

**NUMERICAL IMPLEMENTATION OF A HYDRAULIC MODEL OF
MOISTURE TRANSFER IN HYDROMORPHIC MEDIA**

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One of the most important tasks of geohydrodynamic forecasting related to land reclamation is predicting changes in the groundwater regime and managing the process of moisture transfer in the upper layers of the aeration zone. In this regard, when developing mathematical models of moisture transfer, it is necessary to take into account the physico-mechanical properties of the soil and ground, the hydro-physical characteristics of the layers, and the conditions under which moisture enters the soil and ground, etc.

It is known that soil represents a dispersed body, meaning it consists of a large number of particles of different sizes, mostly small and very small ones. As a result, the well-known fact follows that soil is a porous body, i.e., it is penetrated in all directions by a large number of interconnected gaps between the particles. It is precisely in these gaps — the pores — that the moisture entering the soil and ground in various ways accumulates.

Due to the fact that soil pores are generally very small in size, the behavior of water entering them has several distinctive characteristics. Naturally, we are interested in the size of the pores, their shape, and so on. The only thing that can be established through simple observation is that the size of the pores increases as the mechanical composition becomes coarser — that is, the larger the particles that make up the soil or ground, the larger the pores. However, such a simple conclusion is also

insufficient. Therefore, it is natural that researchers have long sought to describe soil or ground porosity in greater detail.

In the search for such a description, several approaches have emerged. Some researchers chose to create suitable simple models that could replace such a complex system as soil or ground. Others engaged in direct study of the latter. In our study of the laws governing moisture movement in soil and ground, we used the **Slichter model** (“Ideal Soil-Ground Model”) as the basis.

This model lends itself easily to mathematical simulation. The spherical particles that make up the “Ideal Soil-Ground” can be arranged in different ways relative to each other. During modeling, it was also assumed that the particles are arranged uniformly with respect to each other. In other words, soil porosity was represented as a three-dimensional spatial grid consisting of nodes (pores) of various shapes and sizes, connected by narrow passages (throats) between the pores.

In the numerical implementation of the hydraulic model of moisture transfer developed by us, the natural parameters of the research object were used [1,2]:

$$\theta(\hat{z}, \tau) = \frac{e^{-\gamma\tau}}{\Delta_0} \left\{ \left[\exp\left(\frac{Pe(1-\sqrt{D})}{2}\hat{\psi}\right) - \exp(\lambda\hat{\psi}) \right] \exp\left(\frac{Pe(1+\sqrt{D})}{2}\hat{z}\right) + \right. \\ \left. + \left[\exp(\lambda\hat{\psi}) - \exp\left(\frac{Pe(1-\sqrt{D})}{2}\hat{\psi}\right) \right] \exp\left(\frac{Pe(1-\sqrt{D})}{2}\hat{z}\right) \right\} \quad (1)$$

where: $D = Pe^2 - 4\gamma Pr$, here, $Pr = \frac{Pe}{Re}$ - Prandtl diffusion number, $Re = \frac{u_{\text{фил}} l}{\kappa_0}$ - number Reynolds and $Pe = \frac{u_{\text{фил}} l}{\kappa}$ - Peclet number, empirical coefficients: $\gamma = 3,5$ и $\lambda = 1$.

During field studies, it was established that the area of the experimental site is **59 hectares**, and the mechanical composition of the soil is **light and medium loam**, with particle fractions ranging from **0.001 to 0.25 mm**. It was also determined that, within the studied territory, the **average groundwater depth** is approximately **1.5 meters**.



The **height of capillary rise** was determined using the formula for calculating the height of capillary rise in **unsaturated soils**. When substituting the given parameters, the **height of suction** was obtained. The height of suction under full saturation is **zero**. As the soil moisture decreases, the suction height increases in absolute value.

The **relationship between suction height and moisture content** varies among different soil types and is determined **experimentally**. For our calculations, this relationship was represented by the following **expressions** [3]:

$$\psi = 2H_k(1 - \theta) + H_0 \quad \bar{\theta} = \frac{\theta - \theta_0}{\theta_m - \theta_0} \quad (2)$$

Here is a **clear and accurate English translation** of your text:

Where:

- **soil moisture content;**
- **maximum water-holding capacity;**
- **moisture content corresponding to maximum molecular retention;**
- **reduced height of capillary rise;**
- **pressure jump at full saturation.**

It should be noted that the relationship between the suction height and moisture content is not straightforward. For example, during the drying of a previously fully saturated soil, the relationship between moisture content and suction height is described by a curve in which each value of suction height corresponds to the **maximum possible moisture content**. In the opposite process, when dry soil is moistened, the **minimum moisture values** correspond to the same suction heights. These two curves form the two main branches of hysteresis.

We all know that the sorption of water vapor by soil, as well as by many other adsorbents, is accompanied by the phenomenon of hysteresis. This phenomenon consists of the following: if we take the same soil sample and first saturate it with moisture by placing it sequentially in a series of chambers with increasing relative air humidity and allowing it to reach full equilibrium in each chamber, and then dehydrate the same sample by placing it in the same chambers



but in reverse order (i.e., with decreasing relative humidity), then in the second case (i.e., during dehydration), the amount of sorbed moisture at identical relative humidity will always be **higher** than in the first case (i.e., during wetting).

The alternation of drying and wetting processes forms an infinite number of hysteresis scanning curves within the region bounded by the main dependency branches.

The **moisture transfer coefficient** is also significantly dependent on moisture content. This dependency relates the moisture transfer coefficient to moisture content using a power-law function [3]:

$$\kappa = \kappa_0 \overline{\theta}^n \quad (3)$$

Here is a **clear and accurate English translation** of the text:

Where:

- **filtration coefficient.**

The exponent n depends on the nature of the distribution of pore sizes. For homogeneous rocks, n ranges from 1 to 4. However, in highly heterogeneous rocks, the value of the exponent may be significantly higher.

Various methods exist for determining the filtration coefficient:

- | | | | |
|---|-------------------|----------------------|----------------|
| a) | Field | investigation | method; |
| b) | Laboratory | investigation | method; |
| c) Method based on empirical formulas. | | | |

To determine the value of the filtration coefficient, we used the **field investigation method**. For this purpose, at the experimental site, we drilled **three test pits** (with a distance of 1.6 m between them) in the shape of a unit cube (volume of 1 m³) down to the soil layer under study (Fig. 1).

The bottom level of the observation pits was lowered by 10 cm through leveling. Then, a 40 cm layer of water was poured into the working pit and the water level was maintained constant by supplying water (in the amount of 0.2 liters). The research continued until water (a wet spot) appeared on the walls of the observation pits. In other words, **after 39 hours**, a wet spot appeared on the walls of the observation pits.

Using the well-known formula for determining the filtration rate:

$$u_{\text{фи}} = \frac{s}{t} = \kappa_0 \frac{H}{l} \quad (4)$$

where:

- (t) – the time of appearance of water (moisture) on the wall of the observation pit;
- (Δh) – the difference between the water level in the working pit and the wet spot level in the observation pit;
- (L) – the distance between the walls of the working pit and the observation pit;

Would you like this in a **more scientific/academic wording**, for example:

- *the time required for moisture to appear...*
- *the hydraulic head difference...*

$s = \sqrt{l^2 + h^2} \approx 30 \text{ cm}$ - Here is a clear English translation of that phrase:

"the shortest path traveled by water from the working pit to the observation pit;"

$h = 0,5 \text{ cm}$ - Here is the **accurate English translation** of your text:

the difference between the bottom level of the working pit and the wet spot level.

Taking into account the field data and formulas (4) and (3), the following values were obtained for **medium loamy soils**:

$$u_{\text{фи}} = 0,77 \frac{\text{cm}}{\text{час}} , \kappa_0 = 0,585 \frac{\text{cm}}{\text{час}} = 0,14 \frac{\text{м}}{\text{сут}} , \bar{\theta} = 20,44 , \kappa = 11,96 \frac{\text{cm}}{\text{час}} \quad (5)$$

Before proceeding to the numerical implementation of equation (1), it is necessary to determine the numerical values of the geohydrodynamic similarity parameters. In this regard, using the field investigation parameters and equation (5), we obtained:

$$\text{Pr} = 0,49 , \text{Re} = 39,5 \text{ и } \text{Pe} = 19,31 .$$

(6)

Taking into account (5), (6), and (1), after the corresponding mathematical operations, a solution of equation (1) was obtained. To check the adequacy of the hydraulic model, the results of the numerical solution of the equation were compared with the results of the field studies. The convergence of the results is satisfactory, with an error of no more than 4%. The comparison of the results is presented in the form of graphs (Fig. 1).

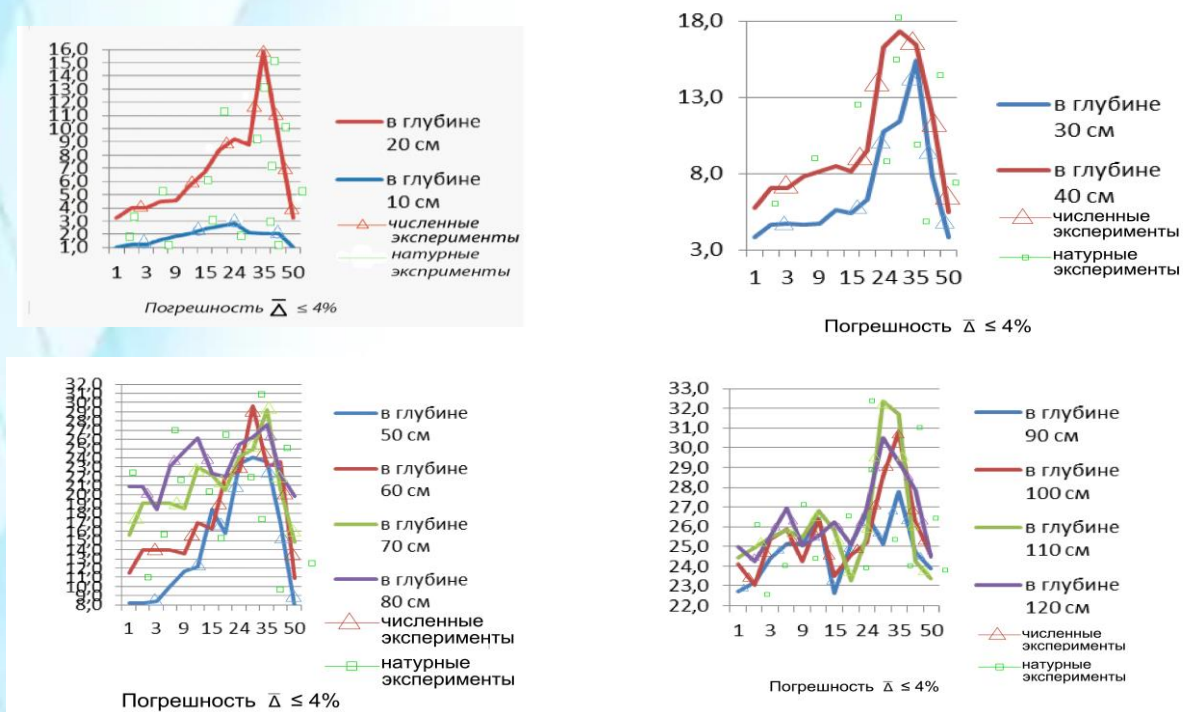


Fig. 1. Graph of the function

Conclusion.

The developed hydraulic relationships take into account conditions close to real processes of moisture transfer in the upper layers of the aeration zone, caused by fluctuations in groundwater levels. The results obtained from the research make it possible to create conditions for subirrigation in areas of agricultural crop irrigation.

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