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The influence of percentage share of municipal landfil leachates in a mixture with synthetic wastewater on the effectiveness of a treatment process with use of membrane bioreactor

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ABSTRACT

The investigations were focused on the determination of the most favorable amount of leachates treated along with a synthetic sewage in a membrane bioreactor. The leachates percentage share was changed over a range of 3–40 vol%. COD and BOD_5 of the leachates varied from 3,000 to 3,500 mg/dm^3 and from 170 to 280 mg/dm^3 respectively. The leachates were characterized by a high concentration of ammonia nitrogen (over 1,000 mg/dm^3) and low BOD_5/COD ratio (0.06 in average), which indicated their negligible susceptibility to biodegradation.

The concentration of activated sludge in the membrane bioreactor was maintained within 3.5–4.0 g/dm^3, the sludge load with contaminants reached the level of 0.1 gCOD/g_{DM}d while the oxygen concentration in the aeration tank was 4.0 mgO_2/dm^3. The system operated in a 12-h cycle. The degree of impurities removal was assessed analyzing changes in the following indicators: COD, BOD5, TOC, N-$NO^-{}_3$, N-$NH^+{}_4$, P_{tot}.

The results revealed that the volume of leachates in the treated mixture of sewage should not exceed 10 vol%. All the tests showed a decrease in COD and BOD_5 of around 90%. The only indicator which exceeded the permissible value was nitrate nitrogen. Thus, the leachates purified by activated sludge were additionally treated by reverse osmosis.

Keywords: Membrane bioreactor; Landfill leachate; Activated sludge; Reverse osmosis

1. Introduction

The deposition of wastes on landfills, even those properly designed and exploited, may cause many environmental problems. One of them is the formation of leachates, the result of water percolation through the wastes dump [1–3]. They have a serious impact on the ground and groundwaters, not only in the neighborhood of the landfill, but also in distant areas [3,4].

The leachates are a serious environmental hazard according to their significant load, high concentration of toxic substances, changeable composition and amount. Their treatment is much more complicated in comparison with municipal wastewaters and often requires the integration of physical, chemical and biological methods [2,5]. The application of membrane bioreactors combining activated sludge method with pressure-driven membrane techniques seems to be a proper solution for leachates utilization. The presence of membrane modules in the system eliminates the necessity of using of secondary settling tanks and

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Table 1
The characteristics of the leachates, synthetic sewage and permissible values of particular parameters

Parameter	Unit	Leachates	Synthetic sewage	Permissible values*
COD	gO_2/m^3	3,000–3,500	680	125
BOD_5	gO_2/m^3	200–260	240	25
TOC	gC/m^3	300–600	118.5	30
Ammonium nitrogen	gNH_4^+/m^3	950–1,550	16,5	10
Nitrate nitrogen	gNO_3^-/m^3	0–6	7	30
Total nitrogen	gN/m^3	~2000	300	70
Total phosphorus	gP/m^3	0–20	15	2
pH	–	8.1–8.5	6.8–7.5	6.5–9.0

*Permissible values of impurities indicators of disposed wastewaters established by the Decree of Minister of Environment from 28th of January 2009 regulating the conditions, which must be fulfilled for wastewaters disposed into waters and ground, and for substances especially hazardous for water environment.

ensures the longer retention time of hardly degradable high-molecular substances in the bioreactor. It makes also possible to apply high concentrations of activated sludge, what results in lower substantial load [6–8].

In Europe over 100 wastewater treatment installations using membrane bioreactors were built, in USA there are more than 200 of them [9,10].

The studies were focused on the determination of the effectiveness of the municipal landfill leachates treatment in the membrane bioreactor with internal capillary membrane module. The proposed solution may become a serious competitor for classical activated sludge method in SBR reactors as it integrates advantages of the biological process and pressure-driven membrane techniques.

2. Materials and methods

The leachates collected at the municipal landfill in Tychy constituted the substrate of the study. The analysis of the leachates revealed, that their composition depends on the season and atmospheric conditions. It was observed that in the summer the impurities load was significantly lower than in the winter.

The characteristics of the leachates and synthetic wastewaters are shown in Table 1.

The biological process was carried out under laboratory conditions, using activated sludge taken from the municipal sewage treatment plant in Zabrze.

The measuring system consisted of a surge tank that ensured a constant sludge load and a membrane bioreactor with a microfiltration capillary module installed inside. The raw sewage were pumped from the tank into the bioreactor containing activated sludge. The volume of the reaction chamber was 15 dm^3. The biologically purified leachates flowed inside the capillaries through the walls. The reaction chamber and surge tank were equipped with sensors of sewage level, oxygen concentration and temperature.

The capillary MF membranes were made from polyvinylidene fluoride and possessed pores of diameter equal 0.04 μm. The filtration area was 0.45 m^2. The construction of the membrane module enabled the backflushing of the capillaries with the permeate [11]. The scheme of the apparatus set is demonstrated in Fig. 1.

The membrane bioreactor had a double aeration system i.e. fine bubble and coarse bubble aeration. The former ensured a proper oxygen concentration during removal of carbon compounds and nitrification while the latter prevented fouling of the membrane during denitrification.

The operation of the membrane bioreactor was based on the assumption that the activated sludge adsorbed and oxidized the contaminants present in the treated sewage while the membrane acted as a filter which retained biomass and refractory macromolecular compounds.

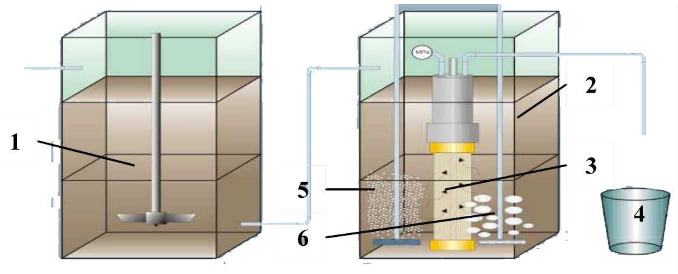

Fig. 1. The scheme of the apparatus set: the equalization tank (crude sewage tank), (2) the aeration chamber, (3) the capillary membrane module, (4) the effluent tank, (5) fine-bubble aeration, (6) coarse-bubble aeration.

Table 2
The working parameters of the membrane bioreactor

Parameters	Unit	Values
Biomass concentration	g/dm^3	4
Oxygen concentration	gO_2/m^3	~4
Activated sludge load with contaminations	$gCOD/g_{DM}d$	0,1
Hydraulic retention time	d	2–3
Activated sludge age	d	15

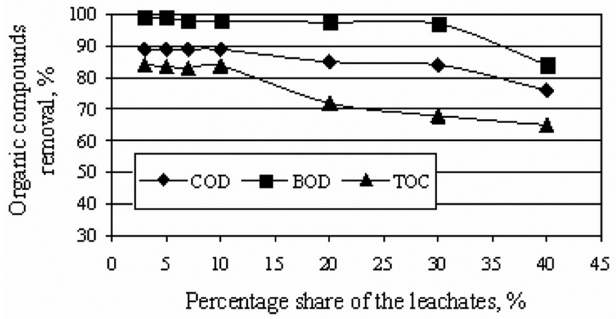

Fig. 2. The dependence of the degree of removal of organic compounds on the percentage share of the leachates in the mixture with synthetic sewage.

The membrane bioreactor acted as the SBR with 12-h cycle. The reactor filling took 0.5 h, the denitrification process lasted 3.5 h and the nitrification process went on 7 h. The sedimentation and collection of clarified sewage took 1 h. The working parameters of the membrane bioreactor are shown in Table 2.

The investigations covered the determination of the most favourable amount of leachate treated along with synthetic sewage. Those tests were made with various leachates shares varying from 3 vol% to 40 vol%. The treatment processes were carried out under constant activated sludge load equal to 0.1 $gCOD/g_{DM}d$.

The main criterion for the estimation of the effectiveness of the treatment process was the change of content of impurities expressed as: pH, COD, BOD_5, TOC, IC, TC, total phosphorus, total nitrogen, nitrate nitrogen and ammonium nitrogen. The oxygen concentration was measured with oxygen analyzer CO-411, the phosphates and nitrates concentrations were obtained using ionic chromatography (DIONEX DX-120 chromatograph by AGA Analytical was used for that purpose). The evaluation of different carbon forms content was made with the use of carbon analyzer Multi N/C by Jena Analytik. The total nitrogen and ammonium nitrogen concentrations as well as COD were determined according to Merck analytical methods, while BOD_5 was analyzed with the OXI Top WTW measurement system.

3. Results and discussion

The aim of the biological co-treatment process of the investigated leachates was to mineralize organic compounds and remove biogenic substances, nitrogen and phosphorus. The process was carried out for 30 days with preceding set in of the activated sludge.

It was found that with the increase of the leachates share in the mixture the increase of organic compounds content could have been observed in the membrane bioreactor effluent. Fig. 2 shows the dependence of the degree of removal of the contaminants load expressed by the decrease of COD, BOD_5 and TOC in treated sewage on the volumetric share of the leachates in mixture with the synthetic sewage.

The highest decrease of COD was obtained for the mixture in which the leachates share did not exceed 10 vol.%. In case where the mixture feed contained not more than 10 vol.% of the leachates COD in the treated sewage outflow was 71 mgO_2/dm^3, and the COD removal degree was 89%. In case where the feed mixture contained 40 vol.% of the leachates, COD in the treated sewage was equal to 320 mgO_2/dm^3, what disqualified the outflow to be led away to natural water.

The decrease of BOD_5 was high in the whole range of investigated compositions of the mixture instead of the one containing 40 vol.% of the leachates. In that case BOD_5 in the treated sewage exceeded the permissible level and was equal to 30 mgO_2/dm^3. The highest decrease of BOD_5 was noted for mixtures containing 3–10vol.% of the leachates. The BOD_5 removal efficiency for those shares was 98–99% respectively. The obtained BOD_5 for treated sewage was at the level of 2 mgO_2/dm^3.

Similar dependences were observed in the analysis of TOC concentration, for which the removal effectiveness decreased with the leachates share increase over 10 vol.%. The concentration of TOC for 10 vol.% of the leachates share was decreased from 173 mg/dm^3 in the crude mixture to 22 mg/dm^3 in the treated sewage, what corresponds to the degree of removal equal to 83.8%. It was shown that the sustenance of the leachates share in the mixture in the range of 3–10 vol.% allowed to decrease the concentration of organic compounds to the level, that the treated sewage could be directly removed to the natural collector.

The change of concentration of biogenic elements in the treated sewage depending on the crude mixture composition is represented in Fig. 3.

It can be easily noticed that the degree of removal of the ammonium nitrogen was the highest in comparison

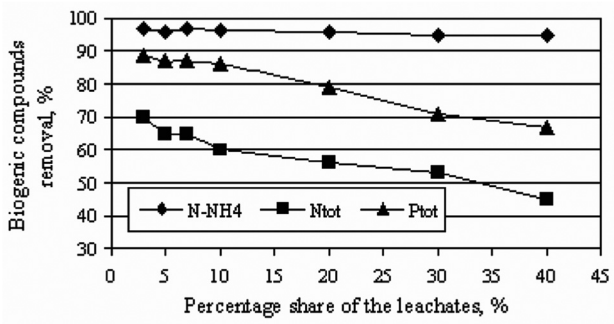

Fig. 3. The dependence of degree of removal of biogenic elements on the percentage leachates share in the mixture with the synthetic sewage.

with other biogenic compounds and exceeded 95% for all investigated percentage shares of the leachates. The amount of leachates in the mixture with the synthetic sewage did not influence on the effectiveness of the removal of N-NH_4^+. The concentration of the ammonium nitrogen in the reactor outflow during the nitrification process did not exceed 6.5 mgN-NH_4^+/dm^3. The lowest concentration of N-NH_4^+ (3 mgN-NH_4^+/dm^3) was obtained when the feed mixture contained 3 vol.% of the leachates, while the highest concentration (6.5 mgN-NH_4^+/dm^3) was obtained for 40 vol.% of the leachates in the feed.

It was also shown that the increase of the percentage share of the leachates resulted in the increase of the nitrate nitrogen concentration in the membrane bioreactor outflow. It changed from 76 mgN-NO_3^-/dm^3 (3 vol.%) to 220 mgN-NO_3^-/dm^3 (40 vol.%). The decrease of the degree of removal of the total nitrogen concentration from 62% (3 vol.%) to 45% (40 vol.%) was also observed.

The increase of the percentage share of the leachates in the mixture with the synthetic sewage had the influence on the effective removal of the total phosphorus. The highest degree of removal of total phosphorus was observed for the leachates share in the feed in the range of 3–10 vol.%. This degree was equal to 89%, and the concentration of the total phosphorus in the treated sewage varied from 1.8 mgP/dm^3 to 2.0 mgP/dm^3. In case when the leachates share in the feed mixture was equal to 40 vol.%. The concentration of the total phosphorus in the treated sewage increased to 8 mgP/dm^3, and the degree of its removal decreased to 67%. It can be assumed that the reason of the total phosphorus removal degree decrease was the increase of nitrates concentration under the applied process conditions.

As the permissible concentration of the total nitrogen and nitrate nitrogen in the treated sewage were exceeded, it was decided that additional reverse osmosis process treatment for the biologically treated sewage should be applied. The flat osmotic SE type membrane was used in the process. The high pressure filtration process was carried out in the plate-frame membrane module SEPA CF-NP (Osmonics). The applied transmembrane pressure was equal to 2.0 MPa, and the linear velocity of the feed was 2 m/s.

The treatment process with the activated sludge load of 0.1 gCOD/g_{DM}d and the leachates share in the mixture not exceeding 10 vol.% resulted in obtaining the effluent suitable to be disposed to the natural collector regarding organic compounds content. However, it could not have been done as the permissible biogenic compounds concentrations in the effluent were exceeded. It was decided that the membrane bioreactor effluent would be additionally cleaned in the reverse osmosis process. The obtained permeate fulfilled the conditions for treated wastewaters that could be disposed to the natural collector. The final parameters of the treated sewage are shown in Table 3.

4. Conclusions

Obtained results of the investigations allow to conclude that:

- The increase of the leachates share in the mixture negatively influences on the biological treatment

Table 3
Effectiveness of additional treatment of sewage by reverse osmosis

Parameter	Sewage after membrane bioreactor, mg/dm^3	The sewage after the additional reverse osmosis process	
		Concentration, mg/dm^3	Retention, %
COD	71	1.5	97.9
BOD_5	2	0.0	100
TOC	22	1.0	95.5
Ammonia nitrogen	2,5	0.05	80
Nitrate nitrogen	94	3.5	96.3
Total nitrogen	120	22	81.7
Total phosphorus	2	0.0	100

process. The leachates share in the mixture in the range of 3–10 vol% enabled to decrease the organic substances content in the membrane bioreactor effluent to the level permissible for treated wastewaters disposed to the natural collector. The increase of the concentration of the leachates resulted in the decrease of the degree of organic compounds removal;

- The degree of the ammonium nitrogen removal was the highest and obtained the level greater than 95% for all investigated compositions of feed mixtures. The amount of the leachates in the crude mixture did not influence on the effectiveness of $N\text{-}NH_4^+$ removal;
- It was observed that the increase of the leachates share in the mixture resulted in the increase of the nitrate nitrogen concentration in the membrane bioreactor outflow. The permissible concentration of the nitrate nitrogen was already exceed when the feed mixture contained 3 vol.% of the leachates. The concentration of the nitrate nitrogen for such a composition of the mixture was equal to 76 $mgN\text{-}NO_3^-/dm^3$;
- The highest degree of removal of the total phosphorus was obtained for crude mixtures containing the leachates share in the range of 3–10 vol.%. It was equal to around 89%;
- Additional treatment of the biologically treated sewage in the reverse osmosis process allowed to remove the treated sewage to the natural collector. The degree of removal of the organic and biogenic compounds was greater than 95%.

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