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NATURAL AND SYNTHETIC SOLID CARRIERS IN FLOW MODULE FOR MICROBIAL SEWAGE FILTRATE PURIFICATION

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The aim of the research was to develop theoretic principles of an efficient biotechnology for microbial purification of concentrated sewage filtrate from a wide range of organic and non-organic compounds, and experimentally confirm these principles. The experiment combined conventional microbiological, physical and chemical methods in which ten different types of solid carriers, both natural and artificial, were used. A comparative analysis of these types of solid carriers used in the flow system and a structured evaluation of treatment parameters was provided. The obtaining results demonstrated the effectiveness of the use of method sewage microbial purification in a flow system. Developed principles can be used as a basis for new efficient biotechnologies for sewage microbial purification.

Key words: microbial purification, toxic filtrate, sewage, inert carriers.

One of the most significant unresolved issues in the world is the neutralisation of one of the most dangerous anthropogenic waste — mixed food waste of metropolises. Not less relevant is the neutralisation of toxic sewage filtrate from mixed food waste fermentation.

Sewage filtrate from food waste fermentation (hereinafter — ‘filtrate’) is a concentrate of a wide range of organic compounds which inhibit the activity of both anaerobic and aerobic microorganisms. It contains volatile fatty acids (acetate, propionate, butyrate, etc.), alcohols (methanol, ethanol, propanol, etc.), aldehydes, ketones as well as sulphur-containing and toxic chemicals such as hydrogen sulphide, mercaptans and their derivatives [1]. As a consequence, the filtrate is generally more toxic than domestic sewage. It is also more difficult to treat due to its containing a wide range of toxic compounds in a very high concentration with the atomic carbon content in the range of 10.000–50.000 mg/l [2]. This high concentration of organic matter excludes the possibility of purification with conventional aerobic structures (aerotanks and their analogues) which is apparent from the stoichiometric imbalance of electron donors (organic matter) and their acceptors (O_2). Indeed, the O_2 content in the air is only 21% and its filtrate diffusion speed is several times less than its consumption by microorganisms.

Consider the general scheme of the organic matter oxidation using an example of glucose as it is the major compound of polymers which is present in food fermentation sewage filtrate (starch and cellulose). The general scheme of full oxidation of glucose is as follows:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O.$$

As we can see from the equation, full oxidation of 180g of glucose requires 192g of oxygen (i.e., 32g × 6). The above mentioned carbon content in the filtrate of 10.000 to 50.000 mg/l corresponds to glucose content of 22.857 to 114.280 °C is 8.9 mg/l (according to Henry’s Law). Consequently, the quantity of dissolved oxygen may not be sufficient for chemical decomposition of there present toxic organic compounds, for which more complicated mechanisms, such as bacteria metabolic cycles, are necessary.

At present, microbiological methods are the most effective and safe for sewage filtrate treatment [3–9]. Microorganisms are natural biocatalysts capable of auto selection and adaptation to treatment of sewage of any organic contaminants content. Effective biotechnologies are being developed now for landfill leachate treatment using microorganisms that also prove to be resistant to heavy metal ions [10]. Furthermore, microbiological treatment methods compared to others are significantly more efficient [3, 4, 8].

Microbiological destruction of a wide range of polycarbonic organic compounds occurs due to the forming of a microbial succession. The succession lies in that the end products (exometabolites) of 'primary' microorganism-destructors are the primary substrates for 'secondary' microorganisms-destructors. The classical succession model was developed by G.O. Zavarzin for methanogenic microbial communities [11]. According to this model, at the first stage, aerobic, facultative anaerobic and 'primary' anaerobic hydrolytic microorganisms (e.g., *Clostridium*) decompose complex polymeric compounds (proteins, cellulose, etc.) to alcohols and fatty acids. At the second stage, 'secondary' anaerobes decompose alcohols and acids to CH_4, CO_2 and H_2O. It must be emphasized that this type of succession occurs consequently, each stage one at a time. Certain quantity of organic matter is input into a treatment plant or cultivator whence microorganisms successively decompose it into its end products. Au contraire, in flow systems organic compounds are input continuously.

According to our concept, in flow systems, microorganisms which perform a successive destruction of organic matter may be placed along the sectioned flow module (SFM). In this case, the alteration of physiological groups in a microbial community is being performed not in time but in space. Therefore, by our definition, this type of succession is 'spatial'.

The proposed concept of spatial succession for treatment of the filtrate containing a wide range of organic matter in high concentration is set as follows:

1. In a flow system, the microbial succession is defined not in time but in space.
2. At ultrahigh concentrations of organic matter (10.000–50.000 mg/l[1]) its destruction is commenced by anaerobic microorganisms.
3. At anaerobic conditions, organic matter concentration is reduced by 10–100 times.
4. Following the deconcentration of the organic matter, there appear conditions for the development of aerobic and facultative anaerobic copeocarbotrophic[2] microorganisms. Henceforth, the treatment is completed in an aerobic flow system.
5. Successively in the flow system, copeocarbotrophes are followed by meso-carbotrophes[3] and then by oligocarbotrophes[4].
6. For the spatial succession providing sewage purification from organic matter to occur, the use of inert carriers is necessary to immobilise the above microbial groups (copeocarbotrophes etc.)
7. Following the decrease of dissolved organic matter content to trace concentrations (1–2 mg/l) occurs a succession from microorganisms to lower invertebrates (infusoria etc.)
8. Invertebrate organisms remove the excess microbial biomass by consuming it. Due to this, the spatial succession in a flow system not only purifies the filtrate from a wide range of concentrated organic matter, but also from excess microbial biomass.

The purpose of our study was to develop theoretic principles of an effective and efficient biotechnology for concentrated sewage filtrate treatment from a wide range of organic and non-organic matter.

Materials and Methods

We made a section flow module (SFM) in a shape of a long box (10×10×100 cm) from transparent plastic 4mm width (Fig. 1, *1*). We then divided the SFM into ten sections by partitions with evenly spaced apertures (D = 5 mm) (Fig. 1, *2*). The volume of each section was 1.000cm^3. Each section's aeration was provided by means of air flow from a compressor pump (Fig. 1, *3*) through a sprayer. The excess air from every section was removed through a gas outflow pipe with a cotton filter. The flow of liquids was supported by a cultural liquid filtrate inflow from an additional Module 1 (Fig. 1, *5*) and its outflow to an additional Module 2 (Fig. 1, *6*). We set the average velocity of the flow at 200 ml/hour.

[1]Hereinafter concentrations are provided of atomic carbon, unless specified otherwise

[2]Copeocarbotrophic microorganisms — microorganisms with high optimal level of carbon in the medium (more than 10 mg/l)

[3]Mesocarbotrophes — microorganisms with medium optimal level of carbon in the medium (around 5 mg/l)

[4]Oligocarbotrophes — microorganisms with low optimal level of carbon in the medium (1 mg/l or less)

We filled each section of the SFM with an inert carrier (Fig. 1, *4*), thus immobilising the microorganisms and forming the biofilm. We did not sterilise the carriers to preserve their indigenous microflora and protozoa alive.

The following inert carriers were used:

1. *Basalt wool*. Synthetic mineral carrier. Is not a microbial growth substrate. Has a very ramified structure, which means a wide accretion surface. Does not absorb microbial biomass and does not obstruct the flow. Is suitable for multiple use after rinsing and calcination.

2. *Basalt thread*. Unlike basalt wool it has less ramified structure (thread-like) and accordingly a smaller accretion surface. May be regenerated in the same manner as basalt wool.

3. *Polyethylene packaging net (string bag)*. Synthetic organic carrier. Is not a microbial growth substrate. Net cell size — 0.7cm^2, thread width — 1–1.2mm. Easily rinsed. Does not tend to stick even with microbial biomass on it.

4. *Capron thread (D 0.5–0.6mm)*. Synthetic organic carrier. Is not a microbial growth substrate. Is widely used as a carrier in sewage treatment biotechnologies all over the world. Easily rinsed. Has a firm linear structure which prevents sticking.

5. *Polyethylene foam*. Synthetic organic carrier. On accretion, a thick biofilm is formed.

6. *Hay*. Natural organic carrier. To some extent may be used by microorganisms as a nutrient substrate. Has its own microflora and is a habitat for many protozoa (euglenas, infusoria, amoebas) and small invertebrates (nematodes, etc.).

7. *Straw*. Natural organic carrier. To some extent may be used by microorganisms as a nutrient substrate. Has a larger accretion surface compared to hay due to its pipe-like structure. The inner surface of stems can carry facultative and obligate anaerobes.

8. *Dry stems of marygolds (Tagetes genus)*. Natural organic carrier. To some extent may be used by microorganisms as a nutrient substrate. Has its own microflora and protozoa which is different from that of other natural carriers.

9. *Dried mixed weed stems*. Natural organic carrier. To some extent may be used by microorganisms as a nutrient substrate. Has different from other natural carriers microflora and protozoa.

10. *Wood shavings*. Natural organic carrier. Resistant to microbial decomposition. Easily rinsed. Has a rigid structure which prevents sticking. The accretion surface is smaller compared to all above carriers.

We measured the RedOx potential (Eh) and pH of the filtrate by pH-meter-millivoltmeter 'pH-150 MA' using three electrodes. For Eh measurement we used a platinum electrode 'EPV-1' ('ЭПВ-1'), for pH measurement — a glass electrode 'ESK4/10603-' ('ЭСК-10603/4') and a chlorine-silver flowing comparison electrode 'EVL-1M3' ('ЭВЛ-1M3'). We used standard buffer solutions to verify pH and Eh measurements, in particular for pH measurement verification we used solutions of KH_2PO_4 (pH=1.68), NaH_2PO_4 (pH = 6.86) and $Na_2B_4O_7 \cdot 10H_2O$ (pH = 9.18) prepared in accordance with the manufacturer's instructions (OJSC 'Kyiv plant RIAP'); and for the Eh measurement

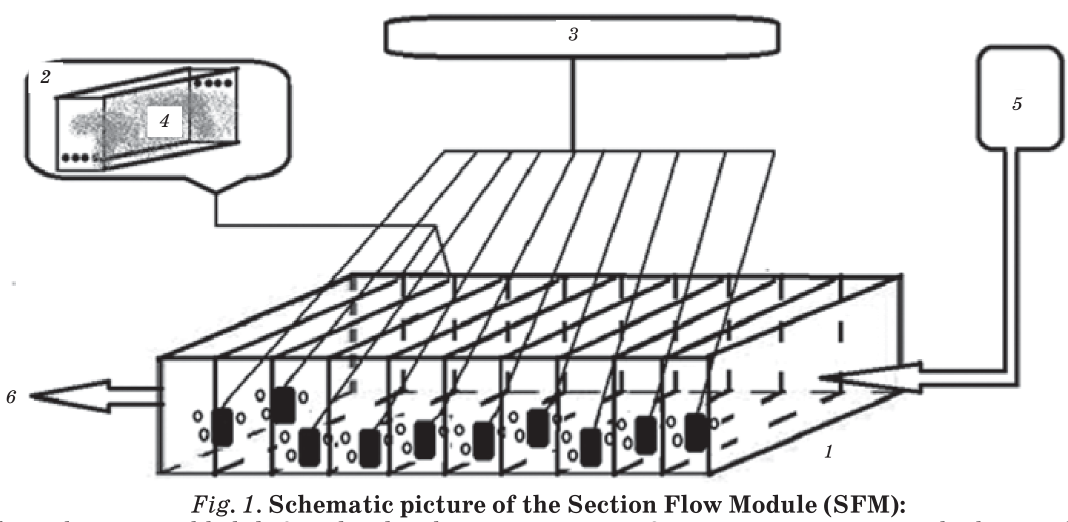

Fig. 1. **Schematic picture of the Section Flow Module (SFM):**
1 — body with a removable lid; *2* — dividers between sections; *3* — compressor pump, which provides the aeration; *4* — inert carriers; *5* — additional Module 1; *6* — additional Module 2 (treated water)

verification we used the following three buffer solutions: ferrycyanidic with Eh = +273 mV (13.5 g/l of $K_3[Fe(CN)_6]$ and 3.8 g/l of $K_4[Fe(CN)_6]\times 3H_2O$), Iron (II) citrate (10 g Fe(II/l) with Eh = −150 mV [12] and 1.5% Titanium (III) citrate with Eh = −440 mV [13]. The measurement accuracy for pH was ±0.1 units and for Eh it was ±10mV.

The concentration of dissolved carbon in the filtrate was measured with the permanganate method [14].

The optical density was measured photometrically with the photocolourimeter 'KFK-2MP' ('КФК-2МП') at a wavelength λ = 540 nm, optical step 3 mm. Boiled filtered tap water was used as a control solution.

The microscopy of the carriers and the liquid was performed with the optical microscope 'Lomo Mikmed-2' ('Ломо Микмед-2') using the 'squashed drop' method at multiplication ×1500.

For observation of invertebrates the 'hanging drop' method was used at multiplication ×150.

The quantitative assessment of alive microorganisms was performed after cultivation on Petri dish on glucose-potato agar for 14 days at 27 °C.

Results and Discussion

Sewage filtrate treatment effectiveness criteria

We determined that the representative indicators of spatial succession for the treatment of filtrate along the SFM are the following:

- RedOx potential (Eh, mV) and pH
- Concentration of dissolved organic matter (by atomic carbon concentration)
- Total microorganisms count (by optical density)
- Copeocarbotrophic and oligocarbotrophic microorganisms count (CFC concentration and the number of morphotypes) and the level of settlement on inert carriers.

Negative values of RedOx potential mean the domination of anaerobic processes of dissolved organic matter destruction. Indeed, at high concentrations of organic matter and under deficit of oxygen, microorganisms reduce the RedOx potential to negative values. On the other hand, the reduction of organic matter concentration implies high (positive) RedOx potential of the medium as a result of the domination of a high-potential terminal electron acceptor, O_2 (E_0'). Therefore, an increased reading of RedOx potential means a reduction of the organic compounds' concentration in the solution, which is a measurement of effectiveness of the treatment.

Mixed food waste fermentation filtrate contains proteins and amino acids in high concentrations. Expectedly, after their decomposition due to de-amining of NH_2-group, the alkaline compounds such as NH_3 and NH_4^+ will form. Thus, an increased reading of pH of the medium is an indicator of destruction of the dissolved organic matter.

Furthermore, it is obvious that a decrease in the quantity of copeocarbotrophic and an increase in the quantity of oligocarbotrophic microorganisms indicates effective purification of the filtrate, as well as a decrease in the total count of microorganisms in it.

Henceforth, we controlled the effectiveness of sewage treatment on the basis of these indicators: Eh, pH, atomic carbon concentration, the total count of microorganisms and, specifically, the count of copeotrophic and oligotrophic microorganisms.

Comparison of effectiveness of inert carriers

All used carriers have the following common features: large surface area, multiple use capacity after rinsing, accessibility. However, the use of these materials as inert carriers in flow systems has not yet been sufficiently studied. To find an optimal carrier type, screening, i.e., experimental verification of its effectiveness in the SFM, is necessary.

All the carriers turned out to be suitable for microbial growth (for typical examples refer to Fig. 3). Whilst at the beginning of the experiment the microorganisms were evenly spread across the filtrate, after 14 days they were concentrated around surfaces of the carriers. First indicators of microbial biofilm forming were observed on the 14^{th} day of the experiment. The accretion was clearly visible in the microscope and appeared like an accumulation of microbial cells on the surface of the carrier. On the 21^{st} day of the experiment, microbial biomass conglomerations were clearly visible with a naked eye on all the carriers having an appearance of fluffy grey sediment. In the first four sections, due to high concentration of organic matter, microorganisms were actively accumulating not only on the carriers' surfaces but as well in the filtrate itself. This manifested itself by an increased turbidity of the filtrate subsequently clearing up in the next sections where the concentration of organic matter and microorganisms was lower (Fig. 2).

Natural organic carriers (hay, straw, wood shavings, etc.) contained their own indigenous bacteria, microscopic algae, protozoa, invertebrates. On the 28–30th day these organisms gradually colonised sections with synthetic carriers as well.

It must be mentioned that invertebrates from natural carriers were playing a very important role in the final sewage purification from bacterial biomass. They were accumulating around bacterial biofilm on inert carriers and, effectively, eating bacteria. Furthermore, the active development of the invertebrates indicated a significant decrease or possibly an elimination of the sewage toxicity.

We earlier demonstrated that a natural community of soil spore-forming microorganisms of genera *Bacillus* and *Clostridium* provides an effective destruction of environmentally dangerous mixed food waste (on an example of rotten potatoes) with a simultaneous synthesis of clear energy source (H_2) and extraction of toxic metals or their compounds (Hg^{2+}, Cu^{2+}, Co^{2+}, Ni^{2+}, Fe^{3+}, CrO_4^{2-}) from a solution [15].

Therefore, for the development of an effective biotechnology of mixed food waste filtrate neutralisation we used a two-staged anaerobic-aerobic purification method. We demonstrated that at the first stage in the SFM the anaerobic microorganisms' community decreased the concentration of organic compounds from 10 to 1 mg/l. However, the non-zero values of the end concentration

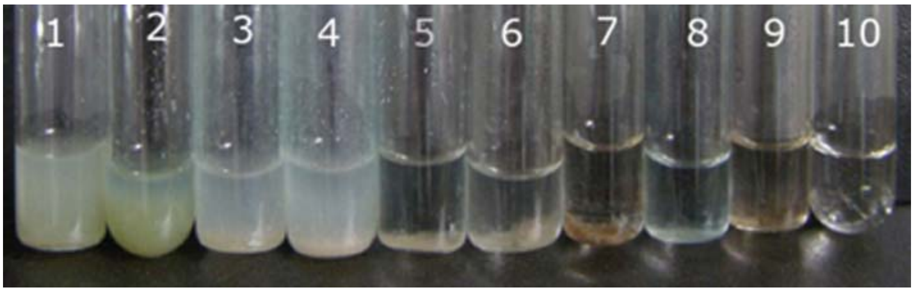

Fig. 2. **Gradual clearing of sewage from first to last sections of the SFM.** Numbers represent the number of module sections in the flow direction

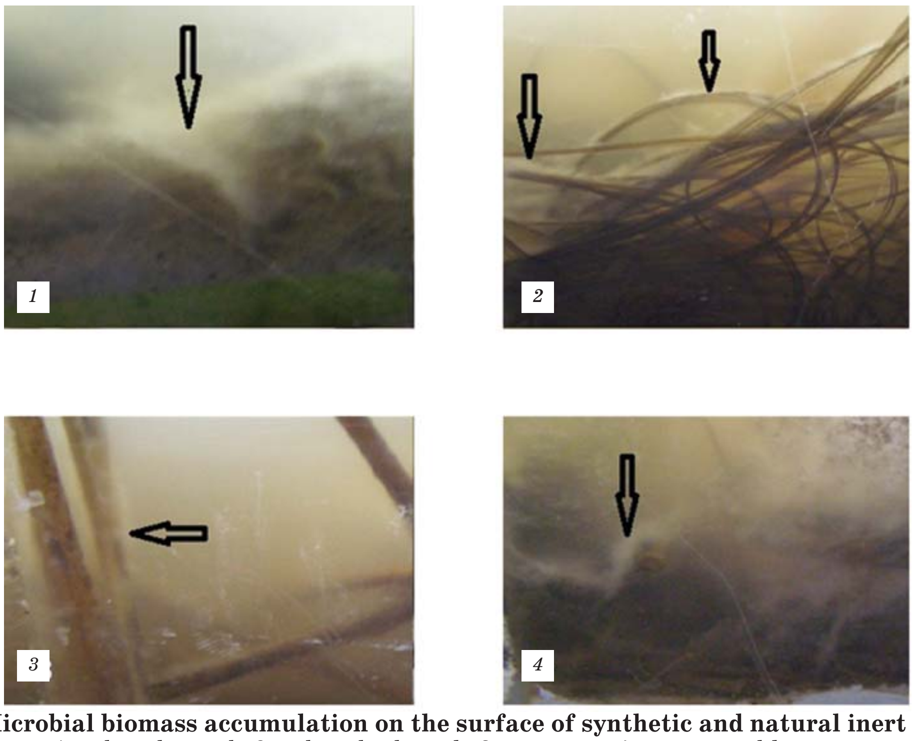

Fig. 3. **Microbial biomass accumulation on the surface of synthetic and natural inert carriers:** *1* — basalt wool, *2* — basalt thread, *3* — straw, *4* — marygolds stems

indicated that the capabilities of the anaerobic treatment method were exhausted. This could possibly be due to the inhibiting effect on anaerobic microorganisms of their end exometabolites. Therefore, we further used the method of aerobic aftertreatment for reducing the organic compounds to disappearingly small trace concentrations. Indeed, organic acids and alcohols, that are the end metabolites for anaerobes are also quite suitable carbon and energy sources for aerobic microorganisms.

To reach the maximum effect of purification we considered the principles of 'mixed' organic matter destruction by microbial communities.

The results of the experiment confirmed the suggested concept of the microbial spatial succession in a flow system (SFM) (Fig. 4).

According to the listed theoretical principles, along the flow system we observed the variability in the values of pH, Eh and organic compounds concentration as well as microbial succession from copeocarbotrophes to oligocarbotrophes.

pH dynamics. pH parameter was increasing gradually from 7.9 in the first section to 9.0 in the last one. It is known that the filtrate of mixed food waste contains a considerable amount of proteins (meat waste). During protein decomposition, the ammonification process is taking place, i.e. the splitting of amino groups and their accumulation in the medium as NH_4^+ or NH_3. These compounds alkalise the medium. This explains the increase of pH from 7.9 to 9.0. Therefore, sewage alkalisation along the module is an indicator of organic matter concentration reduction and the effectiveness of the treatment.

RedOx potential (Eh) dynamics

During the treatment, we observed an increase of RedOx potential from −350 mV to +423 mV (Fig. 4). According to classic principles described by Jacob [16] in 1970, negative Eh values are registered during microorganisms' growth under anaerobic conditions or under oxygen deficiency in the medium. Forced aeration was performed in all sections of the SFM, but nevertheless the Eh values in first two sections were very low: −350 mV and −210 mV. This is explained by the considerate prevailing of organic matter concentration over dissolved O_2. Therefore, under the conditions of the terminal electron acceptor (O_2) deficiency, microorganisms were consuming organic compounds under anaerobic conditions. Increasing of RedOx value by 140 mV corresponds to a decrease in organic matter concentration in the filtrate from 10.0 mg/l to 8.0 mg/l. The same regularities were true for whole length of the SFM. The decrease in the organic compounds' concentration in the filtrate was going along with the increase in its RedOx potential. Indeed, along the SFM (from the third to the tenth section) the Eh was rising from +85 mV to +423 mV along with the decrease in the organic matter concentration from 5.5 mg/l to 1.0 mg/l. This implies that microorganisms were destructing organic compounds thus decreasing their concentration along the module. This, in turn, led to a decrease in oxygen deficiency and to a gradual shift of the microbial metabolism from anaerobic to aerobic. Thus, RedOx potential is a technological indicator of treatment effectiveness: the increase of values from

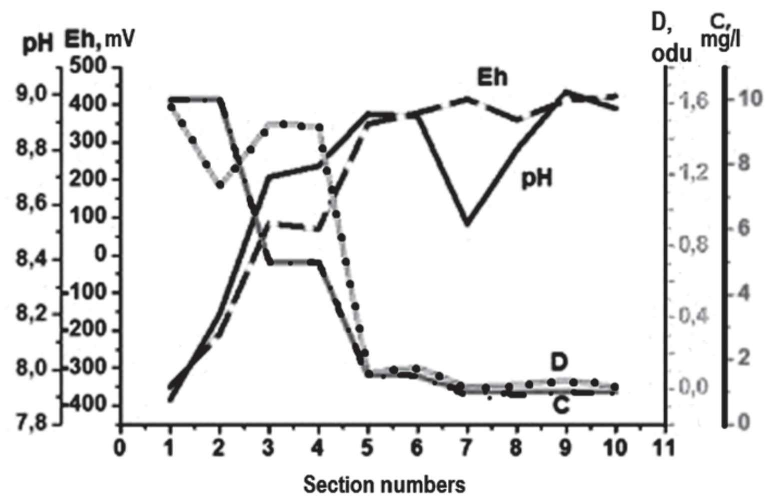

Fig. 4. **Dynamics of Eh and pH values in correlation with alive microorganisms count (D in optical density units) and organic matter concentration reduction (C in milligrams of carbon per litre) at the full SFM length after 21 days of the commencement of the flow**

negative to positive values confirmed the decrease of organic matter concentration in the filtrate. Also, based on a sharp increase of Eh in 4^{th} and 5^{th} sections (+50 mV and +300 mV, respectively) we concluded that in the middle of the SFM the filtrate was almost clean.

Decrease in the concentration of dissolved organic compounds. The effectiveness of the use of the spatial succession of microorganisms for sewage treatment is evidenced by a decrease of the organic matter content in the module — from 10.0 mg/l to 1.0–1.5 mg/l. Obviously, along the module the anaerobic metabolic type was replaced by the aerobic. The decrease of organic matter concentration in the filtrate strongly correlated with the decrease in its optical density (Fig. 4). The latter means a decrease in the microorganisms count in the filtrate, which was confirmed by the microscopy and quantitative assessment of microorganisms on the agar medium. Indeed, the value of colony forming units (CFU) per ml in the first section was in the range of 1×10^6 while in the tenth section it was 1×10^3 units. Consequently, along the module there was a correlation between organic compounds concentration in the filtrate and the quantity on microorganisms: a decrease in the former leads to a decrease in the latter.

Based on the collected data, the use of the microbial spatial succession in a section flow module with natural organic carriers provides fast and effective filtrate purification from dissolved organic compounds and excess microflora. The proposed indicators such as RedOx potential and pH of the medium help to evaluate the effectiveness of the toxic filtrate purification. E.g., in the 4^{th} and 5^{th} sections, simultaneously with an increase in Eh and pH the organic matter and microorganisms content is decreased.

Invertebrates (Fig. 5), present on natural carriers, being very sensitive to soluble organic toxins and heavy metals as well as abrupt changes in pH and Eh values, indicate the non-toxicity of the environment. As we demonstrated, they performed the final purification of the filtrate from the excess biomass. This was an unexpected additional purification mechanism that we identified after using natural carriers for microorganisms attaching.

As the result of a balanced functioning of microorganisms and invertebrates on the outflow from the last (tenth) section of aerobic module we obtained water with properties maximally close to the ones in natural water systems (Eh = +423 mV, pH = 8.95, dissolved carbon concentration — less than 1.5 mg/l). It is obvious that this system provides high level of filtrate purification from dissolved carbon and excess quantity of microorganisms.

As can be seen from these indicators a spatial succession is observed in the module: aerobic microorganisms are replacing anaerobic; oligotrophic microorganisms are replacing copeotrophic.

We also identified the advantages of natural carriers usage over synthetic. Natural organic carriers provide effective attachment of microflora to their surfaces without excess accretion and forming of stagnation accumulations. They also are a source of eukaryotic organisms that regulate microorganism quantity in the environment.

As the final stage of treatment and the illustration of environmental safety of the treated water on the outflow we used a model of a fresh water ecosystem — a pond. The model represented an aquarium filled with soil, most typical representatives of plants (duckweed, ceratophyllum), animals (pond snails, dragonflies, small fish) and water with phyto- and zooplankton (daphnia, cyclops).

For the duration of two years, this ecosystem was supplied by the treated water

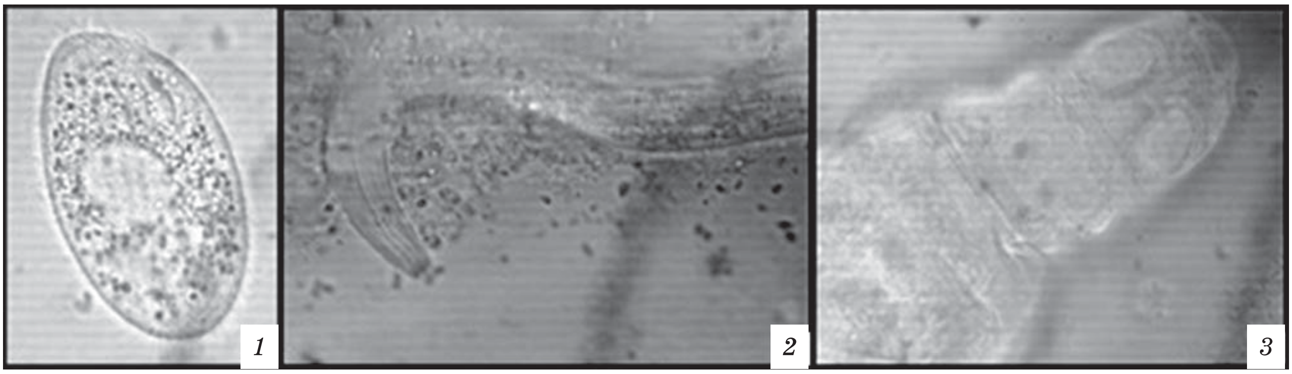

Fig. 5. **Alive invertebrates in the module sections with natural organic carriers (multiplication ×1500):**
1 — euglena; *2* — nematode; *3* — rotifer

Fig. 6. **Animal world representatives in the model ecosystem:**
1 — dragonfly; *2* — dragonfly larva; *3* — pond snail, insect larva

from the last section of SFM. During the whole experiment period, the system remained in a balanced state, excess concentration of organic matter or presence of pathogenic microorganisms were not detected. RedOx potential (Eh) was +430 mV and the pH value was 7.3 which corresponded to normal values of these indicators in natural water ecosystems. In the model ecosystem, different groups of plants and animals were actively developing (Fig. 6), that confirms the environmental safety of water obtained after treatment in the SFM.

The use of the spatial succession of microorganisms in a section flow module on natural carriers provides fast and effective sewage treatment by its purification from dissolved organic compounds and excess microflora thus making it suitable for a return to natural ecosystems. These findings may be used for the development of new environment protection water purification technologies for use in industries with high output of filtrates highly contaminated with organic matter.

The created model of the spatial succession has the features of the filtrate purification in flow systems, in particular, from the solution gradually are filtered dissolved organic compounds and microbial biomass.

The developed approach is effective as a basis for new biotechnologies of deep filtering of wastewaters (both industrial and household) contaminated with organics and filtrates of landfills to the state of 'ecologically clean water'.

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ПРИРОДНІ ТА СИНТЕТИЧНІ ТВЕРДІ НОСІЇ У ПРОТОЧНОМУ МОДУЛІ ДЛЯ МІКРОБНОГО ОЧИЩЕННЯ ФІЛЬТРАТІВ СТІЧНИХ ВОД

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Метою дослідження було розроблення теоретичних принципів ефективної біотехнології очищення концентрованого фільтрату від широкого спектра органічних та неорганічних сполук і експериментальне підтвердження цих принципів. Експеримент включав стандартні мікробіологічні та фізико-хімічні методи, у яких було використано десять різних типів твердих носіїв, природних та штучних. Подано опис і порівняння характеристик інертних носіїв, використаних у системі. Дано послідовну оцінку показників очищення фільтрату. Отримані результати продемонстрували ефективність даного методу мікробного очищення стічних вод у проточній системі. Розроблені принципи можна використовувати як основу для нових ефективних біотехнологій мікробного очищення фільтратів стічних вод.

Ключові слова: мікробне очищення, токсичний фільтрат, стічні води, інертні носії.

ПРИРОДНЫЕ И СИНТЕТИЧЕСКИЕ ТВЕРДЫЕ НОСИТЕЛИ В ПРОТОЧНОМ МОДУЛЕ ДЛЯ МИКРОБНОГО ОЧИЩЕНИЯ ФИЛЬТРАТОВ СТОЧНЫХ ВОД

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Целью исследования была разработка теоретических принципов эффективной биотехнологии очистки концентрированного фильтрата сточных вод от широкого спектра органических и неорганических соединений и экспериментальное подтверждение этих принципов. Эксперимент включал стандартные микробиологические и физико-химические методы, в которых были использованы десять разных типов природных и искусственных твердых носителей. Приведено описание и сравнение характеристик инертных носителей, использованных в системе. Дана последовательная оценка показателей очищения фильтрата. Полученные результаты продемонстрировали эффективность данного метода микробной очистки сточных вод в проточной системе. Разработанные принципы можно использовать как основание для новых эффективных биотехнологий очищения фильтратов.

Ключевые слова: микробная очистка, токсичный фильтрат, сточные воды, инертные носители.