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TECHNOLOGY OF CLEANING OF HIGHLY TURBID WATERS WITH MAN-MADE POLLUTION WITHOUT THE USE OF CHEMICAL REAGENTS

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Reagent-free technology for cleaning highly turbid waters with man-made pollution is an innovative approach to pollution reduction without the use of chemicals. This technology is aimed at removing solid particles and toxic components resulting from industrial activities using physical, electrochemical and membrane cleaning methods. Reagent-free methods allow you to avoid secondary contamination, reduce the cost of chemical reagents and are environmentally safer. This approach has the potential for wide application at industrial facilities, as well as in water treatment systems in areas subject to technogenic influences, which will contribute to environmental protection and improvement of the quality of water resources.

Keywords: *reagent-free cleaning; highly turbid waters; technogenic pollution; Desna River; Snov River; physical cleaning methods; electrochemical methods; membrane technologies; environmental safety; water quality.*

ТЕХНОЛОГІЯ ОЧИЩЕННЯ ВИСОКОКАЛАМУТНИХ ВОД ІЗ ТЕХНОГЕННИМ ЗАБРУДНЕННЯМ БЕЗ ВИКОРИСТАННЯ ХІМІЧНИХ РЕАГЕНТІВ

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У статті доведено, що безреагентна технологія очищення висококаламутних вод із техногенними забрудненнями є інноваційним підходом до зниження забруднення без використання хімічних речовин. Ця технологія спрямована на видалення твердих часток та токсичних компонентів, що утворюються внаслідок промислової діяльності, з використанням фізичних, електрохімічних та мембранних методів очищення. Безреагентні методи дозволяють уникнути вторинного забруднення, знижують витрати на хімічні реагенти та є екологічно безпечнішими. Такий підхід має потенціал для широкого застосування на промислових об'єктах, а також у системах очищення води на територіях, схильних до техногенних впливів, що сприятиме збереженню навколишнього середовища та покращенню якості водних ресурсів.

Метою дослідження є розробка та оптимізація безреагентної технології очищення висококаламутних вод, що містять техногенні забруднення. Дослідження спрямоване на вивчення ефективності різних фізичних, електрохімічних та мембранних методів очищення, які дозволяють зменшити концентрацію *забруднювальних речовин без застосування хімічних реагентів. Це забезпечить створення екологічно безпечних та економічно доцільних рішень для очищення промислових стічних вод, що сприятиме збереженню водних ресурсів і зменшенню негативного впливу на довкілля. Здійснено аналіз якості води в річках Десна і Снов та комплексний аналіз проб води, взятих з цих річок, щоб визначити рівень каламутності, склад і концентрацію техногенних забруднень. Це дозволить оцінити вихідний стан води та виявити основні джерела забруднення. Випробувано різні безреагентні методи очищення води на основі відібраних проб з Десни та Снову, таких як фільтрація, електрофлотація, ультрафільтрація, а також інші фізичні та мембранні методи. Мета – встановити оптимальні параметри очищення для зниження каламутності та видалення техногенних забрудників. Здійснено порівняльну оцінку ефективності кожного методу для умов висококаламутних вод цих річок, враховуючи економічну доцільність і екологічну безпечність. Розроблено практичні рекомендації щодо впровадження безреагентної технології очищення для водойм із подібним рівнем забруднення, орієнтуючись на приклад річок Десна та Снов. Це дозволить сформувати адаптивні підходи до очищення висококаламутних вод з урахуванням специфіки водного басейну України. Дослідження спрямоване на вивчення складу і властивостей цих вод, а також на визначення впливу різних безреагентних методів очищення на зниження рівня забруднення та покращення якості води в умовах антропогенного навантаження. Досліджуються різні методи безреагентного очищення, такі як фізичні, електрохімічні та мембранні, а також їх оптимальні параметри для досягнення максимального рівня очищення.*

Ключові слова: *безреагентне очищення; висококаламутні води; техногенні забруднення; річка Десна; річка Снов; фізичні методи очищення; електрохімічні методи; мембранні технології; екологічна безпека; якість води.*

Surface water sources located in a number of regions of Southern Ukraine are characterized not only by increased turbidity up to 5 g/l, and sometimes more, but also by the presence of man-made pollution in them. Pollutants that are mainly in a dissolved state include phenols, petroleum products, surfactants, biogenic elements, toxic chemicals, and salts of various metals.

Removal of the above-mentioned dissolved substances by traditional reagent-free methods of water purification (settling, filtering) is practically impossible [1, p. 40].

In addition, the disinfection of drinking water by double chlorination, traditionally used at water supply stations in the mentioned regions, is the cause of the appearance in it of a large number of halogen-containing compounds with high carcinogenic activity: chloroform, carbon tetrachloride, trichlorethylene, etc. in minimal concentrations.

Water supply facilities located near the sources mentioned above are mostly characterized by low productivity (up to 200–1000 m^3/day), do not have a sufficient material base for the use of expensive reagent and energy-intensive technologies and operational personnel with the necessary qualifications. For such objects, the task of disposal of reagent-containing sediments formed during water treatment is very expensive and environmentally problematic [2, p. 42].

In this regard, the improvement of existing and the creation of new technologies for reagent-free deep purification of highly turbid waters, which are implemented on compact factory-made water treatment plants, is an important national economic task, especially relevant for Ukraine [3, p. 234].

Scientific novelty of the work:

– new reagent-free technologies and constructions of water treatment facilities and installations (floating water treatment facilities, combined construction «Kivsh-plat») were created, which are based on the principle of economy and environmental safety of using compact devices and equipment;
– obtained new experimental data on water purification from dissolved mineral and organic compounds by means of electrochemical oxidation with deep subsequent sorption purification on filters made of granular activated carbon;
– developed mathematical models for optimizing water treatment system operating modes and software for solving optimization tasks.
– Research methodology includes:
– collection, analysis and generalization of scientific and technical literature for assessment of the temporary state, substantiation of relevance and formulation of the purpose and objectives of

research in the field of purification of highly turbid natural waters containing man-made pollution;
- theoretical studies of substantiation and optimization of water treatment technologies and methods of their engineering calculation;
- experimental studies in laboratory and semi-production conditions of processes and structures of preliminary water treatment, electrochemical oxidation of organic substances in the electrolyzer under the discharge type at low concentrations and filtration through sorption loading.

An analysis of the multi-component system of waste formation and accumulation was carried out. The concept of processes and facilities for preliminary water treatment, electro-chemical oxidation of organic substances in a bulk-type electrolyzer at low concentrations and filtration through sorption loading, a scheme of optimal, from the point of view of environmental safety, waste disposal is proposed.

The obtained results contribute to solving an important task – reducing the impact of man-made formations on the environment.

The selection of the technological scheme and composition of facilities for water treatment is carried out on the basis of a comparison of the quality of water at the source, the requirements for the degree of its purification, taking into account the productivity of the treatment plant and the potential capabilities of the facilities' technologies. The scope of application of new technological schemes of purification can be established on the basis of determining the conformity of technological parameters of new structures (according to research data) to the requirements for the quality of purified water.

In the case when the quality of the source water allows the application of several technological schemes of purification and treatment facilities with different principles of operation, the choice of the most profitable option should be carried out on the basis of a technical and economic comparison of these options.

In order to evaluate the economic effectiveness of the application of the proposed techno-logical schemes for reagent–free treatment of highly turbid waters containing man–made impurities, using a new floating water treatment plant, their indicators were considered in comparison with existing stations of similar performance. As the proposed options are accepted:

Option I – a floating water treatment plant that cleans water not only from suspended and colloidal particles, but also from dissolved mineral and organic compounds directly when taking water from granular activated carbon (at $C_{a<3500}$ mg/l, Q >=200 m^3/day);

Option II – pre–clarification of water from suspended and colloidal particles is carried out at the floating water purification plant «Plate–filter», its further purification from these particles – at the shore filter plant, and purification from dissolved mineral and organic compounds – by electrochemical oxidation with the use of sorption purification on filters made of granular activated carbon, (at $C_{a<5000\,mg}$/l, Q = 200 m^3/day).

As a basic option for the treatment of highly turbid waters, a water treatment plant was adopted according to the scheme: Vertical settling tank – «Struj» – Sorption filter made of granular activated carbon with a capacity of 200 m^3/day (TP № 901-3-91, TP № 901-3-22 86).

The estimated value of the objects is determined in 2020 prices, taking into account the transitional coefficient for capital investment K = 380,000 in the currency of Ukraine – UAH.

A comparative economic assessment was carried out based on specific capital investments, stated costs and cost of water treatment in accordance with the methodology [4, p. 212] by the formulas:

1 $$K = \frac{K_0}{Q};$$

2 $$C = \frac{S_r}{Q};$$

3 $$П = S_r + E_H \times K_0;$$

4 $$З = С + Е_Н \times К;$$

where K is a specific capital investment per 1 m^3 of the station's annual productivity, hryvnias/m^3;

K_0 – capital investment, UAH;

S_r,. – Annual operating costs, hryvnias;

C – the cost of cleaning 1 m^3 of water, UAH /m^3;

$E_н$ – regulatory efficiency ratio of capital investments equal to 0,15;

P – annual specified costs, hryvnias;

З – costs for cleaning 1 m^3 of water are given, hryvnias/m^3.

Capital investment according to comparable options

The results of the calculation of capital investments according to the compared options are given in table 1.

Table 1

Capital investment according to equalizing options

№	Names of the indicators	Unit of measurement	Offered options		Base version
			Option 1	Option 2	VO-»Struya»-SF
1.	General capital investments: including:	thousand hryvnias	66158,0	75935,0	201935,8
	– construction and installation works	«–»	38950,0	41306,0	111796,0
	– equipment	«–»	27208,0	34629,0	90139,8
2.	Specific capital investments	UAH/m^3 man/m	906,27	1040,20	2766,24

Operating costs consist of the following items: salaries of service personnel with deductions for social insurance, energy costs, costs of reagents (if reagent water treatment is provided), depreciation deductions, costs of current repairs and other costs.

Maintenance costs of service personnel are determined on the basis of regulatory recomendations (based on the actual number of service personnel at the node or water treatment station). The mode of operation of water treatment plants is assumed to be three-shift, and the status of periodic observation.

The average salary of workers was 18000 hryvnias [24]. Operation and control of water treatment plants includes operations of starting pumps, control of technological parameters of installations with the help of necessary control and measuring devices.

Additional salary is accepted in the amount of 8 % of the basic salary. It includes payment of basic and additional vacations, payment for night shift work, etc.

Deduction for social insurance is accepted in the amount of 22 % of the annual wage fund.

Electricity consumption is defined as follows.

The annual consumption of electricity used for the operation of pumps is determined by their average specific consumption for lifting 1 m^3 of water according to [33] formulas:

5 $$\rho = 0{,}00273H/\eta, \text{кВт} * \text{год/м}^3;$$

6 $$\rho_{\text{ср}} = 0{,}01 \sum P_1 \rho_1;$$

7 $$A = Q_{dail.\ av.} * n * \rho_{av.} * \delta;$$

where:
ρ – Specific electricity consumption, kWh;
H – necessary height for lifting 1 m of water, m;
η – the efficiency of the pump, equal to 0,58;
P_1 – hourly supply of pumps in % of daily consumption;
ρ_1 – current specific electricity consumption, kWh;
$\rho_{av.}$ – average specific electricity consumption, kWh;
A – annual consumption of electricity, hryvnias;
$Q_{dail.\ av.}$ – average daily water consumption of the settlement, m/day;
n – number of days per year;
δ – cost of 1 kWh of electricity.

Considering the cost of electricity during water treatment by electrochemical oxidation of 0,44 – and the installed power of the GNOM 16-16 N=1,1 kW pump, the annual electricity costs according to the first option are: 41756 kW/year.

At the cost of 1 kWh of electricity 1,54 hryvnias, annual electricity costs will be:

Operating costs according to the compared options, thousand UAH per year 41756 kW/year x1, 54 = 6405.37 thousand UAH (table 2).

Table 2

Operating costs by options

№	Name of the indicators	Offered options		Base version
		Option 1	Option 2	VO-»Stream»-SF
1.	Salary of service personnel	6480,0	9720,0	12960,0
2	Additional wages of employees	518,4	777,6	1,036,8
3.	Social insurance costs	1425,6	2138,4	2851,2
4.	Electricity consumption	6405,37	7614,78	12008,2
5.	Expenses for reagents	–	–	1401,6
6.	Depreciation deductions	4631,06	5315,45	14135,5
7.	Current maintenance costs	661,58	759,35	2019,36
8.	Other expenses	774,55	1050,51	1611,71
9.	Total operating costs	20896,56	27376,09	47981,37

Similarly, according to the second option, when using the GNOM 25–20 pump, with the installed power N=2 kW, the annual electricity costs will be: UAH 7,614,776.000.

Depreciation deductions are taken at 7,0 %, and the costs of current repairs are 1,0 % of total capital investments [12; 24].

As is obvious. capital investment according to the proposed options is 2,6–3,0 times less, and operating costs and the cost of 1 m^3 of purified water are reduced by 1,7–2,3 times. At the same time, the specified costs become 2,0–2,5 times less than in the basic version.

The expected annual economic effect from the application of the proposed technological schemes of water purification was determined according to the following formula:

8 $$A = P_1 - P_2 = [(S_1 + E_H * K_1) - (S_2 + E_H * K_2)];$$

where P_1 and P_2 – the annual stated costs according to the basic and new options, thousand UAH;

S_1 and S_2 – the cost price of the annual production volume of products according to the basic and new options, thousand UAH;

E_H – standard efficiency coefficient – 0,15;

K_1 and K_2 – capital investments according to the basic and new options, thousand UAH.

Thus, the expected annual economic effect from the use of new floating water treatment plants is productivity 200 m^3/day in the first option:

E = [(47981,37+0,15x201935,8)–(20896,56+0,15x66158,0)] = 474510.48 thousand UAH;

in the second proposed option:

E = [(47981,37+0,15x201935,8)-(27376,09+0,15x75935,0=395050.4 thousand UAH.

Therefore, the expected annual economic effect from the use of floating water treatment plants in the first proposed option is UAH 47,4510.48 thousand, and in the second option – UAH 39,5050,40 thousand.

High indicators of economic efficiency of the proposed technological schemes for cleaning highly turbid waters containing man-made impurities with the use of floating water treatment plants are mainly associated with a significant simplification of the technological process of water treatment. At the same time, the compactness of water treatment plants is ensured, a significant saving of metal is achieved, and the operation of the entire complex of the water treatment plant is simplified.

The use of a floating water treatment plant provides a high economic effect also due to the reduction of capital investments in the construction of structures that carry out purification in two stages: preliminary clarification at the place of water intake from a surface source and settling and filtering on land. At the same time, the area under structures is reduced by 10–15 times, the need for construction of structures for collecting, processing and disposal of sediment is eliminated.

This completely reduces the use of the site of sludge accumulators, i.e. a significant area of land is freed and pollution of groundwater and surface runoff of water sources is prevented.

The technical and economic efficiency of the use of floating water treatment plants in the system of wasteless technological schemes of water treatment in two variants has been determined. It was established that the capital investment according to the proposed options is 2,7–3,0 times less, and the operational costs and cost of 1 m of purified water are reduced by 1,7–2,3 times.

At the same time, the indicated costs become 2,0–2,5 times lower than in the basic version.

The expected annual economic effect of the proposed options is UAH 47,4510.48 thousand and UAH 39,5050.4 thousand, respectively.

High indicators of the economic efficiency of the proposed technological schemes are mainly associated with a significant simplification of the technological process of cleaning highly turbid waters. At the same time, the compactness of water treatment plants is ensured, a significant saving of metal is achieved, and the operation of the entire complex of the water treatment plant is simplified.

The basic physico–mechanical and chemical-mineralogical properties of water, as well as the sanitary-bacteriological and hydrobiological composition of water pp. Desna and Snov, were studied. It has been established that the turbidity of water pp Desna and Snov during floods reaches 5–10 g/l and more. A distinctive feature of the dynamics of changes in turbidity is the change in the content of suspended solids during the day and even hours from the average value (1,95 g/l) to the maximum (10 g/l). Types of adsorbed clay particles, including montmorillonite clays, the content of which in the source water reaches 20–30 %, are predominant in the composition of suspended matter in these rivers. These particles have increased physical and chemical exchange capabilities in relation to non-clay particles and significantly affect the aggregative stability of suspended particles. To justify reagentless technologies for cleaning highly turbid waters based on analysis and information on water quality p. Desny and Snov rivers for the period 2013–2019. a database was compiled, a software product was developed in the form of dynamic series, on the basis of which calculated concentrations of characteristic pollutants of man-made origin were determined.

On the basis of well-known theoretical developments and experimental studies of the author, a combined reagent-free technology for the preparation of drinking water from highly turbid water sources containing man-made (anthropogenic) impurities is substantiated, which consists in the pre-treatment of surface water in a water intake bucket-settlement, in the end part of which finely dispersed and colloidal suspensions are placed, and purification from dissolved mineral and organic compounds, including those of man-made origin, is carried out by subsequent electrochemical oxidation in a bulk-type electrolyzer and sorption purification on filters made of granular activated carbon.

The patterns of settling of water in a settling bucket with a system of its forced washing were studied. It was found that with the turbidity of the source water up to 5000 mg/l and the productivity of the «Plate-filter» installation up to 1500 m^3/day, the efficiency of settling waters with different concentrations and hydraulic fineness of the suspension in the source water increases with an increase in the length of settling from 40 to 100 meters slightly (40–52 %).

The results of experimental studies determined the main technological parameters of the «Plate-filter» units for the turbidity of the incoming water up to 4–5 g/l, specific.

On the basis of dimensional theories and methods of similarity, calculated dependences of the degree of water illumination on the main technological and structural parameters of the «Plate-filter» installation operating in reagent-free mode were obtained. The necessary parameters for washing the installation are set: the intensity of the downward flow -10–12 l/cm^2, the duration of washing up to 4 minutes, the relative expansion of the load during washing – up to 35 %.

The laws of electrochemical oxidation of low-concentration organic compounds in backfill type electrolyzers were studied, the effects of specific hydraulic loads and electrochemical characteristics of electrolyzers on the efficiency of oxidation and removal of man-made impurities were determined. Based on experimental studies, it was established that depending on the specific costs

of electricity in the range of 0,05–0,1 A-g/l, the purification effect by oxidizability reaches 13–45 %, and by HPK 35–69 %.

The washing mode of the electrolyzer, as well as the washing and regeneration modes of the sorption units of water purification, were studied. It has been established that the most effective method of activated carbon regeneration is electrochemical regeneration, based on the use of activated carbon directly as a bulk anode, and sodium chloride solution as an electrolyte. In this method, activated carbon is quite resistant to destruction during electrolysis in solutions of alkali metal salts.

Five variants of technological schemes for reagentless deep purification of highly turbid waters containing man-made impurities have been developed for different productivity (up to 1000 m^3/day) and suspension content in the source water (up to 5–10 g/l and more), differing by location location of electrochemical blocks. oxidation, sorption additional purification of inert granular filters. Author certificates and patents for inventions were obtained for 4 plant designs and technological schemes.

Structural and mathematical models of the calculation program have been developed to solve tasks related to determining the optimal control parameters of the main blocks of the technological scheme: Ladle-settlement; «Plate-filter-electrolyzer»; Sorption filter – and the task of optimizing the control directly of the «Plate filter» installation has been solved.

The technical and economic efficiency of using floating water treatment plants in the system of technological schemes for reagentless water treatment in two variants has been determined. It is established that capital investment; proposed new technologies are 2,7–3,0 times less, and the costs and cost of 1 m^3 of purified water are 1,7–2,3 less compared to the basic version: Vertical sump «Struj» – Sorption filter.

Therefore, the main physical-mechanical and chemical-mineralogical properties of water, as well as the sanitary-bacteriological and hydrobiological composition of water pp. Desna and Snov, were studied. It was established that the water turbidity of the Desna and Snov springs during floods reaches 5–10 g/l and more. A distinctive feature of the dynamics of changes in turbidity is the change in the content of suspended solids during the day and even hours from the average value (1,95 g/l) to the maximum (10 g/l). Types of adsorbed clay particles, including montmorillonite clays, the content of which in the source water reaches 20...30 %, are predominant in the composition of suspended matter in these rivers. These particles have increased physical and chemical exchange capabilities in relation to non-clay particles and significantly affect the aggregative stability of suspended particles. To justify reagent-free technologies for cleaning highly turbid waters based on analysis and information on the water quality of the Desna and Snov springs for the period 2013–2019. a database was compiled, a software product was developed in the form of dynamic series, based on which calculated concentrations of characteristic pollutants of man-made origin were determined.

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The results of experimental studies determined the main technological parameters of the «Plate-filter» units for the turbidity of the incoming water up to 4–5 g/l, specific.

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The washing mode of the electrolyzer, as well as the washing and regeneration modes of the sorption units of water purification, were studied. It has been established that the most effective method of activated carbon regeneration is electrochemical regeneration, based on the use of activated carbon directly as a bulk anode, and sodium chloride solution as an electrolyte. In this method, activated carbon is quite resistant to destruction during electrolysis in solutions of alkali metal salts.

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The annual economic effect according to the variants of technological schemes «Plate filter – electrolyzer» – Sorption filter and «Plate filter BNF-NIMI-2» – amounted to UAH 474,510.48 thousand and UAH 395,050.4 thousand, respectively.

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