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OPTIMUM COLLECTION AND CONCENTRATION STRATEGIES OF HYDROBIONTS EXCESS BIOMASS IN BIOLOGICAL SURFACE WATER PURIFYING TECHNOLOGIES

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Abstract. The analysis of perspective collection and concentration technologies of excess biomass in the technologies of wastewater and surface water biological treatment with the use of aquatic organisms has been carried out. The scheme of a life cycle of the aquatic organisms in wastewater and surface water treatment technologies has been proposed. The analysis of technological approaches for biomass collection of three types: aquatic plants and macroalgae; aquatic plants with a developed root system and microalgae of aquatic organisms has been carried out. A strategy for concentrating microalgae has been proposed. The high efficiency of the coagulation-flocculation gravitational thickening method of freshwater microalgae suspensions of the *Microcystis aeruginosa* species has been confirmed in laboratory conditions.

Key words*:* hydrobionts, excess biomass, collection, concentration, surface and wastewater, aquatic plants, microalgae.

1. Introduction

A lot of research has been devoted to the use of aquatic organisms for the treatment of polluted wastewater. A striking example of natural (not artificially organized) treatment of polluted surface waters in the water areas of Ukrainian rivers was the rapid uncontrolled development of algae (and in high extent blue-green algae). They received favourable conditions for development because of the pollution of the hydrosphere by the products of human life activity-compounds of phosphorus and nitrogen. The construction of artificial reservoirs on the Dnieper, the Dniester, the Southern Buh and other rivers of Ukrainian shallow areas, which are well warmed by the sun, also contributed to the development of algae. Algae absorbing pollutants contribute to water purification, but at the stage of

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extinction, they create secondary pollution (release of toxic substances into the air and into the aquatic environment) which cause significant damage to the environment (Malovanyy et al., 2016a). Thus, this example demonstrates both the effectiveness of polluted aquatic environments treatment using aquatic organisms and the risk of secondary environmental pollution due to the lack of full life cycle of aquatic organisms (selection and disposal of excess biomass, increased as a result of treatment processes).

Most studies are devoted to the prospects of polluted aquatic environments purification using aerobic and anaerobic microbiocenoses, microalgae and algae, aquatic hydrobionts, artificially organized wetlands. A lot of studies have been devoted to the use of aerobic and anaerobic microbiocenoses. The results of studies on anaerobic and aerobic purification by microbiocenosis of landfill filtrates are especially widely covered in the scientific literature (Govahi et al., 2012; Dzhamalova, 2015; Payandeh et al., 2017). The optimum schemes of such processes, perspective types of the equipment for their realization, qualitative and quantitative structures of microbiocenoses which are applied in such technologies are established. Therefore, the selection technologies of excess microbiocenosis in these technologies were not the subject of research in this article.

The authors (Dogaris et al., 2020) (consider the prospects of using microalgae in technologies for the purification of contaminated aquatic environments. It is noted that microalgae can be a sustainable addition to integrated technologies for the purification of aquatic environments. According to (Sardi Saavedra et al., 2018; Sniffen et al., 2015), it is most rational to use a consortium of microalgae of optimum, experimentally determined composition in microalgae treatment as part of a comprehensive biological technology for surface and wastewater treatment. The selection of the increased biomass in order to prevent its uncontrolled biodegradation is obligatory. Selected excess biomass should be used as raw material for the production of biofuels and bioproducts (Dogaris et al., 2020).

Much research has been devoted to the use of aquatic plants for the treatment of contaminated surface and wastewater (Soloviy et al., 2019). The most popular plants that can be used for this purpose are *Eichornia crosses*, or water hyacinth, and *Lemna L.* or duckweed.

Nowadays, there is no unanimous opinion on the feasibility of using water hyacinth to purify contaminated surface water (Villamagna et al., 2010; Flyurik et al., 2014). Water hyacinth is considered mainly as a fast-growing aquatic plant that can be effectively used to purify polluted aquatic environments, decontaminate sewage sludge, eliminate odours, and get biomass for various purposes. It is noted that the uncontrolled spread of this plant and the lack of organized selection of biomass increases the biological threat of secondary environmental pollution during the extinction of plants and their biodegradation.

In Ukraine, lesser duckweed (*Lemna minor L.*) and star duckweed (*Lemna trisulca L.*) are the most common species in stagnant waters. The third species - gibbous duckweed (*Lemna gibba L.*), which has swollen scales, is less common in Ukraine than the previous two. However, the description of the research on the use of these plants in biological technologies for surface and wastewater treatment is almost absent.

A lot of studies indicate the effectiveness of wastewater treatment from different types of pollutants (organic pollutants, ammonium nitrogen, heavy metals) using artificial wetlands. The method of wastewater and surface water treatment using wetlands involves the use of sorption processes for treatment of pollutants, chemical redox reactions and biological activity of selected plants inhabiting wetland ecosystems. Sewage treatment with the help of wetlands can take place in natural or artificial conditions, then they are called "wetlands" and "built wetlands" respectively. Such wastewater treatment is widely used in many countries (Austria, Czech Republic, Denmark, Germany, Italy, Poland, Portugal, Korea, Japan, Australia, etc.). Pollution removal in the constructed catchment systems is due to the functioning of the biofilm formed during the flow of wastewater waters across the riverbed. Plants play a supporting role in the wastewater treatment process. Oxygen is produced in the rhizosphere (around the roots of plants), and other parts of the layer are an anaerobic zone and they produce little oxygen. Plants in the constructed wetland systems can be estimated as the elements providing a constant receipt of oxygen from the atmosphere in a channel. Diffusion of oxygen from the atmosphere through reed leaves and stems allows oxygen to enter the root zone and then into the soil ecosystem, where oxygen can be further transferred by molecular diffusion resulting from the chaotic motion of gas particles (Brix, 1993). Plants in the constructed wetland systems can perform the following functions: stabilization of the soil surface and protection from erosive wind, habitat for fauna (especially birds), thermal insulation, protection of filter material from freezing in winter, creating conditions for the development of heterotrophic microorganisms, responsible for the decay of organic matter.

In recent years, there has been a trend towards the construction of hybrid constructed wetlands comprising two or three layers with vertical and horizontal wastewater flow (Gajewska et al., 2009; Masi et al., 2007). According to many authors, hybrid constructed wetlands provide better conditions for biological wastewater treatment (Gajewska et al., 2009; Masi et al., 2007). Using different types of constructed wetlands, it is possible to combine not only different types of plants but also to implement different types of wastewater treatment technologies – with vertical and horizontal flows. Plants such as reeds (Rai et al., 2013), willow (Jozwiakowski et al., 2020), barley, oats, corn, rye (Lapan et al., 2019), as well as combinations from different types of plants (Marzec et al., 2018) were used to form the constructed wetlands.

It should be noted that along with the information on the effectiveness of using different types of hydrobionts to treat polluted aquatic environments, the information on finding effective methods for selecting excess biomass of aquatic organisms, mainly practical (due to the need to prevent secondary pollution by biodegradation products), there is almost no information on the utilization of this biomass. It is only noted that it can be used to produce biogas (Nykyforov al., 2016; Malovanyy et al., 2016b), in animal feed, in composts and for other agricultural purposes (Cleaning…, 2020).

The purpose of the study is an analytical review of the known technological approaches to ensure the full life cycle of hydrobionts in biological technologies, their use for the treatment of contaminated surface and wastewater and the development of optimum strategies for collecting and concentrating hydrobionts for further utilization.

2. Materials and Methods

The object of the research and analysis of the rational processes of excess biomass selection were different types of aquatic organisms that can be used in biological technologies for water treatment:

– microalgae (cyanobacteria *Microcystis aeruginosa*);

– floating aquatic plants (water hyacinth *Eichornia crassipes* and duckweed *Lemna L.*);

– aquatic plants with a developed root system (reeds, sedges).

We analyzed the optimum technologies for collecting these types of aquatic organisms.

Concentration should be performed for fine types of aquatic organisms (microalgae), so we studied the concentration of cyanobacteria Microcystis aeruginosa. To study concentration, suspensions with an initial concentration of microalgae cells from 200 ppm to 1000 ppm (mass fractions on the dry matter) were used.

PAX coagulants have been effectively used for many years in the processes of water and wastewater treatment, lake recultivation etc. (Bigaj et al., 2013). To find the optimal solution for the microalgae thickening, different subtypes of PAX coagulants were tested in this investigation: from low-basicity coagulant PAX-18 to high-basicity coagulant PAX-XL19H. Polymeric flocculants of medium to high molecular weight and with the corresponding charge density are found as the most effective in the microalgae suspensions (Granados et al., 2012). In this work, the effect of both PAX coagulants, polymeric flocculant A100 and their combinations on the aggregation of cyanobacterial biomass, by analogy with the coagulation-flocculation process in water treatment, was investigated.

Industrial coagulants and flocculants manufactured by P.P.H.U. WĘGLO-STAL (Poland) were used to test the method of concentrating the aqueous suspension of blue-green algae by the coagulation-flocculation:

– polymer-aluminium coagulants of brands PAX-18 and PAX-XL19H:

– flocculant of brand A100.

Reagents of appropriate composition were added to the test suspension. The concept of using reagents in the minimum possible concentrations was adopted (in order to increase the technical and economic indicators of concentration). Mass concentrations of coagulants PAX-18 and PAX-XL19H were 10 ppm and 1 ppm, and the concentration of flocculant A100 was 10 ppm and 1 ppm when used without coagulants and only 1 ppm when used with coagulants. The dynamics of the concentration of the suspension of Microcystis aeruginosa suspension was studied at the initial concentration of cells in dry matter C_0 = 500 ppm. The dry matter content of the suspension was determined by a standard method.

3. Results and Discussion

In the life cycle of hydrobionts, in the case of their use in biological technologies for wastewater and surface water treatment, 4 stages can be distinguished (Fig. 1).

The intensity of the implementation of the first stage is determined by the degree of compliance of the purification conditions with the optimum conditions for the development of hydrobionts. Besides environmental factors (temperature, light, hydrodynamic regime, climatic conditions, pH of the aquatic environment and its chemical composition, etc.), the concentration of the main nutrients plays an important role: nitrogen and phosphorus compounds, from which the hydrobionts purify water environment and which are a source of excess biomass of aquatic organisms.

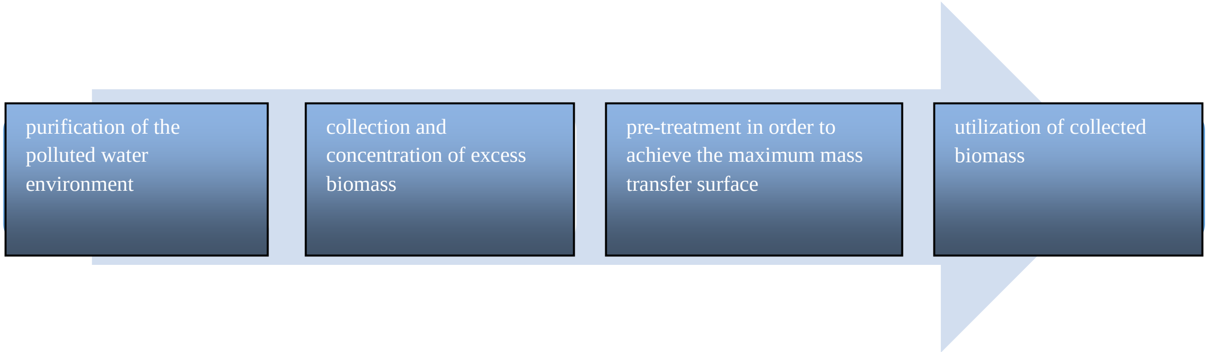

Fig. 1. Life cycle of hydrobionts in wastewater and surface water treatment technologies

The implementation of the second stage – the collection and concentration of hydrobionts for their further utilization is largely determined by the type of hydrobionts used in biological technology for the treatment of polluted aquatic environments.

Pre-treatment of collected and concentrated biomass of hydrobionts can be carried out using fine grinding and grinding, ultrasonic cavitation, hydrodynamic or vibrohydrodynamic cavitation.

Utilization of the collected biomass can be implemented by obtaining energy carriers (biogas or biodiesel), organic or organo-mineral fertilizers, protein and other products necessary for the economy.

Considering promising technologies for collecting and concentrating of hydrobionts, it is necessary to separate 3 groups of technologies and equipment for collecting and concentrating excess biomass of hydrobionts, increased in the polluted wastewater and surface water treatment process:

1. collection of floating aquatic plants and macroalgae biomass;
2. collection of aquatic plants with a developed root system biomass;
3. collection and concentration of microalgae.

3.1. Collection of the biomass of floating aquatic plants and macroalgae

Collecting aquatic plants is a technologically advanced process for which the existing technological equipment is used. Figure 2 shows the technology of collecting water hyacinth.

Fig. 2. Collection of water hyacinths by a specialized water combine

3.2. Collection of the biomass of aquatic plants with a developed root system

The use of dredgers can be called the most effective way to purify the water surface from excess biomass of hydrobionts: reeds, sedges, algae and other wild crops that pollute the ecosystem of the reservoir. Professional productive equipment allows us to cope with the problem of excess biomass selection not only quickly but also with all the basic parameters, such as the depth of mowing vegetation to prevent the resumption of its rapid growth in the water.

Floating mowers with rakes, dredgers with buckets and other professional equipment – the only type of equipment that can effectively perform work on purifying ponds, improving the ponds, lakes and riverbeds ecosystem, clearing the water area for various purposes to prevent rapid growth of distant vegetation. In addition, due to the high productivity of such equipment, work on cleaning the reservoir is performed in the shortest possible time, which allows us to avoid making adjustments to the schedule of basic tasks for the operation of the reservoir in full accordance with its purpose. The mechanized method of cleaning reservoirs from algae and reeds is accompanied by the possibility of a careful collection of mowing products and their storage in specially designated areas with subsequent utilization.

Fig. 3. Using a floating mower to collect excess reed biomass

3.3. Collection and concentration of microalgae

Industrial technologies for collecting and concentrating microalgae have not yet been developed. That is why the uncontrolled development of microalgae in the river water areas in the absence of technologies for the extraction of their biomass poses a significant environmental threat during their extinction and biodegradation. The complexity of the implementation of these technologies is due to the fine size of microalgae and the proportionality of their density with the density of water. Therefore, their separation is possible only under conditions of extraction from places of concentration in natural conditions due to hydrodynamic conditions of reservoirs (from stagnant zones created by the appropriate relief of the shoreline, the arrangement of dams, upper reaches of hydroelectric power plants). Further concentration of the collected suspension should be carried out in the field of gravitational forces, the use of coagulation – flotation methods for concentrating suspensions of microalgae may be promising.

The authors (Zahirniak et al., 2017) propose the removal of cyanobacteria concentrated in places of “natural concentrators” in several stages using overflow thresholds or pumping hoses in the first stage and vertical concentration columns in the second stage. At both stages, the collection and concentration operations are interconnected and complementary.

It is proposed to implement the first stage either in stationary conditions (stationary equipped in cyanobacteria concentration places system of overflow thresholds, submerged pumping hoses, “seines” equipped with pumping hoses) or with the use of floating means (specially equipped vessels, submerged barges).

In our opinion, at the second stage it is advisable to use reagent treatment, which will achieve a greater degree of concentration. The study of the effectiveness of the coagulation - flocculation concentration method (Malovanyy et al., 2019) was performed according to the aforementioned method. The conditions of the reagent research regime are given in Table 1, the research results are shown in Fig. 4.

Table 1

Conditions for conducting studies on the concentration of cyanobacteria aqueous suspension by the coagulation – flocculation method

Reagent composition number	Reagent concentration, ppm		
	PAX-18	PAX-XL19H	A100
1	–	–	–
2	10	–	–
3	1	–	–
4	–	10	–
5	–	1	–
6	–	–	10
7	–	–	1
8	10	–	–
9	–	10	1

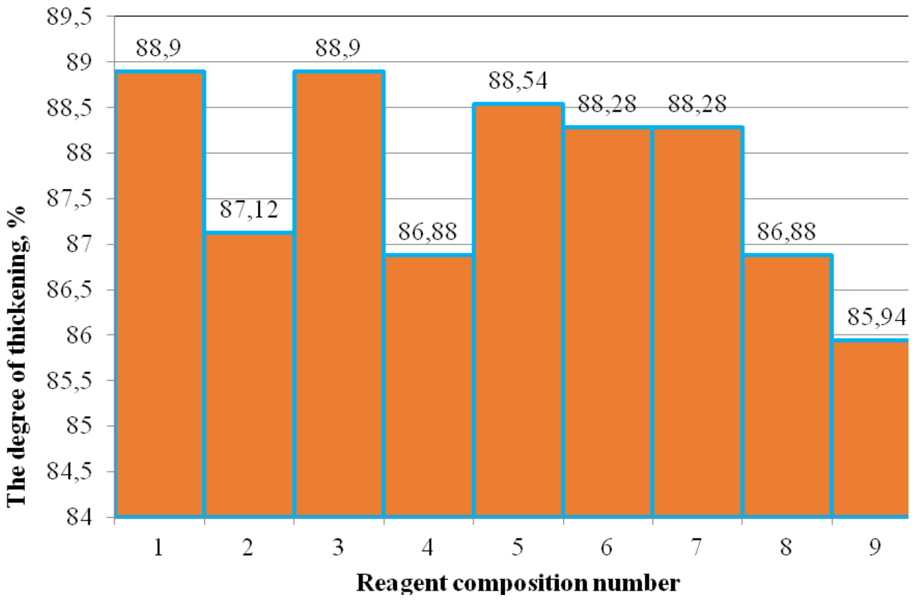

Fig. 4. Dependence of the thickening degree on the reagent composition

Based on the analysis (Fig. 4), the optimum results of thickening (in terms of effect-cost) were obtained with the joint use of coagulants and flocculant A100. At mass concentrations of coagulants PAX-18 and PAX-XL19H 10 ppm and concentration of flocculant A100 1 ppm during 30 min settling after treatment with reagents, the effect of the suspension thickening was achieved by 11.8 and 10.4 times by volume, respectively. The mass concentration of *Microcystis aeruginosa* cells in the sediment as a result of coagulation-flocculation treatment and precipitation increased compared to the initial 9.6 and 9.0 times, respectively, to 4800 ppm and 4500 ppm, respectively.

4. Conclusions

1. The scheme of the life cycle of hydrobionts in wastewater and surface water treatment technologies is proposed, in which 4 stages are distinguished: treatment of polluted aquatic environment; collection and concentration of excess biomass; pre-treatment in order to achieve the maximum mass transfer surface and utilization of the collected biomass.

2. The analysis of technological approaches for the collection of biomass of floating aquatic plants and macroalgae and the collection of biomass of aquatic plants with a developed root system has been carried out. The use of existing technological equipment for these operations is proposed: specialized water combines and floating mowers.

3. The analysis of perspective technologies of collecting and concentrating microalgae is carried out. The use of two-stage processes in this technology is proposed: primary collection by means of overflow thresholds and submerged pumping hoses and concentration in vertical concentration columns.

4. In laboratory conditions, the high efficiency of the coagulation-flocculation gravitational suspensions

thickening method of freshwater microalgae of the *Microcystis aeruginosa* species was confirmed. Aqueous solutions of polymer-aluminium coagulants of brands PAX-18 and PAX-XL19H, as well as flocculant of brand A100 and C494 manufactured by P.P.H.U WĘGLO-STAL (Poland) were used for preliminary coagulation-flocculation suspension treatment.

5. The optimum concentrations of reagents for coagulation-flocculation microalgae thickening of the *Microcystis aeruginosa* species in laboratory conditions were determined. The greatest thickening in the shortest period of time was obtained under the conditions of joint use of coagulant PAX-18 or PAX-XL19H together with brand A100 flocculant. At an initial concentration of *Microcystis aeruginosa* cells (dry matter) of 500 ppm, a mass concentration of coagulants PAX-18 and PAX-XL19H 10 ppm and a concentration of flocculant A100 1 ppm during 30 min settling after treatment with reagents, the effect of thickening suspensions was achieved by 11.8 and 10.4 times by volume. The mass concentration of *Microcystis aeruginosa* cells in the sediment as a result of coagulation-flocculation treatment and precipitation increased compared to the initial 9.6 and 9.0 times, to 4800 ppm and 4500 ppm, respectively.

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