Досліджено очищення стічної води від фосфатів. Предметом дослідження є зв'язок між концентрацією фосфатів на виході з очисної станції і показниками «кількість видів гідробіонтів», «об`єм мулу», «муловий індекс», «доза мулу». Виявлено, що коефіцієнти кореляції змінюються від –0,39381 до –0,0485. Також виявлено, вплив пори року на кількість гідробіонтів. Отримані результати сприяють поліпшенню контролю за процесом очищення води

Ключові слова:стічна вода, фосфати, гідробіонти, об`єм мулу, доза мулу, муловий індекс

Исследована очистка сточной воды от фосфатов. Предметом исследования является связь между концентрацией фосфатов на выходе из очистной станции и показателям «количества видов гидробионтов», «объем ила», «иловый индекс», «доза ила». Выявлено, что коэффициенты корреляции изменяются от –0,39381 до –0,0485. Также обнаружено влияние времени года на количество гидробионтов. Полученные результаты способствуют улучшению контроля за процессом очистки воды

Ключевые слова: сточная вода, фосфаты, гидробионты, объем ила, доза ила, иловый индекс

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EXPLORING CORRELATION BETWEEN HYDROBIOLOGICAL INDICATORS OF AERATION TANKS AND THE CONCENTRATION OF PHOSPHATES IN PURIFIED WASTEWATERS

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1. Introduction

Insufficiently purified wastewater, which is dumped into the surface water bodies, can contain phosphorus, which causes their "algal blooms" due to overfertilization with many negative consequences of this process. Constant contamination that exists in Ukraine of water reservoirs with phosphorus necessitates strengthening control over purification process, which depends on various factors [1, 2]. Control over operation of a biological purification plant is carried out by means of chemical analysis of phosphates presence in the cleaned wastewater as well as hydrobiological analysis of active silt of aeration tank (identifying hydrobiont species, silt volume, silt doses and the silt index) [3, 4]. Existing cases of exceeding the residual concentrations of phosphates in cleaned wastewater compared with the established standards make the task of improving control over the process of purification relevant.

2. Literature review and problem statement

The problems of effective use of indices of active silt are considered in scientific sources [5–17]. It is recognized [5] that to ensure quality of purification process, there is a large number of parameters, the time it takes to determine some of them exceeds period of wastewater at a sewage treatment station. In paper [6], the relevance of developing operational methods for controlling wastewater purification process is substantiated. It is proposed to monitor functioning of an aeration tank by physical indices of hydrobionts [7], as the capacity for purifying wastewater depends on the biomass of active silt. Satisfactorily acting (good) silt has a great diversity as for its species composition and its hydrobiological indices are constantly monitored at sewage treatment stations. In article [8], the existence of hydrobionts that effectively purify wastewater from phosphorus was studied and it was revealed that their biomass under the examined conditions amounted to about 4.8 % of the total mass of active silt.

Under actual conditions of sewage treatment plants, technological control over the process of biological wastewater treatment is carried out using such indices as silt volume, silt dose and the silt index. In literary sources, much attention is paid to the use of computer technologies [9] to control purification of wastewater, which are inaccessible for the majority of sewage treatment plants yet. Changes in the composition of active silt depending on the season were revealed in the study [10], they are necessary to be taken into account to ensure quality of wastewater.

Effective results are ensured by the combination of anaerobic and aerobic processes in biological purification, which also requires control over hydrobiont species [11]. But the conducted analysis reveals that the authors of publications used characteristics that limit definition of hydrobiont species and their biomass and do not take into account quantitative data of connection of the studied characteristics to the indices of purified wastewater. Studies [12] present assessment of environmentally important characteristics of various representatives of active silt; it was revealed that the silt index is usually 80–150 ml/g while at values less than 80 ml/g, increased turbidity of the oversediment fluid is possible.

A special attention is paid to the silt index, a system of monitoring the silt index based on the optical method is proposed, which allows estimating sedimentation properties of silt [13].

The indices of active silt (AS) are believed to depend on the content of wastewater, so it is necessary to consider particular conditions. In paper [14], the ratio of the silt dose by mass and the silt index is analyzed, which allows identifying five zones of the wastewater purification process and it was found that for the biological purification unit of sewage treatment plant in the city of Chernihiv, it is desirable that the value of the silt index is within 150–230 cm^3/g, and in the process of threadlike swelling, the silt index increases from 230 to 900 cm^3/g. It may be noted that the relationship between the indices of active silt and the silt concentration in the purified wastewater are not considered in the work.

To improve the process of biological purification, it is recommended to select anaerobic and aerobic zones in the reactor [15, 16] as well as to take into account the silt age, which, depending on the process, may vary within 2–30 days [17]. The presented publications [5–17] demonstrate the importance of taking into account the indices of active silt when controlling a wastewater purification process, but do not consider the problem of informativeness of indices as well as the existence of relationship between phosphates concentration in the wastewater, purified by biological way, and the above mentioned indices.

Authors of some publications suggest that the possibilities of biological treatment in an aerotank are insufficient for purification from biogenic elements and propose to supplement the process with the reagent methods. Thus, in paper [18], it is proposed to use nanotechnologies for purifying wastewater from phosphates. Article [19] provides information on the partial purification of wastewater from phosphorus with the use of the biological method, it is indicated that many factors, including silt dose, are not always taken into account during operation of sewage treatment plants. It is also recognized that biological method of phosphorus extraction is at present most commonly used, because other methods are complicated due to economic or operational problems [19].

One may see from the examined publications that insufficient attention is paid to correlation between the hydrobiological indices and the wastewater indices, nor it is defined which of the indicators is the most informative. Given certain advantages of biological wastewater purification, we have come to the conclusion that this process requires additional research, especially the problem of purification from phosphates.

To improve the quality of a wastewater purification process at the existing sewage treatment plants, these issues acquire scientific and practical significance.

3. The aim and tasks of the study

The aim of the work is to study correlation between the hydrobiological indices of the process of wastewater purification by a biological way (the number of useful hydrobionts, silt volume, silt dose, the silt index) and phosphates concentration at the outlet of a sewage treatment plant.

To achieve the aim, the following tasks were solved:

– to analyze the results of measuring hydrobiological indices, as well as phosphates concentration in the wastewater at the outlet of the sewage treatment plants of DP «Chernihivvodokanal» (Ukraine) and to identify indices that are the most informative as for the quality of the process of wastewater purification from phosphates;

– to identify possible trends of the considered dependencies for practical use in the control of purification process.

4. Materials and methods of research

The material for the research is the results of measuring hydrobiological indices of purification process in an aerotank with the use of active silt, for six months, from January to July of 2015, in particular, we took into account the number of hydrobiont species (N_G), characteristic for the satisfactory action (CSA) of silt, as well as silt volume (V), silt doze (d) and the silt index (I). At the same time, phosphates concentration (C_p) in the purified wastewater at the outlet of the treatment plant DP «Chernihivvodokanal» was controlled. To obtain data for the laboratory of the sewage treatment plant (STP), the standard methods were used [3, 4].

Identification of the hydrobiont types was conducted according to recommendations [3].

Silt volume, mg/dm^3 is the volume that active silt takes after stilling for 30 minutes, assigned to dm^3 (called “concentration of active silt by volume” or “silt dose by volume”).

Silt dose by mass (silt concentration), g/dm^3, is the mass of sediment obtained by filtering a certain volume of silt mix and subsequent drying. The silt index, cm^3/g is the volume, which is taken by 1,0 gram of a dry silt substance, it also characterizes sedimentation properties of silt. The study of correlation between the indices was carried out using computer program Microsoft Excel, the Korel functions of analysis package. Detection of the hidden trends was conducted with the use of fluctuation smoothing with the help of the moving average (the SMA method – simple moving average) [20]. Determining the additional index of the phase changes (L), introduced in the work, was carried out by using the “Solution search” function of the Microsoft Excel analysis package [21].

5. Results of exploring correlation of hydrobiological indices and phosphates concentrations in the purified wastewater

In this work, Authors conducted examination of the paired correlations between phosphates concentration in wastewater at the outlet of the STP (on the one hand) and hydrobiological indices of an aerotank (on the other hand) and took into account the indices on the days when simultaneous analysis of all the given options was run in the period from January to July, 2015. Results of the analysis are presented in Table 1.

Table 1

Laboratory data of the examined indices for determining their correlation

Number of research i	Number of hydrobiont species CSW, units, N_H	Silt doze by volume, ml/dm^3, V	Silt doze, g/dm^3, d	Silt index, cm^3/g, I	Phosphates at outlet mg/dm^3, C_p
1	11	800	3,6	222	8,97
2	12	660	3	220	4,34
3	13	700	3,3	212	7,74
4	13	780	4,1	190	2,96
5	12	680	2,9	234	9,62
6	14	720	3,3	218	4,7
7	13	840	3,7	227	1,42
8	10	780	3	260	2,51
9	11	700	2,5	280	6,13
10	12	880	3,1	284	1,53
11	13	840	3,4	247	2,3
12	14	740	3,3	224	4,48
13	13	700	3	233	2,48
14	10	740	3,7	200	6,77
15	15	500	2,5	200	2,04
16	14	800	3,6	222	1,89

Calculated with the use of the Microsoft Excel computer program, the Korel functions of the analysis package, the correlation coefficient (K_{cor}) between such indices as the silt index – phosphates, the number of hydrobiont species CSA – phosphates, silt volume – phosphates and silt dose – phosphates are presented in Fig. 1.

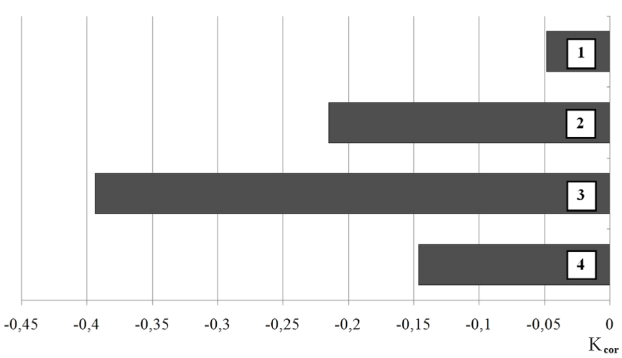


Fig. 1. Indices of correlation between concentration of phosphates in wastewater after purification in aerotank and silt dose (1), silt volume (2), number of hydrobiont species, characteristic for satisfactory performance of silt (3) and the silt index (4)

Relations between phosphates concentration, on the one hand, and the silt index, the number of hydrobionts species CSA, silt volume and silt dose, on the other hand, belong to reverse correlation with the following K_{cor}:

– "silt index – phosphates" provide $K_{cor}=-0,14638$;

– "number of hydrobionts species CSA – phosphates" $K_{cor}=-0,39381$;

– "silt volume – phosphates" $K_{cor}=-0,21502$;

– "silt dose – phosphates" $K_{cor}=-0,0485$.

The obtained data indicate that among the studied indices, the most informative one is the number of hydrobiont species CSA.

In the process of studying dynamics of simultaneous change in the number of hydrobiont species CSA and phosphates concentration in the purified wastewater, the following species were taken into account: Amoeba (Arcella, Euglupha), rotifers (Rotaria, Colurella, Frichocerca, Monostilla), Infusoria (Thuricolla, Vorticella, Epistylis, Lionotus, Oxitricha, Opercularia, Chilodonella, Acineta), Zooglea – bacteria and slime, shell rhizopod (Centropuxis), Shidonotus, Tardigrada. Such representatives identified in active silt of the aerotank as small flagellates, filamentous bacteria, Peranema– euglenozoa flagellates, Nematoda, rotifers were referred to the hydrobionts that characterize unsatisfactory action of silt.

The dynamics of simultaneous change in the number of hydrobiont species CSA and phosphates concentration in the purified wastewater, presented in Fig. 2, *a,* reveals that the process of change in phosphates concentration proceeds in antiphase to the number of hydrobiont species. To improve visibility of the process, we will change the fluctuation phase; for this purpose, it is proposed to replace the index of the number of hydrobiont species (N_H) with the index of the modified number of hydrobiont species (N_{mod}):

$$N_{mod} = L - N_G, \tag{1}$$

where L is the additional index of a phase change, which is calculated taking into account phosphates concentration and the number of hydrobiont species. Thus, selection of additional index of the phase change was carried out with regard to the necessity of minimum distance between function of phosphates concentration and function of hydrobiont species CSA:

$$\sum_{i=1}^{26}\left(L - N_{H(i)} - C_{p(i)}\right)^2 = \min, \tag{2}$$

where $N_{H(I)}$ is the number of hydrobiont species CSW in i-research, C_p is the original phosphates concentration; i is the number of research, i=1,2,...26.

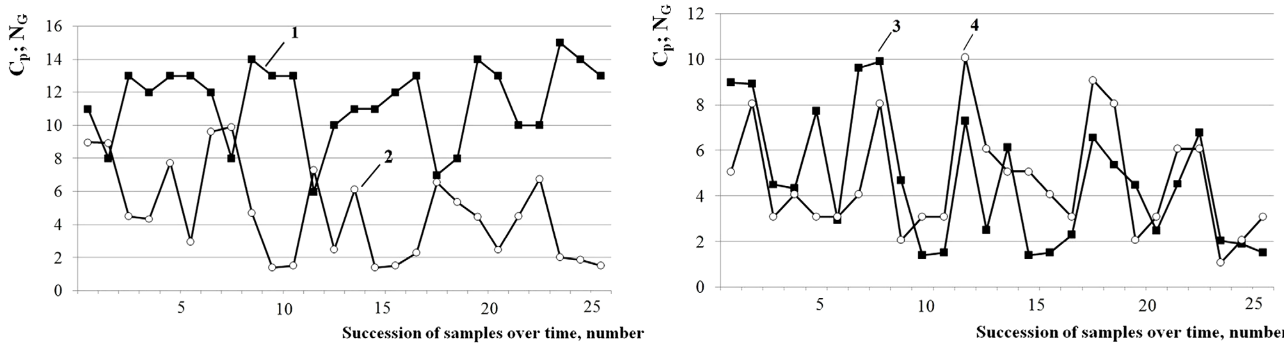
Determining of additional index of change of phase L was carried out using the "Solution search" function of the Microsoft Excel analysis package [21], the obtained value L=16,095 provides for a minimum total of correlations between phosphates concentration and the modified number of hydrobiont species. Some results of calculations of this index are given in Table 2 in columns 4, 5.

The total of the fourth column, Σ=153,872875 is minimal, while a lower value of additional index, for example, L=16.0, provides the total Σ=154,1075, and a higher index, for example, L=16.2, presented in the fifth column, also provides an increase in the total to Σ=154,1595. The value of additional index of the change in phase L=16,095 provides realization of equation (2). Using the "Solution search", we bridge the gap between the values of the modified number of hydrobiont species and phosphates concentration in the same graph.

Results of analysis on the dynamics of changes in phosphates concentration and modified number of hydrobiont species CSA is presented in Fig. 2. The results, presented in Fig. 2, *b*, indicate that a change in phosphates concentration occurs mostly synchronously with the change in the number of hydrobiont species CSA.

Since the fluctuations of the final phosphates concentration somewhat mask relationship between the change in phosphates concentration and the number of hydrobiont species CSA, for better visibility and detection of the trend, we will use the program of fluctuations smoothing using the function of the moving average (SMA) from the Microsoft Excel analysis package. Results of the program performance are presented in Table 3.

The obtained results of the study are shown in Fig. 3, by which it is possible to identify a certain trend.



a *b*

Fig. 2. Dynamics of change in the indices of phosphates concentrations and the number of hydrobionts in purified wastewater: *a* — dependence of phosphates concentration on the number of hydrobiont species CSW of silt in aerotank; *b* — dependence of phosphates concentration on the modified number of hydrobiont species in the aerotank; 1 — number of hydrobiont species CSW; 2, 3 — phosphates concentration; 4 — modified number of hydrobiont species CSW

Table 2

Calculation of modified number of hydrobionts N_{mod}

Number of research i	Number of hydrobiont species CSA, units, N_H	Original phosphates concentration, C_p	$(L-N_{H(I)}-C_{P(I)})^2$ for L=16.095	$(L-N_{H(I)}-C_{p(I)})^2$ for L=16.2	$N_{mod}=L-N_H$ for L=16.095
1	11	8.97	15.01563	14.2129	5.095
2	8	8.93	0.697225	0.5329	8.095
3	13	4.5	1.974025	1.69	3.095
4	12	4.34	0.060025	0.0196	4.095
5	13	7.74	21.57603	20.6116	3.095
6	13	2.96	0.018225	0.0576	3.095
7	12	9.62	30.52563	29.3764	4.095
8	8	9.91	3.294225	2.9241	8.095
9	14	4.7	6.786025	6.25	2.095
10	13	1.42	2.805625	3.1684	3.095
11	13	1.54	2.418025	2.7556	3.095
12	6	7.3	7.812025	8.41	10.095
13	10	2.51	12.85223	13.6161	6.095
14	11	6.13	1.071225	0.8649	5.095
15	11	1.41	13.57923	14.3641	5.095
16	12	1.53	6.579225	7.1289	4.095
17	13	2.3	0.632025	0.81	3.095
18	7	6.56	6.426225	6.9696	9.095
19	8	5.37	7.425625	8.0089	8.095
20	14	4.48	5.688225	5.1984	2.095
21	13	2.48	0.378225	0.5184	3.095
22	10	4.53	2.449225	2.7889	6.095
23	10	6.77	0.455625	0.3249	6.095
24	15	2.04	0.893025	0.7056	1.095
25	14	1.89	0.042025	0.0961	2.095
26	13	1.54	2.418025	2.7556	3.095

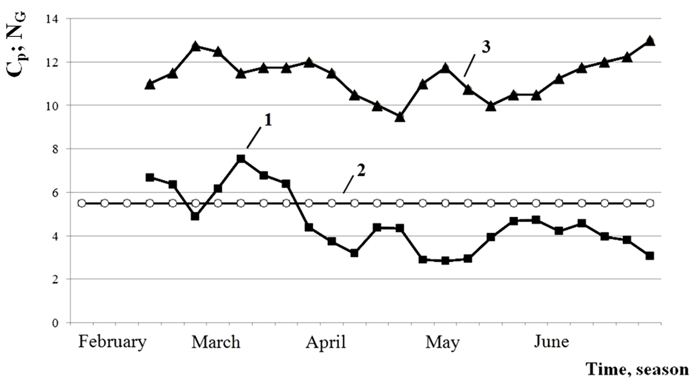


Fig. 3. Dynamics of change in phosphates concentration in the wastewater purified by biological way and the number of hydrobiont species CSA over measurement period using SMA: 1 – phosphates concentration; 2 – maximum permissible phosphates concentration in purified wastewater; 3 – the number of hydrobiont species CSA

Table 3

Results of calculation of SMA (simple moving average) by four points for the number of hydrobiont species CSA and original phosphates concentration

No. of research, i	N_H, units	C_p, mg/dm^3	SMA of number of hydrobiont species, N_H, units	SMA phosphates concentration C_p, mg/dm^3
1	11	8.97	–	–
2	8	8.93	–	–
3	13	4.5	–	–
4	12	4.34	11	6.685
5	13	7.74	11.5	6.3775
6	13	2.96	12.75	4.885
7	12	9.62	12.5	6.165
8	8	9.91	11.5	7.5575
9	14	4.7	11.75	6.7975
10	13	1.42	11.75	6.4125
11	13	1.54	12	4.3925
12	6	7.3	11.5	3.74
13	10	2.51	10.5	3.1925
14	11	6.13	10	4.37
15	11	1.41	9.5	4.3375
16	12	1.53	11	2.895
17	13	2.3	11.75	2.8425
18	7	6.56	10.75	2.95
19	8	5.37	10	3.94
20	14	4.48	10.5	4.6775
21	13	2.48	10.5	4.7225
22	10	4.53	11.25	4.215
23	10	6.77	11.75	4.565
24	15	2.04	12	3.955
25	14	1.89	12.25	3.8075
26	13	1.54	13	3.06

As can be seen from the graph presented in Fig. 3, it is possible to trace the influence of the season on the number of hydrobionts and phosphates concentration in the purified wastewater, because starting from March, phosphates concentration in the wastewater, calculated by SMA, does not exceed a standard norm.

6. Discussion of results of studying the correlation of hydrobiological indices and phosphates concentrations in purified wastewater

The advantage of the conducted study is the fact that we obtained quantitative data of existing relationship between phosphates concentration in the wastewater, purified by biological way, and such indices as “the number of hydrobiont species CSA”, “silt volume”, “the silt index” and “silt dose”.

As a result of the conducted analysis, a correlation character was revealed – it is negative correlation, i. e., an increase in the studied index results in the decrease of phosphates concentration. The informativeness of indices regarding quality of the process of wastewater purification from phosphates decreases in the series: the number of hydrobiont species CSA – silt volume – the silt index – silt dose. It was also found that the change in phosphates concentration in the wastewater purified by biological way mainly occurs simultaneously with the change in the number of hydrobiont species CSA.

The value of the correlation coefficient indicates that purification process is rather complicated, but the use of data, obtained in the study, allows giving preference to one or several indices that are most informative in the course of analysis of purification process. For development of the presented results, it may be useful to build the Shewhart maps or other materials that will contribute to visualization of results and operational control over purification process.

The conducted work is the continuation of development of the operational methods of controlling the wastewater purification process, presented in [5–7].

7. Conclusions

1. The indices of phosphates concentration in the purified wastewater at the outlet of the sewage treatment station within six months’ period were analyzed and their correlation with “the number of useful hydrobionts”, “silt volume”, “silt dose” and “the silt index” was revealed.

2. It was calculated that the coefficients of correlation between phosphates concentration in the wastwater purified by biological way and hydrobiological indices (the number of hydrobiont species, characteristic for satisfactory action of silt, silt volume, the silt index, silt dose) have negative character and vary from $K_{cor.}$=–0,39381 to $K_{cor.}$=–0,0485.

3. The most informative as for the quality of the process of wastewater purification from phosphates among the considered hydrobiological indicators is the index of the number of hydrobiont species CSA, which has the correlation coefficient K_{cor}=–0,39381, as well as the index “silt volume” with the correlation coefficient $K_{cor.}$=–0,21502.

4. The trends of dependencies, applicable for practical implementation in the control over purification process, were revealed:

– a change in phosphates concentration in the wastewater purified by biological way occurs mainly simultaneously in antiphase to the change in the number of hydrobionts, characteristic for satisfactory performance of silt;

– there is a negative effect of winter season on the number of hydrobionts CSA and phosphates concentration of the purified wastewater, which may be connected with wastewater temperature.

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