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TRANSFER PHENOMENA IN ECOLOGICAL SYSTEMS

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ABSTRACT

The phenomenon of transfer finds great application in the problems of hydromechanics of heat and mass transfer associated with structural features and rheological properties of liquid media. A wide distribution of problem solving on the use of ideas about the phenomena of transfer was found in the physicochemical processes of biological media, the processes of transfer of mechanical media, phenomena associated with systems.

The article considers cases of solving hydrodynamic problems using the analysis of transport processes for different types of channel flows described by non-stabilized pulsating flow equations, as well as open channel flows that find their place in practice.

1. INTRODUCTION

The most important substance on planet Earth is definitely water, it is found not only in oceans, seas, rivers and lakes, but also in the biosphere. About 71% of the earth's surface is water, it should also be noted that the human body consists of 55...75% of water and body weight, depending on age. It plays a major role in most processes and phenomena that occur on the planet and beyond.

The water cycle on Earth is based on a continuous closed process of water transfer on the globe, which occurs under the influence of solar radiation and the action of gravity, information fields and other phenomena.

The physical structure of water substances is the product of internal coordinated processes. These processes are based on the fundamental laws of physics-chemistry and transfer phenomena. The transfer phenomenon is widely used as a convenient method in problems of hydromechanics, heat and mass transfer, related to the structural features and rheological properties of liquid media. A wide spread of solving problems using ideas about transfer phenomena is found in physics-chemical processes, biological environments, transfer processes of mechanical environments, phenomena related to hydro pneumatic [1-3].A number of authors, Tager, Laifut, Petukhov, Loitsiansy, Levych, Byrd, and others, dealt with transference phenomena as a mechanism for researching theoretical foundations [1-9]. These studies are related to the transfer of heat and thermal energy, energy transfer processes, diffusion processes of mass transfer, energy transfer processes, in physical and chemical research.

2. EXPOSITION

The formulation and solution of these problems are based on the basic transfer equations. In this regard, when considering the phenomenon of transfer in solid media, it is necessary not only to formulate the basic equations characterizing these phenomena, but also to obtain clear information characterizing the transfer coefficients. Such transfer coefficients are mostly coefficients: viscosity, diffusion, heat transfer. These quantities are dimensional (therefore they are called coefficients conventionally), and depend on a number of physical and chemical properties [3]. Therefore, in many cases, the tasks are related to the correct determination of these transfer coefficients. This is especially important if liquid media exhibit viscosity anomalies or mass transfer processes that are closely related to the phenomena of diffusion and heat transfer and have a complex nature of physical transformations and interactions. In this regard, the work pays enough attention to the issues of determining the transfer coefficients and the factors affecting them. On the based of taking into account such features of the coefficients, the corresponding equations of motion of rheological complex media can be compiled. In this work, the cases of solving hydrodynamic problems using the analysis of transport processes for various types of flows described by non-stabilized flow equations (pulsating flows) in the open channel flows of the Stryi River, which take place in practice, are considered fig. 1.

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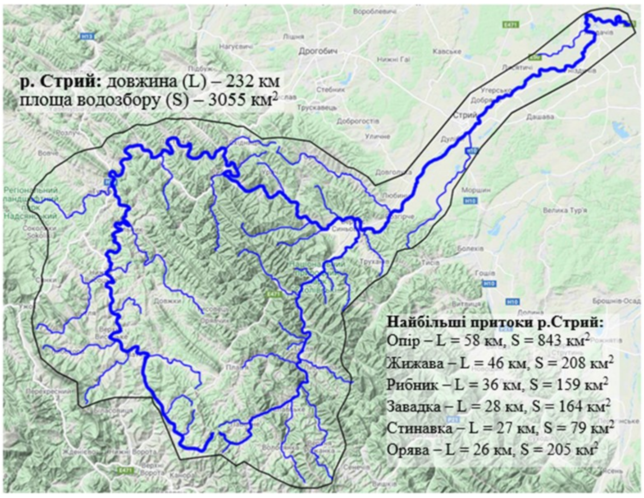

Fig. 1. The catchment area of the Stryi River with the spatial location of its sources and the right tributary of the Opir River near the town of Yavirnyk of the Verkhovyna watershed ridge

When studying mechanical processes in the nature of studying the processes of movement of working fluids, there is a need to choose rational directions of analysis that are in accordance with the nature of the transfer processes [3].

Each of these processes is associated with the corresponding basic transport equations and such auxiliary laws as Newton's law for a viscous fluid and Hooke's law for an elastic body, conditions (equation) of state for a gas, and so on.

Input data and gradient equations together with transfer coefficients are key in transfer processes. Features of the definition for physical chemistry can be characterized by the activation energy and free path length of molecules.

Based on the physical and chemical data of transfer, the basic processes and equations are formed and the corresponding mathematical model is built.

Equations describing transfer phenomena:

$$\begin{cases} impulse\ transfer: \\ \tau = -\mu \times grad\, u \\ Mass\, transfer: \\ j = -D \times grad\, C \\ Heat\, transfer: \\ q_e = -\lambda \times grad\, T \\ Transfer\ of\ electrical\, energy: \\ i = -\rho \times grad\, \varphi \end{cases} \tag{1}$$

where: τ –shear stress [Pa]; j -diffusion flow [kg/s]; q – heat flow [W]; μ - dynamic viscosity [Pa·s]; D - diffusion coefficient [m^2/s]; λ - coefficient of thermal conductivity [W/(m·K)]; u - flow velocity [m/s]; C - concentration of molecules in the substance [kg/m^3]; T - temperature of the medium [K], ρ - the coefficient of electrical conductivity [Ω · m], φ - potential of the electric field [V].

Mixing diffusion is one of the main processes of turbulence.

The transfer of matter occurs due to molecular and turbulent diffusion (mutual penetration of individual particles of matter) and by convection (differences in the average speed of movement in the cross-section of the flow).

There is a significant difference between molecular and turbulent diffusion. In the case of molecular diffusion, the medium consists of discrete particles, while in turbulent diffusion, the medium is continuous.

The characteristic properties of turbulent diffusion are that the particles of the medium retain their initial properties throughout the time interval of movement, but the spatial distribution of the particles changes. There are two main methods of describing the environment, the Lagrange and Euler methods.

For example, the diffusion coefficient can have the following values, depending on the respective environments of the table. 1.

Table 1 *Diffusion coefficients for different media*

Environment	$D\ ,\ m^2/c$
Molecules in gases	1×10^{-4}
Molecules in solutions	1×10^{-9}
Ions in solutions	1×10^{-8}
Colloidal particles	1×10^{-10}
Atoms in solids	1×10^{-12}

Particular attention needs to be given to the determination of the diffusion coefficient D, which is the mass of a substance that has passed through a unit of phase contact surface area at a concentration gradient equal to unity in a unit of time.

For a medium at rest or moving in laminar conditions (when the reis no movement of molar masses), mass transfer occurs due to molecular diffusion. The value of which is characterized by the value of the molecular diffusion coefficient D_m.

For ideal gases, its value is calculated analytically, based on the kinetic theory, for example for air at a temperature of 20°C $D_m = 1{,}9.10^{-6}\ m^2/c$.

For liquids where the kinetic theory does not give clear results, the value of $D_м$ is determined based on empirical data and depends on the physical properties of the liquid and the temperature of the medium. Some D_m data for water are given in Table 2.

Table 2 *Diffusion coefficients for water as a function of temperature*

$T\ ,\ ^oC$	*10*	*15*	*20*	*30*
$D_{м.} \dfrac{м^2}{c} 10^{-9}$	*1,28*	*1,48*	*1,72*	*2,23*

From the table we can see that for water the value of D_m is several orders of magnitude less than for air (approximately 1000 times). However, this does not mean that diffusion is slower in liquids than in gases. Because, in addition to D_m, the mass transfer rate is also affected by the concentration gradient, and it is much greater in liquids than in gases.

In a turbulent flow, the presence of velocity pulsations creates conditions for the chaotic movement of finite volumes of the medium (moles). Since the latter have inertia, a mole that moves at a higher speed, getting into a slower layer of the medium, will accelerate it, and vice versa. Along with the transfer of kinetic energy, there is a transfer of dissolved or suspended particles that are in moles of moving particles. The intensity of mass transfer in this case is characterized by the coefficient of turbulent diffusion D_m, which is not a physical constant, but depends on the hydrodynamic picture of movement.

When mass transfer occurs simultaneously due to molecular and turbulent diffusion, the value of the effective diffusion coefficient D_{ef} is substituted into formula (2), which is determined from the dependence:

$$D_{ef} \approx D_M + D_T \tag{2}$$

In many cases, taking into account the rheological complexity of various media, which, as is known in [5], can have both viscous and elastic properties. To describe rheologically complex systems, mechanical models proposed in the work of Rainer [5] are used. These models are based on in formation about the properties of analogs of the environment.

The set of existing rheological properties can be represented as a tree consisting of ideal bodies. Of them, three bodies are represented in the mechanics of a continuous medium: a solid body of Hooke's law (H), a plastic Saint-Venant body (StV), and a Newtonian fluid (N). More rheologically complex bodies can be obtained by appropriate combinations of the selawsin parallel or series connection, which allows to describe no to nly elongation and shear and counter-stretching. Mechanical models of macrorheology of Newtonian and, accordingly, viscoplastic or Bingham bodies of non-Newtonian fluids can be represented by the following rheological tree.

To solve the practical problems of channel flow, it is necessary to develop a methodology for calculating the distribution of the average velocity of the weighted flow, which is used in a wide range of changes in the conditions of movement of the flow parameters of the carrier liquid and solid particles. To develop a method for calculating the distribution of the averaged velocity along the depth of the suspended flow in open channels, in the case of established (du/dt=0) about one-dimensional (du/dx=du/dz=0) and uniform motion (taking f=s- the concentration of the second phase in the flow) for the carrier fluid and for the flow of suspended particles,we write in the following form

The results of the calculations show that the values with respect to the speed, ie. The difference in velocity of the carrier fluid and the solid particle along the flow depth changes. This is obvious because the distribution of the concentration of suspended particles along the depth of the flow has an exponential character during the movement of a weighted flow in open channels. Hence, as the depth increases, the concentration of suspended particles increases, and here there is a need to take into account the fractional composition, which significantly affects the distribution of the suspended substances is calculated according to the following dependence [6]:

$$\begin{cases} \dfrac{\partial}{\partial y}\left[(1-s)\mu\left(\dfrac{\partial u_1}{\partial y}\right)\right]K(u_1-u_2)-(1-s)L_1u_1=-(1-s)\rho gi \\ \dfrac{\partial}{\partial y}\left[\mu s\left(\dfrac{\partial u_2}{\partial y}\right)\right]+K(u_1-u_2)-sL_2u_2=-s\rho_T gi \end{cases} \tag{3}$$

where ρ, ρ_T are the density of the carrier liquid and the solid particle kg/m^3, I - the slope of the water surface, the density of the carrier liquid and the solid part.

Relative velocity along the flow depth (fig. 2).

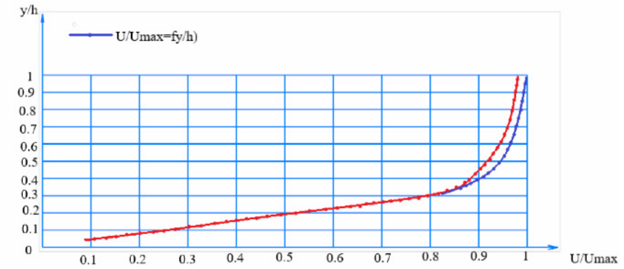

Fig. 2. The result of the calculation of the velocity distribution along the depth of the turbulent suspended flow

Thus, transfer phenomena in this case are characterized by more complex transfer coefficients associated with viscosity and density.

One of the active methods of applying transfer phenomena is the transfer methods of two-phase flows of "suspended" flows. As is known, two-phase flows include dispersions of latexes and emulsions [1-4]. Latexes and emulsions mostly belong to the category of non-Newtonian fluids, therefore their behavior and rheological state can be described by the corresponding equations of non-Newtonian fluids. Modeling of their behavior can be presented in accordance with Rayner's mechanical models. As for dispersed and "suspended" flows, viscosity depends on both the size of solid particles of the liquid medium and their size. For example, in a two-phase flow, liquid-solid particles whose shape is spherical and whose dimensions do not exceed 10 [5].

The viscosity of the mixture can be determined by Einstein's formula. In the case when solid particles have a shape different from a sphere (plate, prism, cube), the coefficient is adjusted. The presence of solid particles in dispersed flows also characterizes the concept of hydraulic coarseness, which in turn affects the velocity profile. Hydraulic coarseness depends not only on the actual size of the particle, but also on its density, shape, surface condition, as well as on the properties of the medium (usually water) in which the particle moves. Two particles, regardless of their density, size and other properties, are considered the same if, under standard conditions, they fall in water at the same speed. With a group fall of particles, the speed of individual particles decreases and depends on the amount of looseness of the particle system (layer) and their size.

Hydraulic coarseness is determined by conducting a fractional or sedimentation analysis of the material.The hydraulic coarseness of particles of suspended substances is calculated according to the following dependence [6]:

$$U_0 = \frac{1000kh_1}{at\left(\dfrac{kh_1}{h}\right)^n} - \omega \tag{4}$$

where, k is the coefficient of utilization of the volume of the building; h1 — depth of the working part of the structure, m; α is a coefficient that takes in to account the effect of water temperature on its viscosity; t is the settling time, s, corresponding to the given effect of cleaning water from suspended substances and obtained in laboratory conditions in a layer of water h = 500 mm; n is an indicator that depends on the agglomeration of suspended substances in the process of their deposition; ω is the vertical component of the velocity of water movement in the structure, mm/s.

The rheological method of determining the shape of particles consists in the fact that diluted aggregate-stable dispersed systems do not form structures, and the refore their rheological properties are close or similar to the properties of the dispersion medium. The dependence of the viscosity of these systems on the concentration of the dispersed phase is linear and is described by the Einstein equation:

$$h = h_0(1 + aj) \tag{5}$$

h, h_0 - viscosity of the dispersion system and dispersion medium; j - volume fraction of the dispersed phase; a - shape coefficient of particles.

Ecological function of hydrodynamically active sections of mountain rivers. Mountain stream hydraulics are characterized by shallow turbulent currents and high relative roughness caused by protruding boulders, bedrock, and wood debris washed down from the slopes. In scientific publications [7, 8] it is shown that, in contrast to rivers with a smaller gradient, these significant elements of roughness account for 80–90 percent of the total roughness of the bed of fast mountain rivers. The speed of the flow changes over relatively short longitudinal distances due to the unevenness of the morphological elements and the presence of thresholds and drops.

For a mountain river basin, hydrodynamically active areas (HAD) are one of the most important ecological and hydrogeochemical factors of water quality formation.

The absolute marks of the sources of 26 main watercourses were determined. According to these data, areas of active cleaning on the GAD, their spatial location and geoecological analysis of tributaries of various orders in the Stryi river basin were identified.

In fig. 3 shows the results of laboratory studies of water flow in a tray on a model site and a natural hydrodynamically active site. In the laboratory of the GVI department, samples were taken from three points, and at the full-scale HAD from four, simulating the area of restoration and stabilization of the river flow. The results of the conducted experiments confirm the similarity of the processes of natural self-purification of river waters in laboratory conditions and the real flow of mountain rivers. Taking into account the complexity of field observations, the possibility of experimental laboratory reproduction of these processes has been obtained, provided that the similarity and criteria for modeling hydraulic phenomena are observed. When the flow passes through the HAD, we can see its significant saturation with oxygen, which contributes to the reduction of ammonium and nitrite pollution.

In fig. 3, they observed a change in the hydrochemical parameters of tap water in the laboratory of the Department of Hydraulic Engineering and Water Engineering, which underwent settling from September 1, 2020 in the tanks of the experimental installation, as well as a significant increase in the content of dissolved oxygen, especially due to an increase in the flow rate. These indicators are somewhat different from natural studies, where samples were taken from the Tyshivnytsia River.

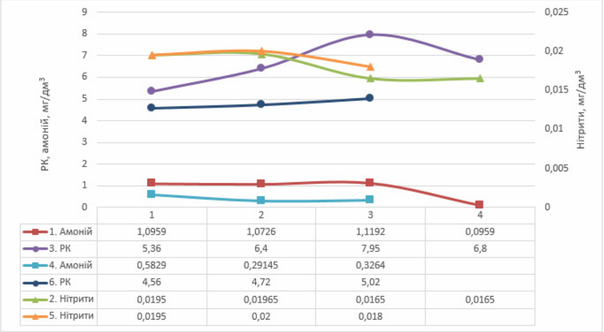

Fig. 3. Comparative analysis of changes in the average values of the chemical composition of water at the model HAD with the results of natural studies (17 experiments)

3. CONCLUSION

Thus, the transfer phenomenon is a good tool for considering physicochemical and ecological systems.

The analysis of the results of long-term studies of indicators of the chemical composition of river water for 2016-2020 showed a significant anthropogenic load on natural waters in the Stryi River basin. However, the landscape basin ecosystem of the Stryi River has preserved the powerful function of self-purification of channel water. It is supported by the mountainous relief of the territory, the hydrological and hydromorphological properties of the river, as well as the presence of hydrodynamically active areas in the mountainous and foothill areas of the basin. We did not observe trends towards a steady increase in the content of pollutants relative to MPC in the studied period.

Physico-chemical and physical indicators of the water intake in Stryi show that the drinking water of the artesian wells is of high quality. The negative effects of river waters of the Stryi river basin on underground water deposits have not been confirmed. The quality of the river water is satisfactory for its use in domestic and drinking water supply and for recreational purposes.

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