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Comparison of the retention of selected PAHs from municipal landfill leachate by RO and UF processes

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ABSTRACT

The aim of the conducted research was to compare the changes in the retention of polycyclic aromatic hydrocarbons (PAHs) during membrane filtration (ultrafiltration—UF and reverse osmosis—RO). In the study, municipal landfill leachate was used. In the first stage of testing, leachates were filtrated on the sand bed (prefiltration). After prefiltration, they were directed to the membrane module for main filtration. The ultrafiltration process was carried out at the transmembrane pressure of 0.1–0.2 MPa. The membrane separation process was based on a capillary membrane type ZW-10. The transmembrane pressure of the reverse osmosis stood at 2 MPa and for this process one nylon membrane (ADF) was used. The prepared samples of the municipal landfill leachates were subjected to extraction with applying 2-propanol. Extracts were cleared on octadecyl C18 columns, and then concentrated in the nitrogen stream. High-performance liquid chromatography HPLC with fluorescence detection (model HPLC THERMO) was used for qualitative and quantitative analysis of PAHs. During the process, a decrease in the concentrations of most tested hydrocarbons was observed. The initial concentrations of PAHs in the municipal landfill leachates were in the range 17.5–30.4 mg / L. The efficiency of the removal of hydrocarbons grouped according to a number of rings was in the range of 48 (for naphthalene) to 73% (for 6-ring of PAHs) in ultrafiltration technique. However, the greater efficiency retention of PAHs was obtained for RO. The average value of the retention coefficient for RO was equal to 71% (for individual hydrocarbons were in the range of 19–100%).

Keywords: Municipal landfill leachates; Membrane techniques; Ultrafiltration (UF); Reverse osmosis (RO); PAHs

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1. Introduction

Polycyclic aromatic hydrocarbons (PAHs) are widespread organic pollutants. Their occurrences in the form of mixture can be observed in all environment components. The molecular structure of all representatives of this group of hydrocarbons is built with two or more condensed aromatic rings. Their appearances in water, soil, wastewater, etc. can be natural but in most cases it is anthropogenic. The fact of their widely distribution in the environment and a well documented negative biological activeness, toxicity, mutagenicity, and carcinogenicity makes this compounds one of the most dangerous organic pollutants [1,2].

PAHs occurrence in municipal landfill leachates combined with the presence of other organic compounds are treated as a serious threat to the local environment. The possibility of migration, contained in leachate pollutants, from landfill to ground water or nearby soils may have some negative consequences. The main sources of toxic compounds in leachates from municipal landfills are deposited materials but they can also be formed during decomposition of organic matter contained in wastes. Most of aromatic hydrocarbons are hardly solvable in water, but their mobility in a liquid phase may be improved as a result of co-migration phenomenon with a soluble organic fraction. Due to their ubiquitous occurrence, recalcitrance, carcinogenic activity, and bioaccumulation potential, the PAHs have a significant environmental concern. Based on their toxicology, 16 PAHs are regarded as priority pollutants by the USEPA and they need to be eliminated from wastewater (e.g. municipal landfill leachates) during treatment [1–5].

The removal of PAHs from the wastewater in the physical processes is mainly carried out using membrane techniques. The possibility of applying individual processes is limited by the size of the molecule retained on the membrane. For this reason, the most important techniques applied in the removal of PAHs are: nanofiltration (NF), reverse osmosis (RO), and ultrafiltration (UF) [6–10]. Ultrafiltration and reverse osmosis being the main topic this paper are membrane processes based on the pressure difference. Ultrafiltration and reverse osmosis being the main topic this paper are membrane processes based on the pressure difference [11]. In most studies described in literary sources, authors examined the separation capacity and the capability of using different ultrafiltration membranes in the removal of the selected organic compounds. Obtained retention coefficients for PAH, THM, and phthalates were in the range of 50.0–99.9% [12]. Other studies were carried out on the application of UF membranes for the removal of PAH from water in the presence of humic substances. This process made it possible to remove over 40% of anthracene, whereas in the presence of humic substances the removal of this compound was equal to 97% [13]. The literature data indicate a high degree of removal of PAHs exceeding 80% from aqueous solutions in the process of ultrafiltration [3]. The former studies by the authors of this publication showed that the removal of hydrocarbons from coke wastewater in filtration and ultrafiltration processes was equal to 85% [14]. The membranes used in these studies allowed one to remove aromatic hydrocarbons at a high level, even though the molecular weights of these compounds are much smaller than the radius of the pores of ultrafiltration membranes and their "cut-off." This may be caused by the adsorption of PAHs on the surface of UF membranes. In the case of ultrafiltration membrane retention, the coefficient increases together with the molecular weight of the retained xenobiotic [14, 15]. The removal of PAHs from water matrix was also carried out with the use of membrane for reverse osmosis (RO-SS10). The retention coefficients were in the range of 70–88% (for the concentrations of PAHs mixture 55–2,300 ng/L). Considering the high degree of removing these pollutants from water, the reverse osmosis is likely to be applied in the technologies for water and wastewater treatment [3]. The combination of ultrafiltration/reverse osmosis with conventional process is also feasible. The aim of the investigation was to explore and compare the changes in the retention of PAHs in municipal landfill leachates during filtration and ultrafiltration/reverse osmosis processes.

2. Raw municipal landfill leachates

Technological research was carried out on leachate collected from the municipal waste landfill. The municipal landfill leachates were characterized by the following pollution indicators: chemical oxygen demand (COD), total organic carbon (TOC), total carbon (TC), and the concentration of PAHs, nitrate nitrogen, ammonium nitrogen, and pH. The characteristics of municipal landfill leachate are shown in Table 1.

The pollutants' indicators which characterize municipal landfill leachates effluents are much higher than standardized values and this prevents their direct discharge into a natural receiver.

2.1. Analytical methods

In order to determine some physicochemical indicators, generally accepted methodologies [16] were used. The value of pH was performed using a potenti-

Table 1
The composition of the raw leachate from municipal waste landfill

Indicator	Raw municipal landfill leachates	Allowable values of sewage pollution*
pH	8.1	6.5–9.0
COD, mg O_2/L	4988.2	125
TC, mg C/L	1759.6	nn.
TOC, mg C/L	676.4	30
Ammonium nitrogen, mg $N - NM_4^+$/L	784.0	10
Nitrate nitrogen, mg NO_3^-/L	29.8	30
PAHs, μg/L	17.5–30.4	nn.

*The Minister of Environment of 28 January 2009 on conditions to be met for the introduction of sewage into the water or the ground, and on substances particularly harmful to the aquatic environment (Journal of law 2006 No. 137, item. 984).

ometric method. For the indication of COD, a test method was performed using a spectrophotometer HACH DR 4000th. The determinations of TOC and TC indicators where performed by high temperature catalytic oxidation using GC Multi N/C 2100 apparatus, while the concentration of nitrate nitrogen and ammonium nitrogen was established using cuvette tests of HACH LANGE firm on a spectrophotometer DR 2800th.

Qualitative and quantitative identification of PAHs was carried out in the raw municipal landfill leachates, after the filtration on the sand bed, after RO and UF. The successive stages of the preparation of samples for the determination of PAHs are presented in the diagram in Fig. 1. The first step in the preparation of samples for the determination of PAH was the liquid–liquid extraction conduced in the ultrasonic field. As organic solvent for organic matter isolation 2-propanol was used. The extraction process was carried out in an ultrasonic bath (30 min of sonification, $f = 40$ kHz). After that, samples were being shaken for 60 min in an automatic shaker. The obtained extracts were poured into centrifugal test tubes and were centrifuged for 10 min with 8,000 rpm. Next, they were dissolved in 250 mL distilled water. Then, the obtained extracts were purified using SPE technique with Bakerbond C18 columns under vacuum conditions. Before the introduction of the extracts, the columns had been conditioned with methanol (3·3 mL) and with distilled water (3·3 mL). For the extraction from the SPE resin, acetonitrile was used (3·1 mL). Subsequently, the extracts were concentrated to the volume of 1 mL under a nitrogen stream. The liquid chromatography (HPLC) is one of the most general methods used to determine PAHs and it is given as the reference method for the determination of those compounds. High-performance liquid chromatography HPLC with fluorescence detection (model HPLC THERMO) was used for qualitative and quantitative analysis of PAHs. PAHs separation was done on the Pinnacle II PAH 4 μm Column. The temperature of the column was 30°C, and the analysis time was 40 min.

In the first step of research, the municipal landfill leachates were treated by the filtration on the sand deposit. The sand deposit was a cylinder shape container filled with three layers of gravel and sand. The layers were composed of: bottom-layer gravel Ø = 1.0 cm, middle-layer gravel Ø = 0.6 cm, and upper-layer sand Ø = 0.1–2.0 mm. The total amount of the filters layer is 50 cm, and the volume of the filter bed is 25 L. The flow velocity of wastewater through the sand deposit was equal to 38–46 dm^3/h. The municipal landfill leachates after the initial filtration process (prefiltration) were directed to the ultrafiltration module in I series and to reverse osmosis module in II series.

In the I series of membrane filtration for municipal landfill leachates treatment, an apparatus with the ultrafiltration module was used. This module was submerged in the cylindrical tank with the volume of 70 L. Performance range of the pump (Vogeslang company) operating in the ultrafiltration system was in the range of 8–72 L/h. During the tests, the efficiency was kept at 12 L/h. The transmembrane pressure of the process was 0.1–0.2 MPa. For ultrafiltration, the capillary membrane type ZW-10 selective for suspended solids, colloids, viruses, and bacteria was used. The diameter of pores in the skin layer of the membrane was 0.04 μm. The surface of the membrane was 0.93 m. A mean volumetric flux of permeate was 0.428×10^{-5} m/m s (an arithmetical average of obtained results during filtration process). The time of experimental was 10 h. Permeate was intermittently extracted with a suction mode of 15 min extracting/45 s backwashing, according to the producer's recommendation. The scheme of the ultrafiltration process is shown in the diagram in Fig. 2

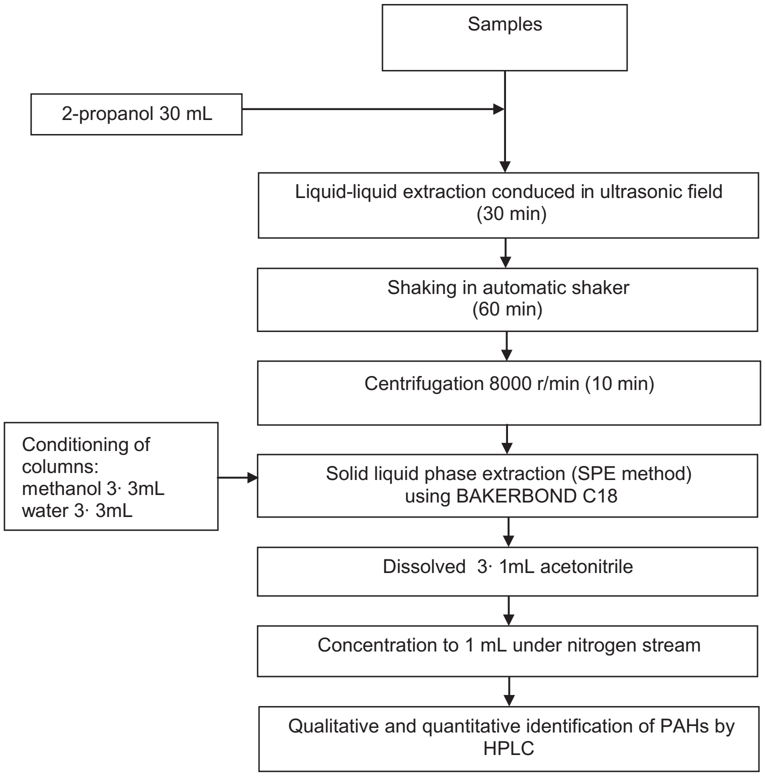

Fig. 1. Diagram of sample preparation to the determination of PAHs.

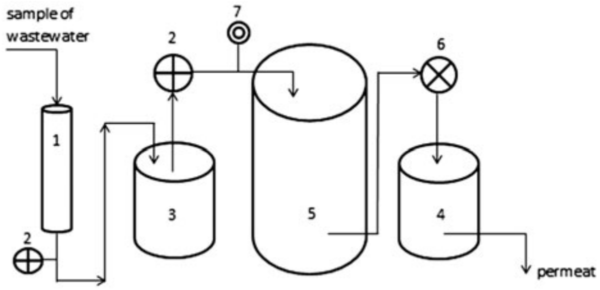

Fig. 2. Scheme of equipment for applied pressure filtration membrane process (UF). 1—sand bed, 2—dosing pump, 3—tank of wastewater, 4—tank of treated wastewater, 5—ultrafiltration module, 6—pressure pomp, 7—manometer.

In the II series, the wastewater after the filtration process was directed to the reverse osmosis module. In the process of high-pressure membrane filtration for municipal landfill leachates treatment an apparatus with a slab-type membrane module SEPA CF-NP of American company GE-Water, a sewage tank (8 L) with a cooler, rotameter, a high-pressure pump, and pressure gauges and valves were used. The scheme of the equipment for RO is shown in the diagram in Fig. 3 The membrane module consisted of two steel plates with a flat membrane. The surface of the membrane was 144 cm^2. The setting operated in cross-flow closed system in which the retentive was recycled to feed tank. For reverse osmosis, one nylon membrane (ADF), produced by GE-Water (USA) was used [17]. The transmembrane pressure of the process was 2 MPa and the linear flow velocity over the membrane surface was 2 m/s. The obtained equilibrium streams

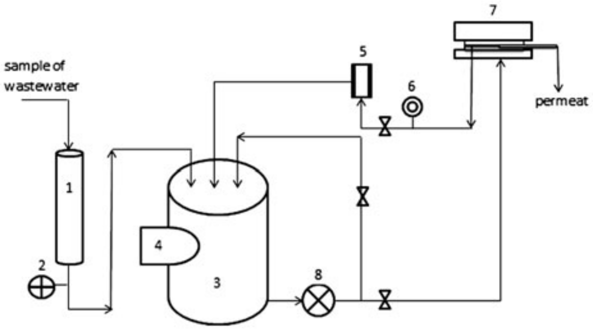

Fig. 3. Scheme of equipment for applied pressure filtration membrane process (RO). 1—sand deposit, 2—dosing pump, 3—tank of wastewater, 4—cooler, 5—rotameter, 6—manometer, 7—membrane module, 8—pressure pump.

were up to 0.29–0.36 × 10^{-5} [$m^3/m^2 \times s$] after 150 min of filtration.

3. Results and discussion

The efficiency of municipal landfill leachates treatment was evaluated on the basis of the degree of pollution load removal. The municipal landfill leachates (after initial filtration) subjected to the membrane module was characterized by the following indicators: pH—8.2, COD—4,644.8 mg O_2/L, TC—1,558.1 mg C/L, TOC—617.2 mg C/L, ammonium nitrogen—669.2 mg N-NH_4^+/L, and nitrate nitrogen—22.5 mg NO_3^-/L. The selected physicochemical properties during technological research in the municipal landfill leachates are shown in Table 2.

The discharge of such wastewater containing high organic content without prior treatment is known to affect adversely the aquatic life, water portability, and agriculture. Thus, legislation is becoming more stringent and the treatment of wastewater is nowadays compulsory in many countries. Based on the obtained results, the processes of filtration and ultrafiltration/reverse osmosis slightly affected the quality of the raw leachate. As can be deduced from the research results, municipal landfill leachates treated in the prefiltration and UF/RO processes still did not meet quality standards set out in the Regulation of the Minister of Environment of 28 January 2009, on conditions to be met by the introduction of sewage into the water or soil, and on the substances particularly harmful to the aquatic environment due to the excessive concentration of COD, TOC, and ammonia nitrogen. The pH of the municipal landfill leachates after filtration on sand deposit was equal to 8.2, after UF was equal to 8.0, and after RO was equal to 9.0. Eventually, pH does not exceed the limit in treated wastewater of 6.5–9.0 [18]. The value of COD decreased from 4,644.8 to 2,494.7 mg O_2/L after filtration and it constantly declined after UF to 2,494.7 mg O_2/L. The highest removal efficiency 97% is obtained for COD after reverse osmosis—139.3 mg O_2/L . The value of COD in the leachate from the landfill could achieve 7,758.08 O_2/L [19]. The Minister of Environment defines the threshold value of the COD in the leachate, which can be introduced into the ground. For some municipal waste landfills, the value of the COD may reach an acceptable level after 50 years after the closure of the landfill, and in some cases after the 200 years. The value of the TC decreased from to 1,558.1 mg C/L after filtration and to 1150.1 mg C/L after UF. The total organic carbon is the most relevant parameter for the global determination of organic pollution of wastewater. After filtration, the TOC decreased to 617.2 mg C/L and after UF declined to 427.8 mg C/L. The concentration of ammonium nitrogen declined during the prefiltration and membrane processes, and finally reached the value of 546.0 mg NH_4^+/L after UF, and the value of 60.2 mg NH_4^+/L after RO. Following the prefiltration and ultrafiltration processes, it showed a decrease in nitrate nitrogen concentration to 9.2 mg NO_3^-/L occurred. The concentration of nitrate nitrogen after RO was equal to 11.0 mg NO_3^-/L.

Table 3 shows the degree of removal of PAHs after an initial filtration and retention coefficients (*R*) after UF and after RO. The concentration of total PAHs in municipal landfill lactates was equal to 30.4 μg/L. The concentrations of all hydrocarbons after the initial filtration on the sand bed declined by 49% and the total concentration of 16 compounds ranged from 10.3 to 14.5 μg/L. The highest decline in the concentrations was reported for 5-ring and 4-ring hydrocarbons and ranged between 58% and 56%, respectively. The decrease in the concentration of 6-ring was 47%. The lowest decline in the concentration was observed for 3-ring PAHs and it was equal to 28%. The concentration of naphthalene declined by an average of 53%. The decrease in the concentration after prefiltration is a result of adsorption on the surface of the sand deposit particles.

Table 2
The composition of the leachate from municipal waste landfill after the filtration and UF/RO processes

Indicator	Municipal landfill leachates after filtration	Municipal landfill leachates after UF	Municipal landfill leachates after RO
pH	8.2	8.0	9.0
COD, mg O_2/L	4,644.8	2,494.7	139.3
TC, mg C/L	1,558.1	1,150.1	–
TOC, mg C/L	617.2	427.8	–
Ammonium nitrogen, mg $N - NM_4^+/L$	669.2	546.0	60.2
Nitrate nitrogen, mg NO_3^-/L	22.5	9.2	11.0

Table 3
Removal of PAHs from municipal landfill leachates

PAHs	The degree of removal after prefiltration (%)	Retention coefficient, after UF (*R*, %)	Retention coefficient, after RO (*R*, %)
Naphthalene	53 ± 2.55	48 ± 0.37	58 ± 2.67
Acenaphthylene	46 ± 0.48	–	19 ± 0.62
Acenaphthene	29 ± 0.23	58 ± 1.11	64 ± 2.81
Fluorene	32 ± 1.46	53 ± 0.38	48 ± 10.84
Phenanthrene	27 ± 0.05	66 ± 4.42	–
Anthacene	49 ± 1.07	59 ± 0.39	77 ± 5.06
Fluoranthene	40 ± 2.01	67 ± 0.01	86 ± 1.50
Pyrene	23 ± 0.14	65 ± 1.03	66 ± 0.70
Benz[a]anthracene	79 ± 1.41	69 ± 2.01	74 ± 0.15
Chrysene	84 ± 0.47	69 ± 7.04	93 ± 2.53
Benzo[b] fluoranthene	53 ± 1.01	73 ± 0.21	83 ± 5.12
Benzo[k] fluoranthene	43 ± 0.16	73 ± 2.03	84 ± 4.32
Benzo[a]pyrene	78 ± 1.40	65 ± 3.06	83 ± 2.50
Dibenzo[a,h] anthracene	59 ± 0.89	–	82 ± 2.39
Indeno[1,2,3,-cd] pyrene	36 ± 5.01	–	60 ± 0.01
Benzo[ghi]perylene	59 ± 2.89	73 ± 0.14	100 ± 0.05

The total concentration of PAHs in municipal landfill leachates after UF was in the range 4.5–5.7 µg/L. Changes in the concentration of 2–3 ring, 4-ring, and 5–6-ring hydrocarbons after UF are presented in Figs. 4–6, respectively.

The retention of all tested PAHs was observed during the ultrafiltration process. The retention coefficients of 3-ring were 59%, 4-ring 68%, and 5-ring 70%, respectively. It was also found that molecular weight of PAHs resulted in the degree of removal. The highest value of the retention coefficient of 73% was observed for macromolecular 6-ring compound: benzo (g,h,i)perylene. In the case of UF membrane, the retention coefficient increased with the molecular weight of

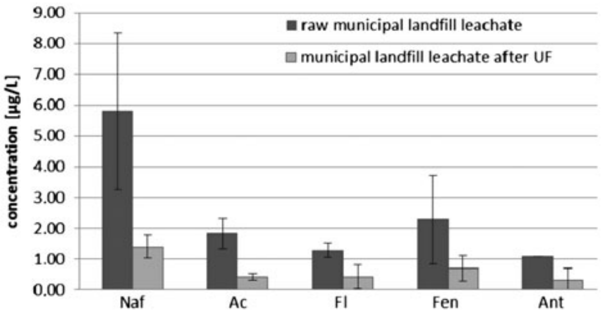

Fig. 4. Average concentrations of 2 and 3-ring PAHs in raw municipal landfill leachate and after ultrafiltration.

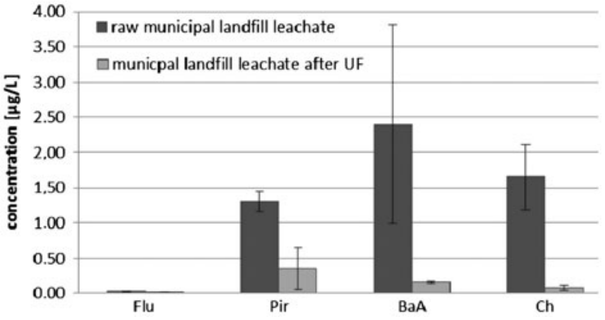

Fig. 5. Average concentrations of 4-ring PAHs in raw municipal landfill leachate and after ultrafiltration.

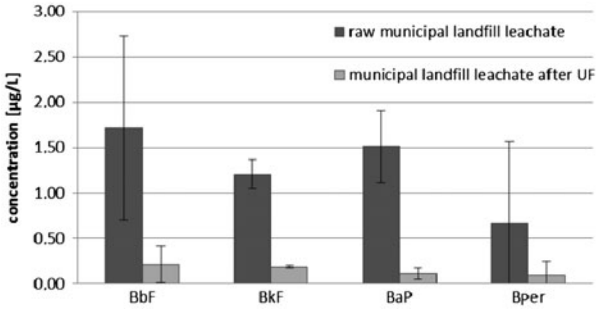

Fig. 6. Average concentrations of 5 and 6-ring PAHs in raw municipal landfill leachate and after ultrafiltration.

the removal compound. The least value of the retention coefficient of 48% was observed for naphthalene, due to the molecular weight of analyzed PAH. The earlier studies of the authors of this publication and studies of other authors confirm the above-mentioned dependence [3,14]. The concentration of B(a)P—the highest of carcinogens was reduced by 65% and the total decline equaled 92%. The total decrease in ultrafiltration process made it possible to remove an average of 64% of PAHs. Including the prefiltration, the overall level of removal PAHs reached 81%. Dudziak et al. indicate that the efficiency of removal of PAHs from water may reach 90% [3]. Due to the interaction between the retained particles and an ultrafiltration membrane (an adsorption of PAHs on the surface and inside the membrane pores caused basically by fouling), relatively a high degree in removal of PAHs from the wastewater was observed, despite the fact that the molecular weight. PAHs are much lower than the “cut-off” (70 kDa) and the pore radius of applied membrane. It may be caused also by adsorption of PAHs into the pore in the skin membrane. The higher retention coeffcient (71%) in removal of PAHs from the municipal landfill leachates was observed in reverse osmosis (UF 64%).

The changes in the concentration of 2–3 ring, 4-ring, and 5–6-ring hydrocarbons after RO are presented in Figs. 7–9, respectively. The total concentration of PAHs in municipal landfill leachates after RO was in the range 3.9–5.1 μg/L. The largest decline in the concentrations was reported for the compounds 5-ring and it was equal to 83%. Concentrations of 5 and 6-ring (characterized by the lowest solubility in water) amounted to an average of 0.65 μg/L and 0.01 μg/L. The concentration of naphthalene declined by an average of 58%. Concentration of 3-rings was the largest and it was equal to 3.9 μg/L. The degree of these compounds' removal ranged from 19% for acenaphthylene to 77% for anthracene. The effectiveness in removal of 4-ring was in the range 66–93%. The mean concentration of 4-ring was maintained at 0.65 μg/L. The concentration of B(a)P was reduced by 83%. In the case of RO, it was also found that molecular weight of PAHs resulted in the degree of removal-compounds of highest molecular mass were better retained than less molecular compounds. Compounds of higher hydrophobicity display higher adsorption on the membrane surface [20]. Including the prefiltration, the overall level to remove PAHs in RO was equal to 89%. It has been found that the effectiveness of hydrocarbons removal in the integrated system with RO was higher than in the integrated system for UF. Nevertheless, it is advisable to precede RO and UF with filtration on sand deposit because of membrane efficiency. Membrane fouling involves the deposition of substances existing in the filtrated sample on the membrane surface and/or in the pores of the substances presented in filtrated sample. In the course of UF and RO separation it caused a decrease in permeate flux volume over time and it is a disadvantageous phenomenon. The significant flux decline could be induced by organic matter fouling on membrane surface. The deposition of organic matter on membrane surface can change the separation characteristic of the membrane. However, reversible fouling in total fouling on the membrane can be eliminated by backwash cleaning.

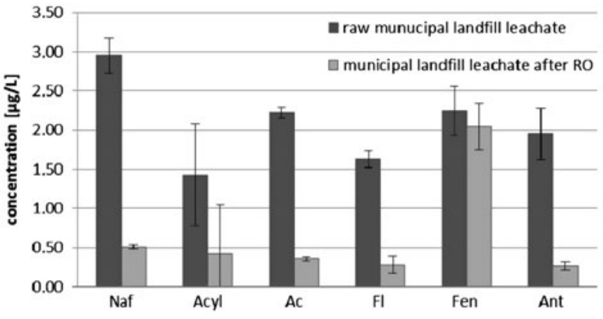

Fig. 7. Average concentrations of 2 and 3-ring PAHs in raw municipal landfill leachate and after reverse osmosis.

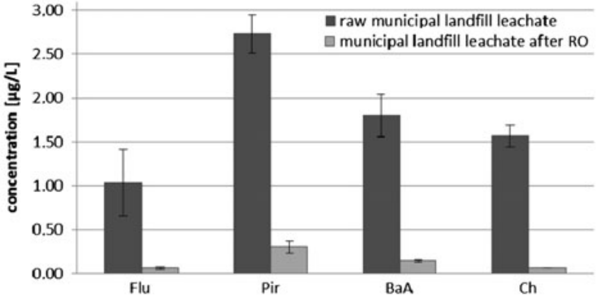

Fig. 8. Average concentrations of 4-ring PAHs in raw municipal landfill leachate and after reverse osmosis.

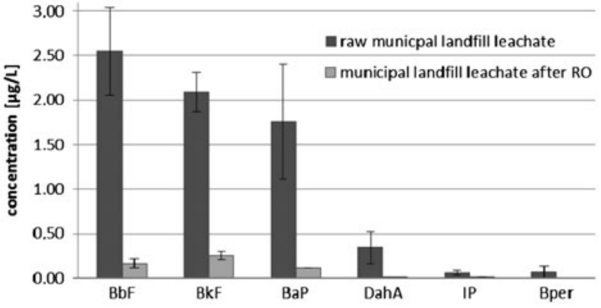

Fig. 9. Average concentrations of 5 and 6-ring PAHs in raw municipal landfill leachate and after reverse osmosis.

Table 4
Values of Student-t distribution ($t_d = 2.776$) by the number of rings

PAHs	Prefiltration	Ultrafiltration (UF)	Reverse osmosis (RO)
Naph	8.53	7.44	11.21
3-rings of PAHs	0.46	4.23	3.65
4-rings of PAHs	2.71	1.48	4.31
5-rings of PAHs	6.76	2.68	6.65
6-rings of PAHs	3.34	7.60	9.84
Total of 16 PAHs	3.92	6.61	6.98

The critical values of Student's t test, determining the significance of the process used in the treatment of PAH concentrations for the studied wastewater are shown in Table 4. The statistical calculations proved that the type of municipal landfill leachate treatment process was statistically significant while determining the total concentration of PAHs (determined value of td is greater than the critical value). For prefiltration process, the greatest statistically significant value for naphthalene was indicated, whereas for ultrafiltration —6-ring compounds. The RO had a statistically significant effect on the concentrations of studied hydrocarbons. The greatest statistically significance was found for reverse osmosis for naphthalene. The use of treatment processes plays a statistically significant role in the removal of PAHs from municipal landfill leachate.

4. Conclusions

(1) The range of concentrations of PAHs in the municipal landfill leachates equaled 17.5–30.4 μg/L. During all the experiments, a decrease in concentration of studied hydrocarbons was observed. The concentrations of all hydrocarbons after the initial filtration on the sand bed declined by 49% and the total concentration of 13 compounds ranged from 10.3 to 14.5 μg/L. This study indicated the necessity of using sand bed filtration in order to protect the membrane from pollutions.

(2) In the process of ultrafiltration, a further reduction in the concentration of PAHs was achieved and the final total content ranged 4.5–5.7 μg/L. The treatment of municipal landfill leachates in the process of ultrafiltration allowed for removing 64% of PAHs. The efficiency of the removal of hydrocarbons grouped according to a number of rings was in the range of 48 (for naphthalene) to 73% (for 6-ring of PAHs-benzo(g,h,i)perylene). The total removal of PAHs during initial filtration and UF equaled to 81%.

(3) The total concentration of PAHs in municipal landfill leachates after RO was in the range from 3.9 to 5.1 μg/L. The investigations confirmed high efficiency in removal of PAHs using a reverse osmosis. The degree in removal of PAHs after RO was 71% (for individual hydrocarbons were in the range 19–100%). The overall level of remove PAHs in RO (after initial treatment on sand deposit) was equal to 89%.

(4) From the selected physical–chemical indicators, the highest removal efficiency 97% is obtained for COD after reverse osmosis. There is also a high degree in removal of ammonium nitrogen after RO and it is equal to 91%. High removal efficiency 70% was obtained for nitrate nitrogen after ultrafiltration. The efficiency in the removal of COD after UF was 50%. A degree in removal of TC and TOC during ultrafiltration was 35% and 37%, respectively. The smallest degree in removal 31% was obtained for ammonium nitrogen after UF. The municipal landfill leachates cannot be discharged into the natural receiver but they can be recycled and used in municipal waste landfill.

(5) High values of retention coefficients suggest that the UF and RO may be used for cleaning the wastewater containing high concentrations of PAHs. However, the research confirms the greater efficiency in the removal of PAHs using the reverse osmosis technique.

(6) A significant flux decline for RO and UF processes was observed—the lower flux for municipal landfill leachate than a stream for distilled water was observed. A decrease in the permeability of the membranes was obtained and it probably affected the retention coefficients of PAHs

in the ultrafiltration and reverse osmosis processes. However, the membrane processes may be applied in the technologies for municipal landfill leachate treatment.

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References

[1] A.K. Haritash, C.P. Kaushik, Biodegradation aspects of polycyclic aromatic hydrocarbons (PAHs): A review, J. Hazard. Mater. 169 (2009) 1–15.

[2] G. Liu, Z. Niu, D. Van Niekerk, J. Xue, L. Zheng, Polycyclic aromatic hydrocarbons (PAHs) from coal combustion: Emissions, analysis, and toxicology, Rev. Environ. Contam. Toxic. 192 (2008) 1–28.

[3] M. Dudziak, K. Luks-Betlej, M. Bodzek, Removal of PAHs from water using membrane processes, Eng. Prot. Environ. (3–4) (2003) 299–311.

[4] M. Włodarczyk-Makuła, Half-life of carcinogenic polycyclic aromatic hydrocarbons in stored sewage sludge, Arch. Environ. Prot. 38(2) (2012) 33–44.

[5] M. Zielińska, J. Sobolewska, K. Bułkowska, I. Wojnowska-Baryła, P. Szelążek, Removal of phenanthrene and 4-phenylphenanthrene from wastewater in an integrated technological system, Desalin. Water Treat. 50 (2012) 78–86.

[6] M. Bodzek, K. Konieczny, Membrane processes in water treatment—State of art, Eng. Prot. Environ. 9 (2006) 129–159.

[7] M. Bodzek, K. Konieczny, Membrane techniques in the removal of inorganic anionic micropollutants from water environment—State of the art, Arch. Environ. Prot. 37(2) (2011) 15–22.

[8] M. Dudziak, M. Bodzek, M. Rajca, The use of ultrafiltration in water treatment, The fate of estrogenic compounds in the aquatic environment, V Conference on Membranes and Membrane Processes in Environmental Protection, Monographs of Environmental Engineering Sciences Committee, 22 (2004) 115–123.

[9] A.L. Kowal, M.– Świderska Bróż, Water treatment, Theoretical background and technological processes and devices, Polish Scientific Publishers, Warszawa, 2007.

[10] K. Luks-Betlej, M. Dudziak, Membrane techniques in water treatment processes, Removal of Polycyclic Aromatic Hydrocarbons and Phthalates using Nanofiltration, Microcystin and other Micropollutants in Drinking Water, The Conference, Lodz, 24–25 April 2003, Paper Int. J. Ecohydrol. Hydrob., Pol. Suppl. 5 (2005) 93–99.

[11] I.G. Wenten, J.Ganesha, Ultrafiltration in water treatment and its evaluation as pre-treatment for reverse osmosis system, Research ReportInstitut Teknologi Bandung, Indonesia (June 2008) (1996).

[12] M.Dudziak, K. Luks-Betlej, A. Waniek, M. Bodzek, Ultrafiltration in the removal of toxic organic micropollutants from natural waters, Eng. Prot. Environ. S1 (2003) 61–71.

[13] M. Kabsch-Korbutowicz, K. Majewska-Nowak, K., Separation of organic micropollutants from water by the ultrafiltration process, Environ. Pollut, Control 1 (68) (1999) 7–12 (in polish).

[14] M. Smol, M. Włodarczyk-Makuła, Effectiveness in the removal of polycyclic aromatic hydrocarbons from industrial wastewater by ultrafiltration technique, Arch. Environ. Prot. 38(4) (2012) 49–58.

[15] M. Bodzek, K. Konieczny, Membrane techniques in the removal of organic pollutant from water environment—State of art, Water Sypply and Water, PZITS, Poznań 2 (2012) 217–154 (in polish).

[16] J. Dojlido, W. Dożańska, W. Hermanowicz, B. Koziorowski, J. Zerbe, Phys-chem. stud. of water and wastewater, ARKADY, Warszawa, 1999 (in polish).

[17] K. Mielczarek, J. Bohdzewicz, Performance prediction of ultrafiltration treatment of post-process coke wastewater based on the assumptions of hydraulic filtration resistance model, Arch. Environ. Prot. 37(4) (2011) 107–118.

[18] The Minister of Environment of 28 January 2009 on conditions to be met for the introduction of sewage into the water or the ground, and the substaces particularly harmful to the aquatic environment (Journal of law 2006 No. 137, item. 984).

[19] J. Koc-Jurczyk, The efficiency of reverse osmosis landfill leachate concentrate treatment by AOP, Inżynieria ekologiczna 31 (2012) 72–79.

[20] M. Dudziak, M. Bodzek, Removal of xenoestrogens from water during reverse osmosis and nanofiltration—effect of selected phenomena on separation of organic micropollutants, Archit. Civil Eng. Environ. 3 (2008) 95–102.