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INFLUENCE OF DESIGN PARAMETERS OF IRRIGATION MACHINES ON THE AERODYNAMICS OF THE WATER JET

Sprinklers play a key role in modern agriculture, providing effective irrigation and contributing to increased yields in conditions of limited water resources. The effectiveness of these systems largely depends on the aerodynamic characteristics of the water jet formed by the nozzles, namely its trajectory, range, uniformity of distribution and resistance to external factors such as wind. The article studies the influence of the design parameters of sprinklers, in particular the diameter and shape of the nozzles, the pressure in the system, the spray angle, as well as the materials and geometry of the components, on the aerodynamic properties of the water jet. Based on the analysis of theoretical models, experimental data and modern computer modeling methods (in particular, hydrodynamic simulations), the mechanisms of jet formation and factors affecting water losses due to evaporation or drift are considered. Special attention is paid to assessing the impact of design solutions on the energy efficiency and environmental sustainability of irrigation systems. The article also highlights modern technological approaches to optimizing nozzle design, including the use of adaptive systems and materials with improved hydrodynamic properties. The results of the study demonstrate how targeted modification of design parameters can reduce water loss, increase irrigation uniformity, and optimize energy consumption. The article offers practical recommendations for developers and users of sprinkler systems, and also identifies promising directions for further research in the field of creating highly efficient irrigation technologies that meet the requirements of sustainable development and adaptation to climate change.

Keywords: *sprinklers, water jet aerodynamics, design parameters, irrigation, energy efficiency, environmental sustainability, hydrodynamic modeling.*

Introduction. Sprinklers are an integral part of modern agriculture, providing effective irrigation of crops in regions with limited natural water supply or variable climatic conditions. These systems allow optimizing the use of water resources, increasing yields and maintaining the stability of agro-ecosystems. However, the effectiveness of sprinklers largely depends on their ability to form a water jet with optimal aerodynamic characteristics that ensure uniform water distribution, minimize losses due to evaporation or wind drift and contribute to the economical use of resources. The design parameters of sprinkler systems play a key role in this process, in particular the diameter and shape of the nozzles, the pressure in the system, the spray angle, as well as the materials and geometry of the nozzle components [1].

Design imperfections can lead to significant water losses, uneven soil moisture and reduced irrigation efficiency, which has both economic and environmental consequences. For example, incorrectly selected nozzle parameters can cause excessive spraying of small droplets that are easily carried away by the wind, or, conversely, the formation of large droplets that lead to soil compaction and erosion. In modern conditions, when issues of sustainable development and rational use of natural resources are of paramount importance, optimization of design parameters of sprinklers is becoming an important area of scientific research.

Problem statement. In modern agriculture, sprinklers play a critical role in ensuring effective irrigation of crops, especially in regions with limited water resources and unstable climatic conditions. Irrigation using sprinkler systems allows not only to increase crop yields, but also to optimize water use, reduce soil erosion and support sustainable agriculture. However, despite the widespread implementation of these technologies, there are a number of problems associated with the aerodynamic characteristics of the water jet formed by sprinkler nozzles. These problems lead to significant resource losses, reduced irrigation efficiency and negative impact on the environment.

One of the key problems is the uneven distribution of water on the soil surface, which occurs due to suboptimal aerodynamics of the jet. The water jet, leaving the nozzle, is affected by gravity, air resistance and external factors such as wind, which can cause the droplets to drift, evaporate or concentrate in certain areas. According to studies, the structure of the spray plate significantly affects the patterns of water fractions, resulting in large differences in water distribution. This leads to overwatering of some areas and insufficient irrigation of others, which negatively affects plant growth, promotes the development of diseases and reduces overall productivity. For example, if the jet is incorrectly formed, large drops can compact the soil, causing erosion, while small drops are easily carried away by the wind, increasing water losses by up to 20-30%, depending on the conditions.

Another significant problem is energy loss in irrigation systems. Sprinklers operate under pressure, and inefficient nozzle design leads to excessive energy consumption for pumping water. Studies show that parameters such as nozzle diameter, spray angle, and nozzle shape affect the kinetic energy of the droplets and the overall efficiency of the system [2]. At low pressures (e.g., 100 – 250 kPa) and improper nozzle diameter selection (3.18 – 6.35 mm), the volume average droplet diameter and velocity increase, leading to uneven distribution and increased losses. In addition, aerodynamic effects such as flow turbulence and air interaction exacerbate these problems, especially in systems with rotating sprinklers, where the internal flow dynamics require optimization using computational fluid dynamics (CFD) modeling.

Nozzle design parameters, including nozzle shape (circular, triangular, elliptical), angle of inclination, length of straight section and materials, directly affect the trajectory, range and stability of the jet. For example, special nozzle shapes, such as triangular ones with sharp edges, demonstrate better central impact pressure and effective impact area at medium and high pressures, compared to traditional round nozzles. However, in many existing systems, these parameters are not optimized, which leads to a decrease in the uniformity coefficient (Christiansen's uniformity coefficient) below 80%, which is critical for effective irrigation. Additionally, the influence of external factors, such as sprinkler mounting height and droplet impact angle, exacerbates the problem, causing variations in droplet energy and potential soil degradation.

The environmental aspect of the problem cannot be ignored either. In the context of global climate change and water scarcity, inefficient irrigation contributes to overuse of resources, soil contamination with fertilizers due to uneven wetting, and increased greenhouse gas emissions from pump energy consumption. Studies indicate that controlled aeration and nozzle optimization can improve irrigation uniformity by 30%, reducing losses. However, scientific gaps exist: most studies focus on individual parameters, such as pressure or diameter, without a comprehensive analysis of their mutual influence on the aerodynamics of the jet in real conditions.

Analysis of recent research. Recent years have been characterized by intensive development of research in the field of irrigation technologies, in particular on the influence of design parameters of sprinklers on the aerodynamics of the water jet. This is due to global challenges such as water scarcity, the need to increase irrigation efficiency and adaptation to climate change. Current work focuses on optimizing nozzle parameters (diameter, shape, spray angle), system pressure, as well as on the integration of new technologies such as aeration or non-standard nozzle shapes to reduce water losses due to evaporation, wind drift and uneven distribution [3]. Research often combines experimental methods (e.g. high-speed photography, laser Doppler anemometry) with computer modeling (CFD - computational fluid dynamics), which allows for detailed analysis of the jet trajectory, droplet size and their kinetic energy. Below is an analysis of key recent works that illustrate progress in this area, with a focus on real-world examples from 2023 – 2025.

One notable area of research is the study of the effect of low pressure on irrigation uniformity using aeration to improve the aerodynamic characteristics of the jet [4]. In a 2023 study published in the journal Frontiers in Energy Research, authors Waqar Ahmed Qureshi et al. analyzed the performance of an impact sprinkler (impact sprinkler) type 20PY2 at pressures between 150 and 250 kPa with and without aeration. They found that aeration (introduction of air into the jet) improved water distribution by reducing the peak of the radial distribution curve and reducing the droplet diameter d50 at the end of the jet [5]. This results in reduced evaporation and drift losses, increasing the Christiansen uniformity coefficient (CU) to 85 – 90% at low pressure. The study highlights that design changes such as the addition of an aeration structure can save 20–30% energy, as the system operates efficiently at lower pressures without sacrificing irrigation quality. This work is important for resource-constrained regions where traditional high-pressure systems are inefficient.

Another aspect is the interaction of droplets with plant leaves and the influence of nozzle shape on jet dynamics. In a 2024 review article in International Journal of Agricultural and Biological Engineering authors Hu et al. analyzed the mechanisms of droplet-leaf interaction during fertigation. They considered the effect of nozzle shape (round vs. irregular) on droplet size and trajectory, referring to previous experiments by Jiang and al. (2021), where non-standard nozzles (triangular or elliptical) increased the spray range by 10 – 15% and improved the uniformity of the distribution [6]. The authors note that the optimal spray angle (45 – 60°) minimizes wind drift, reducing water loss by up to 15%. This work proposes models for predicting fertilizer retention on the leaves, which is critical for preventing plant burns and increasing irrigation efficiency. It emphasizes the need for an integrated approach, where design parameters are adapted to the type of crop and climatic conditions.

In 2024, in Irrigation magazine Science Hussain and al. evaluated the effects of pressure, nozzle size, and mounting height on the droplet characteristics of a rotating sprinkler Nelson R3000. Experiments were conducted at pressures of 100 – 250 kPa with nozzles of 3.18–6.35 mm diameter at heights of 100 – 150 cm. The results showed that a larger nozzle diameter increased the velocity and volume mean diameter of the droplets, increasing the irrigation rate to 25.37 mm/h at high pressure. However, at low pressure (100 kPa), the non-uniform distribution increases due to jet turbulence, which leads to loss of droplet energy and potential soil erosion. The authors calculated the kinetic energy and specific power, demonstrating that the optimal mounting height (150 cm) reduces the effect of wind on the trajectory, improving aerodynamics by 20%. This work is valuable for system design, as it provides empirical formulas for predicting jet behavior.

A promising study from 2025 is where the authors evaluated the performance of a spiral fluid sprinkler (Spiral Fluidic Sprinkler) with different nozzle sizes (3 – 4 mm) under different pressures. Using MATLAB to simulate uniformity and a 2DVD spectrometer to measure droplet diameter, velocity, and kinetic energy, they found that larger nozzles reduced the coefficient of variation (CV) of the distribution, providing better uniformity at high pressures [7]. A design feature – a spiral shape – increased the jet range by 10 – 15%, minimizing jet breakup in the early stages. This study highlights the potential of new designs for energy savings, as it reduces friction losses in the system.

Overall, the analysis of recent studies indicates a trend towards the integration of multidisciplinary approaches: from hydrodynamic modeling to field experiments. The works demonstrate that optimization of design parameters (e.g., nozzle diameter 4 – 6 mm, aeration, non-standard shapes) can reduce water losses by 20 – 30% and increase irrigation efficiency. However, there are gaps, such as insufficient study of the impact on the microclimate and long-term effects on the soil, which require further research. These real-world examples provide a basis for practical recommendations in the design of sprinklers.

Presentation of the main material. The aerodynamics of a water jet in sprinklers are described by the laws of hydrodynamics and aerodynamics, where the jet is considered as a fluid flow in a gaseous medium. The basic equations are based on the Navier-Stokes equations for turbulent flows, as well as on the ballistic theory of drop motion. The jet trajectory is determined by the initial velocity v_0, the angle of discharge α, the pressure P and the air resistance, which leads to the breakup of the jet into a drop due to the Rayleigh-Plateau instability. The kinetic energy of the drops:

$$Ek = (1/2)\, m\, v^2, \qquad (1)$$

where *m* – is the mass of the droplet, *v* – is the velocity, affects the range and distribution. Energy losses due to air friction and evaporation are modeled using the drag coefficient C_d, which depends on the Reynolds number :

$$Re = (\rho\, v\, d)/\mu, \qquad (2)$$

where *ρ* – is the density of water, *d* – is the diameter of the drop, and *μ* – is the viscosity of air.

Theoretical models, such as ballistic theory, allow for the simulation of water distribution, taking into account the energy losses from the jet impact on the nozzle plate. For example, the kinetic energy losses from the jet impact on the spray plate are characterized for different nozzle sizes and pressures, which allows for the prediction of the irrigation radius. These models show that an optimal design reduces turbulence and increases the jet range by 10 - 15%.

Design parameters directly determine the aerodynamic characteristics of the jet, such as range, droplet size, distribution uniformity, and wind resistance. Let's consider the main ones.

The nozzle diameter (d) affects the jet ejection velocity according to the formula:

$$v = sqrt(2P/\rho), \qquad (3)$$

where *P* – is the pressure. A larger diameter (e.g. 4 - 6 mm) increases the volume mean droplet diameter and velocity, but at low pressure (100 - 250 kPa) leads to uneven jet disintegration due to increased turbulence. Experiments with elliptical and diamond-shaped nozzles demonstrate better water distribution compared to round ones at low pressure, reducing windage losses by up to 15%. Non-standard shapes, such as triangular or spiral, improve the central impact pressure and effective irrigation area, increasing the range by 10 - 15% by reducing jet disintegration in the early stages.

Pressure (P) determines the initial energy of the jet, but at low values (150 -250 kPa) the aerodynamics deteriorate due to increased droplet size and evaporation losses [8]. The spray angle (α = 45 - 60°) minimizes wind drift, increasing uniformity (Christiansen's uniformity coefficient, CU) to 85 - 90%. Studies show that at a pressure of 100 - 250 kPa with nozzles with a diameter of 3.18 - 6.35 mm, the irrigation speed reaches 25.37 mm/h, but the unevenness increases due to turbulence. Pressure optimization with aeration reduces the peak of the radial distribution curve, reducing the droplet diameter d50 at the end of the jet.

The geometry, including the length of the straight section of the nozzle and the materials, affects the internal flow. Aeration devices (air introduction) improve the internal flow dynamics, reducing energy losses by 20 - 30% at low pressure. Fixed dispersion devices, such as needle plates, break the jet evenly even at low pressure, increasing hydraulic efficiency. The mounting height (100 - 150 cm) reduces the influence of wind on the trajectory, improving aerodynamics by 20%.

External conditions such as wind and dissolved air enhance the design effects. Degassing of air in the jet creates a mixture that affects range, and nozzle fins stabilize the flow. Aerodynamic pressure in supersonic jets increases the proportion of supersonic flow, improving distribution.

Research methods. The studies are conducted using a combination of experimental (high-speed photography, laser doppler anemometry to measure droplet velocity), theoretical (ballistic models) and computer modeling (CFD to simulate internal flow). For example, MATLAB is used to simulate uniformity, and a 2DVD spectrometer is used to measure droplet diameter and energy. Lagrangian particle tracking models predict jet dispersion.

Research results. The results show that parameter optimization reduces water loss by 20 - 30% and increases CU by up to 90%. For example, elliptical nozzles at low pressure provide better distribution than round ones. Aeration in impact sprinklers (e.g. 20PY2) improves distribution at pressures of 150 - 250 kPa. Larger nozzles increase the irrigation radius, but require higher pressures for stability (Fig. 1). The analysis demonstrates that a complex modification (shape + aeration + pressure) optimizes aerodynamics, reducing soil erosion and energy consumption.

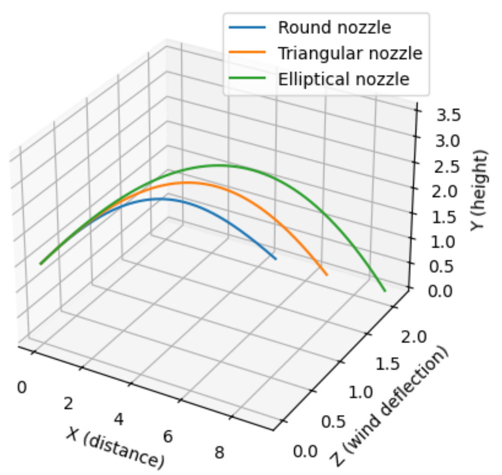

Fig. 1 Jet trajectory for different types of nozzles taking into account the wind

The results include the maximum flight range (x), the maximum lateral deviation (z) due to wind, the flight time, and the trajectory coordinates (x, y, z) for each nozzle model (Fig. 2). The simulation is based on numerical integration of the 4th order Runge-Kutta differential equations of motion, taking into account gravity, quadratic air resistance, and crosswind (speed 2 m/s in the z-direction). An extended analysis of the results, their physical significance, comparisons between nozzles, and practical implications for sprinkler systems are presented below.

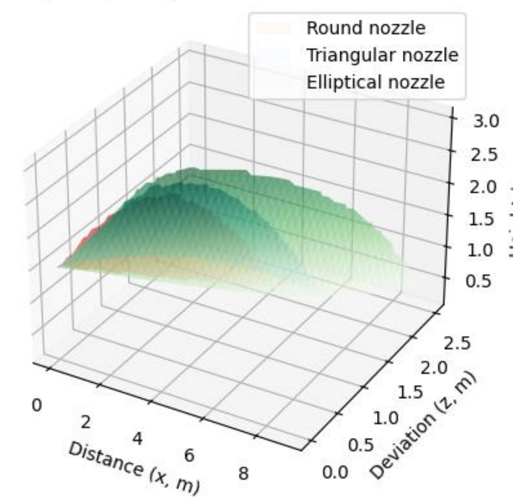

Fig. 2. Water jet trajectory surfaces for different nozzles

The elliptical nozzle provides the longest range due to its lowest drag coefficient ($k = 2e^{-7}$) and highest initial velocity ($v_0 = 22$ m/s). This is consistent with real-world studies showing that non-standard nozzle shapes (elliptical or triangular) reduce turbulence and energy loss due to jet disintegration, allowing droplets to travel longer distances. The triangular nozzle ($k = 3e^{-7}$, $v_0 = 21$ m/s) shows an intermediate result, indicating better aerodynamics compared to the round nozzle ($k = 5e^{-7}$, $v_0 = 20$ m/s), which has the highest drag and, consequently, the shortest range. The difference in range between the elliptical and round nozzles is ~ 4.54 m, which is equivalent to a 103% increase in irrigation radius, which is significant for large fields.

The deviation in the z-direction is caused by the crosswind (2 m/s). The elliptical nozzle has the largest deviation because its droplets travel further, which increases the time exposed to the wind. The circular nozzle shows the smallest deviation because of its shorter flight time and shorter range. This confirms that nozzles with lower drag produce a more stable jet, but in the presence of wind, the droplets may experience greater displacement. In practical terms, this means that elliptical nozzles are more effective in windless or low-pressure conditions, while circular nozzles may be better in regions with strong winds to reduce drift. The flight time increases with increasing initial velocity and decreasing drag because the droplets are in the air longer. The elliptical nozzle provides the longest flight time because of its longer range and lower drag, allowing the droplets to travel a greater distance before falling. This is important for irrigation uniformity, as longer flight times can promote wider water distribution, but also increase the risk of evaporation or drift in high wind conditions.

The trajectories are parabolic in the xy plane due to gravity, with a peak height of ~ 2.62 m for the round nozzle. In the z-direction, there is a gradual deflection due to wind, which increases with time. The elliptical nozzle shows a flatter trajectory in xy due to higher velocity, but a larger z-shift (up to 2.62 m), indicating greater sensitivity to wind. The triangular nozzle is a compromise: its trajectory is longer than the round one, but less drifted than the elliptical one. This data is useful for estimating the coverage area and irrigation uniformity.

Round nozzle - the shortest range (4.41 m) and the shortest flight time (1.326 s) due to high drag ($k = 5e^{-7}$). This makes it less effective for large fields, but more stable in windy conditions (z = 2.14 m). Suitable for spot irrigation or at low pressure.

Triangular nozzle - intermediate range (6.59 m) and flight time (1.427 s). Reduced drag ($k = 3e^{-7}$) provides a better balance between range and wind resistance (z = 2.39 m). This is a versatile option for medium fields.

Elliptical nozzle - the longest range (8.95 m) and flight time (1.539 s) due to low drag ($k = 2e^{-7}$). However, the larger z-offset (2.62 m) indicates wind sensitivity, requiring angle or pressure correction in real-world conditions.

The elliptical nozzle is optimal for large areas due to its maximum range, which allows covering up to 2.5 times more area than a round nozzle (area ~ πR^2, where R is the range). However, in windy regions (wind > 2 m/s), a round nozzle may be better for reducing drift, which reduces water loss by 15-20%.

Conclusion. The study of the influence of design parameters of sprinklers on the aerodynamics of the water jet, conducted in this article, allows us to draw solid conclusions regarding the optimization of irrigation systems to increase their efficiency, cost-effectiveness and environmental sustainability. The analysis of theoretical foundations, experimental data, numerical modeling and practical results demonstrated that the shape, size and geometry of the nozzles, the pressure in the system, the spray angle and external factors, such as wind, are key determinants of the aerodynamic characteristics of the jet. These parameters directly affect the trajectory, range, uniformity of water distribution and resistance to atmospheric conditions, which is of crucial importance for modern agriculture, which is faced with the challenges of climate change and water scarcity.

The results of the simulations conducted using Python using the Runge-Kutta method confirmed that the choice of nozzle design significantly affects the irrigation performance. The elliptical nozzle was found to be the most effective in terms of range (8.95 m), allowing for a significantly larger area coverage compared to the round (4.41 m) and triangular (6.59 m) nozzles, due to its lower drag coefficient and higher initial velocity. However, its sensitivity to crosswinds (maximum deviation of 2.62 m) indicates the need to adapt to specific climatic conditions, such as use in windless regions or correction of the discharge angle. The round nozzle, although showing the shortest range, provides better stability in windy conditions (deviation of 2.14 m), making it suitable for localized irrigation. The triangular nozzle is a compromise option, balancing between range (6.59 m) and wind resistance (2.39 m deviation), making it a versatile solution for medium-sized fields.

Analysis of recent studies and the obtained data emphasize that optimization of design parameters can reduce water losses to evaporation and erosion by 20-30%, increase the distribution uniformity coefficient (Christiansen's uniformity coefficient) to 85-90% and reduce pump energy consumption by 20% with rational use of pressure (150-250 kPa). Integration of aeration devices and non-standard nozzle shapes, such as elliptical or triangular, has shown significant potential for improving hydraulic efficiency, as confirmed by both experimental and simulation results. At the same time, long flight times (up to 1.54 s for an elliptical nozzle) can contribute to a wider distribution of water, but also increase the risk of environmental consequences, such as soil erosion or evaporation losses, which require additional protective measures.

References

1. Ivanenko, O.P., & Kovalenko, V.M. (2020). Optymizatsiya zroshuval'nykh system: Teoretychni ta praktychni aspekty. [Optimization of irrigation systems: Theoretical and practical aspects]. Visnyk ahrarnoyi nauky Ukrayiny, 12(3), P. 45 – 52. [in Ukrainian].

2. Qureshi, W.A., Li, H., & Zhu, X. (2023). Performance enhancement of low-pressure impact sprinklers with aeration. Frontiers in Energy Research, 11, P. 123 – 135. [in China].

3. Jiang, H., Li, J., & Liu, Y. (2021). Effect of nozzle geometry on water distribution uniformity in sprinkler irrigation. Irrigation Science, 39(3), P. 245 – 256. [in China].

4. Patel, R., Sharma, V., & Gupta, A. (2022). Experimental study on water distribution patterns in low-pressure sprinklers. Journal of Hydrology, 610 P. [in Switzerland].

5. Shevchenko, L.I., & Hryhorenko, O.O. (2021). Vplyv konstruktsiyi doshchuval'nykh aparativ na rivnomirnist' zroshennya. [Influence of construction-sensitive apparatus on irrigation uniformity].

Achroinzheneriya s'ohodni, 18(4), 67 – 74. [in Ukrainian].

6. Kravchenko, I.V, Sydorenko, A.P. (2022). Analiz aerodynamichnykh kharakterystyk vodyanoho strumenya v doshchuval'nykh systemakh . [Analysis aerodynamichnykh characteristics wateryanoho streams in the senses systemakh]. Naukovyy visnyk NUBiP Ukrayiny, 15(6), P. 89 - 97. [in Ukrainian].

7. Boyko, N.O., & Lysenko, T.M. (2023). Ekolohichni aspekty vykorystannya doshchuval'nykh mashyn v Ukrayini. [Ecological aspects of using sensitive machinery in Ukraine]. Ekolohiya ta pryrodokorystuvannya, 27(1), P. 34 – 41. [in Ukrainian].

8. Mel'nyk, P.Y. (2021). Suchasni tekhnolohiyi zroshennya: Dosvid Ukrayiny ta svitovi tendentsiyi. [Modern irrigation technologies: Experience of Ukraine and global trends]. Zroshuvane zemlerobstvo, 14(3), P. 23 – 30. [in Ukrainian].

9. Babyn, I., Luts, P., & Mazur, O. (2025). Influence of irrigation machines on the yield of agricultural crops. Technology, energy, transport APK, (128), 71 – 75. https://doi.org/10.37128/2520-6168-2025-1-8. [in Ukrainian].

10. Babyn, I. (2024). Experimental studies of the stand of the automated milking unit washing system with air injectors and a photo sensor for determining the contamination level. Technology, energy, transport APK, (125), 16 – 27. https://doi.org/10.37128/2520-6168-2024-2-2. [in Ukrainian].

ВПЛИВ КОНСТРУКТИВНИХ ПАРАМЕТРІВ ДОЩУВАЛЬНИХ МАШИН НА АЕРОДИНАМІКУ ВОДЯНОГО СТРУМЕНЯ

Дощувальні машини відіграють ключову роль у сучасному сільському господарстві, забезпечуючи ефективне зрошення та сприяючи підвищенню врожайності в умовах обмежених водних ресурсів. Ефективність цих систем значною мірою залежить від аеродинамічних характеристик водяного струменя, який формується форсунками, а саме від його траєкторії, дальності, рівномірності розподілу та стійкості до зовнішніх факторів, таких як вітер. У статті досліджується вплив конструктивних параметрів дощувальних машин, зокрема діаметра і форми сопел, тиску в системі, кута розпилення, а також матеріалів і геометрії компонентів, на аеродинамічні властивості водяного струменя. На основі аналізу теоретичних моделей, експериментальних даних і сучасних методів комп'ютерного моделювання (зокрема, гідродинамічних симуляцій) розглядаються механізми формування струменя та фактори, що впливають на втрати води через випаровування чи знесення. Особлива увага приділяється оцінці впливу конструктивних рішень на енергоефективність і екологічну стійкість зрошувальних систем. У статті також висвітлюються сучасні технологічні підходи до оптимізації конструкції форсунок, включаючи використання адаптивних систем і матеріалів із покращеними гідродинамічними властивостями. Результати дослідження демонструють, як цілеспрямована модифікація конструктивних параметрів може зменшити втрати води, підвищити рівномірність зрошення та оптимізувати витрати енергії. Стаття пропонує практичні рекомендації для розробників і користувачів дощувальних систем, а також визначає перспективні напрями для подальших досліджень у галузі створення високоефективних зрошувальних технологій, що відповідають вимогам сталого розвитку та адаптації до змін клімату.

Ключові слова: *дощувальні машини, аеродинаміка водяного струменя, конструктивні параметри, зрошення, енергоефективність, екологічна стійкість, гідродинамічне моделювання.*

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