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Models of Distribution of Flow Parameters in Intensive Garden Irrigation, System Pipes

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Annotation: The mathematical description of the movement of water in the systems of irrigation pipelines, based on the equation of continuity of the medium, the system of Navy-Stokes equations. The resulting mathematical package describes a system with distributed parameters and is performed based on the condition of dynamic balance at the point of flow, taking into account the dependence on the nature of the flow and the physical properties of the environment. Calculation is executed with use of functions Besseliya. Methodology for calculating the hydrodynamic component of water movement in irrigation water supply systems. Pipelines are universal in nature and can be used in the calculation, construction and assessment of the stability of water supply hydraulic systems; the technique can be used to describe the object of operation in the construction of control systems for the hydraulic parameters of the water supply system.

Keywords: pipeline, irrigation systems, non-uniformity, liquid, water, strength, function, three-dimensional, water supply, hydrodynamics, hydrostatics, quasi-one-dimensional, unsteady, flow, potential, surface, coordinate system, stresses, projection, velocity, cylindrical coordinates, unsteady motion , asymmetric, viscous, compressible fluid, plastic pipe.

I. INTRODECTION

To solve specific problems in irrigation water supply systems, quasi-one-dimensional models of unsteady flows can be used. In such models, the state of the flow of the working medium at each moment of time is characterized by the values of pressure, velocity and density averaged over the cross section, while the enumerated hydrodynamic quantities obtained by averaging over the flow cross section with the coefficients of momentum, kinetic energy and hydraulic resistance are introduced into the equations. Theoretical and experimental studies show that the instantaneous averaging coefficients of hydrodynamic quantities differ from quasi-stationary values [1].Linear mathematical model of unsteady fluid motion in a pipe.

When a fluid flows, the medium continuity condition obtained by

when selecting an elementary volume with an inhomogeneous medium $\rho = f(x, y, t)$, [3].

$$\varepsilon = \omega\varepsilon_0\sqrt{\frac{\rho}{B_{tr}}},$$

The medium continuity equation in the Cartesian coordinate system has the form:

$$\frac{\partial\rho}{\partial t} + \frac{\partial(\rho u_X)}{\partial x} + \frac{\partial(\rho u_Y)}{\partial y} + \frac{\partial(\rho u_Z)}{\partial z} = 0, \qquad (1)$$

$$\begin{cases} X = \dfrac{\partial U(x,y,z)}{\partial x} \\ Y = \dfrac{\partial U(x,y,z)}{\partial y}; \\ Z = \dfrac{\partial U(x,y,z)}{\partial z} \end{cases}$$

Where $\partial U(x,y,z),$ – potential function.

The square of the fluid flow rate at a point at a given moment $u^2 = u_x^2 + u_y^2 + u_z^2,$

In this system, the particle strain rates are directed along its axes. The shape of surfaces orthogonal to strain rates and stresses at a point does not depend on the chosen coordinate system, therefore, the dependence of stresses $(\sigma_x, \sigma_y, \sigma_z),$ from the partial derivatives of the corresponding velocity components will take the form:

$$\sigma_x = 2\mu\frac{\partial u_x}{\partial x}; \sigma_y = \frac{\partial u_y}{\partial y}; \sigma_z = \frac{\partial u_z}{\partial z};$$

$$\left\{ \tau_x = 2\mu\theta_1 = \mu\left(\frac{\partial u_y}{\partial z} + \frac{\partial u_z}{\partial y}\right); \tau_y = 2\mu\theta_1 = \mu\left(\frac{\partial u_x}{\partial z} + \frac{\partial u_z}{\partial x}\right); \tau_z = 2\mu\theta_1 = \mu\left(\frac{\partial u_y}{\partial x} + \frac{\partial u_x}{\partial y}\right); \right.$$

Where $\mu -$ dynamic viscosity of a moving fluid.

Consider the question of determining the forces arising at the point of the flow due to viscosity for the flow of a Newtonian fluid. Let the projection on the axis of forces viscosity, referred to a unit of volume and acting at a point determined in stream coordinates (x, y, z):

$$\frac{\partial \sigma_x}{\partial x} + \frac{\partial \tau_z}{\partial y} + \frac{\partial \tau_y}{\partial z} = \mu\left[2\frac{\partial^2 u_x}{\partial x^2} + \frac{\partial}{\partial y}\left(\frac{\partial u_y}{\partial x} + \frac{\partial u_x}{\partial y}\right) + \frac{\partial}{\partial z}\left(\frac{\partial u_x}{\partial z} + \frac{\partial u_z}{\partial y}\right)\right];$$

$$\frac{\partial}{\partial x}\left(\frac{\partial u_x}{\partial x} + \frac{\partial u_y}{\partial y} + \frac{\partial u_z}{\partial z}\right) = 0, или \frac{\partial}{\partial x}\left(\frac{\partial u_x}{\partial x}\right) = -\frac{\partial}{\partial x}\left(\frac{\partial u_y}{\partial y} + \frac{\partial u_z}{\partial z}\right);$$

$$\mu\left[\frac{\partial^2 u_x}{\partial x^2} + \frac{\partial^2 u_x}{\partial y^2} + \frac{\partial^2 u_x}{\partial z^2}\right]; \mu\left[\frac{\partial^2 u_y}{\partial x^2} + \frac{\partial^2 u_y}{\partial y^2} + \frac{\partial^2 u_y}{\partial z^2}\right]; \mu\left[\frac{\partial^2 u_z}{\partial x^2} + \frac{\partial^2 u_z}{\partial y^2} + \frac{\partial^2 u_z}{\partial z^2}\right];$$

Уравнения Эйлера примут вид:

$$\begin{cases} \frac{\partial u_X}{\partial t} + u_X\frac{\partial u_X}{\partial x} + u_Y\frac{\partial u_X}{\partial y} + u_Z\frac{\partial u_X}{\partial z} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + X + \frac{\mu}{\rho}\left[\frac{\partial^2 u_x}{\partial x^2} + \frac{\partial^2 u_x}{\partial y^2} + \frac{\partial^2 u_x}{\partial z^2}\right]; (2) \\ \frac{\partial u_Y}{\partial t} + u_X\frac{\partial u_Y}{\partial x} + u_Y\frac{\partial u_Y}{\partial y} + u_Z\frac{\partial u_Y}{\partial z} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + Y + \frac{\mu}{\rho}\left[\frac{\partial^2 u_y}{\partial x^2} + \frac{\partial^2 u_y}{\partial y^2} + \frac{\partial^2 u_y}{\partial z^2}\right]; (3) \\ \frac{\partial u_Z}{\partial t} + u_x\frac{\partial u_Z}{\partial x} + u_Y\frac{\partial u_Z}{\partial y} + u_Z\frac{\partial u_Z}{\partial z} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + Z + \frac{\mu}{\rho}\left[\frac{\partial^2 u_z}{\partial x^2} + \frac{\partial^2 u_z}{\partial y^2} + \frac{\partial^2 u_z}{\partial z^2}\right]; (4) \end{cases}$$

The resulting system of equations is called Navier-Stokes [2].

This system of equations describes the conditions of dynamic equilibrium at the point of flow under the condition that the real fluid of the medium is replaced by a continuous medium in which stresses are not normal to the areas on which they arise. The values of the derivatives characterizing the presence of additional stresses, apart from pressure, depend on the nature of the flow and the physical properties of the medium. When describing the unsteady motion of the working medium in a cylindrical round pipe, the flow is assumed to be axisymmetric with sufficiently small changes in temperature and pressure so that the viscosity of the medium can be assumed to be constant.

The bulk viscosity of the medium in the processes under study may not be taken into account. Under the assumptions made, equation (2) is described in cylindrical coordinates, the x axis of which is directed along the pipe axis, and the coordinate r is measured along the radius of the pipe cross section, is reduced to two Navier–Stokes equations:

$$\frac{\partial u_x}{\partial t}+u_x\frac{\partial u_x}{\partial x}+u_r\frac{\partial u_x}{\partial r}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+\nu\left[\frac{4}{3}\frac{\partial^2 u_x}{\partial x^2}+\frac{\partial^2 u_x}{\partial r^2}+\frac{1}{r}\frac{\partial u_x}{\partial r}+\frac{1}{3}\frac{\partial}{\partial x}\left(\frac{\partial u_r}{\partial r}+\frac{u_r}{r}\right)\right]; \quad (5)$$

$$\frac{\partial u_r}{\partial t}+u_r\frac{\partial u_r}{\partial x}+u_x\frac{\partial u_r}{\partial r}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+\nu\left[\frac{4}{3}\frac{\partial^2 u_r}{\partial r^2}+\frac{4}{3r}\frac{\partial u_r}{\partial r}+\frac{4u_r}{3r^2}+\frac{\partial}{\partial x}\left(\frac{1}{3}\frac{\partial u_x}{\partial r}+\frac{u_r}{x}\right)\right]; \quad (6)$$

Where (u_x, u_r) – velocity projections on the x and r axes. Equation (5) in cylindrical coordinates has the form

$$\frac{\partial \rho}{\partial t}+\rho\frac{\partial u_r}{\partial r}+\rho\frac{\partial u_x}{\partial x}+u_r\frac{\partial \rho}{\partial r}+u_x\frac{\partial \rho}{\partial x}=0; \quad (7)$$

The system of equations (5) ... (7) can be simplified if we neglect the terms, the order of which is much lower than the order of the terms held in the equations. The unsteady motion of a viscous compressible medium in a pipe is described by a system consisting of two equations: $\frac{\partial u_x}{\partial t}=-\frac{1}{\rho}\cdot\frac{\partial p}{\partial x}+\nu\left[\frac{\partial^2 u_x}{\partial r^2}+\frac{1}{r}\cdot\frac{\partial}{\partial x}\left(\frac{\partial u_r}{\partial r}+\frac{u_r}{r}\right)\right]$ (8)

$$\frac{\partial \rho}{\partial t}=\rho\frac{\partial u_r}{\partial r}+\rho\frac{u_r}{r}+\rho\frac{\partial u_x}{\partial x}=0; \quad (9)$$

$$\frac{\partial}{\partial r}\int_0^{r_0}2\pi r u_x dx=-\frac{1}{\rho}\frac{\partial}{\partial x}\int_0^{r_0}2\pi r p dr+\nu\int_0^{r_0}2\pi r\left[\frac{\partial^2 u_x}{\partial r^2}+\frac{1}{r}\frac{\partial u_x}{\partial r}\right]dr+ \quad (10)$$
$$+\frac{\nu}{3}\frac{\partial}{\partial x}\int_0^{r_0}2\pi r\left(\frac{\partial u_r}{\partial r}+\frac{u_r}{r}\right)dr;$$

$$\frac{\partial}{\partial r}\int_0^{r_0}2\pi^2\rho dr+\rho\int_0^{r_0}2\pi^2\left(\frac{\partial u_r}{\partial r}+\frac{u_r}{r}\right)dr+\rho\frac{\partial}{\partial x}\int_0^{r_0}2\pi^2 u_x dr=0; \quad (11)$$

$$\tau_{OH}=-\rho\nu\int_0^{r_0}2\pi r\left.\frac{\partial u_x}{\partial r}\right|_{r=r_0}; \quad (12)$$

Increment dr_0 expressed in terms of the stress increment in the pipe wall:

$$dr_0=\frac{r_0}{E_{CT}}d\sigma, \quad (13)$$

Where E_{CT} – modulus of elasticity of the wall material.Так как $\sigma=\frac{pr_0}{\delta}$ то $d\sigma=\frac{1}{\delta}\left(r_0\frac{\partial p}{\partial \rho}+p\frac{\partial r_0}{\partial t}\right)dt;$

(14)

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Using the integrals and the above transformations, equation (10)

after dividing all its members by πr_0^2 let's look at:

$$\frac{\partial \upsilon}{\partial t} = -\frac{1}{\rho}\frac{\partial p}{\partial x} - \frac{2\tau_{OH}}{\rho r_0} + \frac{2\nu r_0}{3\delta E_{CT}}\frac{\partial^2 p}{\partial x \partial t}, \qquad (15)$$

Where $\upsilon = \frac{Q}{\pi r^2}$ the average velocity of the medium over the pipe section at the considered moment of time. To clarify the influence of the last term on the right side of equation (15), we write

it in the form:
$$\frac{\partial \upsilon}{\partial t} = -\frac{1}{\rho}\frac{\partial}{\partial x}\left(p - \frac{2\rho\nu r_0}{3\delta E_{CT}}\frac{\partial p}{\rho r_0}\right) - \frac{2\tau_{OH}}{\rho r_0}, \qquad (16)$$

$$\frac{\partial \rho}{\partial t} + \frac{2\rho r_0}{\delta E_{CT}}\frac{\partial p}{\partial t} + \rho\frac{\partial \upsilon}{\partial x} = 0, \qquad (17)$$

Eliminating the derivative from equation (17), the equation will take the form:
With a linear model of unsteady flow, the most complete understanding

$$W_{t\nu}(s) = \frac{\tau(s)}{\upsilon(s)}, \qquad (18)$$

Where τ(s) and υ(s) – Laplace images of non-stationary shear stress
on the pipe wall and medium velocity averaged over the flow section, respectively.
To determine the transfer function, we use equation (8), neglecting in it those terms that, as shown above, are small. As a result, we have:

$$\frac{\partial u_x}{\partial x} = -\frac{1}{r}\frac{\partial p}{\partial x} + \nu\left[\frac{\partial^2 u_x}{\partial r^2} + \frac{1}{r}\frac{\partial u_x}{\partial r}\right], \qquad (19)$$

The same equation can be obtained if the medium is considered incompressible and its motion in a round cylindrical tube is still considered outside the initial section.

$$\frac{\partial^2 u_x}{\partial r^2} + \frac{1}{\rho}\frac{\partial u_x(s)}{\partial r} - \frac{s u_x(s)}{\nu} = P_x(s), \qquad (20)$$

Where s – variable in the Laplace transform; $u_x(s)-$ image according to Laplace

local speed u_x; $P_x(s)-$ image according to Laplace $\frac{\partial p}{\partial x}$.

The solution of equation (20) has the form:

$$u_x(s) = C_1 j_0\left(jr\sqrt{\frac{s}{\nu}}\right) + C_2 Y_0\left(jr\sqrt{\frac{s}{\nu}}\right) - \frac{P_x(s)}{\rho s}, \qquad (21)$$

Where $J_0\left(jr\sqrt{\frac{s}{\nu}}\right); Y_0\left(jr\sqrt{\frac{s}{\nu}}\right),-$ zero-order Bessel functions, respectively

first and second kind; C1 and C2 are integration constants[3].

According to the law of viscous friction $\tau = -\rho\nu\frac{\partial u_x}{\partial r},$ (22)

$$\tau(s) = -\rho\nu\frac{\partial u_x(s)}{\partial r}, \qquad (23)$$

Differentiating function (13) with respect to and substituting the result into the relation

(23), we get

$$\tau(s) = -\frac{P_x(s)}{\rho s^2} \frac{j\nu P_x(s)\sqrt{\frac{s}{\nu}} \cdot J_1\left(jr\sqrt{\frac{s}{\nu}}\right)}{J_0\left(jr_0\sqrt{\frac{s}{\nu}}\right)}, \qquad (24)$$

$$W_{\tau\nu}(s) = \frac{j\rho(s) J_1\left(jr_0\sqrt{\frac{s}{\nu}}\right)}{\sqrt{\frac{s}{\nu}} J_2\left(jr_0\sqrt{\frac{s}{\nu}}\right)}, \qquad (25)$$

The transfer function (25) describes the generalized law of the hydraulic friction resistance of the pipe in an unsteady laminar flow of the medium. To simplify the solution, we use the approximated equation. This equation is found after expanding the numerator and denominator of the transfer function (25) into power series with the transition to the originals $\tau_{OH}(t)$ and $\upsilon(t)$ [4]. The equation looks like:

$$\sum_{n-0}^{\infty} a_n D^n \tau_{OH}(t) = \frac{2\rho\nu}{r_0} \sum_{n=0}^{\infty} b_n D^n \nu(t), \qquad (26)$$

где $D = \dfrac{d}{dt}$, $\quad a = \dfrac{r_0^{2n}}{n!(n+2)2^{2n}\nu^n}$, $\quad b_n = \dfrac{r_0^{2n}}{n!(n+1)2^{2n}\nu^n}$,

$$W_{\tau\nu}(s) = \frac{4\rho\nu}{r_0}\left(1 + 1{,}5\frac{r_0^2}{\nu} + 2\frac{r_0^4}{\nu^2}s^2\right), \qquad (27)$$

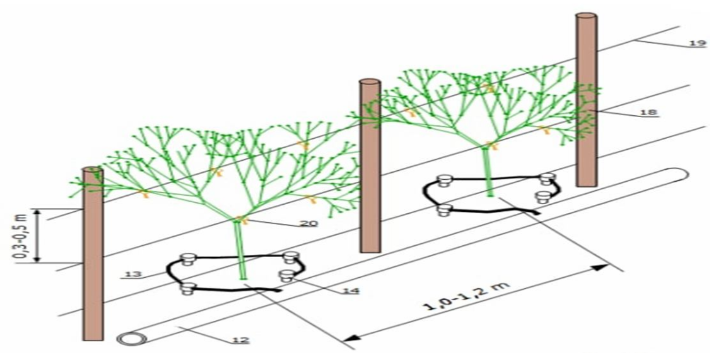

Fig1. Scheme of intensive underground irrigation of gardens.

If you associate the process with coordinate systems, the formula will look like this:

$$\begin{aligned}
&2\rho h_n U_H^2\left(B_n - b_c - b_{\text{япс}} - b_{nc}\right) + 2\rho h_{nc}\int_0^{b_c} U^2 dx + 2\rho h_{nc} U_{nc}^2 b'_{\text{япс}} + \rho h_{nc}\int_0^{b_n} U^2 dx + \\
&\rho h_{pc}\int_{b_n}^{b^*} U^2 dx + \rho h_{pc}\int_{b_{nл}}^{b_p} U^2 dx + \rho h_{nc}\int_{b_p}^{b^*} U^2 dx + 2\rho h_{pc} U_{pc}^2 b_{\text{яс}} = 2\rho h_n U_n^2\left(B_n - b_{\text{ян}} - b_n\right) + \\
&+ 2\rho h_n \int_0^{b} U^2 dx + 2\rho h_n U^2 b_{\text{ян}} + \rho h_n \int_0^{b_n} U^2 dx + \rho h_p \int_{b_n}^{b^*} U^2 dx + \rho h_n \int_0^{b_p} U^2 dx + \rho h_n \int_{b_p}^{b^*} U^2 dx + \rho h_p U_p^2 b_{\text{я}} + \\
&+ 2\rho \int_0^x \int_0^{B_n} \frac{\lambda_n}{2} U^2 dxdy + \rho \int_0^x \int_0^{B_p} \frac{\lambda_p}{2} U^2 dxdy;
\end{aligned} \qquad (28)$$

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$$\begin{aligned}
&2\rho h_n U_H^2\left(B_n - b_c - b_{янс} - b_{nc}\right) + 2\rho h_{nc}\int_0^{b_c} U^2 dy + 2\rho h_{nc} U_{nc}^2 b'_{янс} + \rho h_{nc}\int_0^{b_n} U^2 dy + \\
&\rho h_{pc}\int_{b_n}^{b^*} U^2 dy + \rho h_{pc}\int_{b_{пл}}^{b_p} U^2 dy + \rho h_{nc}\int_{b_p}^{b^*} U^2 dy + 2\rho h_{pc} U_{pc}^2 b_{яс} = 2\rho h_n U_n^2\left(B_n - b_{ян} - b_n\right) + \\
&+ 2\rho h_n\int_0^{b} U^2 dy + 2\rho h_n U^2 b_{ян} + \rho h_n\int_0^{b_n} U^2 dy + \rho h_p\int_{b_n}^{b^*} U^2 dy + \rho h_n\int_0^{b_p} U^2 dy + \rho h_n\int_{b_p}^{b^*} U^2 dy + \rho h_p U_p^2 b_я + \\
&+ 2\rho\int_0^x\int_0^{B_n}\frac{\lambda_n}{2}U^2 dy dx + \rho\int_0^x\int_0^{B_p}\frac{\lambda_p}{2}U^2 dy dx;
\end{aligned} \tag{29}$$

$$\begin{aligned}
&2\rho h_n U_H^2\left(B_n - b_c - b_{янс} - b_{nc}\right) + 2\rho h_{nc}\int_0^{b_c} U^2 dz + 2\rho h_{nc} U_{nc}^2 b'_{янс} + \rho h_{nc}\int_0^{b_n} U^2 dz + \\
&\rho h_{pc}\int_{b_n}^{b^*} U^2 dz + \rho h_{pc}\int_{b_{пл}}^{b_p} U^2 dz + \rho h_{nc}\int_{b_p}^{b^*} U^2 dz + 2\rho h_{pc} U_{pc}^2 b_{яс} = 2\rho h_n U_n^2\left(B_n - b_{ян} - b_n\right) + \\
&+ 2\rho h_n\int_0^{b} U^2 dz + 2\rho h_n U^2 b_{ян} + \rho h_n\int_0^{b_n} U^2 dz + \rho h_p\int_{b_n}^{b^*} U^2 dz + \rho h_n z + \rho h_n\int_{b_p}^{b^*} U^2 dz + \rho h_p U_p^2 b_я + \\
&+ 2\rho\int_0^x\int_0^{B_n}\frac{\lambda_n}{2}U^2 dz dy + \rho\int_0^x\int_0^{B_p}\frac{\lambda_p}{2}U^2 dz dy;
\end{aligned} \tag{30}$$

Pre-irrigation soil moisture is determined by the requirements of plants, with its decrease, short-term inhibition of plants is possible; after irrigation, the moisture content depends on the water-holding capacity of the soil, it is usually not adjusted to the FPV (limiting field moisture capacity) in order to avoid water losses due to seepage. The smaller the humidity control range, the lower the norm, which is favorable for plants and soil, but watering should be more frequent. Irrigation rates are also affected by the thickness of the soil layer and the lithological structure of the underlying soils. On thin soils underlain by well-permeable soils, the norms are reduced to reduce the deep filtration of irrigation water. The terrain also has an effect: at large slopes of the earth's surface, irrigation rates are less because of the danger of soil erosion. On saline soils, irrigation rates are higher than on non-saline ones. From the experience of land irrigation, the limits of irrigation norms have been established for different irrigation methods: with surface irrigation - 60 ... 100 mm, with sprinkling - 20 ... 70, with drip - 5 ... 10, with subsoil - 40 ... 80 mm .

The timing and norms of irrigation are set by various methods. On operating irrigation systems, irrigation dates are set by measuring moisture reserves at key points, or by plant condition, which is less accurate; irrigation norms - based on experience.

When designing irrigation systems, a design irrigation regime is developed for the year of estimated availability. The rates and timing of irrigation are determined by the balance method of A. N. Kostyukov, in which the balances of moisture reserves in the settlement layer are analyzed sequentially for short settlement periods - phases of plant development, decades, weeks. The water reserves in the calculation layer are determined at the end of each calculation period, and if the reserves become less than the allowable, watering is prescribed, it is convenient to do this graphically. An example of determining by a graphical method the norms and terms of irrigation according to the graphs of the dependence of soil moisture and irrigation over time is shown in Fig.2.

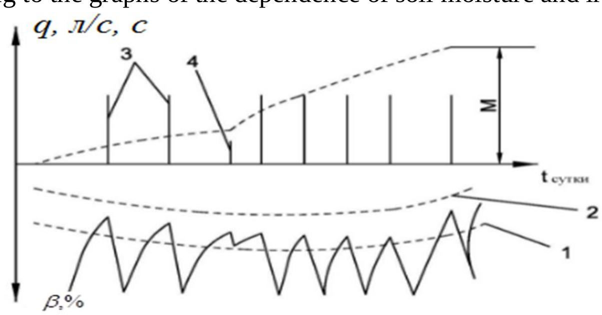

Fig.2. Graph of the relationship between soil moisture and irrigation:

1 - Line of optimal humidity Wmax; 2 - line of the minimum allowable humidity for a given crop Wmin; 3 - watering; 4 - precipitation; q - irrigation intensity; β - soil moisture; M - irrigation rate

At the beginning of the growing season, soil moisture is usually higher than optimal, but gradually it decreases (Fig. 2). At the moment of approaching the permissible minimum, the first watering should be given, which will increase the humidity for a while, until a second watering is required after a period of time t if precipitation does not fall. The process continues until the end of the growing season. The duration of one irrigation, i.e., the time from the beginning to the end of irrigation, is called the irrigation period, which depends on the technique and technology of irrigation, organization and productivity of labor, the area of irrigated plots, and the type of crops. The duration of the irrigation period can be from 3...5 to 12...15 days.

With the addition of equation (26), the system of equations (18), (19) will be closed and, under given boundary conditions, completely describes the unsteady laminar motion of a viscous compressible fluid in a plastic pipe. When using equation (26), the number of terms in its left and right parts should be limited in accordance with the required accuracy of the calculation. In a number of cases it is sufficient to take the first two or three terms on the left and on the right. Most real periodic processes in a hydraulic system can be represented by the sum of a finite number of harmonic components (harmonic oscillations). When the working medium fluctuates in a pipeline or in any other pressure channel, the distribution of flow velocities over the flow cross section differs from the law that describes this distribution in the case of steady-state movement of the medium. Thus, when a laminar fluid flow oscillates in a round cylindrical pipe, the parabolic distribution of velocities is violated, which, as is known from hydraulics, is characteristic of a laminar steady motion of a fluid in a pipe [4].

The system of equations (19), (21), (24), (25), (26), (27), (28), (29), (30) is used to describe hydrodynamic systems with distributed parameters.

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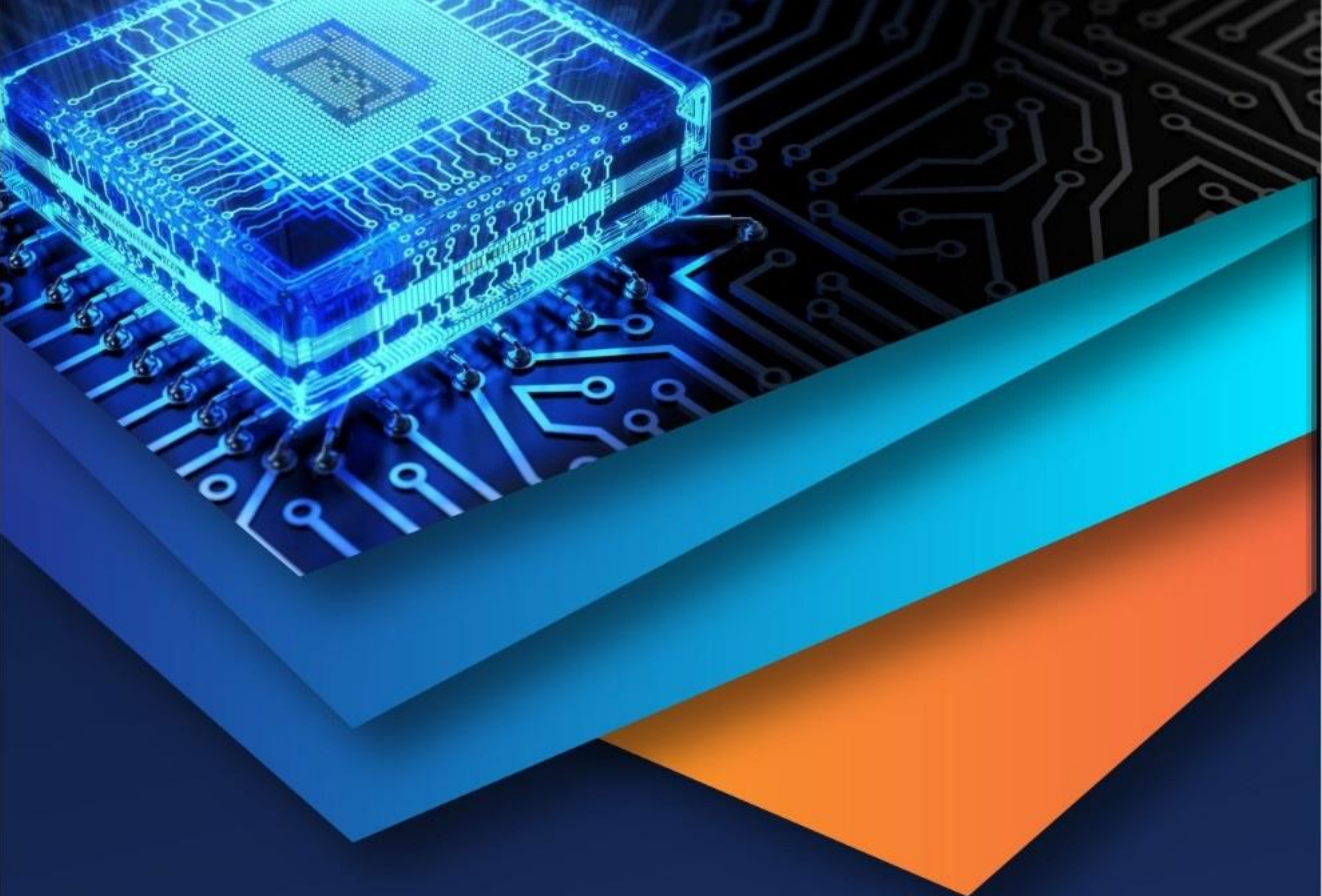

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