑ_{sh} = 3 m/s, the takeoff distance is equal to L = 3.1 meters. the takeoff distance at ϑ_{sh} = 5 m/s is L = 1.7 m, at ϑ_{sh} = 7 m/s is L = 0.1 meters. Under the influence of wind speed, the deformation of the trajectory of the water drop fly willalso lead to an increase in the distance *Δh*. The *Δh* value increases from *Δh*=1.2 meters to *Δh*=1.3 meters under the influence of wind speed (Akhmetov et al., 2021; Zhanikulov et al., 2022; Khudayorov et al., 2023b; Akhmetov et al., 2023; Sevryugin, 2024; Alimova et al., 2024). Further increase in wind speed allows the takeoff distance to have a negative value.

At wind speed ϑ_{sh} = 0 m/s, the drop of water is evenly distributed over the surface of the field in the form of an ellipse. With increasing wind speed, a sharp shift in the distribution along the direction of the wind is observed.

The calculations made showed that in this case, the time of the water drop's flight also changes.

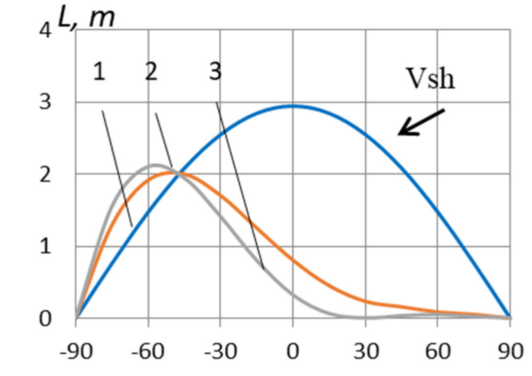
The distribution graph on the field surface of the flow of water (Figure 2 and Figure 3) was obtained by projecting the flight distance of a drop of water flying from the deflector segments onto the XZ axes.

The change in the takeoff distance of a water drop depends on the value of the changing $\vartheta_i(t)$- the take off speed of the drop and ϑ_{sh}-the wind speed, and the K(t)-the variable coefficient of the environment. When the wind direction is in the direction of the flow of water, an increase in the distance of the water drop and the time of takeoff can be seen.

The graph shows that at ϑ_{sh} = 0 m/s (Figure 3a) the water drop has a fly distance of L = 2.94 m. When the wind speed is equal to ϑ_{sh}= 2-3 m/s, the takeoff distance decreases and l = 1.93-1.99 m, it should be noted that the greatest values of the water drop speed belong to the drop of water, which is shot out of segments located at 45-60o degrees. Under the influence of wind speed, there is a deformation of the drop velocity, which is rained from the segments of the 1st half of the deflector.

The graph in Figure 3b shows the distribution of the flow of water on the field surface as a result of the deformed velocity. The graph shows that the distribution of the water flow is shifted along the Z-axis and |-6.2;0.2| localizes in the cross section.

The variation in the distance to fly a drop of water under the influence of the wind blowing in the direction of water drop is depicted in the graph in Figure 3. When the wind speed changes in the range ϑ_{sh} = 2-3 m/s, the takeoff distance of the water drop from the 1st half of the deflector will have a critical small value. Reaches its maximum value in the 2nd half of the deflector. Wind speed reaches L = 8 m when ϑ_{sh} = 3 m/s.



a) 1- ϑ_{sh}= 0 m/s; 2- ϑ_{sh}=2 m/s;3- ϑ_{sh}=3 m/s

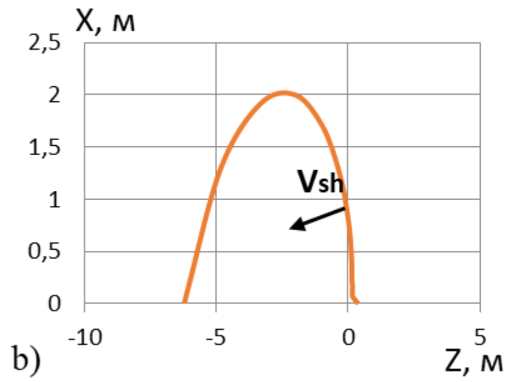
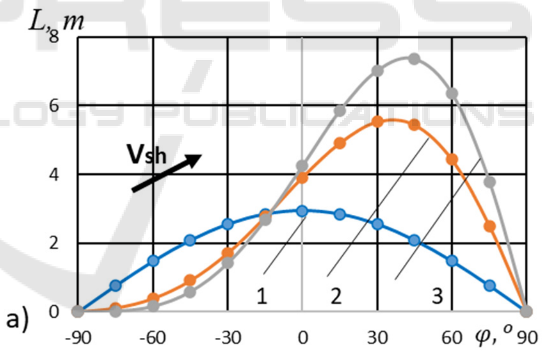
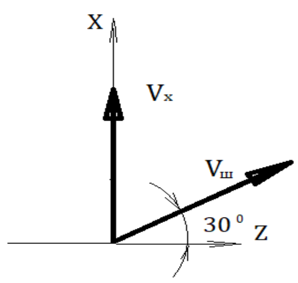


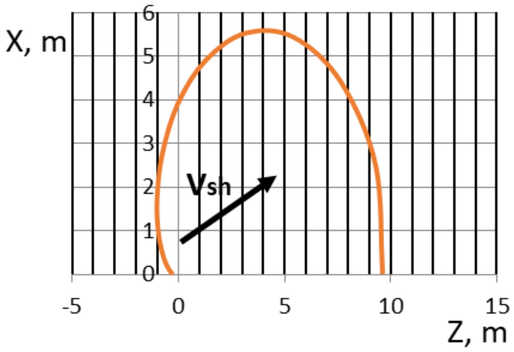
Figure 2: The distribution of the water drop on the field surface when the wind speed is directed against the water flow and the effect of the wind speed on the flight distance: a) the influence of wind speed on the distribution of the water flow on the field surface; b) the epic of the distribution of water flow on the field surface.

The graphs in Figure 3b show the Epura of distribution on the field surface of a drop of water under the influence of wind blowing at an angle θ= 30º in the direction of rainmaking. Under the influence of wind, water droplets shift from octant I to octant II of the XOZ coordinate system.



1- ϑ_{sh}= 0 m/s; 2- ϑ_{sh} =2 m/s; 3- ϑ_{sh} =3 m/s





b)

Figure 3: The distribution of the water drop on the field surface when the wind speed is directed along the water flow and the effect of the wind speed on the flight distance: a) the effect of the wind speed on the distribution of the water flow on the field surface; b) the epic of the distribution of the water flow on the field surface.

4 CONCLUSIONS

When the initial takeoff speed of the water drop is less than the wind speed, the takeoff distance of the water drop will have a negative value. the flight distance of a drop of rainwater from H = 2.0 meters is reduced from L = 7.54 meters to L = 4.0 meters under the influence of wind with a speed of ϑ_{sh} = 7 M/s. The results obtained indicate that the condition $\vartheta_B > \vartheta_{sh}$ must be met in order to reduce the blowing of a drop of water under the influence of the wind.

Taking into account the fact that as a result of the calculations performed, rain irrigation machines should carry out effective irrigation under conditions with a wind speed of up to 7 m/s (ATT), it is necessary to construct the device to ensure the height of rainmaking at a value of h = 0.7 m and the initial flight speed of the water drop at a $\vartheta_A = 7 - 8$ m/s.

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