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TECHNOLOGICAL MODELING OF THE PROCESS OF REAGENT REMOVAL OF PHOSPHORUS FROM WASTEWATER

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Abstract

The work is devoted to the study of the technology of urban wastewater treatment, specially designed to remove the biogenic element phosphorus. An analytical review of the achievements and publications on the study of the process of wastewater dephosphotation by the reagent method is given. Based on the analysis carried out, the results of our own experimental studies are proposed and substantiated. The dependence of the effect of dephosphotation of wastewater on the dose of the reagent when using mineral coagulants, taking into account changes in environmental conditions, has been established. To optimize the cleaning process, mathematical modeling methods based on influencing and determining factors were used. Graphs and regression equation obtained, which determine the dependence of the residual concentration of wastewater phosphates on the dosing conditions of the aluminum polyoxychloride reagent.

Keywords: wastewater treatment, dephosphotation, optimal planning, multifactorial experiment, aluminum polyoxychloride.

ТЕХНОЛОГИЧЕСКОЕ МОДЕЛИРОВАНИЕ ПРОЦЕССА РЕАГЕНТНОГО УДАЛЕНИЯ ФОСФОРА ИЗ СТОЧНЫХ ВОД

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Реферат

Работа посвящена исследованию технологии очистки городских сточных вод, специально предназначенной для удаления биогенного элемента фосфора. Приводится аналитический обзор достижений и публикаций по изучению процесса дефосфотации сточных вод реагентным методом. С учетом проведенного анализа предлагаются и обосновываются результаты собственных экспериментальных исследований. Установлена зависимость эффекта дефосфотации сточных вод от дозы реагента при использовании минеральных коагулянтов с учетом изменения условий среды. Для оптимизации процесса очистки использованы методы математического моделирования на основе влияющих и определяющих факторов. Получены графики и уравнение регрессии, которые определяют зависимость остаточной концентрации фосфатов сточных вод от условий дозирования реагента полиоксихлорида алюминия.

Ключевые слова: очистка сточных вод, дефосфотация, оптимальное планирование, многофакторный эксперимент, полиоксихлорид алюминия.

Introduction

The study of the mechanisms of complex processes and the properties of multicomponent systems, as well as their optimization in modern mathematical theory, makes it possible to model wastewater treatment processes based on influencing and determining factors. The object of the study was the reagent dephosphotation of wastewater using the method of optimal planning of the experiment [1].

A multifactorial experiment is widely used in modern scientific activity and is an effective means of processing and planning experimental studies. The effect of wastewater treatment, the residual content of impurities will be a response function with optimal design of the experiment. Mathematical models obtained using the methods of planning experiments are usually called experimental-statistical [2]. At the same time, the value of a mathematical description lies in the fact that it gives information: about the patterns of influence of individual factors on the response function; allows you to quantify the value of the response function for given values of factors; can serve as a basis for optimizing the process, its imitation [3].

Removal of biogenic elements (compounds of nitrogen and phosphorus), leading to eutrophication of water bodies, is currently one of the main directions in the field of wastewater treatment. The removal of nitrogen and phosphorus by the biological method are interrelated. Due to rather stringent requirements for the content of phosphorus in purified water, priorities are shifting towards the removal of phosphorus. When using a biological cleaning method, the efficiency in reducing the concentration of phosphorus is 78-80%. At the same time, the biological treatment process is considered to be very sensitive and unstable. The use of the method of chemical removal of phosphorus makes it possible to reduce its concentration at the outlet of the treatment plant by 95% (up to 0,5 mg/dm^3).

In papers [4,5], the issues of mathematical modeling of the processes of flotation wastewater treatment are considered. Descriptions of thermodynamic and kinetic models of the flotation process are given. It is shown that the use of mathematical models of wastewater treatment devices allows optimizing their technological and economic performance without significant costs for additional experimental studies. Known is the development of a software package that mathematically describes the dynamics of anaerobic wastewater treatment using the example of traditional type reactors and reactors in which the stages of acid and methane fermentation are spatially separated [6], the process of membrane wastewater treatment has been studied [7]. Mathematical processing of the results of experimental studies with the help of interpolation polynomials has been carried out, a functional dependence of the change in the physicochemical parameters of the processes of membrane wastewater treatment has been established.

The essence of the method of chemical removal of phosphorus from wastewater is the addition of reagents, the formation and precipitation of undissolved phosphorus compounds and their removal with sediment. As reagents can be used:

- calcium compounds (calcium oxide CaO and calcium hydroxide $Ca(OH)_2$);
- aluminum compounds (aluminum sulfate $Al_2(SO_4)_3 \cdot 18H_2O$, aluminum oxychloride $Al_2(OH)_5Cl$, etc.);
- iron compounds (iron (III) chloride $FeCl_3 \cdot 6H_2O$, iron (II) sulfate $FeSO_4 \cdot 7H_2O$, etc.);

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– natural materials (clays, limestone, zeolite, dolomite, etc.);
– production waste (blast-furnace slag, sludge from water treatment facilities).

In works [8-11] the main attention is paid to the study of wastewater dephosphotation methods and the efficiency of their use. Each of the described methods has its own effect on the removal of phosphates from wastewater through the use of special reagents and their physical properties. There are known studies on mathematical modeling of wastewater dephosphotation processes by the method of a full factorial experiment [12-14]. In particular, the work [14] considers the features of constructing a mathematical model for the process of reagent dephosphotation of highly concentrated wastewater from a pig farm using iron sulfate as a reagent. A characteristic equation has been obtained for calculating the efficiency of removing phosphorus compounds depending on the dose of the reagent, temperature, and Eh. The work [15] analyzes the effect of phosphate ions on the cooling pond of the Rostov NPP and considers the use of a dephosphotation unit in the scheme of reconstructed treatment facilities in the «free» mode zone to reduce it using «Aqua-Aurat 30» as a coagulant. A comprehensive assessment of the efficiency of removing phosphorus compounds from wastewater with its accumulation in activated sludge is known using the innovative reagent preparation VTA Biokat P500 [16]. The results of joint biological and physicochemical purification are presented [17]. Because of modeling, the advantages of using combined chemical-biological dephosphotation of wastewater in aerotanks are shown. The need to improve biotechnologies for the removal of nitrogen and phosphorus from urban wastewater is being actualized [18].

Taking into account the analysis of publications and achievements in the field of optimizing the process of wastewater treatment from biogenic elements, the task of our own research was to obtain experimental-statistical regression equations that reflect the effectiveness of reagent treatment.

The purpose of the performed scientific research was to establish the dependence of the effect of dephosphotation of urban wastewater on the dose of the reagent when using various types of reagents by trial coagulation, taking into account changes in environmental conditions. To achieve this goal, the following research tasks were set to be solved:

1) an analytical review of the application of the method of reagent removal of phosphorus;
2) study of the kinetics of the process of chemical dephosphotation of wastewater;
3) selection of the optimal dose of coagulant depending on the ratio of the concentration of the reagent for metal to the initial concentration of phosphorus (Me:P ratio) at different pH and temperature values.

Materials and methods

Studies of the chemical dephosphotation of wastewater were carried out with the possibility of practical application of the reagent method for removing phosphorus at existing sewage treatment plants in the city of Brest [19, 20]. In the work, methods were used for determining wastewater phosphates, trial coagulation to select the optimal dose of the reagent, and technological and mathematical research methods were used, taking into account the current legal acts. Trial coagulation in the treatment of wastewater was carried out with a 1% solution of the coagulant polyoxychloride aluminum «Aqua-Aurat 30» (with a mass fraction of Al_2O_3 30%) at an initial concentration of phosphates of 10 mg/dm^3. Positive dynamics of purification was also obtained as a result of trial coagulation with iron sulfate (III) $Fe_2(SO_4)_3 \cdot 7H_2O$ reagent (the dose of a 1% solution varied from 18 to 63 mg/dm^3). Taking into account the analytical review of the application of the method of reagent removal of phosphorus and the study of the kinetics of the process of chemical dephosphotation of wastewater, the optimal design of the experiment was carried out using aluminum polyoxychloride.

Results and discussion

In the framework of experimental studies, in order to determine the optimal values of the parameters of the technological process of coagulation of phosphorus compounds in wastewater when modeling the treatment process, we considered the dependence of the residual concentration of phosphates, *Cres*, mg/dm^3, on three factors (table 1):

1) β-factor, taking into account the excess of the reagent, required for the deposition of 1 mol of phosphorus, mol/mol, over the calculated stoichiometric amount;
2) pH values of the medium;
3) ambient temperature, t, °C.

Table 1 – Conditions for conducting a complete factor experiment

Characteristics of the experiment plan	pH	β	t, °C
Basic Level	7,5	1,5	15
Variation interval	1	0,5	5

When conducting research on the treatment of a model solution with a phosphate concentration of 10 mg/dm^3 with «Aqua Aurat 30» reagent, it was established:

1) with an increase in the dose of coagulant (increase in the value of the β-factor), the cleaning effect is achieved from 68 to 91,5%;
2) the maximum effect of removing phosphates is at pH in the range of 6,5–7,5;
3) dephosphating efficiency increases with increasing temperature.

Based on the results of experimental data processing, the regression equation *Cres = f (pH, β, t)*, mg/dm^3, was compiled in the form of a polynomial of the second degree from three variables:

$$Cres = 1{,}24\,\beta^2 - 5{,}38\,\beta + 0{,}43\,(pH)^2 - 6{,}45(pH) + 0{,}01\,t^2 - 0{,}19\,t + 32{,}35. \quad (1)$$

The developed experimental-statistical model (1) makes it possible to represent the response surface on the factorial plane by lines of dependence of the residual concentration of phosphates *Cres* on the β-factor (the ratio of the concentration of the reagent for the metal to the initial concentration of phosphorus) and external environmental factors (Fig. 1, 2).

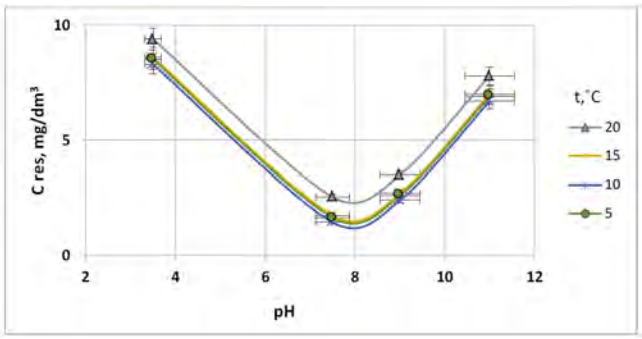

Figure 1 – Influence of the pH parameter on the process of phosphate removal at different water temperatures t,˚C, and β-factor=2,17

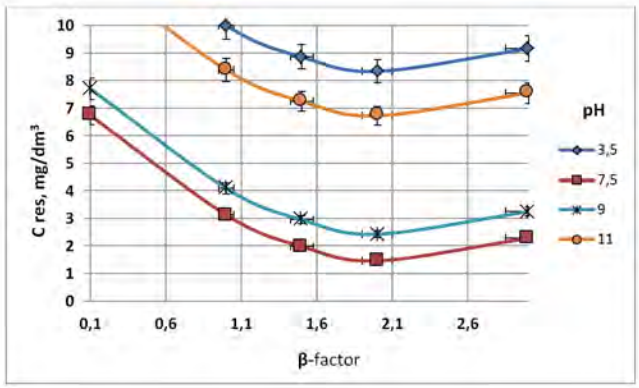

Figure 2 – Influence of β-factor on the process of phosphate removal at different pH and water temperature t=9,5˚C

With the help of the obtained equation, it is possible to predict the efficiency of dephosphotation in a certain mode of conducting the wastewater treatment process. The reproducibility of the experiments was checked using the Cochran test (Gcalc=0,298; Gtabl=0,616). The significance of the regression coefficients was determined taking into account the value of Student's criterion (t=2,57 for the confidence probability P=0,95 and 5 degrees of freedom). The adequacy of the dependencies was confirmed by Fisher's test at a 5% significance level (Fcalc=3,54, Ftabl=5,05).

Table 2 shows the results of the effect of the dose of the injected reagent on the residual concentration of phosphates at different pH values at a wastewater temperature of 10°C.

Table 2 – Effect of pH and dose of the injected reagent on the effect of phosphate removal at a temperature of 10 °C

The hydrogen index pH	Residual phosphate concentration (*Cres*) and removal effect (*Эres*) at β-factor					
	1		1,5		2,0	
	Cres , mg/dm^3	*Эres* , %	*Cres* , mg/dm^3	*Эres* , %	*Cres* , mg/dm^3	*Эres* , %
6,5	3,20	68	2,11	78,9	1,22	87,8
7,5	3,12	68,8	1,98	80,2	1,46	85,4
8,5	3,00	70	2,00	80	1,55	84,5

An analysis of the equation for determining *Cres* depending on pH, β, t made it possible to establish that the minimum residual concentration of phosphates in the process of chemical wastewater treatment is achieved at certain values of the studied factors: pH=7,5; β=2,17; t=9,5 °C; the β-factor and pH of the medium have the greatest influence on the cleaning effect.

Conclusion

1. Removal of nutrients is an urgent task in the field of water resources protection; Analytical and experimental studies of the process of chemical dephosphotation of wastewater using reagents of aluminum polyoxychloride and ferrous sulfate were carried out.
2. Based on the results of a three-factor experiment using the «Aqua-Aurat 30» coagulant, a second-order regression equation was obtained, which is an experimental-statistical model of the process of reagent wastewater treatment from phosphates; all regression coefficients of the equation are significant.
3. At an initial concentration of phosphates of 10 mg/dm^3, the optimal values of the reagent dephosphotation parameters were established, at which the lowest residual concentration of phosphates in the treated water is achieved: pH=7,5; β=2,17; t=9,5 °C.
4. The resulting mathematical model of the process of reagent dephosphotation of wastewater makes it possible to select the optimal dose of coagulant depending on the ratio of the concentration of the reagent for metal to the initial concentration of phosphorus at various pH values and ambient temperatures.

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