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# CONSTRUCTION OF A MODEL OF THE IMPACT INTERACTION BETWEEN A WATER JET AND A VERTICAL WALL

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***This work investigates the process of interaction between the droplet phase of a two-phase flow "droplet-air" and a vertical wall; the subject of this study is the trajectory of motion and characteristics of water droplets in a two-phase flow when they collide with a vertical surface. The task addressed is to reduce water losses when it is supplied by a fire hose to a vertical wall while splashing upon impact.***

***The droplet motion was modeled within the framework of the Lagrangian approach, in which the dynamics of each droplet were described by the equations of motion in three-dimensional space taking into account the forces of aerodynamic resistance and gravity. To take into account the stochastic nature of droplet sizes and transverse velocity components, $10^5$ trajectories with diameter distribution according to the Rosin-Ramler law were simulated.***

***It was established that the density distribution of a water particle reaching the vertical wall has a unimodal character. With increasing water supply pressure, the fraction of water reaching the wall increases significantly, and the maximum of the distribution density becomes more pronounced. In particular, when water is supplied by a fire hose with a nozzle diameter of 19 mm at an angle of 35° from a distance of 25 m, the fraction of water that does not reach the wall decreases from 49% at a pressure of 40 m to 8% at a pressure of 70 m.***

***It is shown that the interaction of droplets with the wall occurs mainly under the spreading and splashing modes, while the deposition and reflection modes account for less than 1%. With increasing pressure, the fraction of spreading droplets decreases, and the fraction of splashing droplets increases. Under the splashing mode, on average, about 50% of the drop mass is lost. As a result of taking splashing into account, the water distribution density along the vertical wall changes from unimodal to bimodal, where the second maximum corresponds to the zone of predominant droplet spreading***

***Keywords: two-phase jet, drop zone, fire hydrant, droplet-vertical wall interaction***

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## 1. Introduction

The issue of efficient water supply to the fire site remains key in modern firefighting because water is the basic fire extinguishing agent due to its high heat of vaporization, availability, and low cost [1]. The most effective way to extinguish a fire is to extinguish it at the initial stage of its evolution, when the ignition source is still small, the temperature is low, and the combustion products have not had time to spread [2]. Early extinguishing is especially important for critical infrastructure facilities, high-rise buildings, industrial enterprises, and warehouses, where the rapid spread of fire could lead to catastrophic consequences. The best solution for ensuring a prompt response without human intervention is automated fire extinguishing systems.

The high specific heat capacity of water allows it to be effectively used not only for direct extinguishing but also for cooling technological equipment [3] or load-bearing structures [4] under the thermal effects of fire. However, the effectiveness of water fire extinguishing depends significantly on the correct choice of jet delivery parameters: pressure, barrel angle, nozzle diameter, distance to the target, and the nature of jet interaction with the surface. Studies on water jet dynamics, in particular its droplet breakage and interaction with obstacles, are critical for the optimization of automated fire extinguishing systems and firefighting robots [5].

Therefore, research into design of automated water delivery systems for fire extinguishing is relevant.

## 2. Literature review and problem statement

Parameters of periodic-pulse action installations for generating a finely dispersed water jet were experimentally substantiated in [6]; the optimal values of water pressure, shock wave velocity, as well as droplet dispersion were determined. However, most attention was paid to the formation of the jet near the barrel, without considering its further movement in the air. In [7], the movement of a two-phase "liquid-gas" jet was considered, but it is formed by a pulsed high-speed water jet, the characteristics of which differ significantly from the jet formed by a fire hose. In [8], for a horizontally located fire hose with a diameter of 13 mm, the sizes and speeds of the drops into which a continuous jet breaks up were experimentally determined. However, the trajectories of the movement of drops in the air and their interaction with obstacles were left out of consideration. Similar data on the distribution of droplet sizes in agricultural sprayers (which are close to fire hoses in terms of the formation mechanism) were analyzed in detail in [9]. It is noted that the Rosin-Rammler law or the lognormal law is most often used to describe the distribution of drop diameters. However, the trajectory of drop motion in the air is not considered.

In [10], models for predicting the trajectory and point of impact of a foam jet from a fire monitor were built, taking into account the angle of elevation, pressure, and nozzle diameter. The unknown coefficients included in the model were determined based on experimental data. The disadvantage of this approach is the need to determine the coefficients when changing the conditions of the jet supply. In [11], a model of the movement of a water jet after leaving the fire hose was constructed, which includes the area of the jet core and the drop zone. A feature of the model is the mutual influence of the drop and gas phases of the jet on the movement of each other: drops, losing momentum due to aerodynamic resistance, give it to the air. However, the interaction of water droplets with obstacles was not investigated in the work. In [12], an analytical model was proposed that takes into account the jet disintegration on the droplet and aerodynamic resistance. It was shown that the range decreases with increasing Froude number at the nozzle outlet. However, the interaction of the jet with obstacles was not considered in the work. In [13], CFD (computational fluid dynamics) methods were used to determine the trajectory of the water jet and its delivery to the combustion chamber. However, in the work, the interaction of the jet with obstacles was ignored.

In [14], the phenomenon of splashing when water is supplied to a vertical wall using nozzles was experimentally investigated. The fraction of water that remains on the wall and flows down it was determined. At the same time, the case of the disintegration of a continuous jet on a drop was not considered. In [15], the interaction of water droplets with different types of horizontal surfaces was experimentally investigated: dry, covered with a thin water film, covered with a layer of water. It was shown that the velocity of the drop affects the mode of its interaction with the surface, but numerical estimates for the fraction of water that is splashed are not given. In [16], the modes of interaction of drops with the wall were determined (deposition, rebound, spread, splash). It was shown, in particular, that the splashing mode for a wet surface occurs at much higher droplet energies than for a dry one. However, the study considers the behavior of one individual drop. In [17], the mechanisms of high-speed droplet spraying ($We = (2000 \div 30000)$, $Re = (8000 \div 100000)$) upon impact on a dry smooth surface were experimentally studied. At the same time, the jet from a fire hydrant is a stream of many drops that sequentially hit a vertical wall with the accumulation of a liquid film and the influence of gravity. In [18], the interaction of a sequence of drops with the wall was experimentally studied. It was found that the frequency of droplet fall significantly affects the interaction mode. The value of the droplet energy at which spraying occurs is the lower, the higher the frequency of drops. In [19], machine learning methods were used to determine the criteria that most affect the interaction mode of a droplet with a dry surface. It was shown that the most significant are the Weber, Reynolds, Ohnesorge, and capillarity numbers. But the trajectory of the droplets before they hit the wall is ignored. In [20], the jet falling onto a horizontal surface was investigated and it was shown that, depending on the Weber number, the fraction of water sprayed ranges from 1% to 70%.

All this gives grounds to argue that it is advisable to conduct research aimed at building a model of the interaction of a water jet with a vertical wall after exiting the fire hydrant.

## 3. The aim and objectives of the study

The aim of our work is to build a model of the interaction between a water jet and a vertical wall after exiting the fire hose, which takes into account the loss of part of the water due to splashing when hitting the wall. In practice, this opens up opportunities for the optimal selection of water supply parameters for cooling the walls of vertical technological equipment. This, in turn, makes it possible to increase the efficiency of fire extinguishing.

To achieve this goal, it is necessary to solve the following tasks:

– to determine characteristics of the movement of the droplet phase of the jet at the moment of collision with a vertical wall;

– to determine the mode of interaction of individual drops with the wall.

## 4. The study materials and methods

The object of our study is the process of interaction between the droplet phase of the two-phase flow "droplet-air" and a vertical wall; the subject of our work is the trajectory of motion and characteristics of water droplets in the two-phase flow "droplet-air" when colliding with a vertical surface. The principal hypothesis assumes that the motion of the two-phase flow at the moment of collision with the wall can be described as the motion of individual water droplets interacting with a gas jet, which arises as a result of the capture of ambient air by the water jet. The basic assumptions are the normal velocity distribution in the cross-section of the jet, as well as the absence of secondary crushing or coalescence of droplets.

A water jet from a fire hydrant with a diameter of 19 mm, designed to supply a continuous jet of water under a pressure of (20 ÷ 70) m, was investigated. To determine the trajectory of the water jet within the area of its continuous core, the equation of motion of a material point in the gravitational field was used. The motion of the droplet phase was described in the Lagrangian formulation, where the dynamics of individual drops were modeled by a system of equations of motion in three-dimensional space taking into account the forces of gravity and aerodynamic resistance. The gas phase of the jet was represented by integral equations of conservation of mass and momentum. The numerical integration of the system of differential equations for both phases was performed by the 4th-order Runge-Kutta method. Analysis of the trajectories of droplets when supplying water from the fire hydrant was carried out using simulation modeling methods. The Delphi 12 programming environment (USA) was applied to implement the specified methods.

## 5. Results of building a model of interaction between the droplet phase of a jet and a vertical wall

### 5. 1. Determining the characteristics of drop movement at the moment of collision with a vertical wall

The water jet after exiting the fire hydrant can be conditionally divided into two sections:

– the zone of existence of the jet core;

– the droplet zone.

In the first section there is a continuous jet core, which has a conical shape due to the detachment of water droplets from the jet surface. In the second section, the movement of individual drops and trapped air takes place (Fig. 1). The origin of the coordinates was taken as the point of exit of the water jet from the hydrant.

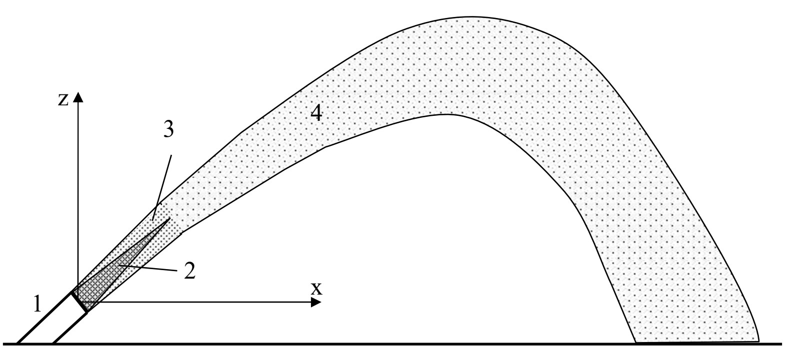


Fig. 1. Water jet movement diagram: 1 – fire hose; 2 – jet core; 3 – jet core area; 4 – drop zone

The coordinates of the cone vertex corresponding to the jet core take the form [11]:

$$\begin{cases} x_c = L_c \cos\theta; \\ z_c = L_c \sin\theta - \dfrac{gL_c^2}{2v_0^2}, \end{cases} \quad (1)$$

where $\theta$ is the angle of inclination of the fire hose relative to the horizontal plane; $L_c$ is the length of the jet core

$$L_c \approx 314 D_0; \quad (2)$$

$D_0$ is the diameter of the barrel; $v_0$ is the initial velocity of the jet; $g$ is the acceleration due to gravity. At the point ($x_c$, $z_c$) the jet velocity vector is equal to:

$$\begin{cases} v_{xc} = v_0 \cos\theta; \\ v_{zc} = v_0 \sin\theta - \dfrac{gL_c}{v_0}. \end{cases} \quad (3)$$

The radius of the water jet at this point

$$R_{w0} \approx 5.0 D_0. \quad (4)$$

The local velocity ($u_x$, $u_y$, $u_z$) of the entrained air at a certain point of the cross section depends on distance $r$ to the jet axis:

$$u(r) = u_c \exp\left(-\frac{r^2}{b_0^2}\right), \quad (5)$$

$$b_0 = 10.3 D_0, \quad (6)$$

where $u_c$ is the velocity on the jet axis.

The end of the jet core section is the beginning of the droplet zone. In the droplet zone, the jet motion was modeled as the motion of individual droplets and entrained air. The Rosin-Rammler law was used to describe the droplet diameter distribution [9]

$$F(d) = 1 - \exp\left[-\left(\frac{d}{d_m}\right)^n\right], \quad (7)$$

where $F(d)$ is the fraction of the total volume contained in droplets with a diameter smaller than $d$; $d_m$ is the representative diameter of the drop; $n$ is the scattering measure, $n \approx 3.8$ [8]. The representative diameter of the droplets can be represented by the following expression

$$d_m = 0.113 D_0. \quad (8)$$

The initial coordinates of the drops were taken as:

$$\begin{cases} x_i(0) = x_c; \\ y_i(0) = r_i \cos\phi_i; \\ z_i(0) = z_c + r_i \sin\phi_i, \end{cases} \quad (9)$$

where $r_i$, $\varphi_i$ are realizations of random variables distributed uniformly on the intervals [0; $R_{w0}$] and [0; $2\pi$], respectively. The vector of the initial velocity of the drop:

$$\begin{cases} v_{ix}(0) = 0.89 v_{xc}; \\ v_{iy}(0) = v_{ri}\cos\psi_i; \\ v_{iz}(0) = 0.89 v_{zc} + v_{ri}\sin\psi_i, \end{cases} \quad (10)$$

where $v_{ri}$ is the radial velocity of the drop; $v_{ri}$, $\psi_i$ are realizations of random variables distributed uniformly on the segments [0; $v_{r\max}$] and [0; $2\pi$], respectively

$$v_{r\max} = 0.016 v_0.$$

The motion of a spherical drop in the air is determined by the influence of gravity and aerodynamic air resistance:

$$\begin{cases} \frac{dv_{ix}}{dt} = -\frac{3}{4}\frac{\rho_a}{\rho_\ell} C_D \frac{1}{d_i} w_i w_{ix}; \\ \frac{dv_{iy}}{dt} = -\frac{3}{4}\frac{\rho_a}{\rho_\ell} C_D \frac{1}{d_i} w_i w_{iy}; \\ \frac{dv_{iz}}{dt} = -g - \frac{3}{4}\frac{\rho_a}{\rho_\ell} C_D \frac{1}{d_i} w_i w_{iz}, \end{cases} \quad (11)$$

where ($w_{ix}$, $w_{iy}$, $w_{iz}$) – droplet velocity relative to the surrounding air; $w_i$ – velocity modulus; $\rho_a$, $\rho_\ell$ – air and water densities, respectively; $C_D$ – drag coefficient.

The system of differential equations (11) together with the initial conditions (9), (10) determine the motion of water droplets in the droplet zone. The gas phase of the jet was simulated assuming its axisymmetric nature and Gaussian character of the velocity distribution in the cross section [11].

It was assumed that the vertical wall is located perpendicular to the $X$ axis at a distance $x_w$ from the barrel. For the numerical solution of the system of differential equations of water droplet motion in air (11) with the initial conditions (10), (11) the Runge-Kutta method was used, in which additional checks were performed:

– if $z_i(t) \le 0$, then it was assumed that the droplet fell to the ground without reaching the wall;

– if $x_i(t) \ge x_w$, then it was assumed that the drop reached the wall and the mode of their interaction was determined.

The calculation stopped when one of the above conditions was met. As an example, Fig. 2 shows the distribution density $f_z$ of water along the height of a vertical wall, provided that it is supplied by a fire hose with a nozzle diameter of 19 mm from a distance of 25 m at an angle of 35° to the horizon. The distribution density was calculated from the following formula

$$f_z(z) = \frac{V(z, z+\Delta z)}{V_{total}\Delta z}, \quad (12)$$

where $V(z, z + \Delta z)$ is the volume of water that fell into the interval $(z, z + \Delta z)$, $V_{total}$ is the total volume of water supplied by the barrel; $\Delta z = 0.25$ m. For calculations, the trajectory of $10^5$ drops was modeled.

In this case, there is an inequality

$$\int_0^\infty f_z(z)\,dz < 1,$$

since a certain proportion of the water does not reach the wall.

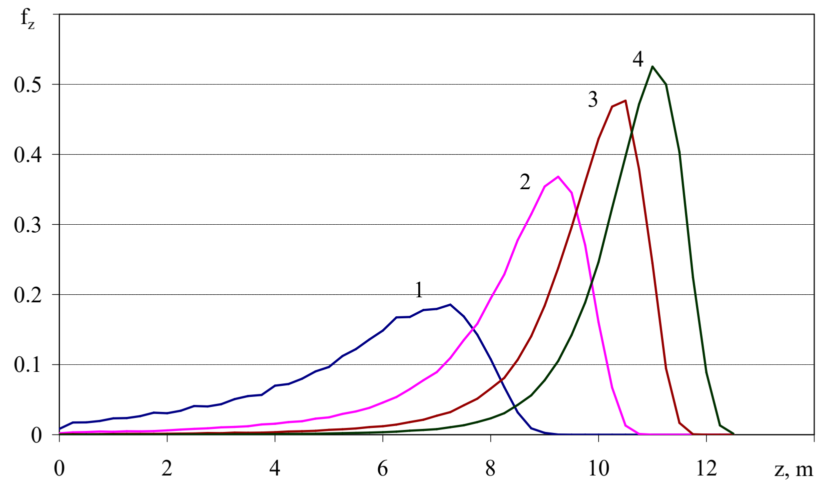


Fig. 2. Density distribution function of the vertical coordinate of the point of impact of a water drop on a vertical wall depending on head: 1 – $h$ = 40 m; 2 – $h$ = 50 m; 3 – $h$ = 60 m; 4 – $h$ = 70 m

**5. 2. Determining the interaction mode of individual drops with the wall**

The interaction mode of a drop with the wall is determined by the dimensionless Weber numbers We and Reynolds numbers Re for the drop:

$$\mathrm{We} = \frac{\rho v_{in} d_i}{\sigma}; \quad (13)$$

$$\mathrm{Re} = \frac{\rho v_{in} d_i}{\mu}, \quad (14)$$

where $\rho$, $\mu$, $\sigma$ are the density, dynamic viscosity, and surface tension of water; $d_i$ is the diameter of the water drop; $v_{in}$ is the modulus of the normal component of the velocity of the $i$-th drop. The normal component of the velocity of the drop can be found through the velocity vector ($v_{ix}$, $v_{iy}$, $v_{iz}$) and the normal vector to the wall surface ($n_x$, $n_y$, $n_z$)

$$v_{in} = \frac{v_{ix}n_x + v_{iy}n_y + v_{iz}n_z}{\sqrt{n_x^2 + n_y^2 + n_z^2}}. \quad (15)$$

In particular, for a vertical wall located perpendicular to the $X$ axis at a distance $x_w$ from the hose, formula (15) gives

$$v_{in} = v_{ix}(x_w),$$

where $v_{ix}(x_w)$ is determined from the solution to the system of differential equations (11).

Depending on the range of values of numbers (13), (14), the following modes of interaction of the drop with the wall are possible [16]:

– deposition – the drop sticks to the wall, remaining completely on it

$$We < 5;$$

– rebound – the drop completely bounces off the wall

$$5 \le We < 10;$$

– spread – the drop spreads along the wall, remaining completely on it

$$10 \le We < We_{cr}; \tag{16}$$

– splash – the drop breaks up, part remains on the wall, the other part bounces off

$$We \ge We_{cr} = \frac{K_{cr}^2}{\sqrt{\mathrm{Re}}}, \tag{17}$$

where $K_{cr} = 57.7$ [19].

The fraction of water that is reflected from the wall as a result of splashing is described by the empirical expression

$$\beta = 0.2 + c \cdot r, \tag{18}$$

where $r$ is a random variable uniformly distributed on the interval [0; 1]; $c = 0.6$. Substituting (13), (14) into inequality (17) gave the condition for the spraying mode in the following form:

$$\frac{\rho v_{in} d_i}{\sigma} \ge K_{cr}^2 \left(\frac{\rho v_{in} d_i}{\mu}\right)^{-0.5};$$

$$v_{in} d_i \ge \frac{1}{\rho}\sqrt[3]{K_{cr}^4 \sigma^2 \mu}. \tag{19}$$

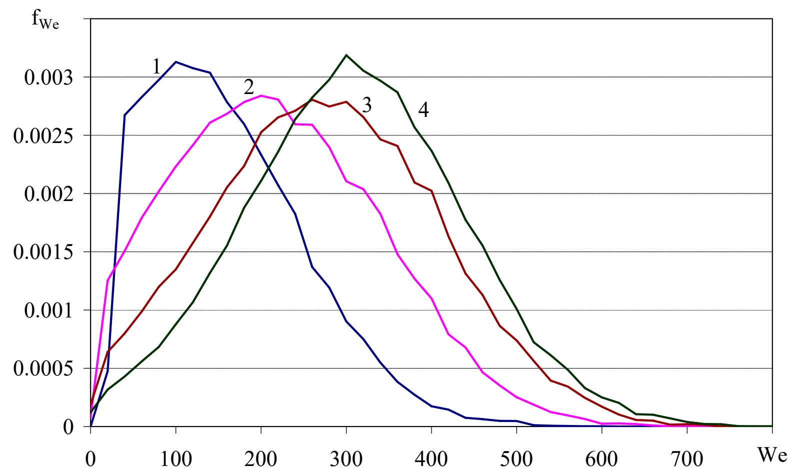


Fig. 3. Density function of the distribution of Weber number values at the point of impact of a drop on a vertical wall depending on head: 1 – $h$ = 40 m; 2 – $h$ = 50 m; 3 – $h$ = 60 m; 4 – $h$ = 70 m

As an example, Fig. 3 shows the distribution of values of the Weber number of drops $f_{We}$(We) when supplied by a fire hose with a nozzle diameter of 19 mm from a distance of 25 m at an angle of 35° to the horizon.

The density was calculated using a formula similar to (12). Fig. 4 shows the water particles corresponding to the above modes of interaction of the drop with the wall under the condition of water supply by a fire hose with a nozzle diameter of 19 mm from a distance of 25 m at an angle of 35° to the horizon.

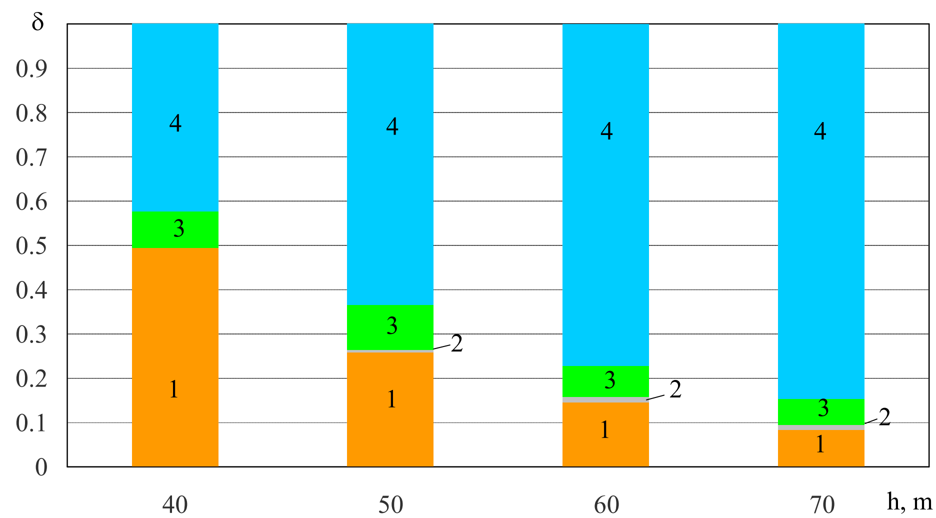


Fig. 4. Distribution of the total volume of water by modes of interaction of a drop with a wall when water is supplied by a fire hose: 1 – does not reach the wall; 2 – sticking and reflection; 3 – spreading; 4 – splashing

Fig. 5 shows the distribution of water flow for the same supply conditions, where the effects of the interaction of the droplet phase of the water jet with the vertical wall are taken into account.

Analysis of the dependences shown in Fig. 5 reveals that with increasing water supply pressure, the proportion of water remaining on the wall and participating in its cooling approaches 50%.

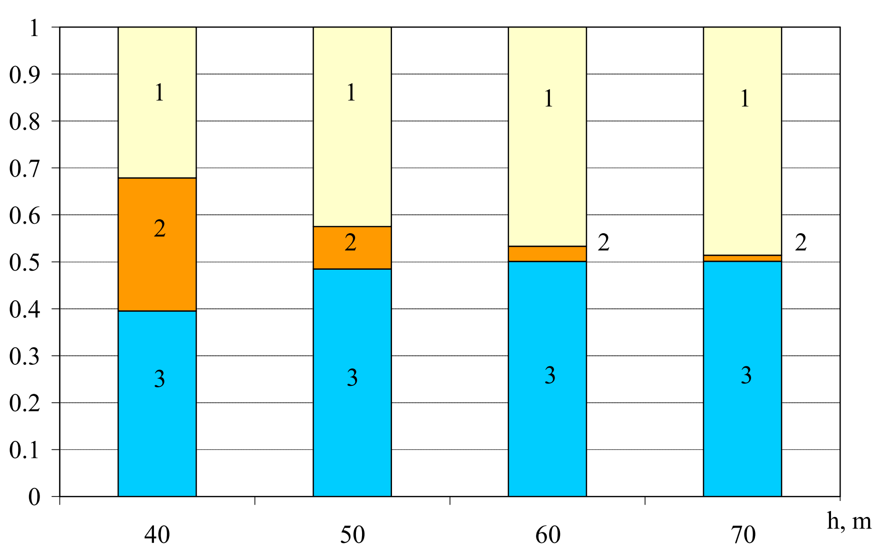


Fig. 5. Distribution of water consumption when it is supplied by a fire hose to a vertical wall depending on head: 1 – reflected from the wall after the collision; 2 – did not reach the wall; 3 – remained on the wall

Fig. 6 shows the density of water distribution remaining on the wall, taking into account reflection losses and ground drop.

Analysis of the graphical dependences in Fig. 2, 6 reveals that taking into account the reflection of water after the jet hits a vertical wall does not change the nature of the distribution.

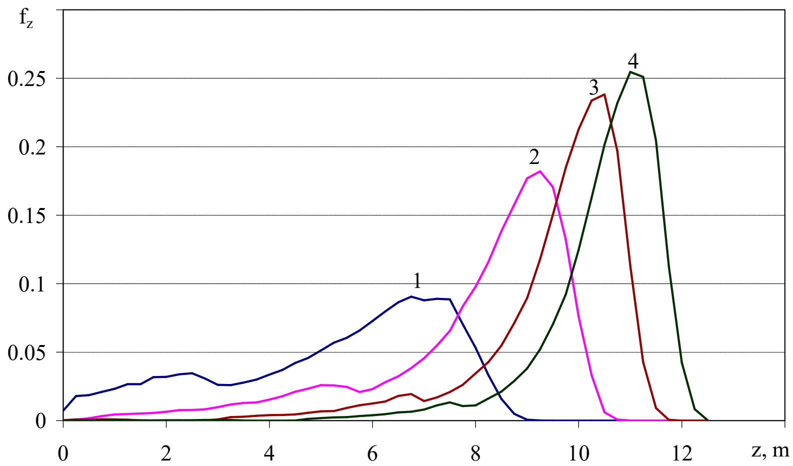


Fig. 6. Density distribution function of water remaining on the wall, taking into account reflection losses and ground fallout: 1 — $h = 40$ m; 2 — $h = 50$ m; 3 — $h = 60$ m; 4 — $h = 70$ m

## 6. Discussion of results based on the construction of a model of water jet motion in the air

After the fire jet exits the barrel, it gradually loses its continuity due to the gradual detachment of individual drops from the jet surface (Fig. 1). In the area of the jet core, its motion is determined by the initial velocity, the angle of inclination of the barrel to the horizon, and the force of gravity – formulas (1), (2). In the drop zone, the jet has no core and is a two-phase flow – individual drops and entrained air. At the beginning of the drop zone, the jet radius is determined by dependence (4), and the droplet velocity on its axis – by formula (3). Due to the random components of the velocity in the transverse direction acquired during the destruction of the jet, as well as the random nature of the diameter of the formed drops, there is a gradual increase in the jet radius. Less massive drops are braked faster in the air and do not reach the vertical wall, falling to the ground (Fig. 2). Increasing the proportion of water reaching the wall can be achieved by increasing the water supply pressure and increasing the nozzle diameter. In the first case, the initial water velocity increases, and in the second, the droplet diameter – formula (8). Increasing the water pressure not only increases the proportion of water reaching the wall but also makes the impact site more compact – the maximum density of water distribution along the wall becomes more pronounced with increasing head (Fig. 2).

The behavior of a droplet when hitting a vertical wall is determined by the values of the Weber numbers (13) and Reynolds numbers (14). From (13), (14) it follows that more massive drops will have larger values of the Weber number not only due to a larger diameter, but also due to a higher velocity. Analysis of the density of the water mass distribution by the Weber number value (Fig. 3) reveals that with increasing water pressure, the average value of the Weber number of the droplet increases, and the distribution becomes more symmetrical.

Analysis of the distribution of the total volume of water by the modes of interaction of the droplet with the wall (Fig. 4) shows that a small proportion of water falls on the modes of sticking ($We < 5$) and reflection ($5 \leq We < 10$). The main mode of interaction of the droplet with the wall is the splashing mode. The critical value of the Weber number at which splashing occurs was chosen for a dry wall, based on the results given in [18]. Due to the high values of the wall irrigation intensity, (4 ÷ 10) l/s, the movement of the water film formed on the wall has a turbulent character. As a result, surface tension forces do not prevent the separation of splashes from the surface of the film.

Water losses when it is applied to a vertical wall are caused by two factors:

– separation of water drops from the jet and their falling to the ground due to loss of speed;

– reflection or splashing of the drop after hitting the wall.

Water losses due to the fact that it does not reach the vertical wall can be reduced by increasing the water pressure. Whereas at a water head of 40 m about 49% of the water did not reach the wall, then at a pressure of 70 m – only 8% (Fig. 4). An increase in the Weber number of drops leads to a decrease in the proportion of droplets that spread (16) and an increase in the proportion of droplets that splash (17) – Fig. 4. This is explained by the fact that the splashing mode occurs when the product of the drop velocity and its diameter exceeds a certain constant – formula (19).

The fraction of water remaining on the wall increases monotonically with increasing head and approaches the value of 0.5 (Fig. 5). This value is due to the random dependence of the fraction of the splashed drop (18), the mathematical expectation of which is 0.5. This result is qualitatively confirmed both by observations, which indicate that when water is supplied to a vertical wall, its losses are about 50%, and by experimental studies [14, 20].

A comparison of the water distribution density along the wall height at the moment of impact (Fig. 2) and the water distribution density remaining after reflection (Fig. 6) indicates the emergence of another local maximum, as a result of which the distribution density function becomes bimodal. The local maximum appears in the region where the droplet spreads along the wall surface (16). This mode of interaction of drops with the wall is the most optimal, but its practical implementation is complicated by the random nature of the droplet sizes (7) formed during the destruction of a continuous jet. One way to increase the water utilization factor is to reduce the dispersion of the droplet Weber number with a simultaneous shift of the distribution mode to the region of the droplet spreading mode (16). This can be achieved by reducing the water head while simultaneously reducing the distance between the barrel and the wall if safety requirements allow.

The advantage of the constructed model of interaction between a water jet and a wall is the ability to determine the parameters of water distribution along the wall when it is supplied from a fire hydrant depending on the supply parameters. The model makes it possible to determine the proportion of water that is lost on the way to the wall and the proportion of water that is reflected from the wall after hitting it. The practical significance of the results is to increase the water utilization factor by optimally choosing the parameters of its supply: distance, angle of inclination, nozzle diameter, and head. This is of particular importance for fire protection systems in which human participation should be minimized, in particular, for stationary water cooling installations and fire robots.

The proposed model of interaction between a water jet and a vertical wall could be used when selecting forces and means to protect technological equipment from the thermal effects of fire [21]. Another direction is its application in the design of automated fire extinguishing systems at critical infrastructure facilities [22].

The limitation of the model is the possibility of its use for fire hydrants designed to supply a continuous water jet in the absence of wind.

The disadvantage of the constructed model is that it is based on the assumption of axisymmetricity of the gas phase of the jet and the absence of interaction of drops with each other when moving in the air.

Prospects for further research are associated with increasing the water utilization factor by selecting the drop size and speed at the moment of impact on the wall.

## 7. Conclusions

1. The characteristics of droplet motion at the moment of collision with a vertical wall have been determined using a model of two-phase jet motion in air. The system of differential equations describing the motion of an individual droplet was solved numerically using the Runge-Kutta method. To take into account the random nature of droplet size and the transverse components of its velocity, the motion of $10_5$ drops was simulated. The density distribution of the water fraction that reached the vertical wall is described by a unimodal function. With increasing head, the fraction of water reaching the wall increases, and the maximum density distribution becomes more pronounced. In particular, when water is supplied by a fire hose with a nozzle diameter of 19 mm at an angle of 35 degrees from a distance of 25 m, the fraction of water that did not reach the wall decreases from 49% at a head of 40 m to 8% at a head of 70 m.

2. We have shown that for the sizes and velocities of drops formed when water is supplied by a fire hose, the interaction of drops with a vertical wall occurs mainly in the spreading or splashing modes. Other modes of interaction (deposition and reflection) account for no more than 1%. In this case, an increase in the water supply head leads to a decrease in the proportion of drops interacting with the wall under the spreading mode and an increase in the proportion of splashing drops. The consequence of interaction between a drop and a wall under the splashing mode is the loss of an average of 50% of water. Taking into account splashing, the density of water distribution along the vertical wall acquires a bimodal character – the second maximum corresponds to the area on the wall where the interaction of drops under the spreading mode takes place.

## Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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The study was conducted without financial support.

## Data availability

The data will be provided upon reasonable request.

## Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

## Authors' contributions

**Oleksii Basmanov:** Conceptualization, Software, Writing – original draft; **Volodymyr Oliinyk:** Supervision, Writing – review & editing**; Oleksandr Telelym:** Methodology, Project administration**; Dmytro Chalyy:** Validation, Investigation**; Iryna Chala:** Writing – review & editing; **Vasyl Maliarchuk:** Formal analysis, Visualization; **Anastasiia Hryshchenko:** Data curation, Software**; Artem Huz:** Writing – review & editing.

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