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O. R. Byelyanska*,
orcid.org/0000-0001-8026-8004,
K. S. Krasnikov,
orcid.org/0000-0002-4241-0572,
V. H. Nakonechnyi,
orcid.org/0000-0002-8789-8348

Dniprovskyi State Technical University, Kamianske, Ukraine
* Corresponding author e-mail: belyans@ukr.net

RESEARCH ON AN ECO-SAFE FILTRATION PLANT FOR WASTEWATER TREATMENT MADE OF NATURAL RAW MATERIALS

Purpose. To develop a new eco-safe filtration plant for wastewater treatment based on natural and secondary raw materials, which will allow rational use of natural resources with further mathematical modeling of hydrodynamics of mixing treated wastewater in biopoods to predict removal of residual concentrations from the filter.

Methodology. A complex of modern methods of theoretical and experimental research was used to solve the tasks. Concentration of pollutants was determined using methods of atomic adsorption spectroscopy, titrimetry and gravimetric methods, as well as pyrometric analysis. A laboratory installation was created, which included a receiving tank, a filter column, and a tank for collecting purified wastewater. Prediction of distribution and mixing of treated effluent in biopoods was carried out using mathematical and computer software.

Findings. An environmentally safe filtration plant (containing sand, fallen leaves of linden, poplar, and plastic residues separated by a polymer mesh) was created to purify wastewater from suspended substances and nitrates. Kinetics of changes in concentration of suspended solids and nitrates in urban wastewater were studied. When using the filtration plant, concentration of suspended solids decreased by 85–92 %. Concentration of nitrates in purified water processed with such a plant is reduced from 12 to 0.25–0.05 mg/dm^3. A mathematical model concerning distribution of purified water in a biopond was obtained, which allows predicting possible migration distributions of residual concentrations in purified water during its natural movement downstream.

Originality. For the first time, influence of the species origin of fallen leaves on the performance indicators of wastewater filtration plant of urban sewage treatment constructions was investigated, which made it possible to substantiate a new way of disposal of this type of waste. For the first time, it was established that wastewater treatment using an eco-safe filtration plant based on natural and secondary raw materials, containing layers of sand, fallen oak, linden, and poplar leaves, gives an opportunity to reduce contents of suspended solids in wastewater by 1.5 times of the maximum permissible concentration; and such treatment also reduces concentration of nitrates by 4 times from the initial level. Pollutants from wastewater are mechanically fixed in pockets (microcracks, cracks) of fallen leaves, formed during drying of leaves, which is explained by hardening of intercellular spaces with formation of a specific geometry of holes. For the first time, mathematical modeling of purified wastewater movement in a biological pond with a complex geometry was performed, which allows estimating the concentration of the pollutant at its outlet from the pond.

Practical value. The created environmentally safe wastewater filtration plant gives an opportunity to perform not only filtering, but also an effective biological purification of wastewater from nitrates on the surface of layers of fallen leaves. The wide use of the proposed installation will allow attracting plastic of polyethylene bottles used in everyday life as a secondary raw material. Based on the proposed mathematical model of movement of purified liquid containing residual concentrations of pollutants, it is possible to carry out qualitative forecasting and optimization of the process of cascade wastewater treatment at industrial and economic enterprises.

Keywords: *waste water, fallen leaves, pyrometric analysis, filtration, biological cascade ponds*

Introduction. In our difficult times, environmental protection is increasingly becoming the most important task of mankind [1]. In particular, in Ukraine, due to military aggression and a decrease in the financing of communal enterprises, it is becoming more difficult to implement a high-quality wastewater treatment technology. Increased concentrations of nitrogen in wastewater entering treatment facilities reduce quality of wastewater treatment by 30–40 %, which leads to destruction of activated sludge in the biological treatment department, and as a result, to release of such toxic effluents into the environment [2]. Wastewater treatment facilities in Ukraine were built in the 70s and 80s of the *20th* century, and they require significant modernization, and the issue of disposal of generated waste remains open [3].

An interesting and at the same time scientific and practical issue consists in creation of combined filtration plants for further purification of wastewater based on natural secondary raw materials (sand, fallen leaves), which will allow one not only to filter wastewater, but also to remove nitrate anions. Such filtering filtration plants will help to increase the ecological safety of the city by means of replacing dangerous burning of leaves with a safer use of such leaves as a filter material and preventing the plague of fish and green scum of the Dnipro River by reducing concentration of pollutants in wastewater.

Literature review. Until now, scientists have considered creation of new technologies with modern hardware design [4] and sufficient funding. Of course, such methods can simultaneously solve many problems. But everyone comes to the conclusion that modern treatment technologies should be environmentally friendly, with a limited amount of generated solid waste and sediments. Thus, creation and installation of a reverse osmosis system [5] at sewage treatment plants produces a large number of spent membranes that are accumulated for years and are not disposed of. At the same time, establishment of sections for mechanical after-treatment by filtering before the section for biological treatment will contribute to the intensification of work of the latter [6].

When analyzing the possible environmentally safe filtering layers and the possibilities of their further disposal, the main options were determined: river sand, fallen leaves. In addition to physical retention of suspended particles such filter layers can perform additional biological treatment [7]. Dry, fallen leaves in the water environment perform filtration (sedimentation of suspended substances on the leaf surface), absorption (absorption of biogenic elements and some organic substances in leaf stomata (microscopic holes in the leaf epidermis), accumulation (accumulation of certain metal compounds and difficult-to-decompose organic substances) [8].

The works contain a detailed review of jug filters. Special attention is paid to the use of a plastic carrier for sorption materials that does not react with water, designed to separate the adsorbent and prevent its sticking during the process of treatment [9].

There are a number of industrial filters using a plastic mesh for mechanical water purification. Such meshes are easy to manufacture and further process [10].

The use of crushed plastic fraction from food and beverages as a secondary raw material as a rigid frame for filtering layers will give an opportunity to create an effective filtration plant.

Spent filtering layers can be used in the technology of obtaining fertilizers for park areas and green forest plantations [11] or in construction [12].

At the same time, accumulation of fallen leaves in city landfills and their subsequent disposal by burning leads to ecologically dangerous consequences, air pollution, poisoning of the population.

The authors analyzed methods of disposal of fallen leaves. It was determined that during burning of leaves, all pollutants accumulated by plants are released into the atmosphere in the form of combustion products. In order to improve ecological condition of regions, it is proposed to dispose of tree leaves by briquetting them using hydraulic presses [13].

Municipal waste (fallen leaves of Dnipro city) was studied. One of the limiting factors in the use of fallen leaves is their dustiness. The authors suggest washing the leaves thoroughly before using them as a secondary raw material. From an ecological and toxicological point of view, it is recommended to reuse fallen leaves for the economic sector. Fallen leaves in Dnipro city have the 4th class of danger [14].

One of the methods for processing fallen leaves consists in their composting. Fallen leaves can be used to improve soil conditions through bioconversion. The results of the research showed the possibility of using fallen leaves (collected in different areas of the city of Lviv, Ukraine) as a substrate for cultivation of *Eisenia foetida* with addition of zeolite flour as an ion exchanger and an enterosorbent. Such additives have a positive effect on the enzyme activity of the *Oligochaeta* population as decomposers that actively use organic substances for composting and utilization [15].

The possibility of using sorbents based on the composition of paper mill waste and fallen leaves of green areas of the city as sorbents for the elimination of environmental consequences of accidents and technological spills in oil production transport was investigated. Sorbents have been created which are characterized by universality of application and have pronounced absorption properties in relation to the main classes of oil products and carbohydrates that are transported in bulk. Absorption capacity of the studied sorbent after 50 min is 2.0–4.2 g/g, which is competitive in comparison with traditional synthetic sorbents [16]. Therefore, the use of fallen leaves in a filtration plant for wastewater treatment is ecologically justified and is of scientific and practical value.

In addition, the use of modern methods of thermometry [17] to analyze fallen leaves for radiation safety [18] is an important aspect in the process of selecting materials for further processing into secondary raw materials. In up-to-date developed cities development of technogenically dangerous zones is observed. Such zones are in particular polluted with radioactive elements [19]. Thus, in some enterprises there is a release of radioactive substances into the environment, soil, water, and air; and in this way radioactive pollutants reach plants. It is known that 36 years after the Chornobyl accident, the zones of radiation contamination have not been eliminated, but are gradually dispersing; radiation dust is gradually migrating from one area to another [20].

Mathematical modeling of wastewater treatment allows scientists to reduce waste of time and financial resources for conducting hundreds of experiments. First-order partial differential equations are often used to model migration of water pollutants in bioponds. Thus, the authors of this work [21] proposed a mathematical model that takes into account the average rate of pollutant removal and predicts changes in their concentration. The authors also analyzed the possibilities of bioponds to purify water from the COVID-19 virus in the wastewater of several cities. The graphs show a comparison of the average concentration of the virus in the dynamics.

The work [22] investigated the effect of artificially created ponds with a specially selected plant planted on the bottom and used to effectively purify water in the pond. Mathematical modeling was carried out using first-order models, linear regression and mass balance.

The authors of the article [23] paid attention to the study on water treatment facilities in the city of Jaworne (Poland). A number of pollution indicators such as BOD_5, COD_{Cr}, nitrogen and phosphorus concentrations were used as performance indicators. Using the Monte Carlo method, the authors conducted an analysis of pollution indicators. Comparison of the obtained results with experimental data made it possible to assert effectiveness of the specified method for predicting the operation of the facilities.

The article [24] is devoted to a comparative analysis of the latest methods of wastewater treatment from pollutants, including suspended substances and organic pollutants. The cleansing properties of *Moringa oleifera* were studied. Its ability to deactivate bacteria and viruses in water was also revealed. The experimental model consists of three containers: for seed coats, seeds and potter's stones.

Based on the above, the analysis of literary sources showed opportunities for improving and clarifying existing models by means of taking into account arbitrary geometry of ponds and uneven concentration of pollutants in ponds, which can significantly increase accuracy and affect modeling results.

Purpose. To investigate a new eco-safe filtration plant for wastewater treatment based on natural and secondary raw materials in a diverse sequence of loading into the filter, which will allow rational use of natural resources with further mathematical modeling of hydrodynamics of mixing treated wastewater in bioponds to predict removal of residual concentrations from the filter. To investigate the possibility of using crushed polyethylene raw materials, in particular food and beverage bottles, for an additional dense layer of wastewater filtration.

Methodology. In the process of research, a laboratory installation (plant) was created, which included a collection tank, a filter column, and a tank for collecting purified water.

A mixture was used of big-leaf linden (*Tiliaplatyphyllos Scop.*) and poplar (*Populus alba L.*) leaves in a ratio of 1:1, oak (*Quercus*) and maple (*Acer platanoides L.*) in a ratio of 1:1, river sand, crushed plastic with a diameter of 0.5–0.8 cm (Fig. 1).

Sampling of fallen leaves was carried out in the period of October-November. Sampling was made according to DSTU ISO 10381-2:2004, DSTU ISO 10381-2:2004, DSTU 4287-2004. Averaging at the sampling sites was carried out by the method of quartering for a square area of 200 m^2 or more.

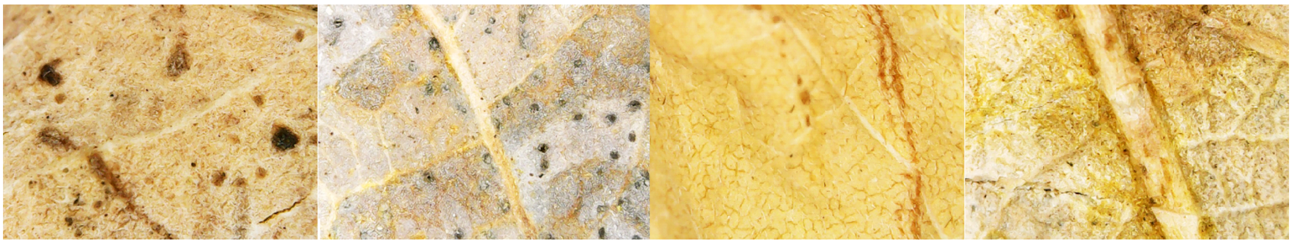
Prior to leaf sampling, a pyrometric analysis of the area where the materials were directly collected was conducted: analysis of fallen leaves and sand.

Application of the thermometric method is based on the idea that during the radioactive decay of elements, thermal energy is released and this should be reflected in a change in the temperature field on the surface of the soil.

A Benetech-GV-533A pyrometer was used for pyrometric (thermometric) shooting.

Characteristics of the Benetech-GV-533A pyrometer are as follows: measurement range is $-50 \div +530$ °C; accuracy is ± 1.5 °C or ± 1.5 % (more than 3 values); response time is 0.5 s.; surface emissivity is 0.1–1.0 (0.95 by default); spectral range is 5–14 μm.

The method of pyrometric (thermometric) research consisted in measuring the temperature with a 2×2 meter observation network. Before measuring, the soil surface was cleared



a b c d

Fig. 1. Photos of samples of fallen leaves:

a – maple (Acer platanoides L.); b – oak (Quercus); c – big-leaf linden (Tiliaplatyphyllos Scop.); d – poplar (Populus alba L)

until black or dark brown soil appeared. The temperature was measured immediately in the amount of three measurements at one point. Average temperature values were recorded. Processing of the research results was carried out by drawing up maps of the soil surface temperature distribution in the Surfer 8.0 software environment. The method of triangulation with linear interpolation based on a square nodal network was used to construct the maps.

The photometric method was used to determine the concentration of nitrates in wastewater. The gravimetric method was used to determine amounts of suspended solids.

Wastewater for research was collected at the Municipal Production Enterprise of the Kamianske City Council "Miskvodokanal" in Kamianske. The initial concentration of suspended substances in wastewater was 140 mg/dm^3, pH was 7.6, nitrate concentration was 12 mg/dm^3, temperature was 15 °C.

Task of the article. Purpose of the article is to research effectiveness of wastewater treatment at an eco-friendly filter plant based on natural and secondary raw materials, followed by forecasting of non-stationary liquid flows and pollutant concentrations in a cascade of purifying reservoirs with a defined topography. The task was set to experimentally investigate effectiveness of using fallen leaves as a filter layer of a wastewater filtration plant in order to protect the environment from pollution by suspended substances and Nitrate anions, with the prediction of what will happen with the help of mathematical modeling of hydrodynamics.

Presentation of the research. According to the results of pyrometric measurements on the territory of selecting fallen leaves, maps of the soil surface temperature distribution were constructed (Fig. 2). The presented area serves as an example of the average values of radiation in the city of Kamianske, which allows collecting ecologically clean material. Temperature fluctuations in the area range from –2.5 to +1.5 °C (Fig. 2).

Anomalies of reduced values and negative temperatures are more pronounced and stretch from east to west.

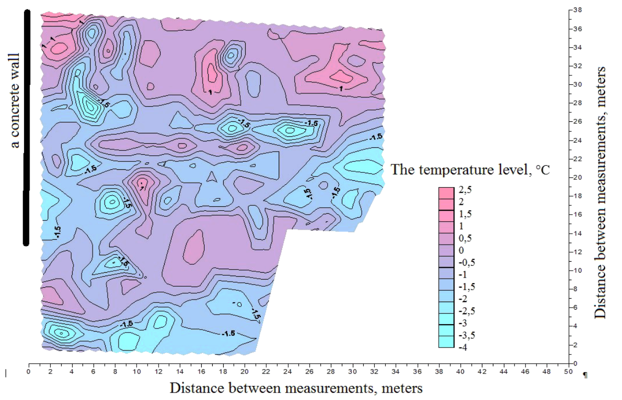


Fig. 2. Maps of the soil surface temperature distribution: the color scale characterizes the temperature level, °C; black line is a concrete wall; the coordinate system is conventional (metric system)

We studied the content of impurities in wastewater after its purification by the filtering method using various variations of alternating filtering layers in the filter depending on time (Fig. 3). In the research process, a mixture of dry fallen linden and poplar leaves was used, because poplar leaves have sorbing properties that help to speed up the filtration process, reduce contents of suspended solids in wastewater, and retain nitrogen compounds.

Fallen leaves of horticultural crops are classified as a sample of waste, which is waste obtained in the process of cleaning streets and other public places. According to the hazard class, fallen leaves are low-hazardous.

At the outlet of the filtration plant, with an initial concentration of 140 mg/dm^3, there is a decrease in concentration of suspended substances on the filter by 1–15, 2–12 and 3–10 mg/dm^3. Therefore, the most comparatively effective filter is the one with the sequential use of fallen linden and poplar leaves, sand and plastic residues.

The content of nitrate anions (when using the proposed filtration plant containing leaves – sand – plastic) decreased from 12 to 0.25–0.05 mg/dm^3.

Kinetics of changes in concentration of nitrate anions depending on time of filtration when using the following loading sequence of filtering layers: a mixture of fallen linden and poplar leaves *2*, oak and maple leaves *1*, sand and plastic residues (Fig. 4).

So, after 1 hour and 15 minutes of filtration, a decrease in contents of nitrate anions from 12 to 0.05 mg/dm^3 is observed when using a filtration plant not only of a mixture of linden and poplar leaves, but also of oak and maple leaves. At the same time, the increased content of tanning substances and the natural structure of oak and poplar leaves contributes to

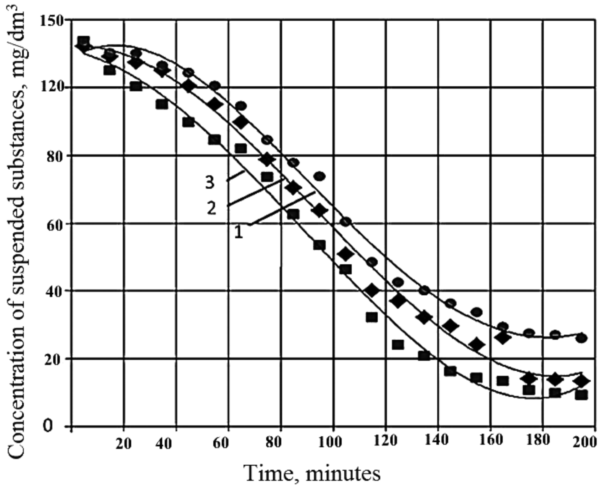


Fig. 3. Kinetics of changes in the concentration of suspended substances in wastewater when using an ecological filtration plant:

1 – plastic – sand – leaves; 2 – sand – plastic – leaves; 3 – leaves – sand – plastic

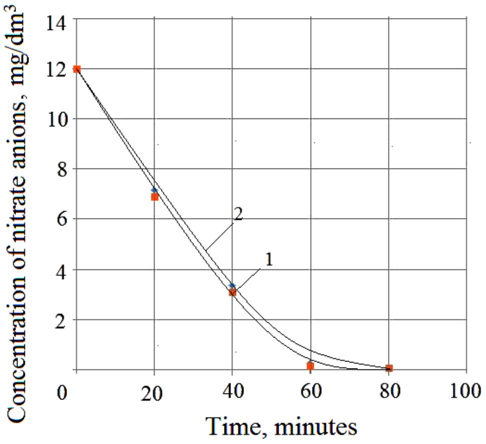


Fig. 4. Kinetics of changes in concentration of nitrate anions depending on time of filtration when using different layers of dry leaves:

1 – oak and maple leaves; 2 – linden and poplar leaves

the resistance of the leaf layer to fermentation processes and helps to use such a filter repeatedly. After 30 times of filtration efficiency of wastewater treatment decreased by 0.5 %.

The mechanism of sorption on the surface of fallen leaves can be explained as follows. Pollutants from wastewater are mechanically fixed in pockets (microcracks, cracks) of fallen leaves, formed during drying of leaves, which is explained by hardening of intercellular spaces with formation of a specific geometry of holes.

Therefore, the obtained data on the efficiency of wastewater treatment using a filter layer made of fallen leaves are consistent with the data obtained by scientists Yu. V. Zelenko and M. L. Soroka on the use of fallen leaves as a sorption material [1, 16].

During the filtration process, it was determined that the obtained filtrates were transparent and partially colored, but after each filtration intensity of the filtrate color decreased. Based on the results of this research, it is recommended to use the proposed filters based on fallen leaves at a filtration temperature of 10–25 °C for 60–90 minutes. If the temperature of wastewater rises above 25 °C, the efficiency of treatment may be suppressed due to partial fermentation of leaves. Due to the technological features of treatment facilities, wastewater moves through pipelines located underground, thus the temperature of wastewater is maintained above 10 °C.

Taking into account the fact that during the cleaning process, a certain removal of suspended substances to further treatment facilities is possible, mathematical modeling of wastewater flows with the remains of suspended substances in biological ponds was carried out.

The mathematical model is based on the assumption of an unchanged geometry of the ponds. The geometry is arbitrarily set at the beginning of the experiment. Also, the influence of the pollutant on the movement of the liquid can be neglected. Flows are assumed to be inviscid.

The geometry of two connected biological ponds of urban sewage treatment facilities was chosen for modeling. The considered ponds are located on the territory 2,244 m long and 1,630 m wide. Less than half of this area is actually occupied by ponds. The first pond has an almost elliptical shape. Clarified water goes from it to the biopond through a long thin channel. The biopond has a more complex geometry to slow down the flow and allow the nature to remove residual pollutants. Water crosses the biological pond and passes through a short channel connected to a third long reservoir flowing to the river. The difference in the height of the ponds is about one meter. Depth of the ponds varies from three meters (in the center of the pond) to zero near the shoreline. The first pond is deeper than the biopond.

Hydrodynamics in ponds can be predicted using the following physical laws:

1. Conservation of mass of liquid and pollutant.
2. Conservation of liquid momentum.

The specified laws are expressed mathematically by the following equations

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{v}) = 0;$$

$$\frac{\partial c}{\partial t} + \nabla (c\vec{v}) = D_c \nabla^2 c - kc;$$

$$\frac{\partial \vec{v}}{\partial t} + \vec{v} \cdot \nabla \vec{v} = \frac{1}{\rho} \nabla \cdot (\tau - pI),$$

where ρ is liquid density; k is the sedimentation coefficient of pollutants, which mostly occurs during slow movement of liquid through the first pond; τ – deviatoric stress; p – pressure; I is the identity matrix.

Boundary conditions at the inlet to the first pond represent the place where the substance enters it with a given velocity and concentration (the values may change depending on the time of day). At the outlet from the third pond, water with the remains of the pollutant enters the river – the boundary conditions correspond to a zero concentration gradient and velocity. In the SPH method discussed below, this boundary condition is easily satisfied by particles freely leaving the computational domain.

The boundary conditions are represented by the entrance to the first pond and the outlet from the third pond (which is connected to the river). The first pond is a source of pollutants and momentum, while the second pond has free permeability conditions.

To calculate the model, a popular computational method is used – Smoothed Particle Hydrodynamics (SPH) [24]. One of the advantages of SPH is conservation of mass, and in our case, it is contaminant conservation. In addition, SPH has adjustable calculation accuracy in regions that require this.

According to the method, the liquid is represented by material particles with their masses, $\vec{r}$ positions velocities and other quantities. To determine the value of a certain quantity at a point, the expression [25] is used

$$f(\vec{r}) = \sum_{i=1}^{N} \frac{m_i}{\rho_i} f(\vec{r}_i) W(\vec{r} - \vec{r}_i, h),$$

where m_i, ρ_i and $f(\vec{r}_i)$ are mass, density and concentration of pollutant i^{th} particle, W is the core of smoothing. As you can see, there is smoothing between neighboring particles. The more particles are involved in the simulation, the better the solution is, especially in regions with complex geometry and flow.

Particles move and interact with each other using a core of smoothing with an appropriate smoothing length h. For this study, we avoid using the Gaussian core and choose a more suitable piecewise Wendland core [26]

$$W(d,h) = \alpha_d \begin{cases} \left(1 + 2\frac{d}{h}\right)\left(2 - \frac{d}{h}\right)^4 & 0 \le \frac{d}{h} \le 2 \\ 0 & 2 < \frac{d}{h} \end{cases},$$

where α_d is a constant dependent on h^3; $d = |\vec{r} - \vec{r}'|$ is a distance between particles; h is the smoothing length.

Boundary conditions on solid surfaces are set using the Monaghan and Kaitar method with stationary particles placed on these surfaces. Particles cause other particles to move in the opposite prop from any solid surface.

Numerical integration of particle acceleration and velocity can be performed by the well-known leapfrog method. However, this work uses a modification presented in another author's thesis (Cossins, P. J., University of Leicester, 2010) in order to avoid the implicit calculation scheme. The time axis is divided into n layers, and the position of the particle on the next layer is calculated using the following steps [26]

$$\vec{r}^{\,n+1/2} = \vec{r}^{\,n} + \frac{\delta t}{2}\vec{v}^{\,n};$$

$$\vec{v}^{\,n+1} = \vec{v}^{\,n} + \delta t \vec{a}^{\,n+1/2};$$

$$\vec{r}^{\,n+1} = \vec{r}^{\,n} + \frac{\delta t}{2}(\vec{v}^{\,n} + \vec{v}^{\,n+1}),$$

where δt is the time step that divides the time axis into intervals; $\vec{a}$ is particle acceleration. This scheme takes slightly longer to compute but is more accurate than the semi-implicit Euler scheme.

The developed computer program visualizes water bodies in the form of a background image and calculates the velocities on the grid by averaging the particle velocities in each grid cell. The arrow consists of two connected white lines and is rotated using a transformation matrix to show the local velocity direction

$$\begin{bmatrix} \vec{v}^{\,x}/|\vec{v}| & -\vec{v}^{\,y}/|\vec{v}| \\ \vec{v}^{\,y}/|\vec{v}| & \vec{v}^{\,x}/|\vec{v}| \end{bmatrix},$$

where $|\vec{v}|$ is the value of velocity which affects the length of the arrow.

The concentration of the pollutant is visualized against the background of the arrows using shades of blue color (Fig. 5). The higher the concentration, the lighter the color is. Thus, the highest concentration is predicted to be in the first pond, and it gradually decreases on the way to the second pond.

In the first pond, two vortices are formed: a small one – near the inflow of waste water, and a large one – rotating almost in the center of the pond.

Due to the complex geometry of the second pond (biopond), most of the water and pollutants are first captured by the vortex and retained in the biopond, increasing the time for natural treatment and restoring the balance of substances.

A narrow channel connecting the second pond and the third pond reduces the speed and gives an opportunity to regulate the volume of purified water released into the third pond and into the river. The presented mathematical model predicts the movement of liquid in ponds with complex geometry (Fig. 5).

Conclusions. For the first time, influence of the species origin of fallen leaves on the performance indicators of wastewater filtration plant of urban sewage treatment constructions was investigated, which made it possible to substantiate a new way of disposal of this type of waste.

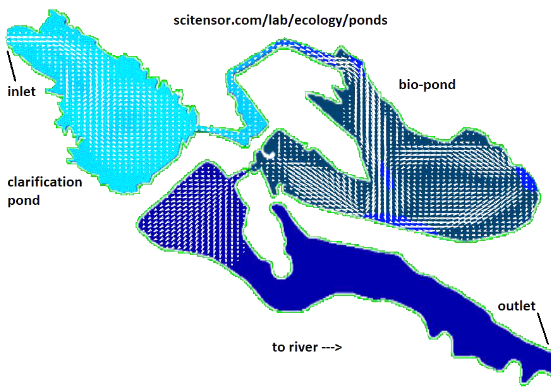


Fig. 5. Geometry of the considered ponds is obtained from a topographic map: arrows indicate direction and magnitude of the calculated velocity field after 100,000 seconds of the model time; the maximum concentration of the pollutant is marked in light blue (clarified pond), while the dark regions have very little concentration

Research on dependence of efficiency indicators of wastewater treatment on suspended substances and Nitrate anions and on factors of species origin and time of contact with sorbate received further development, which made it possible to substantiate the possibility of using fallen leaves and a filter layer based on them for additional treatment of urban wastewater. Proposed is an alternative filter layer for the filtration plant of the wastewater treatment process from suspended substances and nitrate anions based on fallen leaves. For the first time, an eco-safe filtration plant was created based on natural and secondary raw materials including fallen leaves of linden, poplar, oak and maple, sand and crushed plastic of polyethylene bottles, waste from the use of packaged food and beverages, which allows reducing contents of suspended substances in wastewater by 1.5 times the maximum permissible concentration and reduces concentration of nitrates from 12 to 0.25–0.05 mg/dm^3.

Forecasting of non-stationary liquid flows and pollutant concentration in a cascade of purification reservoirs with a defined topography was performed. The model makes it possible to estimate concentration of the pollutant at its outlet from the last pond into the river, depending on its quantity at the point of discharge into the first pond. Sufficient adequacy (within 18 %) of the mathematical model of the dynamics of pollution concentration in ponds is verified by comparing the modeling results with the values obtained during measurements directly in the ponds and at the outlet to the river. Data from the analyzed literary sources are also compared. Based on the obtained forecast, optimization of the process of cascade wastewater treatment of enterprises is planned.

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Дослідження екобезпечної фільтрувальної установки очищення стічних вод із природної сировини

*О. Р. Бєлянська**, *К. С. Красніков, В. Г. Наконечний*
Дніпровський державний технічний університет, м. Кам'янське, Україна
* Автор-кореспондент e-mail: belyans@ukr.net

Мета. Створити нову екобезпечну фільтрувальну установку очищення стічних вод на основі природної та вторинної сировини, що дозволить раціонально використовувати природні ресурси, із наступним математичним моделюванням гідродинаміки змішування доочищених стічних вод у біоставках для прогнозування виносу залишкових концентрацій з фільтру.

Методика. Для вирішення поставлених завдань використовували комплекс сучасних методів теоретичних та експериментальних досліджень. Концентрацію забруднювачів визначали за допомогою атомно-адсорбційної спектроскопії, титриметрії та гравіметричного методу, пірометричного аналізу. Створена лабораторна установка, що містить приймальну ємність, колонку фільтрувальну, ємність для збору очищеної стічної води. Прогнозування розподілу та змішування очищеного стоку в біоставках проводили із застосуванням математичного та програмного апарату ПК.

Результати. Створена екобезпечна фільтрувальна установка, що містить у своєму складі пісок, опале листя липи, тополі, пластикові залишки, що розмежовані полімерною сіткою, для очищення стічної води від зважених речовин і нітратів. Досліджена кінетика зміни концентрації зважених речовин і нітратів у міській стічній воді. Концентрація зважених речовин зменшилася на 85–92 % при використанні фільтрувальної установки. Концентрація нітратів в очищеній воді на такій установці зменшується з 12 до 0,25–0,05 мг/дм^3. Отримана математична модель розподілу очищеної води по біоставку, що дозволяє спрогнозувати можливі міграційні напрямки розповсюдження залишкових концентрацій в очищеній воді при її природному русі за течією.

Наукова новизна. Уперше досліджено вплив видового походження опалого листя на експлуатаційні показники фільтрувальної установки стічної води міських очисних споруд, що дало можливість обґрунтувати новий шлях утилізації цього виду відходів. Уперше встановлено, що очищення стічних вод при використанні екобезпечної фільтрувальної установки на основі природної та вторинної сировини, яка містить шари піску, опалого листя липи й тополі, дозволяє знизити вміст завислих речовин у стічних водах у 1,5 рази від гранично допустимої концентрації, у 4 рази зменшує концентрацію нітратів від початкової. Забрудники зі стічних вод механічно закріплюються в кишеньках (мікрощілинах, тріщинах) опалого листя, які утворилися при висушуванні листя, що пояснюється затвердінням міжклітинників з утворенням специфічної геометрії отворів. Уперше виконане математичне моделювання руху доочищеної стічної води, яка пройшла очищення, у біологічному ставку зі складною геометрією, що дозволяє оцінити концентрацію забруднюючої речовини на виході її з останнього ставку.

Практична значимість. Створена екобезпечна установка фільтрування стічної води дозволяє виконувати не тільки фільтрування, але й ефективне біологічне очищення від нітратів стічної води на поверхні шарів опалого листя. Широке використання запропонованої установки дозволить залучити в якості вторинної сировини використаний у побуті пластик поліетиленових пляшок. На основі запропонованої математичної моделі руху очищеної рідини, що містить залишкові концентрації забрудників, можливо здійснювати якісне прогнозування та оптимізацію процесу каскадного очищення стічної води промислових і господарчих підприємств.

Ключові слова: *стічна вода, опале листя, пірометричний аналіз, фільтрування, біологічні каскадні ставки*

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