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STUDYING THE EFFICIENCY OF SOIL DECONTAMINATION WHEN USING A DEVICE WITH THE BIOSORBENT "ECONADIN"

O. Siemaka
Tovarystvo z Obmezhenoiu Vidpovidalnistiu Skandynavski Novitni Tekhnolohiyi
Zaliznychne shoes str., 47, Kyiv, Ukraine, 01103
E-mail: oleksiisiemaka@gmail.com

Yu. Shatokhina
PhD, Associate Professor
Department of Public Administration and Organizations' Management
Educational-Scientific Institute of Menagment and Administration
Chernihiv National University of Technology
Shevchenka str., 95, Chernihiv, Ukraine, 14027
E-mail: juliaaabest@gmail.com

L. Klintsov
PhD, Associate Professor
Department of computer Science
Chernihiv Institute of Business and Law
Honcha str., 37, Chernihiv, Ukraine, 14000
E-mail: lnklintsov@ukr.net

Досліджено ефективність очищення грунту від забруднення нафтопродуктами за допомогою запатентованого перфорованого пристрою циліндричної форми діаметром 0,04 м з площею отворів 0,04 м^2 з біосорбентом «Еконадін». Процес очищення грунту відбувався протягом 35 діб. В якості модельного забрудника використано бензин марки А92.

Дослідження проведено для того, щоб поліпшити процес очищення від нафтопродуктів шляхом транспортування біосорбенту у глибинні шари грунту В результаті дослідження встановлена залежність концентрації забруднювача (C) у грунті від відстані (R) до пристрою: $C=-0,00009134R^2-0,001017858R+0,07274845$. Виявлена з метою управління процесом очищення залежність дозволяє розробити методичні рекомендації з використання запропонованого пристрою. На основі моделі Мальтуса, поєднаної з процесом дифузії, отримано дані, які пояснюють механізм знешкодження бензину бактеріями, розташованими у дослідженому пристрої. В заданих умовах очищення відбувається шляхом міграції бактерій в шар грунту з коефіцієнтом дифузії $D=0,08801$ см^2/добу і константою власної швидкості росту популяції $r=0,165168$.

Отримані результати є важливими і корисними для управління процесом очищення і розробки методичних рекомендації з використання запропонованої конструкції. Даний підхід дає можливість розрахунку знешкодження бензину при зміні граничних умов, зокрема, радіуса циліндру спеціального пристрою з біосорбентом, граничної відстані від нього та часу ефективного використання пристрою. Для інших грунтів та забруднювачів запропонований комбінований метод, який включає метод Мальтуса і заснований на описі процесу дифузії, також може бути застосований після експериментального визначення параметрів r, D та C_0

Ключові слова: забруднення нафтопродуктами, пристрій з біосорбентом, управління процесом очищення грунту, дифузія, біосорбент

1. Introduction

It is known that the technologies to control and protect the environment from significant amounts of pollutants that have accumulated as a result of activity of industrial enterprises for a long time up to now, remain to be explored in detail [1–4].

Thus, paper [1] outlines the problem of pollution with oil products, which had been gradually accumulated, to be turned into an underground lake, which creates a threat to water resources of Chernihiv oblast (Ukraine). This situation has necessitated the design of a device for transporting bacteria-destroyers [2]. Purification from petroleum products is a challenge even at water treatment stations while existing procedures of control over the process of cleaning, as shown in study [3], are not sufficiently informative and operational. Given that petroleum products are used as raw materials for synthetic fibers, the toxic waste from these industrial sites is preserved in ponds-collectors, which are a threat to the environment, as noted in paper [4].

Ukraine has a wide network of technical means that work with oil and oil products. Soil contamination occurs due to emergencies in the oil and gas sector that cover all climatic and economic areas. According to [5], production of 1 ton of oil is accompanied by the destruction or pollution of soil with a volume of 1.0÷1.3 m^3. Contamination occurs not only in the surface layer of soil, but also in its deep layers; oil products gradually migrate and reach groundwater horizons, thereby polluting them with toxic substances. Disposal of oil products in deep layers of soil is fundamentally different from the neutralization of surface layers. The primary method for delivering biodestroyers to deep layers implies wells that host carriers of bacteria [2]. The bacteria, due to their mobility, migrate through the pores of the soil and consume oil products that are destroyed in such a way; in addition, the bacteria increase their number, as long as they have food and suitable conditions for existence.

Specifically, there is an urgent problem of pollution with oil products related to a variety of situations in the location of pollutants, which complicates the application of known puri-

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fication methods. Considerable attention is paid to the use of sorbents and biosorbents in order to restore polluted waters and soil surfaces [6, 7]. Special attention is to be paid to the decontamination of not only the surface but deep layers of soil in the case of threat of oil pollution of soil waters and further uncontrolled spread of a pollutant into water objects [8].

2. Literature review and problem statement

The main measures for the elimination of oil spills and oil products in soil in the considered sources of information come down to a soil surface cleaning using the method of bioremediation. This term is understood to be the reclamation with introducing sorbents to the upper layers of soil, pumping out pollution, collecting from the surface of a solid cover, and introducing different kinds of destroyers to the contaminated areas of soil [8, 9].

Publications [10–12] addressed some of the socio-economic and environmental issues related to cleaning the areas contaminated with petroleum products. Specifically, paper [10] argues that a long-term research in the area of the Niger Delta, Nigeria, has not found any advantages in any particular approach to cleaning the environment from contamination by oil. Bioremediation (sometimes in a combination with other technologies) is recognized to be promising due a low cost of the process. It is believed that the inconsistency of standards in a given process is also a complicating factor [10].

The authors of study [11] point to the significant growth of publications dealing with oil pollution of the environment. Over 2004÷2008, there were 2 % of such publications, while over 2014÷2015 similar publications accounted for 61 %. Some important issues such as the impact of environmental pollution by oil products on human health have been insufficiently investigated; these studies account for only 1 % of the specified publications [11]. However, the negative impact of contaminated water on human health is beyond any doubts.

Thus, paper [12] emphasizes that over the past 20÷30 years one of the most important findings is that the purification of groundwater from pollution is very difficult; and it is necessary to prevent such pollution. Special attention [12] is paid to the bacteria that can consume, as a nutrient substrate, the polycyclic aromatic hydrocarbons and other contaminants and convert them into harmless compounds. It was established that the creation of the necessary conditions for these bacteria, for example, increasing the level of nitrogen, ensures an increase in the growth rate of oil degradation. It is stated that the task on decontamination has remained urgent due to the fact that there are many different scenarios of contamination – each area has its own unique geology, layers of soil, precipitation, the rate of water flow, oxygen levels, etc.

The experiments conducted in Georgia [13] estimated the risk of penetration of oil pollution into the underground water depending on the type of soil. Based on the study into plants and microorganisms, the authors presented a technology for their combined application for the phytoremediation of soils. However, heavy fractions of petroleum hydrocarbons were not destroyed effectively by this method. An increase in the degree of purification was achieved by using the preparations of biosurfactants (bacterial surface-active substances) in order to remove hydrocarbons from soil along the pipelines.

Particular attention [14] is given to the bioremediation of Libyan soil, contaminated with oil products, using microorganisms located on the straw of peas. It was found that such a treatment led to the highest degree of cleaning the soils contaminated with hydrocarbons (96.1 %).

Control over pollution of groundwater, as proposed in [15], implies using certain bacteria that could be used as biomarkers. For instance, there is possibility of using the bacteria *Dehalococcoides spp.* during bioremediation of groundwater contaminated with trichlorethylene.

Review [16] provided information on the application of biological factors as a promising alternative in the oil industry and the bioremediation of oil spill. The authors believe that the biologically active substances are not competitive with chemical surfactants from the economic point of view. It is recommended to conduct a detailed study into the production of biologically active substances from agricultural waste in order to reduce industrial costs and to ensure the large-scale production of these natural compounds. The versatility and efficiency, demonstrated when applying biologically active substances in the chain of production of oil and while removing hydrophobic pollutants, make these compounds promising candidates for biomolecules. However, the authors did not specify it was applied to the deep layers of soil.

Paper [17] addresses the yeast *Candida*, mannoselethritriolithic lipids (MELs), produced by the yeast *Pseudozyma,* and ramnolipids derived from *Pseudomonas*. Despite the current enthusiasm of these compounds, there are some remaining problems. The review highlights the problems that remained, and points to the prospects for the imminent commercial utilization of the new generation of microbial biological factors.

Forming a biosorption complex (biosorbent) [18] makes it possible to clean light sandy soils from the aged concentrated contaminants both at the surface under aerobic conditions and in the depth. The complex preserves the viability of cells of microorganisms, has high destructive activity to the hydrocarbons of oil. The reported research demonstrated a change in the concentration of oil pollution of sandy soil from 30÷40 % to 1÷5 % of oil in the process of biodestruction in 140 days. Testing the biosorbent at an industrial facility in a fuel depot when cleaning sandy plots with old oil contamination has shown the effectiveness of cleaning to be 90 %. However, the authors confined themselves only to the surface test on soil.

An analysis of contemporary literary sources that we conducted also reveals that there is a problem related to the choice of a technology for purifying from local organic contaminants. Specifically, there is the issue of decontamination from petroleum products, which had been gradually accumulated at different depths of soil, and pose a threat to ground waters. In addition, it appears that the control and purification technology that employs biosorbents have not been paid sufficient attention to.

An analysis of the scientific literature has shown that researchers are mainly engaged in the development of new effective biopreparation; they test them under laboratory conditions and at the surface of soil. Authors report results of their research using charts or indicating the percentage of purification, achieved as a result of application of biosorbents. Such an approach is unacceptable for the purification of deep layers of soil, which are reached by the biosorbent delivered through a cylindrical well, because it fundamentally changes the boundary conditions compared to surface application. Therefore, the development of a model of the biosorbents activity in deep soils required the selection of laboratory conditions that make it possible to stabilize temperature fluctuations and a change in humidity under natural conditions.

To resolve the task on cleaning the layers of soil at different depths, a set-up [2] was proposed earlier, which contains the microorganisms-destroyers of oil products (preparation "Econadin"). The design is executed in the form of a perforated pipe with a flange in the form of a drill. This makes it possible to transport a shell with microorganisms to the deep layers of soil.

A variant for solving the task could be the purification of deep layers of soil with a biosorbent, which is transported by a specialized device.

3. The aim and objectives of the study

The aim of this study is to elucidate the mechanism of the purification process, which would ensure the elaboration of practical recommendations on managing the process of cleaning the deep layers of soil by a biosorbent, placed in the specialized device [2] (hereinafter referred to as a specialized device with a biosorbent or SDB).

To accomplish the aim, the following tasks have been set:

– to examine changes in a contaminant concentration around a cylindrical SDB at the model laboratory equipment and to estimate the dependence of soil decontamination depending on distance to the location of SDB;

– to elucidate the mechanism of gasoline neutralization by bacteria based on the derived mathematical model;

– to devise practical recommendations for the use of the device.

4. Materials and methods to study the application of the device with a biosorbent for the decontamination of deep layers of soil

The research was conducted at the model equipment, which included a container the size of 440×440×440 mm, filled with sandy soil. We used gasoline of grade A92 as a pollutant of the environment. To prevent the evaporation of gasoline, the container was covered with a plastic wrap. Free air access to the biosorbent was supplied through an upper opened part and inner openings of SDB. In order to develop a model of work of biosorbents in deep soils, we selected such laboratory conditions that would make it possible to stabilize temperature fluctuations and a change in humidity under natural conditions.

The starting concentration of pollutant in the sandy soil was 87.0242 μg/cm^3. An experimental sample of SPB with a diameter of 0.04 m with an area of openings of 0.04 m^2 was installed in the center of the container. 54.8 g of biosorbent of the preparation "Econadin" were placed inside SPB. The soil decontamination process using SDB lasted for 35 days. We determined the concentration of pollutants in the course of the experiment applying a gravimetric method in line with procedure MVV No. 081/12-0725-10 [19] at the State ecological inspection body in Chernihiv oblast and at the Department of Water Supply and Drainage of the Chernihiv National Technological University (Ukraine) [8].

The effectiveness or a degree of soil decontamination (E) was estimated using formula:

$$E=((C_{in}-C_{ik}):C_{in})\cdot 100\ (\%), \quad (1)$$

where C_{ik} is the residual pollutant concentration μg/cm^3, C_{in} is the initial concentration of the pollutant, μg/cm^3.

We processed the results of the experiment and performed analytical study into determining a mathematical model of dependences between control indicators by employing the software Microsoft Excel.

5. Results of studying the application of the device with a biosorbent for the decontamination of deep layers of soil

The result of the performed experiment is the defined change in the concentration of contaminant in the examined soil, indicated by the existence of a dependence of the efficiency of soil decontamination on distance to SDB. Table 1 demonstrates that the maximum efficiency of soil decontamination E=83.1 % was detected at a distance of up to 20 mm from SDB. An increase in the distance from the SDB location to 60÷140 mm leads to that the efficiency of decontamination equals E=66÷48 %, and at a distance of 200 mm the degree of decontamination reduces to 16.7 %. With the further growth of distance, the effectiveness approaches zero.

Thus, the residual contamination of soil samples with oil-derived products upon completing the experiment, given in Table 1, makes it possible to assess the mechanism of gasoline neutralization. In order to obtain an adequate mathematical model, we conducted a search using the model of Malthus [20, 21] together with a model of diffusion [22, 23]. The Malthus model, which explains a growth in the population of bacteria in a confined space, was combined with the diffusion model, which models the propagation of bacteria to new territories. Underlying the Malthus model is the assumption on that an increase in the population of species over time t is proportional to this number and to the interval of time over which the increase occurred:

$$\frac{dX}{dt}=r\cdot X, \quad (2)$$

where r is a constant of the natural growth rate of population in soil; X is the number of bacteria, pcs/days; t is the time, 24 hours.

Table 1

Determining an effective distance to the carrier of a biosorbent when cleaning the deep layers of soil from oil products

No. of entry	Distance to the carrier of a biosorbent, L_i, cm	Residual pollutant concentration, C_{ik}, μg/cm^3	Initial pollutant concentration C_{in}, μg/cm^3	Decrease in pollutant concentration, C_i=C_{in} C_{ik}, μg cm^3	Soil decontamination efficiency, E_i, %
1	2	14.70	87.0242	72.3242	83.10815
2	4	18.15	87.0242	68.8742	79.14373
3	6	29.16	87.0242	57.8642	66.49208
4	8	30.225	87.0242	56.7992	65.26828
5	10	33.12	87.0242	53.9042	61.94162
6	12	36.66	87.0242	50.3642	57.87379
7	14	45.18	87.0242	41.8442	48.08341
8	16	53.25	87.0242	33.7742	38.81012
9	18	62.505	87.0242	24.5192	28.17515
10	20	72.45	87.0242	14.5742	16.7473

The solution to this equation, as it is known from [22], is a function:

$$X(t) = X_0 \cdot \exp(r \cdot t), \qquad (3)$$

where X_0 is the initial size of population in the estimated volume.

We assume that the number of bacteria is proportional to the amount of neutralized gasoline over a certain time in a certain volume, which is why, instead of the size of the population of bacteria in the preparation "Econadin", which proliferate and migrate from the device into the soil, one can use the amount of neutralized gasoline. Thus, equation (3) is substituted with equation (4):

$$C_{i(\Delta\tau)}^{`} = C_i \cdot \exp(r \cdot \Delta\tau), \qquad (4)$$

where C_i is the reduction in the concentration of gasoline under the action of bacteria in the i-th volume, μg/cm^3:

$$C_i = C_{in} - C_{i\kappa}, \qquad (5)$$

$\Delta\tau$ is the time interval, days.

The basis chosen for the derivation of estimation formulae in numerical integration was the method of mass balances [23].

The calculated difference equations, which were used in the calculations, are given below.

$$C_1' = \left(\frac{D \cdot \Delta\tau}{\Delta R}\right) \cdot \left(\frac{F_{0-1} \cdot (C_0 - C_1) - F_{1-2} \cdot (C_1 - C_2)}{V_1}\right) + C_1 \cdot \exp(r \cdot \Delta\tau);$$

$$C_2' = \left(\frac{D \cdot \Delta\tau}{\Delta R}\right) \cdot \left(\frac{F_{1-2} \cdot (C_1 - C_2) - F_{2-3} \cdot (C_2 - C_3)}{V_2}\right) + C_2 \cdot \exp(r \cdot \Delta\tau); \qquad (6)$$

$$C_{10}' = \left(\frac{D \cdot \Delta\tau}{\Delta R}\right) \cdot \left(\frac{F_{9-10} \cdot (C_9 - C_{10}) - F_{10-11} \cdot (C_{10} - C_{11})}{V_{10}}\right) + C_{10} \cdot \exp(r \cdot \Delta\tau),$$

where F_{0-1} is the area of surface between SDB and the first ring, $F_{0-1}=2\pi R_1 \cdot h$, cm^2; R_1·is the radius of SDB surface, cm; h is the height of the ring, cm, constant for each ring; F_{1-2} is the area of surface between the first and second rings, $F_{1-2}=2\pi R_2 \cdot h$, cm^2; R_2 is the outer radius for the first ring and the inner radius for the second, cm; V_1 is the volume of the first ring of soil near SDB, $V_1=\pi(R_2^2-R_1^2)\cdot h$, cm^3; $V_i=\pi(R_{i+1}^2-R_i^2)\cdot h$, cm^3, volume of the i-th ring is $i=1\div11$, where i is the number of the corresponding ring.

Fig. 1 schematically shows the splitting of the finite-difference model into ring planes, in which concentrations of gasoline are evenly distributed.

Initial and boundary conditions: the initial decrease in concentrations in rings $C_1 \div C_{11}=0$; C_i, where i ($i=1\div11$) is the number of the corresponding ring, μg/cm^3, $R_i=\Delta R*i$ is the radius of the corresponding ring, cm; ΔR is a step in radius, cm; $\tau=0\div35$ is the time, day; $\Delta\tau$ is a step in time (0.2 day, accepted under condition for a stable process of calculation in the matrix of finite differences [24]); D is the diffusion coefficient of bacteria from "Econadin" cm^2/day.

The concentration of C_0, μg/cm^3, as a potential of reduction, in the cylinder with "Econadin" is assumed to be constant and is calculated in the process of searching for a solution.

The problem was solved using an explicit method [24].

The concentration C_{11} reflects the isolation of the tenth ring from an external influence, created by the wall of the experimental container, which is why C_{11}=const and equals zero.

The concentration of bacteria in SDB is C_0, and r is a constant of the natural growth rate of the population; following the operation of selection, they are constant over the process of modeling. Values for these indicators were selected by using the function "Search for solutions" in the spreadsheet Microsoft Excel. The selection employed a method of minimization of mean-variance between the experimentally derived decrease in the concentration of a pollutant ($C_{in}-C_{ik}$) and the respective concentration, computed using a difference model. We derived the following parameters for the model: D=0.08801 cm^2/day, r=0.165168, C_0=0.062796 μg/cm^3. The model has a determination coefficient R^2=0.965505. Results of the model's work are shown in Fig. 2.

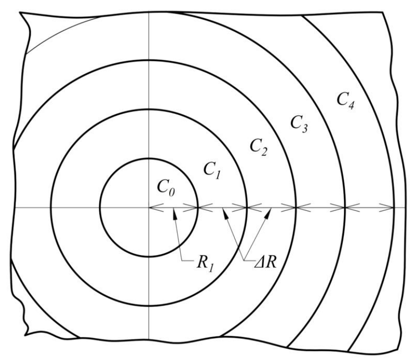

Fig. 1. Schematic of the finite-difference model: C_0 – initial concentration, $C_1 \div C_{11}$ — decrease in the concentration in rings, R_1· — radius of SDB surface, ΔR – a step in radius

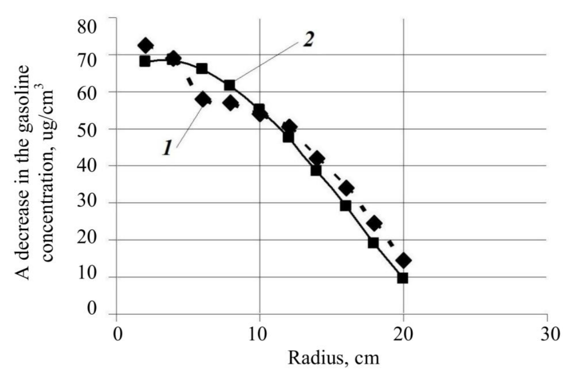

Fig. 2. Comparison of experimental data with the data from the devised model: 1 — actual data, 2 — Malthus model

Graphs in Fig. 2 demonstrate sufficient correlation between experimental data and the results of solving the finite-difference model. We can assume that the application of the Malthus model in a combination with the diffusion of bacteria rather well elucidates the mechanism of gasoline neutralization by bacteria that migrate from the device into soil over 35 days.

This model enables the calculation of gasoline neutralization at a change in boundary conditions, such as the radius of a cylinder with SDB, the time the device is uses, and the limit of distance from the cylinder. However, this model is not convenient enough to be uses in engineering calculations due to its complexity.

In order to control the process of cleaning a contaminated soil using the proposed device, we shall conduct, by using the spreadsheet Microsoft Excel 7, the approximation of experimental data employing the method of least squares. The result of approximation is shown in Fig. 3.

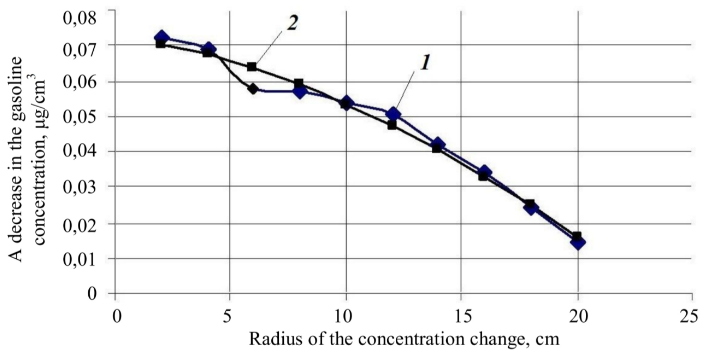

Fig. 3. Polynomial approximation model of experimental data on soil decontamination from gasoline using a device with a biosorbent: 1 – actual data, 2 – polynomial model

The polynomial model of second order, constructed by a least square method, takes the following form:

$$C=-0.00009134R^2-0.001017858R+0.07274845. \quad (7)$$

This model possesses a high coefficient of determination $R^2=0.983$, thereby adequately describing data from the experiment.

6. Discussion of results regarding the effectiveness of the application of the device with a biosorbent to decontaminate deep layers of soil

Experimental studies have confirmed the effectiveness of soil decontamination from gasoline using the biosorbent "Econadin", which is transported inside the depth of soil using the original design of SDB. In order to control the process of decontamination, we have constructed a mathematical model based on the Malthus model, combined with the process of diffusion, which makes it possible to elucidate the mechanism of gasoline neutralization by bacteria that proliferate and migrate from the device into soil. For the assigned conditions, we have obtained the following parameters for the model: $D=0.08801$ cm^2/day, $r=0.165168$, $C_0=0.062796$ μg/cm^3. For other soils and contaminants, we have proposed a combined method, which includes the Malthus method and which is based on the description of a diffusion process; it could also be applied upon determining the parameters r, D and C_0 experimentally.

The practical result of this study is the derived dependence of the impact of distance from the device with a biosorbent on the efficiency of soil decontamination, which makes it possible to devise a scheme of SDB location depending on operating conditions.

Thus, if it is required to clean deep layers of soil in the terrain where there is no threat to pollute groundwater, it is possible to use a gradual prolonged soil decontamination using SDB. To this end, the device is placed along the perimeter of the contaminated territory at a certain distance from each other. Depending on the chosen diameter of SDB, the distance may vary. For example, a distance between SDB could be 0.2÷0.4 m at their diameter of 0.04 m. Next, SDBs are periodically rearranged so that the circle is narrowing.

Over 35 days, the device effectively operated within a radius of 20 cm; SDB can be then moved to the next area, while bacteria would continue to act at the previous location. The considered scientific literature revealed that even the surface soils decontamination required a much longer time – 120÷140 days.

In the case when there is a need for an urgent decontamination at the threat posed by the pollution of groundwater, the number of SDB is calculated as follows: SDB is placed along the perimeter of a cleaned area (first row) at a distance that ensures maximum efficiency while devices in the following rows are arranged in a checkerboard pattern.

The disadvantages of our study include the missed opportunity to explore different kinds of contamination and rocks in soil, both separately and in combination. Results of this study are valid for the decontamination from gasoline in in a sandy soil under the assigned specific conditions.

The research could be further developed in order to identify the features of decontamination in different layers of soil, which would be complicated when determining such particular parameters as a coefficient of diffusion.

7. Conclusions

1. We have simulated the process of soil decontamination using a specialized device with a biosorbent (SDB), the carrier of bacteria-destroyers in the form of the preparation "Econadin", based on the acquired experimental data. For the assigned conditions: the initial concentration of gasoline of grade A92 in a sandy soil is 87.0242 μg/cm, decontamination duration is 35 days, and under other conditions for the experiment, we derived a polynomial model with a determination coefficient of 0.983. Thus, the dependence of a pollutant concentration C in soil on a distance R to SDB takes the form: $C=-0.00009134R^2-0.001017858R+0.07274845$.

2. We have established a distance to the carrier of a biosorbent, which is effective in terms of decontamination: the maximum efficiency of soil decontamination E=83.1 % was identified at a distance to 20 mm from SDB. Increasing the distance to SDB location to 60÷140 mm results in the decontamination efficiency E=66÷48 %, and at a distance of 200 mm the degree of decontamination reduces to 16.7 % and then approaches zero. Taking the acquired experimental and simulated data into consideration, our recommendations for the decontamination of deep layers of soil using SDB are as follows. The distance between SDB could be 0.2÷0.4 m at their diameter of 0.04 m. Depending on the chosen diameter of SDB, the distance between them can vary.

3. Based on the Malthus model, combined with the process of diffusion, we acquired data that define the mechanism of gasoline neutralization by the bacteria from the examined device, SDB. The initial concentration of bacteria in the preparation "Econadin" corresponds to the amount of the neutralized contaminant $C_0=0.062796$ μg/cm^3. Gasoline neutralization is achieved through the migration of bacteria into a soil layer with a diffusion coefficient $D=0.08801$ cm^2 day and a constant of the population growth natural rate $r=0.165168$.

This approach enables the calculation of gasoline neutralization and ensures control over a decontamination process at a change in boundary conditions, in particular, a radius of the cylinder of the device with a biosorbent, maximum distance from it, and the duration of effective use of the device.

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DEVELOPMENT OF THE METHODOLOGICAL APPROACH TO THE SELECTION OF TECHNOLOGIES FOR ENVIRONMENTALLY-SAFE WATER DRAINAGE IN POPULATED AREAS

N. Teliura
Senior Lecturer
Department of Environmental Engineering
O. M. Beketov National University of Urban Economy in Kharkiv
Marshala Bazhanova str., 17, Kharkiv, Ukraine, 61002
E-mail: nata.teliura@ukr.net

Розроблено методичний підхід вибору технологічного заходу екологічно безпечного водовідведення в населених пунктах, розташованих на евтрофованих водних об'єктах. Використання такого підходу дозволяє задіяти спеціалістів місцевих органів влади різного профілю до управління екологічною безпекою населених пунктів з позицій їх сталого розвитку.

Сутність методичного підходу полягає у використанні методу аналізу ієрархій (МАІ). Для нього запропоновано і використано критерії, що сформульовані як складові сталого розвитку – екологічні, соціальні та економіко-технологічні. Відповідні спеціалісти, як експерти, спираючись на інформацію різного типу (статистичну, прогнозну, даних безпосередніх вимірів) по конкретному населеному пункту, дають власні судження відносно пріоритетності переваг критеріальних ознак. Результати оброблення суджень експертів за формальною процедурою МАІ є основою для прийняття рішень при виборі технологічних заходів екологічно безпечного водовідведення в конкретному населеному пункті.

Багатокритеріальна ієрархічна структура вибору технологічних заходів представлена послідовністю дій, що включають три етапи: побудову ієрархічної моделі порівняння критеріальних ознак; формування матриць попарних порівнянь елементів кожного рівня ієрархії та визначення їх локальних вагових коефіцієнтів; визначення глобальних вагових коефіцієнтів, індексу узгодженості та вибір найкращого варіанту. Перевагою запропонованого багатокритеріального методичного підходу є можливість ув'язати в єдиний алгоритм виробки рішення вихідні дані, що різняться як за своїм змістом (екологічні, соціальні та економіко-технологічні), так і за формою представлення (статистичні, прогнозні, дані безпосередніх вимірів, експертні оцінки).

Апробація розробленого методичного підходу проводилась на прикладі типового населеного пункту, розташованого на евтрофованому водному об'єкті – джерелі питного водопостачання та рекреаційного використання. Отримані результати, незважаючи на достатньо велику розмірність масиву елементів ієрархії, показали досягнення прийнятного рівня узгодженості, що свідчить про їх достовірність.

Розроблений методичний підхід може бути використаний при обґрунтуванні удосконалення чи побудові нової системи водовідведення населеного пункту розташованого на евтрофованому водному об'єкті

Ключові слова: екологічна безпека, населений пункт, технологічний захід екологічно безпечного водовідведення, метод аналізу ієрархій

1. Introduction

It is important to ensuring social and economic development of the state and of a separate populated area (PA), during which the quality of life of the population increases, and to reduce the impact on the nature. This leads to the creation of the environment, which is beneficial for human health and is a strategic goal of the policy of environmental safety.

Ensuring a beneficial environment for human life must be based on the criterial features of sustainable development. A beneficial environment can be defined as a safe environment, including water sites, sources of satisfying drinking

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