Methodology for determining the physical parameters of wastewater discharge into surface water bodies of different types has been developed, which allows to determine the precipitation kinetics of wastewater impurities and their dependence on concomitant factors. The proposed methodology allows, based on the hydraulic size, to determine the deposition rate of particles of different size and shape contained in the wastewater and to determine the factors that affect the process of different shapes and masses particles mixing. The algorithm of measures of preliminary sewage treatment by enterprises before discharge into surface reservoirs is offered in the work. The implementation of the proposed algorithm will determine the impact of wastewater on the quality and chemically-biological composition of surface water bodies of Ukraine, as well as significantly improve the quality characteristics of surface and groundwater, which are water supply source for all residents of cities and towns of Ukraine.

**Keywords:** wastewater, surface waters, mixing, precipitation

**Introduction.** The problem of the aquatic environment quality in the World the long time has been one of the most important problems of human society [1-5]. As for Ukraine, the scale of anthropogenic impact on water bodies has already reached a critical point [6-8]. Today, there are not surface water bodies left in Ukraine that would not change as a result of anthropogenic impact. The pollution level of rivers and lakes, as a result of harmful substances incoming, has reached critical levels. The results of sanitary and hygienic surface aquatic ecosystems assessment in Ukraine suggest that the main risk factor for human health is the use of surface and groundwater from different types of water sources (wells, pump rooms, etc.).

According to the current legislation of Ukraine, all wastewater must be treated from toxic impurities before being discharged to surface water bodies. Today, to meet these requirements, depending on the chemical composition of wastewater, various methods and ways to restore their quality characteristics are used [3, 9-12].

Industrial and domestic wastewater, before being discharged to surface water bodies, are subjected to purification to the required quality by mechanical, chemical,
physically-chemical and biological methods. These methods are divided into recovery and destructive. Recovery methods involve the removal from wastewater and further processing of all valuable substances contained in them. At destructive methods, pollutants are destroyed by oxidation or reduction, and the products of destruction are removed from the water as gases or sediments [1, 3-5, 11].

1. Description of physical parameters of reverse waters

Depending on the aquatic environment into which the wastewater enters, the processes of pollutants destruction contained in them and their transfer rate into certain distances (or suspended impurities sediment) will depend on many factors, namely: gravity, centrifugal force, gravitational force and centrifugation [3, 13].

The wastewater impurities deposition kinetics in hydroecosystems will be different and will depend on many parameters of a particular surface water body (flow rate, depth, temperature, chemical composition, density, etc.).

The main parameter in the calculation of deposition (hydraulic size) is the particles sedimentation rate to the reservoir bottom. When a particle is deposited on the reservoir bottom under the gravity action, the driving force of a solid particle with a diameter \( d \) is described by the difference between its weight:

\[
G = m_r q = \pi \frac{d^3}{6} p_r q, \tag{1}
\]

and an Archimedean repulsive force equals the liquid weight in the volume of the particle:

\[
A = m_0 q = \pi \frac{d^3}{6} p_0 q, \tag{2}
\]

\[
G - A = \pi \frac{d^3}{6} q(p_r - p_0), \tag{3}
\]

where \( p_r \) — solid particle density, \( \text{kg/m}^3 \), the resistance force of the aqueous environment, in which the particles contained in wastewater fall into, according to Newton will be presented as:

\[
R = \int \frac{\pi d^3}{4} \cdot \frac{p_0 W_0^2}{2}, \tag{4}
\]

where \( \int \) — the resistance coefficient of the aquatic environment, which depends on the particles deposition mode in the surface water. The deposition rate can be found from the condition of equality of force driving of the particle and resistance force of the aquatic environment into which the particle enters:

\[
W_0 = \sqrt{\frac{4d_r (p_r - p_0) q}{3\int p_a}}, \tag{5}
\]
In the laminar deposition mode at $f=24/R_e$ we obtain the Stokes formula:

$$W_0 = \sqrt{\frac{4}{3} \frac{qd_r^2 (p_r - p)}{18h_0}},$$

which is also a minimum particles size, when a deviation from Stokes' law is observed and at $R_e \leq 10^{-4}$ very small particles deposition rate begins to be affected by the temperature factor of the aquatic environment molecules. Calculations have shown that at $d_r = 0.1\text{mcm}$ the particles don’t sediment and chaotic Brownian motion is observed.

Non-spherical particles deposition rate is less than spherical particles deposition rate. For non-spherical particles, in the formulas for the equivalent diameter $d_e$ determination, the volume $V_r$ or the mass $G_r$ of particles entering the aqueous medium is used:

$$d_e = \sqrt[3]{6V_r / \pi} = \sqrt[3]{6G_r / \pi p_r},$$

When the wastewater sedimentation, there is a limitation of deposition, which is accompanied by the collision of particles, friction between them and changes in the velocities of large and small particles. This process occurs when wastewater enters lakes or other surface water bodies where there is no flow. If the wastewater enters rivers at different flow rates, the deposition and dissolution processes of their impurities are described taking into account many physicochemical, temperature and other factors. The turbulence, coagulation and hydrodynamic complexation affect the process of different shapes and masses particles mixing in the total volume of the hydroecosystem [2].

The inhomogeneous particles separation rate in the field of centrifugal forces is higher compared to these particles separation rate in the field of gravity. The mathematical relation of the speed of the centrifugal force to the force of gravity can be carried out by comparing the accelerations acting on the particles of impurities when entering the river with a certain flow velocity in the centrifugal and gravitational fields. In general, the centrifugal force $P_c (H)$ is equal to:

$$P_c = \frac{mU_o^2}{r} = \frac{GU_o^2}{qr},$$

where $m$ — particle mass (kg); $G$ — particle weight (H); $U_o$ — angular velocity (m/sec); $r$ — radius of rotation (m).

Dilution of wastewater is a process of reducing the concentration of impurities in the reservoirs into which they discharge, caused by mixing the wastewater with the aquatic environment. The intensity of the dilution process is quantitatively characterized by the multiplicity of dilution:

$$n = (C - C_r / C - C_r),$$
where \( C_0 \) — concentration of impurities in wastewater, discharging into reservoirs (mg/m\(^3\)); \( C_r \) и \( C \) — concentration of impurities in the reservoir before and after wastewater discharging respectively.

In flowing water bodies with a directed flow, the multiplicity of dilution in the calculated line \( n \) is determined by the formula:

\[
n = \frac{(mQ + q)}{q},
\]

where \( m \) — mixing factor, which indicates what part of the water flow in the reservoir is involved in mixing; \( q \) — volume consumption of wastewater, discharging into surface water body with volume consumption of water \( Q \) in the reservoir.

With complete mixing of the wastewater, the concentration of impurities in the reservoir at any time is equal to:

\[
C = \frac{t(C_0 q + \sum C_{gr} Q)}{V},
\]

where \( t = \frac{V}{\rho + \sum Q_{in}} \) — period of complete water exchange in the reservoir; \( V \) — reservoir volume; \( Q_{in} \) — water consumption in the reservoir without impurities.

Connection between sanitary requirements to the discharge conditions into reservoirs, ie compliance of the water composition and properties of reservoir used for water use with the established standards (Maximum Allowable Concentration) and the required degree of wastewater treatment before discharge into reservoirs in general can be described by the formula [3]:

\[
C_c q + C_p mQ \leq (mQ + q)C_{mp},
\]

where \( C_c \) — concentration of pollutants (amount of harmful substances) of wastewater at which admissible norms will not be exceeded; \( q \) — water consumption discharge into the surface water body; \( C_p \) — the concentration of the same type of pollution in the water of the reservoir above the place of discharge of the considered runoff; \( Q \) — water consumption in the reservoir; \( C_{mp} \) — maximum permissible concentration of pollution (harmful substances) in the water of the reservoir.

The concentration of pollution \( m \) depends on many factors: the design of the outlet, the distance to the calculated line of discharge, hydraulic and hydrological parameters of the surface reservoir [4].

Converting formula (12), you can get the value of \( C_c \), ie, the value of the pollutants concentration (harmful substances) in wastewater, which must be achieved as a result of their treatment and disposal by previous methods at enterprises:

\[
C_c \leq mQ(C_{mp} - C_p)q + C_{mp},
\]

It should be noted that the conditions of wastewater mixing with the lakes and storage reservoirs are significantly different from the conditions of their mixing in rivers. The impurities concentration decreases significantly in the initial mixing zone, but complete mixing occurs at much greater distances from the place of discharge than in rivers. In addition, the mixing in time, direction and value of air velocity over lakes
and storage reservoirs, which carry pollution in different directions from the discharge place. The mixing process and the chemical reactions rate that occur in lakes and storage reservoirs are influenced by the season and water temperature. Therefore, enterprises and organizations that discharge waste water into stagnant reservoirs should carry out the necessary and mandatory pre-treatment measures and make calculations of the wastewater treatment required degree according to the following algorithm:

1) to calculate the maximum permissible concentrations (MPC) of pollutants in wastewater:

\[ C_c \leq C_B + m(C_{mp} - C_B) \]  \hspace{1cm} (14)

2) to determine the concentration of suspended solids in wastewater:

\[ C_B = V + mp \]  \hspace{1cm} (15)

3) to determine the allowable value biological oxygen demand (BOD) in wastewater:

\[ L_c = \frac{n-1}{10-K_{c_i}}(L_{nD} - L_B 10^{-K_{c_i}}) + \frac{L_{mp}}{10-K_{c_i}} \]  \hspace{1cm} (16)

where \( L_c \) — BOD in a stagnant reservoir before discharge; \( K \) — deposition rate constant \( O_2 \) in a stagnant reservoir;

4) to determine the allowable value BOD in wastewater by dissolved \( O_2 \):

\[ L_c = \frac{n-1}{K}(C_{O2n} - K_{Lc} - C_{O2n+1}) - \frac{C_{0n-1}}{K} \]  \hspace{1cm} (17)

where \( C_{O2n} \) — concentration of dissolved \( O_2 \) in a stagnant reservoir before discharge; \( C_{O2n-1} \) — MPC of dissolved \( O_2 \), which must be in the settlement line after the discharge;

5) to determine the max allowable \( T^o \) of wastewater:

\[ T_c = nT_a + T_B \]  \hspace{1cm} (18)

where \( T_a \) — water temperature of surface watercourse after discharge; \( T_b \) — water temperature of surface watercourse before discharge.

6) to determine the permissible content of acid or alkali in waterwater, using a set of water samples with the following chemical analysis according to the formulas:

\[ C_{CT_k} = (n-1)C_K \]  \hspace{1cm} (19)

\[ C_{CT_L} = (n-1)C_L \]  \hspace{1cm} (20)

To establish the environmental risk during the discharge of wastewater to surface water bodies [14], to ensure environmental safety of surface water bodies, it is advisable to compare the experimental data with calculated by the formula [15]:

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\[
S_{\text{max}} = S_n + S_{cm} \cdot B \left[ \frac{0.14 \cdot q_{cm} \sqrt{N}}{x \cdot (Q_e + q_{cm}) \varphi} \right],
\]

where \( S_n = \frac{S_e \times Q_e + S_{cm} \times q_{cm}}{Q_e + q_{cm}} \) — the average concentration of impurities, mg/l; \( S_{cm} \) — the concentration of impurities in wastewater, mg/l; \( B \) — the average width of the riverbed, m; \( q_{cm} \) — water runoff, m³/sec; \( Q_e \) — river consumption, m³/sec; \( \overline{H} = \frac{H}{B} \) — relative depth of the river; \( H \) — average depth of the river, m; \( \varphi \) — tortuosity parameter; \( x \) — distance from the source of pollution, m; \( C = \frac{1}{n} \times R^n \) — Shezi coefficient; \( n \) — roughness factor; \( R = \frac{\omega}{\chi} \) — hydraulic radius, m; \( \chi = B + 2H \)

\( \omega = B \times H \quad N = \frac{M \times C}{g} \quad M = 0.7 \times C + 6 \quad g \) — acceleration of gravity, m/sec²

1.2. Methodology of determination of physical parameters of reverse waters. The results of comparing experimental data (samples taken at the mixing places of wastewater with surface waters of a small river) with the calculated ones are presented in Fig.1.

![Fig. 1. The results of comparing experimental and calculated data](image)
It follows from the graph that the experimental results are quite accurately corrected with the calculated data.

A comparison of experimental studies results and the results obtained by formula (21) gives grounds to apply a mathematical model to predict the ecological state of reservoirs in real time to predict the spread in the water column and bottom sediments of toxic metals such as Cu, Zn, Ni, Mn and Cr.

The results of calculations (21) allow us to predict the reduction value of qualitative indicators of the pollutants concentration in surface water bodies (Fig. 2).

![Graph showing concentration reduction](image)

**Distance from pollution source, m**

Fig. 2. Dynamics of pollutants concentration reducing in surface water bodies from a distance

According to the predicted results, the maximum pollutants concentration reduction in surface water bodies, after mixing with wastewater, occurs at a distance to 200 m from the mixing point.

**Conclusions.** The proposed methodology to determine the physical parameters wastewater discharge into surface water bodies of different types allows:

— to determine the precipitation kinetics of impurities in wastewater and their dependence on concomitant factors;
— on the basis of hydraulic size to determine the deposition rate of different size and shape particles contained in wastewater;
— to determine the factors that affect the mixing process of different shapes and masses particles, the multiplicity of dilution in flowing and non-flowing reservoirs;
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— to determine the characteristics and mixing factors of wastewater in river ecosystems, lakes and storage reservoirs;
— to propose an algorithm of measures of preliminary wastewater treatment by enterprises before discharge into surface water bodies.

Implementation and application of this methodology will determine the impact of wastewater on the quality and chemically-biological composition of surface water bodies of Ukraine, as well as significantly improve the quality of surface and groundwater, which is a water supply source for all residents of cities and towns of Ukraine.

References

Методологія визначення фізичних параметрів зворотніх вод при їх надходженні до поверхневих водойм різного типу

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Розроблена методологія визначення фізичних параметрів зворотніх вод при їх надходженні до поверхневих водних об’єктів різного типу, яка дозволяє визначити кінетику осадження домішок зворотніх вод та їх залежність від супутніх чинників. Запропонована методологія дозволяє, на основі гідравлічної крупності, визначати швидкість осадження різних за розміром та формою частинок, що містяться у зворотніх водах та визначати чинники, які впливають на процес змішування частинок різної форми та маси. В роботі запропонований алгоритм заходів переднього очищення стічних вод підприємствами перед скидом до поверхневих водойм. Реалізація запропонованого алгоритму заходів дозволить визначати вплив зворотніх вод на якість та хіміко-біологічних склад поверхневих водних об’єктів України, а також суттєво підвищити якісні характеристики поверхневих та підземних вод, які є джерелом водопостачання для всіх мешканців міст та селищ України.

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