Розглянуто ефективність роботи мембранного біореактору (МБР) при очистці стічних вод біологічним методом. Експериментальні дослідження проводились на тестовому мембранному біореакторі виробництва фірми «Альфа Лаваль» (Данія). Застосування мембранного біораектору має наступні відмінності від традиційних споруд біологічної очистки: відсутність споруд для відстоювання стоків, концентрація активного мулу до 12–13 г/л тощо. У випадку застосування МБР процес відстоювання замінюється фільтрацією, промивка мембранних модулів проходить без спорожнення ємностей та без вилучення модулів з ємностей. В процесі апробації мембранного біореактору на базі модульної установки виробництва фірми «Альфа Лаваль» (Данія) для очистки побутових стічних вод був досягнутий режим очистки, який відповідає вимогам на скид. Ефективність очистки за основними показниками склала: ХПК – 93 %, БПК5 – 99 %, завислими речовинами – 98,5 %, азотом амонійним – 98,5 %. За нітратами ефективність роботи МБР склала 89 % після налагодження дози реагенту і дози кисню в зоні нітрифікації. Ефективність за фосфатами у 98,6 % була досягнута після налагодження дози реагенту. Проведені дослідження дозволили отримати стабільний режим роботи МБР з забезпеченням ефективного процесу очистки стічних вод. Наведено залежності динаміки зміни величин основних забруднень стічних вод (ХПК, БПК5, сполуки азоту та фосфору). Це дозволяє досягнути жорстких вимог до скиду стічних вод у водойми та знизити собівартість очистки за рахунок зниження енергоспоживання. Вивчено механізм роботи МБР в умовах очистки реальних стічних вод, що дозволяє визначити умови використання МБР в технології біологічної очистки стічних вод

Ключові слова: біологічна очистка, мембранний біореактор, мікрофільтрація, азот, фосфор, нітрифікація, денітрифікація, реагент

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EXPERIMENTAL RESEARCH INTO THE PROCESS OF BIOLOGICAL TREATMENT OF WASTEWATER WITH THE USE OF THE MEMBRANE BIOREACTOR

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1. Introduction

Water drainage belongs to one of the most essential issues of social importance since it has a direct impact on the state of health of population and radically determines the degree of environmental and epidemiological safety of the regions. Analysis of the drainage systems of settlements in Ukraine shows that their level and quality are poor, and in some regions of Ukraine, these problems have become critical [1].

The exacerbation of the problem lies in an increase in the load on water supplies caused by contamination of water sources, since the main pollutants are domestic and industrial wastewater. Almost all industrial enterprises dump sewage into wastewater drainage facilities without pretreatment, which makes it drainage and treatment difficult. Specificity of water drainage facilities is that faults in its operation, especially breakdowns, do not only economic damage, but also decrease the environmental value of these facilities.

The main problems of wastewater treatment facilities in the post-Soviet countries are: their service life is from 20 to 55 years, and the average service life is 35 years (most sewage treatment plants were built in the 1960–1980s). More than 70 % of wastewater treatment facilities need reconstruction [1].

Based on the above, the problem of household and industrial wastewater in most CIS countries is quite urgent. This problem has been getting more acute for the past 25 years and threatens with disastrous consequences.

Application of the scientific approach and modern developments in the field of biological wastewater treatment will make it possible to solve the problem of reconstruction of wastewater treatment facilities and wastewater treatment in general. One of the most advanced trends in this area is application of membrane bioreactors (MBR), which are widespread in the countries of the European Union, the United States, Japan, and others [2–4].

The main differences of the technology of MBR reactors from the classic treatment scheme are as follows:

– no primary settling is required, however, thin grates of 2–3 mm in gap are needed (mostly to remove hair and bulky waste);

– concentration of sludge is 8–12 (up to 14) g/l, while in the classical scheme it is 3–4 g/l;

– filtering instead of sedimentation causes impossibility of getting suspended substances;

– gravitation operation mode – the absence of a part or of all pumping groups;

– washing without removal of membrane modules out of tanks and without emptying capacities.

Due to forecasted future deficit of the areas, allocated for sewage treatment facilities, and more strict regulations imposed on the drainage that has already been treated, we should expect greater use of the MBR technology in the nearest future. Introduction of the membrane technologies into biological wastewater treatment in the CIS countries is only beginning to emerge and is at the stage of particular facilities. These facilities most commonly operate in the lab mode and the experimental base for studying the MBR operation on actual sewers has not been created yet. That is why the problem of studying and analyzing the impact of the initial qualitative parameters of wastewater on efficiency of MBR operation under actual conditions of wastewater treatment facilities and on an actual sewer remains relevant in the CIS countries.

2. Literature review and problem statement

Introduction of new technologies of wastewater treatment contributes to improvement of the quality of treated water and considerable saving of energy and other resources. The most promising is the technology of wastewater treatment using the membrane bioreactor (MBR) [5]. In MBR technology, the processes of micro-and ultra-filtration are combined with aerobic biological wastewater treatment. Membrane (tubular, hollow fibred or flat-framed) in the bioreactor make it possible to remove pollution from water with high selectivity, due to which purified water contains minimal amount of pollutants.

In paper [6], it was stated that over the past two decades, the technology of membrane bioreactors had taken a significant market share in wastewater treatment. It is expected that the annual growth of the rate of MBR application will be higher than that of other advanced technologies and other membrane processes. Application of aerobic MBR will ensure wastewater re-usage. In this case, the MBR are very compact and efficient systems for separation of suspended and colloidal substances, which can achieve the highest quality standards of wastewater for disinfection and cleaning. In the case of the MBR, less excessive sludge is formed, which results in an increase in the age of active sludge. As a consequence, less sediment, which differs from the sediment of traditional sewage treatment plants, is formed. It is necessary to examine in detail the consequences of this process for the structure and metabolism of microbial suspensions.

The authors of work [7] examined the features of using MBR technologies for treatment of highly concentrated industrial wastewater. As a result of analysis of the experimental data, it was concluded that several factors must be taken into account in order to find suitable operation parameters for the membranes. These include time of membranes operation before pores' clogging, dimensions of solid particles, availability of nutrients for microorganisms, trans-membrane pressure, hydraulic load, etc. The factor of membrane contamination with the biomass in the MBR must necessarily be considered because it is the major problem affecting the MBR productivity and wastewater quality.

Paper [8] considered the possibility of application of the technology for wastewater treatment with the possibility of their use for technical needs of enterprises. Several types of membranes were compared, their technical and economic advantages were shown. The issue of disposal of produced sludge, as well as washing and regeneration of membranes when working with active sludge remains a problem.

More than 10-year experience of operation of membrane bioreactors was analyzed in article [9]. The authors indicate the versatility of this method, for treatment of both urban and industrial wastewater. The combination of the MBR method with reverse osmosis allows obtaining practically clean water, not containing even dissolved impurities. However, there is a need to study in detail the issue of changing the characteristics of active sludge during the MBR operation.

The authors of work [10] proposed the technology of application of the anaerobic membrane bioreactor. This technology proved to be very effective in reducing the chemical oxygen demand (COD), in this case, the removed organic substance turns into a useful energy source – biogas. However, the authors point out the need for further studies of some factors, affecting the cleaning process. These include a decrease in time the hydraulic retention, removal of nutrients, removal of certain microcarbonic substances. It is also necessary to explore the establishment of quantitative mass and energy/economic balances and inclusion of efficient reduction of dissolved methane.

New approaches to the MBR operation are described in [11]. The authors propose a new electrochemical membrane bioreactor (EMBR), which allows obtaining energy from wastewater, as well as reusing treated wastewater. In the process of conducting experimental studies, the authors identified the shortcomings in the EMBR operation. Among them, it is possible to distinguish the need for a plant to collect methane, formed under anaerobic conditions, and insufficient removal of nutrients (nitrogen compounds).

The application of modified pressure membranes in the MBR was considered in [12]. The authors proposed wastewater post-treatment technology, based on modified ultra-filtration pressure membranes, which allows effective removal of biogenic elements, and at constant feeding a coagulant solution, ensuring the removal of phosphates. Increased doses of active sludge in combined membrane-biological treatment (8–12 g/l) enable purification in the low load mode, thus providing stable purification quality and active sludge biocenosis that is resistant to external factors. When conducting experimental research during household wastewater treatment, the authors determined the optimal coagulant dose of 15–30 mg/l by $A1^{3+}$. The resulting method of additional treatment is recommended for usage in wastewater treatment stations with full biological purification, which work with incomplete oxidation of organic substances. The research contains no description of the special features of processes of nitrification and removal of phosphorus compounds in a biological way along with the reagent additional treatment.

Ukrainian developments of the biomembrane technology were started around seven or ten years ago [13, 14]. In paper [13], pilot tests of MBR were described and physiological characteristics of active sludge were identified. The author points out the effective operation of membranes and feasibility of replacing the traditional purification scheme "aeration tank – secondary settler" with the MBR. Feasibility of using MBR was explored in paper [14]. The analysis of existing methods of combating clogging of membranes' pores in the MBR was performed and the most effective of them was selected. However, the authors of this research paid little attention to the processes of removal of biogenic elements (nitrogen and phosphorus). The main factors, affecting nitri- and denitrification and dephosphatation of drains were not analyzed.

3. The aim and objectives of the study

The aim of our experimental research into the process of biological treatment with the application of the membrane bioreactor (MBR) was to determine the operating parameters of the MBR in order to ensure stable and efficient wastewater cleaning from nitrogen and phosphorus compounds.

In the course of the experiment, the following problems had to be solved:

– to identify the patterns of removal of nitrogen and phosphorus compounds from wastewater when cleaning at MBR;

– to establish the features of operation of membrane module, produced by the company "Alfa Laval" (Denmark), in various operation modes of the bioreactor at hydraulic load;

– to justify effectiveness and economic feasibility of using wastewater treatment technology the with application of MBR.

4. Materials and methods for the experimental studies of wastewater treatment at MBR

The pilot studies were carried out in the period from August and October, 2017. Wastewater after mechanical treatment (grates, sand catchers, primary settling tanks) was directed to the tested membrane bioreactor, produced by company "Alfa Laval" (Denmark) (Fig. 1). Then, wastewater in the bioreactor passes through the stages of denitrification, and nitrification, and sludge mixture is separated in the membrane capacity. Separated wastewater was disinfected and directed for discharge into the reservoir.

Filtering sludge mixture occurs in the micro-filtration membranes in the membrane module MFM100-25 (Fig. 2). They are the membranes of the submersible type, which are mounted in the tank and operate in the hydrostatic mode, i. e. the water from the membranes is taken directly under the pressure of the fluid column (without pumps). A fluid column above the surface of the membrane (its upper part) is approximately 80 cm. This equipment is designed according to the standard dimensions of aeration tanks that are 3–5 m deep.

Distinctive features of the operation of the membrane bioreactor, produced by company "Alfa Laval" (Denmark) are gravity operation mode (absence of a part or of all pumping groups) and washing without removing membrane modules out of tanks and without emptying the capacities. The modular plant of the MBR is equipped with everything necessary for normal operation of the bioreactor: recirculation pumps, air blowers, TSR–capacity, CIP–capacity, pump of CIP washing, regulating valves, samplers, and automation system.

Fig. 1. General view of the membrane bioreactor "Alfa Laval" (Denmark)

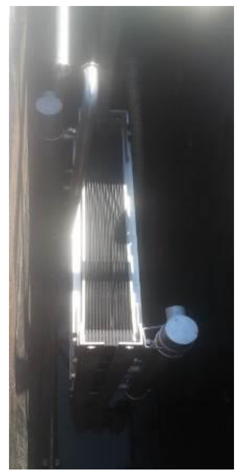


Fig. 2. Micro-filtration membranes in membrane module MFM100-25

For calculation and adjustment of the modular plant MBR, we accepted the wastewater parameters given in Table 1.

Table 1

Qualitative indicators of incoming wastewater

Indicators	Value in the incoming sewer	Requirements for discharge into reservoir (HelCom*)	Standard admissible discharge
Suspended substances, mg/l	80–90	+0.25 to background	7.25
COD, mg/l	200–300	15	30
BOD_5, mg/l	80–150	2	4
Ammonic nitrogen, mg/l	16–22	0.4	General nitrogen – 10
Nitrates, mg/l	0.1–0.3	9	
Nitrites, mg/l	0.05–0.07	0.02	
Phosphorus of phosphates, mg/l	2–4	0.2	General phosphorus – 0.5
General phosphorus, mg/l	2–5	–	
Temperature, °C	20	20	20

*Note: * – HelCom – Helsinki Commission standard for discharge of treated wastewater into the Baltic Sea [15]*

In the process of testing, the operation mode of a plant changed according to the data in Table 2.

Table 2

Operation mode of the plant in the period of experimental tests (August – October, 2017)

Experiment number	Flow rate, l/h	Trans-membrane pressure, mm	Temperature, °C	Membrane area, m^2
1	300	0–40	22.1	25
2	600	≈200	22.3	25
3	600	≈250	22.4	25
4	600	≈300	21.8	25
5	700	≈400	23.6	25
6	700	≈650	24.4	25
Chemical washing of a membrane				
7	600	≈200	23.6	25
8	450	≈200	23.1	25
9	450	≈200	23.7	25
10	450	≈200	24.1	25
11	350	≈200	22.4	25
12	350	≈250	22.6	25
13	350	≈300	22.3	25
14	350	≈300	22.0	25
15	350	≈300	21.5	25
16	350	≈300	21.9	25
17	350	≈300	22.4	25
18	350	≈300	22.2	25
19	350	≈350	20.8	25

The initial period of testing was conducted at a high flow rate of 0.6 m^3/h, and then in the course of the experiment, operation was at the highest flow rate of 0.7 m^3/h.

Testing was continued and completed under conditions of maintaining the stability of results of biological purification operation. In the course of works, the membrane was chemically washed by the method of reagent solution circulation in the system of clean water drainage of the membrane. As a reagent, 20 liters of 15 % solution of sodium hypochlorite were taken for every 500–600 liters of clean water. Washing lasted for 3 hours. Early washing was caused by the outage of the membrane within three days during the initial tests because of a power cutoff. The membrane got covered with sludge as a result of its being in sludge mixture without aeration.

During the tests, there were no jumps of parameters or other negative effects, influencing vital activity of active sludge, including heavy rains. Rainfall might negatively affect the process of biological treatment. However, it often rains in settlements at the seaside and, therefore, this factor is taken into account during the biological wastewater treatment. At stations in continental cities, facilities of biological treatment are usually not adapted to rainy conditions, although it rains heavily there. In this regard, the period of rain would cause a decrease in loading on sludge, which will have a negative effect on membranes, and this should be taken into account in advance. This process was discovered by the producer of the membranes in the course of operation of the equipment at various sites.

Sampling for analysis in the chemical-bacteriological laboratory of treatment facilities was carried out twice a week, as well as at the necessary moment in order to adjust the plant operation work. The following methods of chemical analysis were used in the course of performing analyses: indicators of PO_4^{3-}, NO^{3-}, NO^{2-}, NH_3, COD, BOD_5 were measured by the colorimetric (turbidimetric) method, by colorations intensity; indicators of suspended substances were measured by the gravimetric method using the technique for measuring procedures (TMP) [16].

5. Results of experimental research into the process of biological treatment of wastewater at MBR

The results of the analysis of incoming and treated wastewater (the data of chemical-bacteriological laboratory of treatment facilities) are shown in Tables 3–4.

With regard to insufficient removal of phosphorus compounds, it was decided to dose the reagent in the nitrification zone of the plant. 10 % solution of aluminum sulphate was accepted as a reagent, it was dosed by a pump-dispenser that is included in the plant. The following estimated doses were accepted:

– at concentration of phosphates at the inlet of approximately 2.9 mg/l, the reagent dose is 0.0406 l/h;

– at concentration of phosphates at the inlet of approximately 3.3 mg/l, the reagent dose is 0.0462 l/h.

Table 3

Results of analysis of wastewater, incoming to MBR

Experiment number	At the inlet to membrane bioreactor, mg/l						
	COD	BOD_5	Suspended substances	NH_4^-–N	NO_3^-–N	NO_2^-–N	PO_4^-–P
1	408	180	293	15.5	3.40	0.98	4.6
2	158	80	40	24.7	0.11	0.01	3.2
3	172	103	27	22.2	0.11	0.01	3.5
4	206	120	29	25.3	0.11	0.01	3.1
5	–	–	–	–	–	–	–
6	256	141	31	28.1	0.11	0.01	4.3
7	–	–	–	–	–	–	–
8	–	–	–	–	–	–	–
9	253	87	102	21.9	0.14	0.05	2.6
10	212	103	41	20.4	0.12	0.01	3.8
11	–	–	–	–	–	–	–
12	218	119	20	28.4	0.11	0.05	3.7
13	245	166	41	31.5	0.11	0.04	3.4
14	280	191	96	30.8	0.12	0.01	–
15	238	157	36	30.2	0.11	0.01	–
16	269	130	75	32.1	0.13	0.04	–
17	–	–	–	–	–	–	–
18	257	–	72	24.2	0.11	0.01	3.2
19	214	–	42	26.7	0.11	0.01	3.6
Mean	242	131	67.5	25.9	0.35	0.089	3.2

Table 4

Results of analysis of wastewater that was treated in MBR

Experiment number	At the outlet of membrane bioreactor, mg/l						
	COD	BOD_5	Suspended substances	NH_4^-–N	NO_3^-–N	NO_2^-–N	PO_4^-–P
1	18	2.9	<5	0.41	13.3	<0.01	4.40
2	22	0.7	<5	0.30	6.9	<0.01	3.00
3	20	0.9	<5	0.35	9.5	<0.01	3.20
4	–	–	–	–	–	–	–
5	29	1.0	<5	0.37	12.4	<0.01	4.0
6	–	–	–	–	–	–	–
7	16	–	<5	0.30	14.8	<0.01	3.20
8	17	–	–	0.30	11.6	<0.01	–
9	17	0.4	<5	0.53	10.0	<0.01	4.30
10	16	0.9	<5	–	3.5	<0.01	0.07
11	–	–	–	–	4.0	<0.01	–
12	17	1.0	<5	0.36	12.1	<0.01	0.50
13	13	0.3	<5	0.99	10.1	<0.01	0.05
14	13	0.7	<5	0.35	8.6	<0.01	–
15	17	0.2	<5	0.47	7.8	<0.01	–
16	14	0.4	<5	0.31	7.8	<0.01	–
17	–	–	–	0.47	–	–	2.90
18	13	–	<5	0.41	7.3	<0.01	2.20
19	10	–	<5	0.39	8.1	<0.01	1.7
Mean	16.8	0.85	<5	0.4	9.2	<0.01	2.50

Note: suspended substances are determined in the laboratory by TMP, the measurement limit of which is 5 mg/l. Actual value of attained parameter is approximately 1 mg/l

The dosage of the reagent started after 9 series of experiments. The following results of the reagent operation were obtained (Tables 5–6).

When selecting a dose of the reagent for phosphate removal, nitrification inhibition was observed, which was caused by the excessive dose of the reagent (0.3–0.4 l/h instead of 0.0462 l/h). The dose of the reagent was selected correctly during adjustment of the pump-dispenser, and the wastewater treatment process in the nitrification zone was resumed.

Table 5

Qualitative composition of wastewater at the inlet to MBR at introduction of the reagent

Experiment number	At the inlet to the membrane bioreactor, mg/l						
	COD	BOD_5	Suspended substances	NH_4^-–N	NO_3^-–N	NO_2^-–N	PO_4^-–P
10	212	103	41	20.4	0.2	0.01	3.8
11	–	–	–	–	–	–	–
12	218	119	20	28.4	0.11	0.05	3.7
13	245	166	41	31.5	0.11	0.04	3.4
14	280	191	96	30.8	0.12	0.01	–
15	238	157	36	30.2	0.11	0.01	–
16	269	130	75	32.1	0.13	0.04	–
17	–	–	–	–	–	–	–

Table 6

Results of wastewater treatment with the introduction of the reagent

Experiment number	At the outlet of the membrane bioreactor, mg/l						
	COD	BOD_5	Suspended substances	NH_4^-–N	NO_3^-–N	NO_2^-–N	PO_4^-–P
10	16	0.9	<5	13.6	3.5	<0.01	0.065
11	–	–	–	14.9	4.0	<0.01	–
12	17	1.0	<5	0.36	12.1	<0.01	0.5
Adjustment of the equipment and selection of the correct dose of reagent and oxygen in the nitrification zone							
13	13	0.3	<5	0.99	10.1	<0.01	0.047
14	13	0.7	<5	0.35	8.6	<0.01	–
15	17	0.2	<5	0.47	7.8	<0.01	–
16	14	0.4	<5	0.31	7.8	<0.01	–
17	–	–	–	0.47	–	–	–

During September, denitrification process was adjusted and nitrate concentration at the output was achieved (6–11 series of experiments). Excessive values were associated with high oxygen concentrations in the nitrification zone (7–9 mg/l). As a result, an increased amount of dissolved oxygen got into the denitrification zone during recirculation. Adjustment lead to a decrease in the oxygen dose in the nitrification zone up to 2–3 mg/l, and then the denitrification process was resumed.

Fig. 3–4 show the averaged data on effectiveness of wastewater treatment on the MBR by COD, BOD_5 and phosphates. A series of experiments with equal hydraulic pressure on the membrane plant were selected and mean values of effectiveness of wastewater treatment on the MBR for specified contamination were calculated. The data for plotting the diagrams in Fig. 3, 4 are given in Table 7.

Table 7

Averaged data on effectiveness of wastewater treatment on MBR depending on hydraulic load

Experiment number	Hydraulic load, l/h	Effectiveness, %		
		by COD	by BOD_5	by phosphates
1	300	95.6	99.7	4.4
11–19	350	94.3	98.4	57.8
8–10	450	92.8	99.3	31.6
2–4, 7	600	89.5	99.3	1.6
5–6	700	88.7	99.3	7.0

Fig. 3 shows that the treatment effectiveness by COD and BOD_5 decreases with an increase in productivity of the membranes. Treatment effectiveness by COD has lower values because the organic substances, which cannot be oxidized by a biological method, are probably represented in wastewater as colloids and therefore are caught by the membrane. High effectiveness of the removal of biologically degradable organic substances at MBR indicates complete flow of the processes of biological oxidation of contaminants by microorganisms of active sludge.

The data in Fig. 4 indicate instability of phosphates removal from wastewater at MBR regardless of module performance. The maximum mean value of effectiveness of 57.8 % was obtained given the fact that dispensing of reagent aluminum sulphate was performed in the series of experiments 11–19.

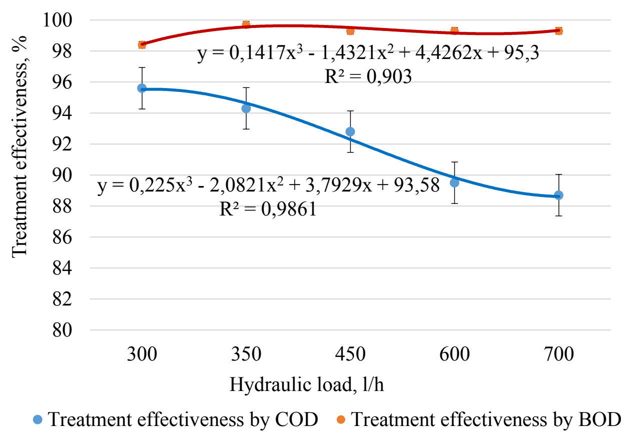


Fig. 3. Effectiveness of wastewater treatment at MBR by COD and BOD depending on hydraulic load

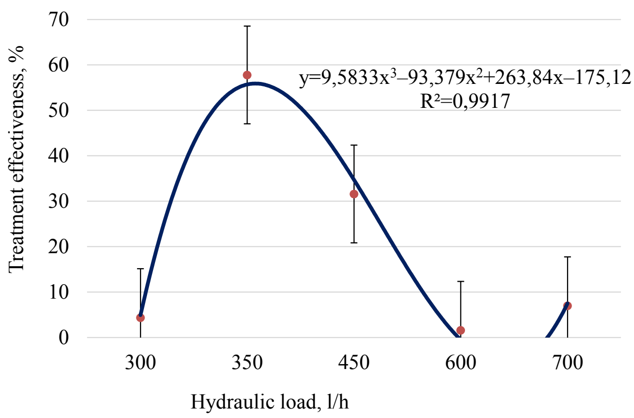


Fig. 4. Effectiveness of wastewater treatment at MBR by phosphates depending on hydraulic load

Since the concentration of phosphates in wastewater without introducing a reagent exceeded the established discharge limit (Table 4, experiments 1–9), the 10 % solution of aluminum sulfate with flow rate of 0.0406– 0.0462 l/h was added to intensify the dephosphatation process. The dose of the reagent ranged between 40 and 50 mg/l, because it depends on the original content of phosphate in wastewater before treatment (Table 5). Fig. 5 shows comparative data on removal phosphates at the same hydraulic load on MBR of 350 l/h with addition of the reagent (experiments 10, 12, 13) and without it (experiments 17–19).

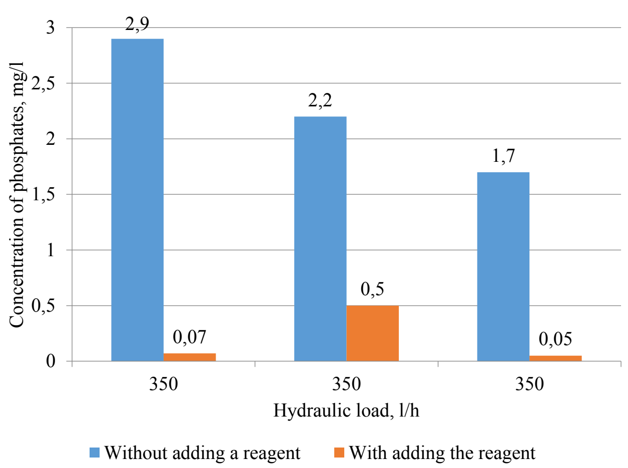


Fig. 5. Phosphate content in the purified sewer after MBR

Analysis of Fig. 5 shows that introduction of the reagent allows decreasing the concentration of phosphate in wastewater that meets discharge requirements. In this case, phosphate removal effectiveness increases from 31.3–52.8 % to 86.5–98.5 %.

The influence of the dose of the introduced reagent on the process of nitrification is shown in Fig. 6–7. The dosage of the reagent was 300 mg/l and 40–50 mg/l. Hydraulic load on the membrane plant amounted to 350 l/h.

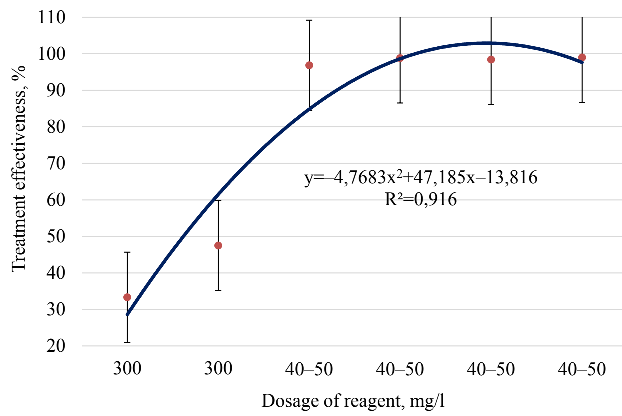
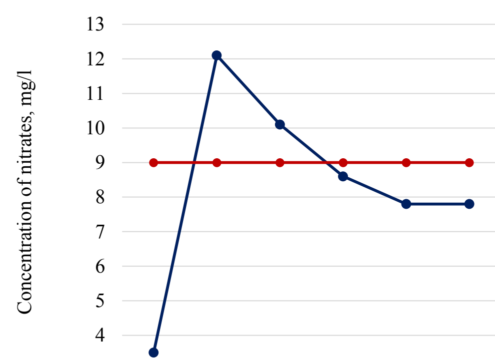


Fig. 6. Influence of the dosage of reagent aluminum sulphate on the process of removal of ammonium nitrogen

Analysis of Fig. 6 makes it possible to identify the following: excessive doses of the reagent aluminum sulphate in 300 mg/l resulted in oppression of microorganisms of active sludge. As a consequence of this, a decrease in the rate of oxidation of ammonia nitrogen to nitrates was found. A decrease in the dose of the reagent up to 40–50 mg/l resulted in restoration of vital activity of microorganisms-nitrificators and ensured treatment effectiveness by nitrogen ammonium up to 98.44–99.03 %.



Dosage of reagent, mg/l	300	300	40–50	40–50	40–50	40–50
At the outlet of MBR	3,5	12,1	10,1	8,6	7,8	7,8
Discharge limit	9	9	9	9	9	9

Fig. 7. Influence of the dosage of reagent aluminum sulphate on content of nitrites in the purified wastewater after MBR

Analysis of Fig. 7 makes it possible to establish that introduction of the reagent – aluminum sulfate in the dose of 300 mg/l dramatically disrupted the nitrification process at MBR. A decrease in a dose of the reagent up to 40–50 mg/l enabled resuming the nitrification process at MBR and ensuring the stability of waste water cleaning from nitrates.

To estimate the economic effectiveness of application of the membrane bioreactor based on the modular plant MFM100-25, manufactured by the company "Alfa Laval"

(Denmark), power consumption of the whole plant was calculated.

Electricity consumption amounted to 4.35 kWh, including:

– compressor for biological processes – 0.7 kW constantly;

– compressor for blowing over membranes – 0.3 kW constantly;

– stirrer for biological processes – 0.4 kW constantly;

– circulation pump membrane capacity – nitrification 1.5 kW in the intervals of 2:1;

– circulation pump membrane capacity – denitrification – 1.5 kW in the intervals of 2:1.

Accordingly, specific power consumption of the pilot membrane will make (0.3 kW/0.6 m^3/h)=0.5 kW/m^3 (0.3 kW – power consumption of a separate membrane; 0.6 m^3/h – performance of a membrane).

The area of the membrane module is 154 m^2, respectively, total power consumption of the modular plant will be 0.3 kW·154 m^2)/25 m^2=1.8 kW.

Power consumption by the biological cleaning system includes power consumption by air blowers to aerate active sludge and consumption by a stirrer in the denitrification zone. Power is also consumed by the recirculation pump. In assessing this type of power consumption, it is necessary to take into account the primary qualitative parameters of the sewer and its flow rate. When the plant is in operation, power consumption for biological processes amounted to kW/m^3. In this case, it is known that specific electricity consumption when applying traditional biological treatment of wastewater in aeration tanks ranges from 0.7 to 1 kW/m^3 and more [17].

6. Discussion of results of experimental research into the process of wastewater treatment at MBR

As a result of experimental research at the membrane bioreactor "Alfa Laval" (Denmark), the treatment mode that corresponds to all requirements for discharge was achieved after adjustment.

According to data in Tables 4, 6 and in Fig. 3, it was revealed that the treatment at MBR is effective in terms of COD (on average by 93 %), BOD_5 (on average by 99 %), and suspended substances (on average by 98.5 %) at different values of hydraulic load on the MBR. It indicates the stability of removal of these contaminations at MBR. It should be noted that removal efficiency of COD and BOD decreased at an increase in hydraulic load. At the maximum load of 700 l/h, efficiency in terms of COD was 88.7 % (Table 7), reflecting a decrease in the filtration ability of the membranes. In connection with this technological process, washing of the membranes is implied. After washing the membrane module, the filtration ability was restored, and effectiveness of membrane operation by COD was 92.8 % at hydraulic load of 450 l/h (Tables 2, 4). Treatment effectiveness in terms of COD has lower values because the organic substances, which cannot be oxidized by the biological method, are probably represented in the runoffs in the form of colloids and that is why they are caught by the membrane.

In the course of the experiment, it was found that the removal of phosphorus compounds from wastewater at MBR plant is an unstable process (Fig. 4). To achieve the required standard for phosphorus content, the reagent should be dosed. The nitrification area in MBR was selected as the point of the reagent introduction. Wastewater treatment at MBR, involving phosphate removal showed average effectiveness of 21.8 % (without introducing the reagent). In connection with this, reagent aluminum sulphate was dosed. The dose of the reagent was determined depending on the original content of phosphates in wastewater and was within 40–50 mg/l. As it can be seen from comparison of the data in Tables 4 and 6, as well as in Fig. 5, only introduction of the reagent allowed achieving the necessary degree of purification from phosphates (98.6 % in series of experiments 10–12). Termination of reagent dosing has resulted in an increase in phosphate content in a purified sewer in excess of the established standard for discharge (Table 4, series of experiments 17–19). That is why, for the process of dephosphatation to be effective, it is necessary to dose the reagent constantly.

It should be noted that attention should be paid to establishing a proper dose of a reagent depending on the initial phosphate content in sewers, otherwise its excess will lead to inhibition of nitrification process. Thus, Fig. 6, 7 show that during experiments with the addition of a reagent, the inhibition of the nitrification process was observed at the excessive dose of the reagent – aluminum sulphate of 300 mg/l. This dose was set on the pump-dispenser by mistake. After a decrease in the dose of the reagent up to 40–50 mg/l (the established dose to remove phosphorus compounds), concentration of ammonia nitrogen and nitrates was within the standard discharge.

To ensure efficient flow of nitrification with a decrease in ammonia nitrogen up to 98.5 %, it is necessary to assign the dose of the reagent correctly (Table 6, experiments 13–17).

It was also noted in the course of the experiments that excessive doses of oxygen in the nitrification zone led to disruption of the denitrification process. Therefore, for the effective flow of the process of denitrification in the nitrification zone, the dose of oxygen dose was decreased from 7–8 mg/l to 2–3 mg/l. This made it possible to ensure an effective operating mode of MBR for nitrification-denitrification. As Table 6 shows, after establishing the correct dose of the reagent (series of experiments 13 and the following) and the dose of oxygen in the area of nitrification, the content of ammonia nitrogen and nitrates in treated sewers was below the established discharge standard.

Calculation of consumed power for operation of MBR, manufactured by company "Alfa Laval" (Denmark), showed that this equipment is much more efficient in terms of electricity consumption (0.18 kW/m^3) compared to power consumption during the traditional biological treatment (0.7–1.0 kW/m^3). It should also be noted that the effectiveness of wastewater treatment in the case of the use of MBR is much higher. These data prove economic feasibility of using the MBR for wastewater treatment.

Research into specific features of removal of nitrogen and phosphorus were carried out with the use of only one type of reagent. The use of other types of reagents for intensification of phosphate removal may reveal the patterns that differ from those described in this paper. Attention should be drawn to iron-containing coagulants and explore the features of their application in wastewater treatment of the MBR.

These studies were conducted at the modular plant of low performance (0.3–0.7 m^3/h). Therefore, it is necessary to study further the operation of membrane modular plant at large wastewater treatment facilities with the performance of at least 2000 m^3/h. It will provide an opportunity to examine the patterns of cleaning by biogenic elements at MBR at high performance and to conduct technical-economic comparison of treatment at MBR and the traditional biological treatment.

7. Conclusions

1. In the course of the experimental research into wastewater treatment at MBR, manufactured by company "Alfa Laval" (Denmark), it was revealed that the nitrification process depends on completeness of the flow of biological oxidation processes. The concentration of ammonia nitrogen and nitrates in the purified sewer depends on the initial concentrations of these contaminants in wastewater, concentration of oxygen in the nitrification zone. Effectiveness of the flow of the nitrification process is affected by the introduction of chemical reagents. Thus, during the research, the inhibition of the nitrification process was observed due to the inflated dose of the reagent aluminum sulphate. At the dose of the reagent of 40–50 mg/l and concentration of oxygen of 2–3 mg/l in the nitrification zone, the decrease in ammonia nitrogen at was 98.5 % at the original content of 30.2–32.1 mg/l and modular performance of the membrane plant of 350 l/h. The content of nitrates in this case did not exceed the established discharge standard and amounted to 7.8–8.6 mg/l.

However, wastewater treatment at MBR, aimed at phosphate removal, demonstrated low performance of 21.8 %. In connection with this, dosing of the reagent – aluminum sulphate was conducted and the dose was 40–50 mg/l. For the effective flow of the dephosphatation (98.6 %), it is necessary to dose the reagent constantly.

2. It was found that during the studies on the membrane module, manufactured by company "Alfa Laval" (Denmark), at different hydraulic loading on membranes, there were no jumps in the parameters of wastewater treatment. It should be noted, however, that at an increase of hydraulic load on the membrane module up to 700 l/h, the filtration ability of the membranes decreases. In this case, effectiveness was 88.7 % in terms of COD and 99.3 % in terms of BOD. Washing the membranes made it possible to restore filtration capacity and to ensure the effectiveness of treatment in terms of COD of 92.8 % at hydraulic load of 450 l/h.

3. In the process of testing of the membrane bioreactor, based on the module plant, produced by company "Alfa Laval" (Denmark) for treatment of domestic wastewater, the effectiveness of application of the MBR technology was substantiated. During the studies, the treatment mode that meets the requirements for discharge was achieved. Calculation of specific power consumption (0.18 kW/m^3) for the operation of the membrane plant showed economic feasibility of application of MBR for wastewater treatment in comparison with the traditional scheme of treatment in aeration tanks (0.7–1 kW/m^3). For the complete technical and economic comparison of MBR technology and the traditional biological treatment, it is also necessary to take into account other economic factors. It is possible to distinguish service life of the membrane, capital and operating costs among them.

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RESEARCH INTO EFFECTIVENESS OF CAVITATION CLEANING OF WASTEWATER OF A FAT-AND-OIL PLANT FROM ORGANIC AND BIOLOGICAL CONTAMINATION IN THE PRESENCE OF VARIOUS GASES

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Використання кавітаційних технологій для процесів очищення стічних вод жиркомбінату один із перспективних методів для покращення показників якості води. Було запропоновано подачу в кавітаційну зону газів різної природи, а саме: азоту, кисню, повітря, суміші азоту та кисню у співвідношенні 1:1.

Досліджено вплив природи барботованих газів, як в умовах дії УЗ так і без нього, на зміну хімічного споживання кисню та мікробного числа. Розраховано ефективні константи швидкості руйнування органічних сполук та біологічних забруднень. Встановлено, що найвищого значення ефективної константи швидкості знезараження води від МО (5,13·10–4 с–1) було досягнуто при барботуванні азоту. Найвищого значення ступеня знезараження води в кавітаційних умовах (99,9 %) було досягнуто в атмосфері азоту, а ступеня руйнування органічних сполук – 64,3 % при одночасній дії повітря та УЗ.

Визначено, що процес руйнування органічних домішок та знезараження стічних вод жиркомбінату можна описати застосувавши кінетичне рівняння першого порядку. Встановлено відносні ряди впливу природи досліджуваних газів на кавітаційне очищення води.

Показано, що очищення стічних вод жиркомбінату при одночасному барботуванні газів у кавітаційне поле при руйнуванні органічних сполук на 5–35,7 %, при знезараженні води від МО на 1–90,5 % ефективніше, ніж дія самого УЗ.

Використання запропонованої кавітаційної технології для очищення стічних вод жиркомбінату дозволяє повністю знезаразити воду від шкідливих МО та одночасного руйнування органічних речовин. Це дозволяє усунути негативний вплив шкідливих речовин, які містяться у стічних водах для збереження навколишнього середовища та водного басейну України

Ключові слова: стічні води, кавітація, очищення, природа газів, органічні сполуки, мікробіологічні забруднення

1. Introduction

One of the relevant issues in the production of food is the disposal of wastewater or subsequent use of water that was already cleaned. Wastewater of oil-fat production is characterized by a high content of organic and biological contamination of different nature. The main pollutants of wastewater of extraction and refining workshops are organic