

MULTI-SPECTRAL TELEVISION MEASURING CONTROL OF INTEGRAL PARAMETERS OF POLLUTION USING HIGHER AQUATIC PLANTS IN A COMPLEX FOR SEWAGE TREATMENT

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Abstract. The aim of the work is to improve the methods and tools of multi-spectral measurement control to improve the accuracy of monitoring the integral parameters of wastewater pollution, which is necessary to ensure their effective purification using higher aquatic plants. The complex for wastewater treatment is improved, which is supplemented with the multi-spectral monitoring system of integrated pollution parameters.

Keywords: ecological monitoring, multi-spectral measurements, water, macrophytes, bio-indication.

Introduction

The relevance of the topic is due to the need for operational control of integral parameters characterizing the state of ecosystems of natural water bodies. Integral pollution control can be performed with the help of bio-indication on various aquatic organisms. The use of macrophytes as indicators of the ecological state of water bodies is extremely attractive, because they are visible and convenient for observing [1–11]. In Directive 2000/60/EC macrophytes are considered as an important “quality element for the classification of the ecological status” of the natural and “ecological potential” of heavily modified and artificial water bodies. In this case, for rivers and lakes, it is recommended to use higher aquatic plants as an “element of biological quality”. When studying heavily modified and artificial water bodies, it is recommended to use “biological quality elements” according to the characteristics of such types of natural surface water bodies with which the water bodies are most similar. Analysis of their optical parameters in the visible and near infrared spectral range using remote monitoring devices is used as one of the methods, which allows us

to quickly obtain information about violations of the normal functioning of aquatic ecosystems [2–3]. This method of monitoring water bodies so far has not found wide application in the monitoring system for water bodies of freshwater ecosystems of rivers and lakes. Improved multilevel systems of optical multi-spectral monitoring enable continuous monitoring of the ecological state of water objects, which allows reducing the cost of monitoring environmental studies with increasing their environmental effectiveness.

Materials and methods

A method of water and soil bio-testing for contamination by pollutants on the basis of a welcome color is known to assess the phytotoxicity of components of agrocenoses, in which the number of dead cells stained with a dye is calculated to determine damage to the leaf and make a damage scale for the biotester [12]. The disadvantage of the method is the need to use the safranin dye to determine the damaged areas or the entire leaf blade, which complicates the procedure of determining the qualitative composition and the number of duckweed leaves, which reduces the reliability of water objects pollution control.

The method of complex phyto-indication of the state of acidification of surface waters with the help of the duckweed's (*Lemna minor* L.) test object is that the duckweed plants are placed in model water bodies having different values of the hydrogen index and the concentration of sulphate and nitrate ions, the growth coefficient is determined by weighing. Further, based on the analysis results, a pollution scale is made. In addition, the change in the hydrogen index in model reservoirs, the appearance of duckweeds of chlorosis and necrosis in plants, a change in the growth and color of the roots are determined. A spectro-photometric

measurement of chlorophylls and carotenoids in a total extract is performed and the activity of the Hill reaction in chloroplasts at the rate of recovery of the electron acceptor is determined. Further, the scale of phase reactions of duckweed (*Lemna minor* L.) for changing the conditions of existence is compiled [13]. The disadvantage of this method is that it requires extracting daffodils to determine chlorophylls and carotenoids in leaves, excluding their further use as a test object, besides the research on the presence of chlorosis and necrosis in the leaves is performed by the operator subjectively, which affects the reliability of the phytoindication state of acidification of surface waters.

To improve the reliability of environmental control of pollution of water bodies with the help of duckweed (*Lemna minor* L.), it is necessary to improve the method of multi-spectral television measurement of water bodies pollution in this way. Plants of duckweed are placed in model aquatic environments and make up a pollution scale, supplemented by the fact that model aquatic environments with small duckweed leaves are kept for 7–14 days at a given temperature and illumination, each day, with the help of a hardware-software unit for controlling and processing multi-spectral images, the relative sizes of the aquatic environment that correspond to the duckweed leaves without and with morphological changes and a clean water surface are determined using the multi-spectrum analysis images which are obtained with a broadband CCD camera when the surface of aquatic media is illuminated by LED sources at the characteristic wavelengths of duckweed chromophors. The concentration of the pollutant in the test sample is determined by regression of the results of experimental studies of the dependence of the relative sizes of the aquatic environment on the concentration of pollutants based on multi-spectral studies of a number of samples with the known concentrations [14]. Fig. 1 shows a block diagram of a control tool that implements the proposed method.

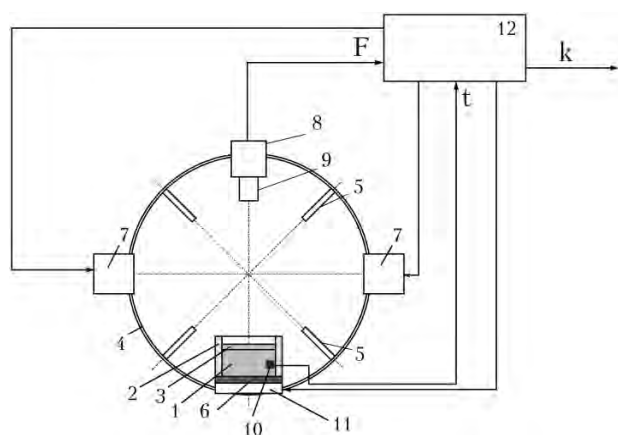


Fig. 1. A tool for multi-spectral television measuring control of pollution of water bodies with the help of duckweed (*Lemna minor* L.)

The control means comprises a model aqueous medium 1 in a quartz cuvette 2, a floating layer of the duckweed test object 3, an integrating sphere 4 coated with a diffusely reflecting coating based on barium sulfate, screens 5 and a coated substrate 6 with an identical integrating sphere, radiation sources 7, a CCD-camera 8, lens 9, temperature sensor 10 heating element 11 hardware-software control and processing unit for multi-spectral images 12.

For the purification of water from pollution with increased environmental hazard, there are complexes consisting of a body of bioreactor filled with water and a layer of higher aquatic plants, pipelines for supplying water for purification and for removing purified water [15–17]. At the same time, the body of the bioreactor is made with the use of heat-insulating materials and is additionally equipped with a translucent coating, as well as a system for the thermal regulation of the internal space and water, including additional convection pipelines located in the body of the bioreactor. In addition, a layer of higher aquatic plants is used by the eichhornia (*Eichhornia crassipes*), the surface of the water is covered with an additional floating thermally insulating material. Eichhornia-complex for water purification from pollution with increased environmental hazard uses a system of thermal regulation of the internal space and water, which are designed to burn environmentally hazardous organic and municipal waste, dried sludge of treatment plants and higher aquatic plants to generate thermal and electrical energy [15]. The disadvantage of the complex is the lack of monitoring of the integral parameters of water contamination passing through the bioreactor, as well as monitoring the state of higher water plants used for water purification.

To improve the efficiency of wastewater treatment using higher aquatic plants, and to ensure reliable monitoring of integral parameters of water pollution, a complex for wastewater treatment and multi-spectral television measurement control of integrated pollution parameters using higher aquatic plants is proposed. It consists of a body of a bioreactor filled with water and a layer of higher aquatic plants, pipelines supplying water for cleaning and drainage of purified water, thermostatic internal space and water control system, floating thermo-insulating material. There is also LED lighting, CCD camera, pulse control unit for illuminators, microcontroller device, control and processing unit for multi-spectral images with LED lighters operating at the characteristic wavelengths of chromophores of higher aquatic plants and connected to the illuminators pulse control unit. The CCD camera is connected to the input

of the control and processing unit of multi-spectral images on the basis of a personal computer which is connected through the microcontroller device to the illuminators impulse control unit and the system of thermal regulation of the internal space and water.

Fig. 2 shows the scheme of the complex for wastewater treatment and multi-spectral television measurement control of integrated pollution parameters using higher aquatic plants.

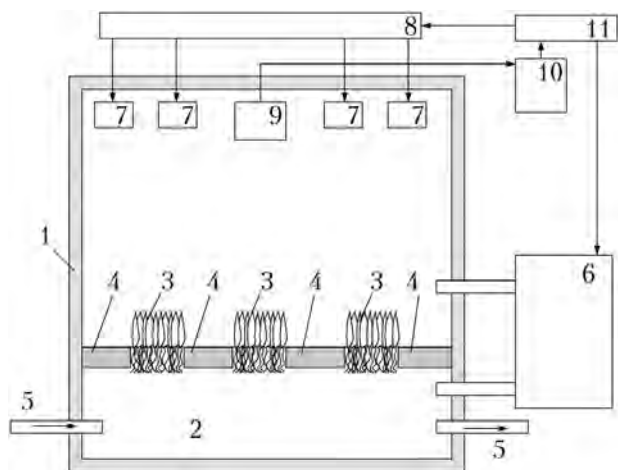


Fig. 2. Complex for wastewater treatment and multispectral television measurement control of integral parameters of pollution using higher aquatic plants

The complex includes a shell of a bioreactor 1 filled with water 2, a layer of higher aquatic plants 3 and a floating thermally insulating material 4. To the shell of the bioreactor, the water supply pipes for cleaning and drainage of purified water 5 are connected, as well as a system for the thermal regulation of the internal space and water 6. In the shell of the bioreactor there are LED lighters 7 connected to the illuminators impulse control unit 8. There is also a CCD camera 9 in the shell of the bioreactor, which is connected to the input of the control and processing unit of multispectral images on the basis of a personal computer 10, which is connected through the microcontroller device 11 to the impulse control unit of the illuminators 9 and a system for the thermal regulation of the internal space and water 6.

Experimental part

The means of multispectral television measuring of water pollution control using duckweed (*Lemna minor* L.) operates as follows. Plants of duckweed (*Lemna minor* L.) 3 are placed in a model aqueous medium 1 in a quartz cuvette 2 located in the integrating sphere 4 on a substrate 6 with a diffusely reflective coating. LED radiation sources 7 ensure the level of illumination

which is sufficient for the growth of plants of duckweed (*Lemna minor* L.). The object of investigation is illuminated by diffuse scattered light reflected from the walls of the integrating sphere 4. The temperature sensor 10 and the heating element 11 are designed to maintain the optimum temperature in the model water environment. Screens 5 prevent direct light from LED radiation sources 7 to the camera or cuvette. Model aquatic environments with duckweed plants (*Lemna minor* L.) are kept for 7–14 days at a given temperature and illumination. The lighting mode is maintained for 18 hours and a dimming mode -for 6 hours per day. Every day the relative sizes of the aquatic environment that correspond to duckweed plants without morphological changes (A), with morphological changes (B) and clean water surface (C) are determined by analyzing multispectral images of the surface of model aqueous media at the characteristic wavelengths of duckweed chromophores. Multispectral images are obtained by illuminating the surface of aquatic media with LED sources 7 at the characteristic wavelengths of chromophores (chlorophyll a, chlorophyll b and carotenoids). A wide-band CCD camera 8 with a lens 9, tuned to a distance to obtain images from the surface of the model water medium, is used.

Multispectral images of the water surface covered with plants of duckweed (*Lemna minor* L.) are shown in Fig. 3. The investigations were carried out under illumination of a test object by LED radiation sources with wavelengths of 465 nm, 525 nm, 590 nm, 625 nm, 820 nm, 860 nm. The width of each of the spectral ranges at 0.5 was from 20 to 50 nm. The image was obtained with a CCD camera MDC140B with a resolution of 1360×1024 and a spectral range of 350–1000 nm.

The concentrations of the main chromophores of the duckweed are calculated as a solution to the inverse optical problem based on multispectral images [18–20]. For each pixel in the image, the distance in the multispectral space is determined to the average values of the luminance coefficient at characteristic wavelengths characteristic of duckweed leaflets without morphological changes, with morphological changes (chlorosis – leaves lose pigments and turn yellow, necroses – localized dead tissue areas, brown or white leaves) and clean water surface and determine whether the pixel of the multispectral image belongs to one of the three classes. The number of pixels and the relative part of the image for each of these zones are counted and the coefficients for the aqueous medium under study and the control sample are calculated.

$$k_{r,c} = \frac{B_{r,c}}{A_{r,c} + B_{r,c}} 100\% \quad (1)$$

A table of the dependence of the coefficients $k_{t,c}$ on the concentration of pollutants $C_{pol i}$ (Table 1) is made for the measurements that were performed every day for

14 days for the test k_t and control sample k_c . A plot of the dependence of the coefficients k_t on the concentration of pollutants is constructed (see Fig. 4).

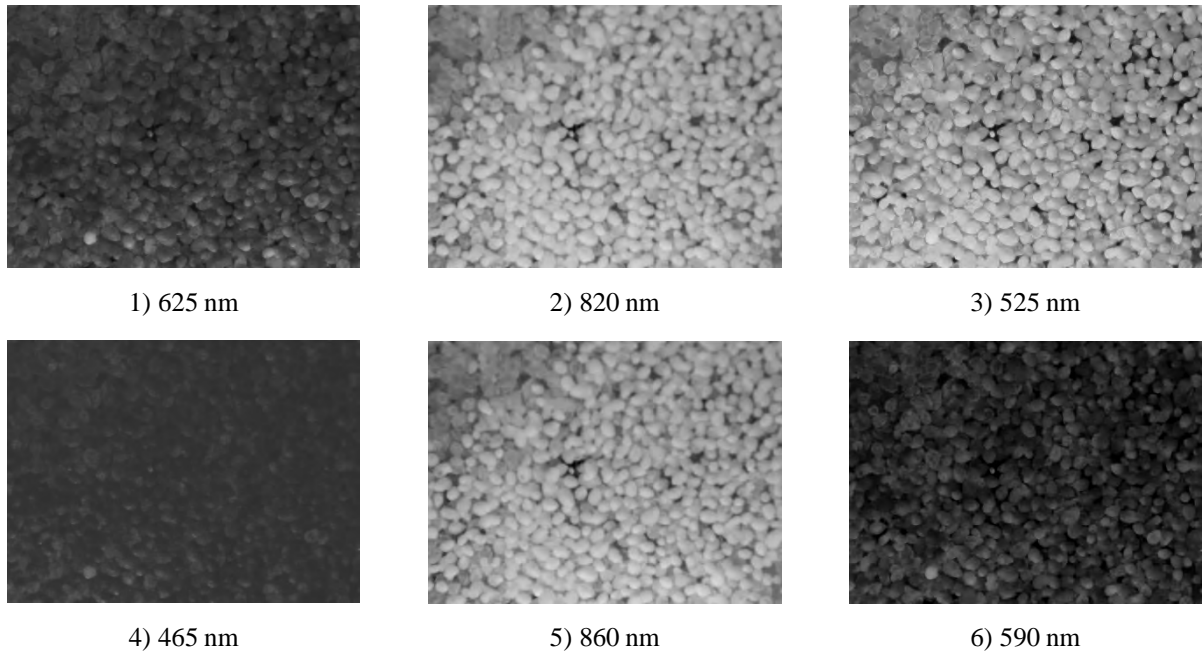


Fig. 3. Multispectral images of the water surface of a duckweed covered with plants (Lemna minor L.)

Dependence of the coefficients k_t on the concentration of pollutants

Table 1

| T, days | $C_{pol 0} = 0$ | $C_{pol i}, \text{mg / l}$ | | | | | |
|---------|-----------------|----------------------------|-----------------|-----------------|-----------------|-----|--------------------|
| | | $C_{pol 1}$ | $C_{pol 2}$ | $C_{pol 3}$ | $C_{pol 4}$ | ... | $C_{pol 10}$ |
| 1 | $k_{c_{-1}}$ | $k_{t_{-1_1}}$ | $k_{t_{-1_2}}$ | $k_{t_{-1_3}}$ | $k_{t_{-1_4}}$ | ... | $k_{t_{-1_{10}}}$ |
| 2 | $k_{c_{-2}}$ | $k_{t_{-2_1}}$ | $k_{t_{-2_2}}$ | $k_{t_{-2_3}}$ | $k_{t_{-2_4}}$ | ... | $k_{t_{-2_{10}}}$ |
| 3 | $k_{c_{-3}}$ | $k_{t_{-3_1}}$ | $k_{t_{-3_2}}$ | $k_{t_{-3_3}}$ | $k_{t_{-3_4}}$ | ... | $k_{t_{-3_{10}}}$ |
| ... | ... | ... | ... | ... | ... | ... | ... |
| 14 | $k_{c_{-14}}$ | $k_{t_{-14_1}}$ | $k_{t_{-14_2}}$ | $k_{t_{-14_3}}$ | $k_{t_{-14_4}}$ | ... | $k_{t_{-14_{10}}}$ |

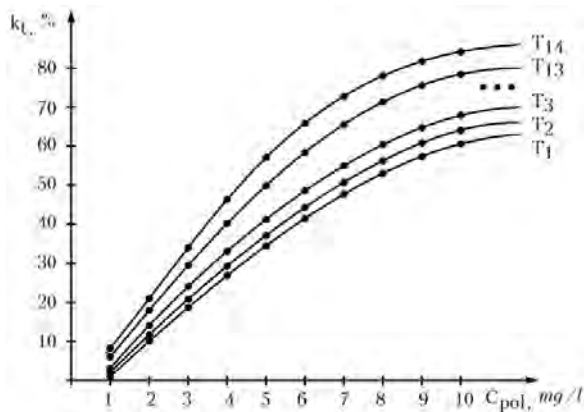


Fig. 4. Dependence of the coefficients k_t on the concentration of pollutants

Using regression with the help of third-order polynomials, the functional dependences of the concentration of pollutants on the coefficients k_t are determined:

$$\begin{aligned}
 C_{pat 1} &= a_{0_1} + a_{1_1}k_{t_{-1_1}} + a_{2_1}k_{t_{-1_1}}^2 + a_{3_1}k_{t_{-1_1}}^3 + a_{4_1}k_{t_{-1_1}}^4, \\
 C_{pat 2} &= a_{0_2} + a_{1_2}k_{t_{-1_2}} + a_{2_2}k_{t_{-1_2}}^2 + a_{3_2}k_{t_{-1_2}}^3 + a_{4_2}k_{t_{-1_2}}^4, \\
 &\dots \\
 C_{pat i} &= a_{0_i} + a_{1_i}k_{t_{-1_i}} + a_{2_i}k_{t_{-1_i}}^2 + \\
 &\quad + a_{3_i}k_{t_{-1_i}}^3 + a_{4_i}k_{t_{-1_i}}^4, \\
 &\dots \\
 C_{pat 14} &= a_{0_{14}} + a_{1_{14}}k_{t_{-1_{14}}} + a_{2_{14}}k_{t_{-1_{14}}}^2 + \\
 &\quad + a_{3_{14}}k_{t_{-1_{14}}}^3 + a_{4_{14}}k_{t_{-1_{14}}}^4.
 \end{aligned}
 \tag{2}$$

The obtained dependences make it possible to determine the concentration of pollutants on the basis of

the known coefficients k_i and testing time T_i . In addition, you can choose the optimal test time, provides the greatest sensitivity of the determination of concentration $C_{pol i}$.

Thus, the measurement of the concentration of pollutants in the aquatic environment is reduced to determining the relative sizes of the aquatic environment that correspond to duckweed plants without morphological changes, with morphological changes and a clean water surface by analyzing multispectral images. With an increase in the concentration of pollutants in the aquatic environment, duckweed with morphological changes increases and without morphological changes decreases. At the same time, the coefficient k_i approaches 100 %. At a low concentration of pollutants, the relative sizes of the zones without morphological changes do not exceed the values of the control sample.

The complex for wastewater treatment and multi-spectral television measurement control of integrated pollution parameters using higher aquatic plants works as follows. The bioreactor 1 is filled with sewage 2 and purified water is withdrawn by means of pipelines 5. Wastewater treatment is carried out using a floating layer of higher aquatic plants 3, for example, eichhornia (*Eichhornia crassipes*). The surface of water free from higher aquatic plants in the bioreactor is covered with a floating thermo-insulating material 4, for example, expanded polystyrene, the spectral characteristics of the diffuse reflection coefficient of which have been previously measured. The shell of the bioreactor is made of materials, which ensure its complete thermal insulation. In the interior of the bioreactor and water, the temperature is maintained that is optimal for the development of those species of higher aquatic plants that is used by the thermal control system 6. Lighting of higher aquatic plants is carried out by LED illuminators 7 in the pulsed mode at the characteristic wavelengths of the pigments with the help of the impulse control unit of illuminators 8. In the upper part of the shell of the bioreactor there is a CCD camera 9 forming an array of multi-spectral images of higher aquatic plants at the wavelengths on which the LED illuminator works.

The control and processing unit for multi-spectral images on the basis of a personal computer 10 processes an array of multi-spectral images of higher aquatic plants and converts it into concentrations of the major chromophores of higher aquatic plants (chlorophyll a, chlorophyll b, carotenoids) in each pixel of the image, which is in fact an indirect measurement of chromophore concentrations using a multi-spectral television method. To improve the accuracy of multi-spectral measurements, an auto calibration with respect

to an object with known spectral characteristics of the diffuse reflection coefficient is carried out, and in this case, relative to the floating thermal insulating material 4. The control and processing unit for multi-spectral images on the basis of personal computer 10 allows to evaluate the state of higher water plants used for wastewater filtration and control of integral parameters of their pollution. Assessment of the state of higher aquatic plants in the control and processing unit of multi-spectral images on the basis of a personal computer 10 is carried out after obtaining the concentration of the main chromophores of higher aquatic plants with the help of an expert system based on fuzzy logic or a neural network. In the case when a significant number of higher aquatic plants lose their pigments and die, the work of the complex ceases with the replacement of the layer of higher aquatic plants with new plants at the stage of vegetative growth. In addition, a personal computer is used to control the operation of the LED illuminators 7 and the thermal control system of the internal space and water 6 by means of a microcontroller device 11.

Results and discussion

As a result of human activities, a great number of different pollutants enter the water bodies together with industrial, communal and agricultural effluents: heavy metals, biogenic substances, organic compounds (pesticides, surfactants, petroleum products), etc. This leads to an excessive anthropogenic load and disturbance of the equilibrium of ecosystems in water bodies. Monitoring of water body pollution [21] by industrial enterprises requires periodic measurement of all parameters, which leads to significant costs for both laboratory investigations and for transporting samples from certain locations. Due to the fact that the subjects of state monitoring of water bodies have limited financial capacity, the control of the ecological state of natural water bodies is very rare. In the intervals between the measurements, the actual state of pollution of water bodies is not controlled, which leads to an increase in the pollution of water bodies and a significant deterioration in their ecological state. Higher aquatic plants have the ability to remove pollutants from water: biogenic elements (nitrogen, phosphorus, potassium, calcium, magnesium, manganese, sulfur), heavy metals (cadmium, copper, lead, zinc), phenols, sulfates, petroleum products, synthetic surface substances and improve such indicators of organic pollution of the environment as biological oxygen consumption and chemical oxygen demand [22]. The proposed improved methods and means of multi-spectral television measurement control using bio-indication on

higher aquatic plants allow to control the integral parameters of pollution and toxicity of sewage with high reliability.

Conclusions

The method of multi-spectral TV measurement control of integral parameters of pollution with the use of bio-indication on higher aquatic plants was improved, which made it possible to increase the reliability of sewage water pollution control.

The complex for wastewater treatment, which uses a bioreactor filled with higher aquatic plants, has been improved, which has increased the efficiency of their purification. The proposed technology of environmental protection can be used for sewage treatment of housing and communal and industrial enterprises.

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