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Development of the Hydrophytic Structure of the Bioplateau Type for the Purification of Water Bodies From ^{137}Cs

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Abstract. A floating structure of a bioplateau has been developed for the purification of water bodies from the toxic substances, the biotic component of which is terrestrial plants. Chemically inert floating materials were used as a substrate for the construction of the bioplateau: perlite, expanded clay, granular foam, vermiculite, cork. Substrate testing has shown that granular expanded polystyrene is the most optimal for the usage. The study of different options for seed germination in the design of the bioplateau has shown that its placement on the top of the substrate is the best option. The usage of perlite in combination with granular foam had created an additional capillary effect, due to which the seeds germinated at a faster rate. To optimize the hydrophytic structure a grid was used, which made it possible to increase the overall density of the bioplateau. An algorithm for creating a «rolled» plant that is suitable for transportation and placement in the surface water bodies that require purification from toxic substances has been developed. There was done a comparative study of the effectiveness of purification of the aquatic environment from ions of radiocesium bioplate with wheat plants of different varieties. It is confirmed that the efficiency of sorption of ^{137}Cs ions by terrestrial plants is influenced by the nature and concentration of macrocations in the aqueous medium.

Key words: water purification, phytoremediation, bio plateau, terrestrial plants, radionuclides, ^{137}Cs.

Introduction

Anthropogenic activities and emergencies have led to significant pollution of the environment, in particular water bodies, which is gaining global scale and causing undesirable consequences for humans and ecosystems (Isaienko, et al., 2018; Pshynko & Honcharuk, 2019). According to the forecasts of the Ukrainian experts, further intensive industrialization will lead to irreversible environmental changes and a catastrophic reduction of relatively clean freshwater resources in Ukraine as a source of drinking water (Iatsyk et al., 2014; Tomiltseva, 2017).

Taking into account the results of monitoring studies in recent years, surface waters of Ukraine are classified as water quality class 3-5, and the most environmentally hazardous toxicants are radionuclides (^{137}Cs) (Demchuk et al., 2010;

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Nigmatullina & Fazlyieva, 2018; Seregin & Ivanov, 2001).

Traditionally, chemical and physicochemical methods are used for wastewater treatment, which have a limited scope, certain advantages and disadvantages and mostly do not allow achieving the normative values of residual concentrations of pollutants entering and accumulating in surface aquatic ecosystems (Filatova, 2015; Pshinko et al., 2018; Vukcevic et al., 2014). Therefore, to improve the ecological status of water bodies, it is necessary to create effective, environmentally safe and cost-effective, compared to existing methods, systems for restoring the quality of large volumes of aquatic environments, which is developing new or improving existing methods of extracting these ecotoxicants from water bodies.

Nowadays much attention is paid to the use of phytoremediation technologies to improve the condition of water bodies. In world practice, various phytoremediation systems are used, in particular hydrophytic structures using higher aquatic plants and aquatic biota (Boog et al., 2019; Nivala et al., 2018; Romanenko et al., 2012; Sharma et al, 2015; Volkova et al., 2018; Xie et al., 2013).

Traditionally, the functioning of the bioplateau is based on the transiting of contaminated water through a system of biofilters located on the soil surface. This treatment scheme makes existing types of plateaus limited in terms of mobility and capacity, and the use of higher aquatic plants as biological components complicates the operation of the plateau. However, it is known that not only higher aquatic plants are characterized by high levels of accumulation of ecotoxicants, but also higher terrestrial plants in aquatic (hydroponic) culture have a high sorption capacity for radionuclides and toxic metals (Lapan et.al., 2019; Lapan et. al., 2020; Mikheev et. al., 2017). Therefore, despite the achievements in the usage of bioplateau, the need for scientific justification for the development of phytoremediation technology, which consists of studying the absorption capacity of terrestrial plants and creating an effective hydrophytic structure such as bioplateau, is an extremely important task.

The process of accumulation of radiocaesium bioplateau with plants can be influenced by a number of factors, in particular by the varietal characteristics of plants, the presence and concentration of macrocations typical of natural reservoirs.

The optimal content of macrocations, typical for natural waters - Na +, K +, Ca2 +, Mg2 +, in the environment is necessary to ensure the processes of metabolism, growth, gene expression, photosynthesis, synthesis of proteins, carbohydrates and other important vital processes in the plant body. It is known (Cornell, 1993) that under natural conditions, even with a relatively high level of radionuclide contamination of the environment (soils or water bodies), the concentration of ^{137}Cs is in many times lower than macrocations, so the efficiency of ^{137}Cs sorption largely depends on the presence and concentration of these elements that can act as specific and non-specific competitors (isotopic or non-isotopic carriers).

Physiologically complete mineral composition of drinking water must meet the following indicators by cations: K^+ – 2–20 mg/l, Ca^{2+} – 25–75 mg/l, Mg – 10–50 mg/l, Na – 2–20 mg/l (DSanPin 2.2.4-171–2010, 2010).

The study was conducted with the purpose of the experimental development of method of water purification of ^{137}Cs ions using a new design of a bio plateau, which is based on the use of terrestrial plants.

During the development of the floating bioplateau with the use of terrestrial plants that have the maximum ability to accumulate radionuclides, the following tasks were set and solved:

- searching for species of terrestrial plants that are able to grow in conditions of high humidity;
- testing of different types of substrates that provide high buoyancy and close connection with the root system of plants;

- testing of substrates and plants for the formation of the floating bioplateaus;
- searching of the optimal means of seed germination (upper location according to the substrate, mixing with the substrate);
- optimization of the hydrophytic structure;
- study of sorption properties of bioplateau with wheat plants of different varieties in relation to ^{137}Cs;
- study of the effect of macrocations on sorption ^{+}Cs.

Material and Methods

As biosorption material the usage of intact higher terrestrial plants and their isolated parts (mainly leaf-stem) is evaluabled. Plant material is an element of the biofilter, which is a system that uses the sorption properties of the root system of intact plants.

The second stage in the construction of a floating bioplateau was the searching for a substrate for the development and growth of the plants. The chemically inert floating materials, such as perlite, expanded clay, granular foam, vermiculite, cork are used. These substrates must meet the following requirements: non-toxicity to plants; minimum porosity – to minimize the ingrowth of roots into the granules of the substrate and ensure the buoyancy of the bioplateau structure.

The third stage in the construction of a floating bioplateau was the combination of different options of seed and substrate. To obtain the required hydrophytic system, a combination of seed variants of promising higher terrestrial plants and substrate was studied. The method of placing seeds on the top of the substrate, below and the method of mixing the substrate with plant seeds was used.

To construct a bioplateau by the method of placing seeds below the substrate, the bottom of the cuvette measuring 21 × 12.5 × 2.5 was covered with seeds, cm^3: peas (40), corn (40), barley (25), oats (25); poured granular foam (1.5 cm); added 100 ml of settled water from the water supply; placed in a thermostat at t = 24 ℃.

Next, a bioplateau was created by mixing the seeds with the substrate: pre-soaked for 8 hours corn (40 cm^3) and peas (40 cm^3) were used. Foam was poured into 21×12.5×2.5 cuvettes and mixed with seeds. 100 ml of settled water from the water supply was added and placed in a thermostat at t = 24 ℃.

The construction of the bioplateau by the method of placing the seeds on top of the substrate was performed in the following order: a cuvette of size 21×12.5×2.5 was used; the bottom was covered with a layer of granular foam (500 cm^3); the surface of the granular foam was moistened; 100 ml of settled water from the water supply was added; with a layer of perlite (70 cm^3) was covered; perlite was moisturized; on the surface was placed the seeds (cm^3): hemp (25), mustard (25), rye (25), oats (25), amaranth (3), flax (15), millet (15), barley (25), rape (10), corn (40), thyme (5), oatmeal (5); the seeds were covered with a layer of perlite (50 cm^3); then it was placed in a thermostat at t = 24 ℃.

To optimize the hydrophytic structure of the bioplateau, a supporting mesh and perlite was used, poured on top of granular foam (70 cm^3).

The design of the bioplateau for the using in the field.

A cuvette measuring 30 × 40 cm was used; a grid was placed on the bottom of a cuvette; the bottom was covered with a layer of granular foam 1.5 cm thick; a layer of perlite was poured on top of the foam; 200 ml of water was poured into the cuvette; during further germination another 600 ml of water was added; a spray to moisten the surface of the substrate was used; a mixture of seeds: corn (200 cm^3) - barley (100 cm^3) - meadow thyme (10 cm^3) was used; a thin layer of perlite was sprinkled on the seeds; the cuvette was placed in a plastic bag to create a wet chamber.

The cultivation of plants in a solution of cesium-137 chloride was performed in glass containers, which were pre-treated for 3 days with 0.1 mg solution of stable cesium chloride to prevent sorption of cesium radioisotope ions by the inner surface of the glass. Settled tap water was used. Once a day the solution was poured into a Marinelli vessel to determine the specific activity of the radionuclide on a gamma spectrometer SEG-001 "APK-C" -63. The initial specific activity of radiocaesium was 2.0-2.2 kBq / l, which according to previous experiments did not cause a significant effect on plant growth and development. Measurements of the specific activity of Cs-137 were performed with the measurement error of 3.8%.

The degree of purification from ^{137}Cs (*DP*, %) was calculated as follows:

$$DP = \frac{(A_0 - A_p)}{A_0} \cdot 100,$$

where A_0, A_p – respectively, the activity of ^{137}Cs ions in the initial solution and in the solution after sorption, kBq/l.

The concentration of Cs^+ ions was determined in the selected samples with a volume of 20 ml on the atomic absorption spectrophotometer C-115-M1 at a wavelength of λ = 852.1 nm. The concentration of Cs ions was determined using a mixture of acetylene with air. The optimal range for determining the concentrations of Cs^+ ions was 5–50 mg/l.

Results and Discussion

At the first stage of the study, pea, corn and barley seeds were placed at the bottom of the substrate - foam. After 3 days of seed germination – peas almost did not germinate, corn and barley showed good results - the seeds began to germinate. After 7 days of incubation, the barley germinated well - the length of the shoots reached about 10 cm; in the version of the bioplate with corn – about 3-5 cm. Peas have sprouted up to 3 cm, there is a bacterial infection of plants. Thus, the construction of a bioplate by seed germination from below does not meet the requirements for hydrophytic structure: the substrate of the bioplate is not necessarily bound by the root system of plants, the buoyancy of the structure is not ensured.

The pea and corn seeds were used to study the variant of seed germination mixed with the substrate. The polyfoam acted as a substrate. It was found that corn mixed with the substrate for 7 days sprouted about 3 cm, peas are not a promising plant, because it has a high level of bacterial infection. Thus, the construction of the bioplateau by mixing seeds with the substrate also does not meet the requirements for the bioplateau: the substrate of the structure is not necessarily bound by the root system of plants, the buoyancy of the bioplateau is not provided.

Another option for designing of the bioplateau was the germination of seeds on top of the substrate. The studies have shown that in all variants of the combination of foam with plants, there was an effect of binding the substrate to the root system and there was a high level of buoyancy of the bioplateau. A weak effect of substrate binding to the root system was observed by combining vermiculite with plants. The variants of the combination of the cork with plants showed a weak effect of binding of the substrate to the root system, as a result of which the buoyancy of the bioplateau is not ensured. Combining expanded clay with plants also gave a weak effect of binding of the substrate and the root system, due to the low buoyancy of the bioplateau.

In the course of experimental studies, it was found that the placement of seeds for germination on top of the substrate is the best option for its germination, which in its turn allowed to obtain a dense structure of the bioplateau for the further research.

The next task was to optimize the hydrophytic structure. To minimize the edge effect (looseness at the edges of the bioplateau), it was decided to use a fine-grained mesh, which allowed to increase the overall density of the bioplateau. For this purpose, when constructing the bioplateau, firstly, a grid was placed on the bottom of the cuvette, then polyfoam and plant seeds (Fig. 1).

Fig. 1. Bioplateau with the using of fine-grained mesh.

To ensure more complete contact of germinating seeds with the substrate, perlite was used, because it in the combination with the foam creates an additional capillary effect, which provides faster seed germination. The components of the bioplateau were placed in the following sequence: mesh - foam - perlite - seeds.

The next stage of the work was the study of the buoyancy of the constructed bioplateau in the laboratory (Fig. 2).

Fig.2. Checking of the floatation of the bioplateau.

Thus, the constructed hydrophytic structure differed from the previous versions by the maximum density and homogeneity of the system, which ensured a high level of buoyancy and ease of transporting the bioplateau to water bodies.

The usage of the bioplateau in the field.

Since it is planned to use a bioplateau to clean xenobiotic-contaminated water bodies, one of the tasks was to test the possibility of transporting the proposed type of bioplateau for placement on the mirror of the reservoir. First of all, an important task was to minimize mechanical damage to bioplateau plants during transportation, so it was decided to focus on the practice of transporting lawn grass in the form of a roll. It was planned to find out the possibility of twisting the plateau into a roll for the purpose of transporting the hydrophytic structure to the required water bodies. In fig. 3 a bioplateau of the rolled type is presented.

Fig. 3. The bioplate that was prepared for the transportation.

The germination of plants to create a rolled bioplateau using a mesh gave a very good result: the bioplateau is quite dense, the root system binds the substrate well, which allows them to be easily twisted into rolls, makes them transportable – in other words, it is possible to deliver and place the bioplateau on the surface of reservoirs (Fig. 4).

Fig. 4. The location of the bioplate on the river.

The laboratory-built floating bioplateau, designed to purify water bodies, has been successfully transformed and tested in an open surface body of water.

To study the effect of plant varietal affiliation on the accumulation of ^{137}Cs wheat plants, bioplates with ten-day-old seedlings were cultured in ^{137}Cs solution. Measurements of the specific activity of 137Cs were measured after 5 and 24 h of incubation of plants in ^{137}Cs solution (Fig. 5).

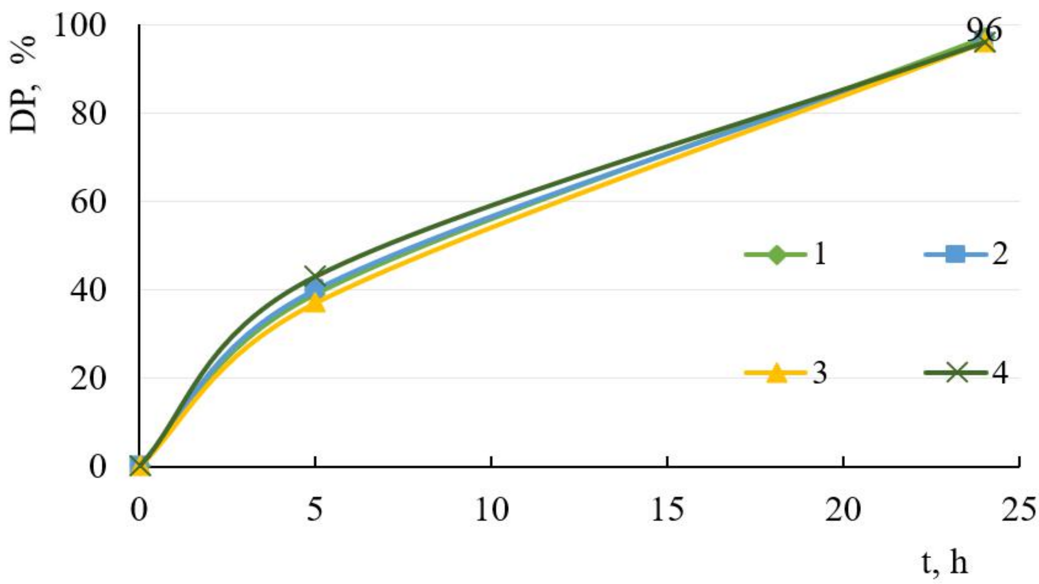

Fig. 5. Dynamics of ^{137}Cs uptake by wheat plants of different varieties; 1 – Polis'ka 90, 2 – Myronivs'ka 808, 3 – Favorytka, 4 – Dons'ka napivkarlyk, A (^{137}Cs)=2,0 кBq/l, Δ= 3,8 %.

It was found that the varietal affiliation of wheat plants at the end had almost no effect on the accumulation of ^{137}Cs. Thus, the degree of purification of water from ^{137}Cs ions will mostly be affected by the species characteristics of terrestrial plants, but taken the results above into consideration, even the species specificity is manifested only in the first stages of observation, and then it is leveled.

The effect of potassium, calcium, magnesium and sodium ions, characteristic of macrocations for natural aquatic environments, on the sorption of ^{137}Cs by terrestrial plants was studied. Fig. 6 presents the results of a study of the effect of the concentration of macronutrient ions on the sorption of Cs^+ by plants of common corn hybrid Dostatok 300 MW.

It is established that the influence of competing ions increases in the series Mg^{2+} <Ca^{2+} <Na^+ <K^+. Magnesium ions at the used concentrations had almost no effect on the sorption of ^{137}Cs, in contrast to calcium and sodium, the presence of which ions reduced the sorption of ^{137}Cs by only 10 % at a concentration of 100 mg/l. Potassium (a chemical analogue of cesium) inhibited the sorption of the latter to such a level at significantly lower concentrations - 10 mg/l. The reason for this may be the competition of these elements for K-transport proteins. It should be noted that the concentration of potassium in natural waters is quite low and is 3-10 mg/l.

The obtained results of the influence of Na^+, K^+, Ca^{2+}, Mg^{2+} on the sorption of ^{137}Cs ions by plants suggest a high level of purification of the water body provided that these competing ions are present in the aquatic environment even in high concentrations, which can be caused, for example, by potassium fertilizers or liming.

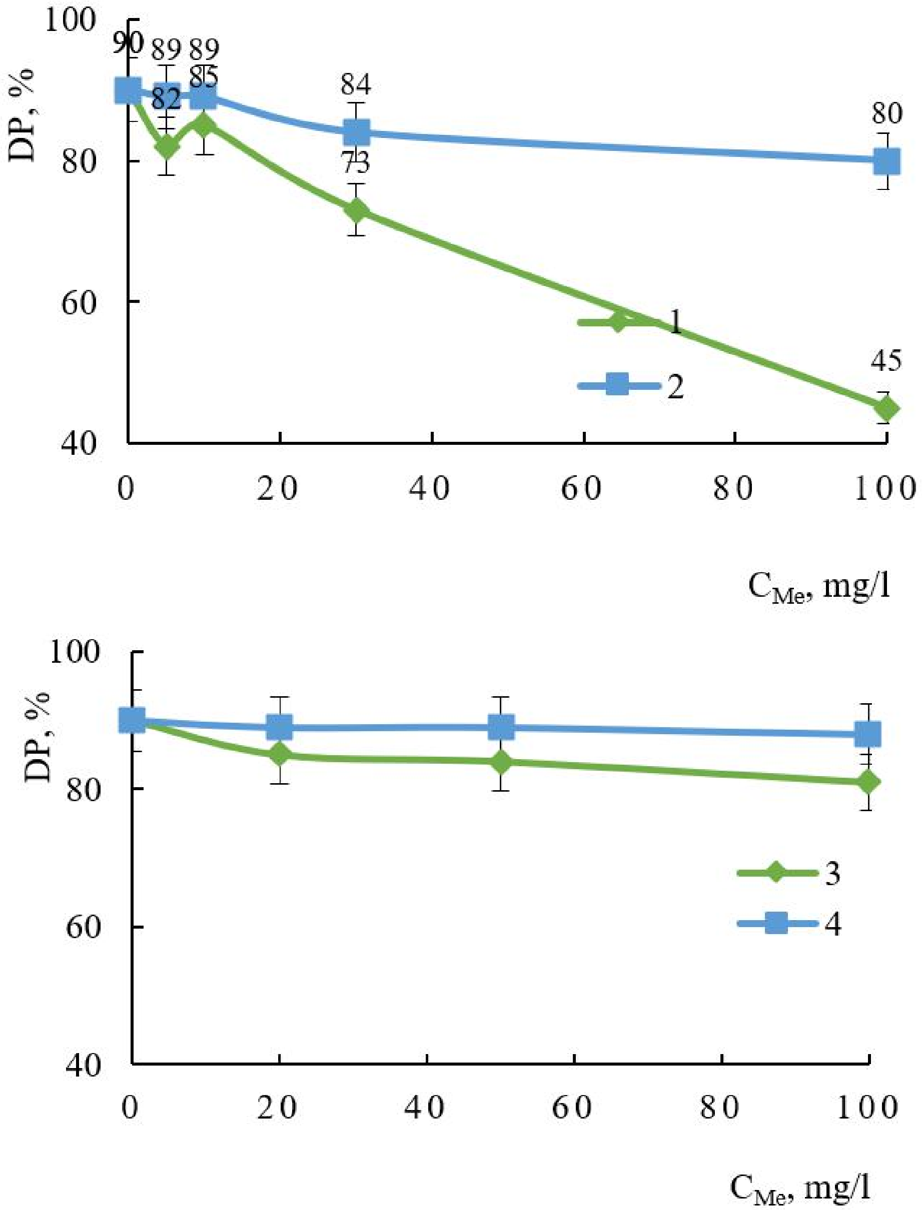

Fig. 6. The effect of the concentration of macrocations (C_{Me}) on the sorption of Cs^+, C_0 (Cs^+) = 10 mg/dm^3, $V_{solution}$ = 500 cm^3, $t_{sorption}$ 7 days, 1 – K^+, 2 – Na^+, 3 – Ca^{2+}, 4 – Mg^{2+}.

Conclusions

Thus, a new method of constructing a floating structure of a bioplateau for purification of reservoirs from toxic substances, the biotic component of which is terrestrial plants, has been developed.

Tests of several types of floating substrates have shown that granular expanded polystyrene is the most optimal for use. It is established that the placement of seeds on the top of the substrate is the best option for its germination. The use of perlite in combination with foam created an additional capillary effect, so that the seeds germinated faster. The required density of the bioplateau, in particular the sealing of the edges of the bioplateau, was provided by a mesh with a small mesh.

The parameters of the bioplateates obtained in the experiments make it possible to transport them in the form of a roll for placement on the surface of reservoirs that require purification from toxic substances.

The sorption properties of bioplateau with wheat plants of different varieties in relation to ^{137}Cs were studied. In the research it was possible to achieve a high (more than 90%) level of water purification from this radionuclide.

It is confirmed that the efficiency of sorption of ^{137}Cs ions by terrestrial plants is influenced by the nature and the concentration of macrocations in the aqueous medium, their influence decreases in a number $K^+ > Na^+ > Ca^{2+} > Mg^{2+}$.

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