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Application of MBR technology for laundry wastewater treatment

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ABSTRACT

The application of membrane bioreactor (MBR) for industrial laundry wastewater treatment is presented. An MBR pilot plant installation was used to test the efficiency of surfactants removal and the influence of treatment time on permeate flux. The installation consisted of (1) biological reactor (three tanks with a total capacity of 600 dm^3), (2) membrane reactor (ZeeWeed 10 membrane module, GE Water & Process Technologies), and (3) dosing station. The hourly flow rate of the wastewater to the biological reactor amounted to Q_h = 25 dm^3 h^{-1}. The effluent from the bioreactor was periodically recycled back to the membrane reactor at Q_h = 125 dm^3 h^{-1}. Despite periodical relaxation and backflush with permeate, after about 11 d of operation the membrane was fouled and chemical cleaning was necessary. The membrane permeability was fully recovered after the applied cleaning procedure. The total efficiency of removal of anionic and non-ionic surfactants was in the range of 87%–95% and 94%–95%, respectively. The COD removal reached 91%–93% and the BOD was almost completely eliminated (99%) indicating high MBR treatment efficiency of the applied industrial laundry wastewater.

Keywords: Laundry wastewater; MBR technology; Microfiltration; Surfactants

1. Introduction

Membrane bioreactor (MBR) combines membrane separation and biological treatment processes in one unit. The suspended biomass is responsible for the biodegradation of contaminants and the membrane allows separating purified water from the wastewater stream. Usually microfiltration (MF) membranes are used in the MBRs, although ultrafiltration (UF) ones can be applied. The membranes allow rejection of particles and bacteria and thus the membrane system replaces the traditional gravity sedimentation unit in the biological activated sludge process. MBRs offer the advantage of high product water quality and low environmental footprint.

MBR technology has a great potential in a wide range of applications including municipal and industrial wastewater treatment and process water recycling [1]. It was reported [2] that the treatment of greywater using MBR resulted in hygienically safe and high quality product which could be reused, alone or combined with rain water, for toilet flushing, laundry washing or for irrigation purposes. The MBR technology was also tested for the treatment of the real winery wastewater generated in a wine-making process in Bodegas Torres facilities, Spain [3]. A small-scale MBR (capacity up to 0.4 m^3 d^{-1}) has been successfully tested in a Chinese textile factory. However, since the MBR permeate contained coloured dyestuff, an additional treatment step such as NF or reverse osmosis (RO) was necessary in order to increase the proportion of the reused water [4]. A laboratory-scale hybrid system coupling MBR with adsorption on powdered activated carbon (MBR–PAC) was developed to treat coal gasification wastewater. The dosage of PAC was 4 g dm^{-3} and the maximum removal efficiencies

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of COD (Chemical Oxygen Demand), total phenols and NH_4^+ reached 93%, 99% and 63%, respectively [5]. A bench scale hollow fibre MBR (HF-MBR) was also utilized for treatment of the real wastewater of the Arak refinery, Iran. The removal rates of COD, BOD_5 (Biochemical Oxygen Demand), TSS (total suspended solids), VSS (volatile suspended solids), and turbidity were 82%, 89%, 98%, 99%, and 98%, respectively [6]. An integrated system using a biofilm-MBR process was applied for shipboard wastewater treatment. All the wastewater streams generated on-board were treated in one plant only instead of two independent treatment systems for black/grey wastewater and bilge water [7].

The MBR systems were also tested in laundry wastewater treatment. It should be noted here that the industrial laundry business is one of the largest consumers of water. Despite a considerable progress in implementation of water-saving procedures in this industry, the commercial laundries are still emitting relatively high quantities of wastewater. Wastewater from industrial laundries contains a high microbiological load and high levels of pollutants (fats, oils, suspended solids, etc.), as well as chemicals and surfactants from dirty clothes and washing operations. These contaminants are difficult to remove from wastewater by conventional processes. Due to its high treatment efficiency, the MBR technology has usually been applied in the laundries to reuse/recycle water and close the water cycle. A research by Nicolaidis and Vyrides [8] examined a full-scale submerged aerobic MBR (9 m^3) over a period of 288 d for treatment of laundry wastewater. It was found that both turbidity and total solids (TS) were reduced by 99%, and the COD removal efficiencies were between 70% and 99% [8]. Another MBR has been successfully tested for 5 years in the form of two pilot plants at the laundry in Darmstadt, Germany. The COD removal efficiency was around 90% [4,9].

In this research work, applicability of MBR technology for industrial laundry wastewater treatment is discussed. Pilot plant investigations tested the influence of treatment time on permeate flux. Moreover, a membrane cleaning procedure was developed. Finally, the product (treated wastewater or permeate) quality was determined.

2. Experimental

The wastewater was obtained from the industrial laundry Albatros Sp. z o. o. Sp. K. (Nowe Czarnowo, Poland). The laundry washes 70 tonnes of mainly hotel linen and towels per day and produces 500 m^3 of wastewater per day. The mechanically treated wastewater taken from a retention tank was used. The applied wastewater was a mixture of the wastewater arising from washing processes and from regeneration of ion exchangers that are used for softening of technological water (polluted mainly by chlorides).

The laundry wastewater was treated in a pilot scale MBR installation presented in Fig. 1. The installation consisted of:

- biological reactor: three tanks with a total capacity of 600 dm^3 operated at internal recirculation rate of Q = 50 $dm^3\ h^{-1}$, mixed liquor suspended solids (MLSS): 8–10 kg m^{-3}, dissolved oxygen concentration: 1–3 mg dm^{-3};
- membrane reactor equipped with the ZeeWeed 10 submerged membrane module (GE Water & Process Technologies, Germany); membrane material: PVDF, nominal membrane surface area: 0.93 m^2, nominal pore size: 0.04 μm, outer/inner fiber diameter: 1.9 mm/0.8 mm;
- dosing station: to obtain the necessary concentration of nitrogen (5 mgN dm^{-3}) the Adblue® solution (32.5% w/w of urea) was dosed at a rate of 2 $cm^3\ min^{-1}$.

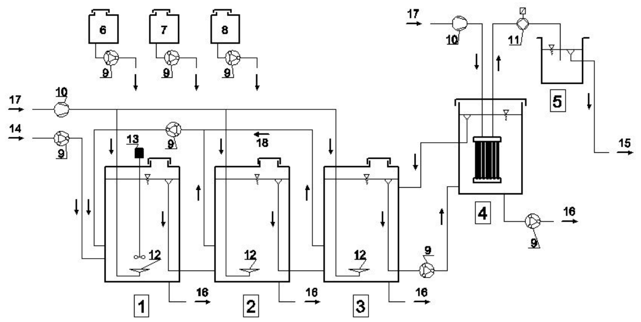

Fig. 1. A schematic diagram of the pilot scale MBR installation.
Note: 1 – anoxic/oxic reactor, 2 – oxic reactor, 3 – oxic reactor, 4 – membrane unit, 5 – permeate tank, 6 – acid container, 7 – antifoam container, 8 – nutrient container, 9 – peristaltic pump, 10 – blower, 11 – permeate pump, 12 – membrane diffuser, 13 – mixer, 14 – raw wastewater inflow, 15 – permeate outflow, 16 – excess sludge, 17 – air, 18 – recirculation of activated sludge.

To maintain the required value of pH (7.7), the pH adjustment using 10% H_2SO_4 solution was performed.

The hourly flow rate of the wastewater to the biological reactor amounted to Q_h = 25 $dm^3\ h^{-1}$. The mixed liquor from the bioreactor was continuously recirculated through the membrane unit at the flow rate of Q_h = 125 $dm^3\ h^{-1}$.

The composition of raw wastewater and the MBR effluent was analysed for:

- chemical oxygen demand (COD) – according to PN-ISO 6060;
- biochemical oxygen demand (BOD) – using Lovibond-BOD-System Oxidirect;
- anionic surfactants concentration – using the cuvette test LCK332 (HACH LANGE);
- non-ionic surfactants concentration – using the cuvette test LCK333 (HACH LANGE);
- Cl^- concentration – using the cuvette test LCK311 (HACH LANGE);
- total phosphorus (P) – using the cuvette test LCK350 (HACH LANGE);
- total nitrogen (N) – using the cuvette test LCK238 (HACH LANGE);
- conductivity and pH – with application of CPC-505 meter.

3. Results and discussion

3.1. Monitoring of laundry wastewater quality

Prior to commencing pilot plant MBR tests, the quality of laundry wastewater was monitored weekly for 46 weeks. The content of anionic and non-ionic surfactants and the values of COD and BOD are presented in Figs. 2 and 3, respectively. The concentration of anionic surfactants amounted to 22.6–50.8 mg dm^{-3} and the concentration of non-ionic

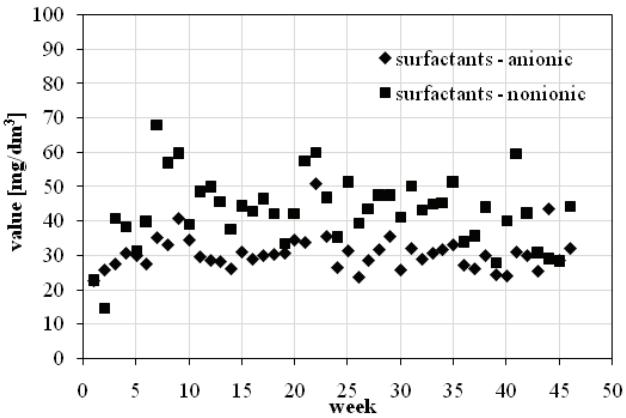

Fig. 2. Concentration of anionic and non-ionic surfactants in the raw laundry wastewater.

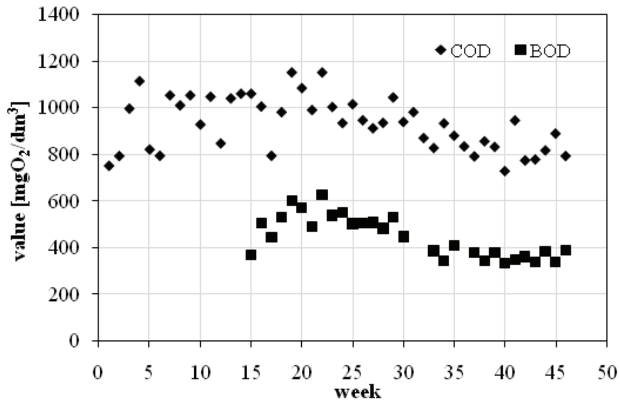

Fig. 3. Changes of COD and BOD of raw laundry wastewater with time.

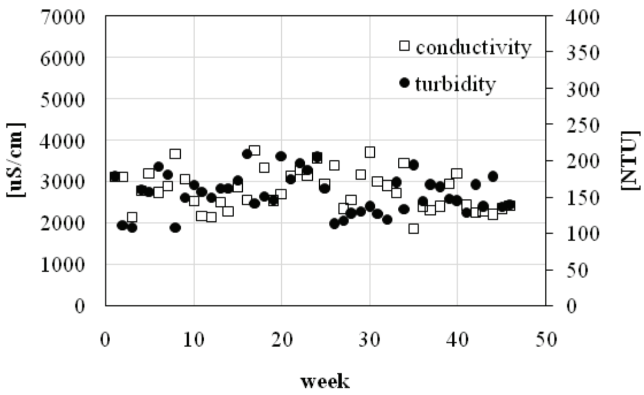

Fig. 4. Changes of conductivity and turbidity of raw laundry wastewater in time.

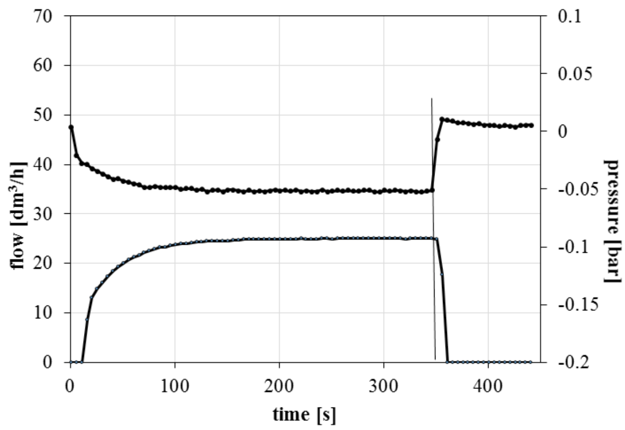

Fig. 5. MBR operating sequence (1 cycle).

surfactants was in the range of 14.6–67.9 mg dm^{-3} (Fig. 2). Median value for anionic surfactants was 30 mg dm^{-3} and for non-ionic surfactants, it reached 43 mg dm^{-3}. The concentration of non-ionic surfactants in the tested laundry wastewater is ca. 50% higher than that of anionic one.

As it can be seen in Fig. 3, the values of COD were in the range of 750–1,150 mgO$_2$ dm^{-3} and BOD ranged from 368 to 626 mgO$_2$ dm^{-3}. Median values for COD and BOD amounted to 933 mgO$_2$ dm^{-3} and 446 mg dm^{-3}, respectively. The ratio of COD/BOD ranged from 1.69 to 2.13 indicating that that the applied laundry wastewater is susceptible to biodegradation. Therefore, application of the MBR technology coupling biological treatment and membrane separation was justified.

As it can be seen in Fig. 4, the values of conductivity were in the range of 1,854–3,757 µS cm^{-1} and turbidity ranged from 108 to 210 NTU. Median values for conductivity and turbidity amounted to 2,755 µS cm^{-1} and 154 NTU, respectively.

3.2. MBR operating sequence

The membrane unit was operated in cycles each lasting445 s. Fig. 5 illustrates the MBR operating sequence for one cycle. The filtration process was conducted for 350 s at the transmembrane pressure of –0.05 bar. During this stage, coarse bubbles of air were continuously supplied to the system in order to prevent solids accumulation on membrane's fibers. After the filtration period, the membrane relaxation lasting 90 s was completed (Fig. 5) without applying pressure on the membrane and only coarse bubble aeration was continued. The rising air bubbles created a scouring effect contributing to the removal of solids deposited onto the membrane surface. The relaxation assists the back transport by ending the convective flow. The last step of the sequence was backflush with permeate (5 s). The aim of this final stage was to remove the foulants from the membrane pores. After the backflush, the next cycle was started.

3.3. Treatment of laundry wastewater in MBR. Permeability and membrane cleaning

Fig. 6 presents the changes in membrane permeability over a 3-week period of laundry wastewater treatment in the MBR pilot plant. The initial permeability amounted to ca. 500 dm^3 m^{-2}·h·bar. However, after 4 d the permeability decreased to 100 dm^3 m^{-2}·h·bar (see Sample 1 in Fig. 6) and remained at that level for 7 d. Then the process was stopped and membrane cleaning was necessary. The membrane was moved to a 15 dm^3 tank and the following chemical cleaning procedure was applied:

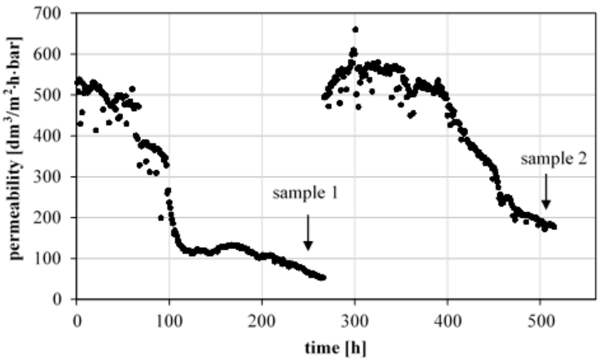

Fig. 6. Changes of the membrane permeability during 3 weeks of MBR operation.
Note: After 218 h (Sample 1) and after 510 h (Sample 2) – the composition of raw laundry wastewater (Table 1) and the MBR effluents (Fig. 7) was analysed.

(1) washing with 0.025% P3-Ultrasil 11 solution (pH 9.5–10.5, time = 2.5 h, temperature = 27°C–31°C);
(2) washing with demineralised water;
(3) washing with 5 g dm^{-3} citric acid (pH 2.3–2.4, 2.5 h, 22°C–30°C);
(4) washing with demineralised water;
(5) washing with alkaline solution obtained by dilution of 20 g dm^{-3} NaOH (pH 10–10.5, 3 h, 24°C–33.5°C);
(6) washing with demineralised water;
(7) washing with diluted NaOCl stabilized solution (250 mg dm^{-3} of active chlorine, pH 10.9, 3 h, 26.5°C–32.5°C).

Application of the above cleaning procedure allowed completely recovering the membrane permeability. The membrane was subsequently mounted in the installation and the MBR operation was started.

After application of the cleaning procedure the membrane permeability remained at a level of ca. 500–600 dm^3 m^{-2} × h × bar for 5 d. After that the permeability gradually decreased to the value of ca. 200 dm^3 m^{-2}·h·bar (see Sample 2 in Fig. 6). Then, the process was stopped and membrane backwash was applied to recover the permeability. The membrane examination revealed the presence of fibers originating from the laundry which could be responsible for the observed fouling of the membrane. Therefore, it was concluded that an additional pre-treatment step, in addition to the applied mechanical pre-treatment of the raw wastewater, such as filtration through microsieves is necessary.

3.4. Treatment efficiency

The composition of the raw laundry wastewater and the MBR effluent was analysed after 218 h and 510 h of MBR operation (corresponding to Samples 1 and 2 in Fig. 6). Table 1 presents the quality of the raw wastewater, whereas the treatment efficiency is summarized in Fig. 7. It can be observed that the content of surfactants as well as COD and BOD values in both samples of the raw wastewater was comparable (Table 1). Similarly, no significant difference between the conductivity and related to this parameter Cl$^-$ concentration was observed.

As can be seen in Fig. 7, the total efficiency of removal of the measured parameters was comparable in both cycles and

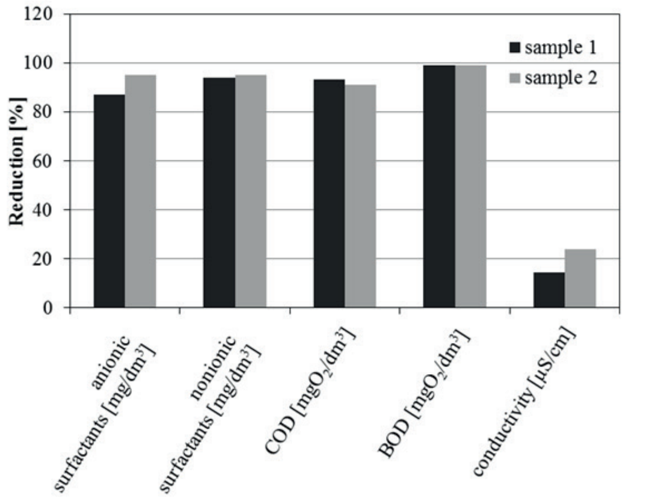

Fig. 7. Total efficiency of removal of organic and inorganic contaminants from laundry wastewater treated in pilot-scale MBR at 218 h (Sample 1) and 510 h (Sample 2).

Table 1
Characteristics of raw laundry wastewater at 218 h (Sample 1) and 510 h (Sample 2)

Parameter	Unit	Sample 1	Sample 2
		Value	
Anionic surfactants	mg dm^{-3}	27.2	23.9
Non-ionic surfactants	mg dm^{-3}	62.1	61.6
COD	mgO_2 dm^{-3}	938	827
BOD	mgO_2 dm^{-3}	479	414
Cl$^-$	mg dm^{-3}	374	338
P	mgP dm^{-3}	4.02	1.92
N	mgN dm^{-3}	9.49	4.01
Conductivity	µS cm^{-1}	2,509	2,757

amounted to 87%–95% in case of anionic surfactants, 94%–95% in case of non-ionic surfactants, 91%–93% for COD and 99% for BOD. A wider range of conductivity removal was observed (14%–24%), which can be attributed to variations in the concentration of inorganic ions in the raw wastewater.

The reduction of total P and total N was in the range of 48%–64% and 71%–86%, respectively. The Cl$^-$ removal reflected the decrease of conductivity of the treated wastewater and during both MBR treatment cycles the Cl$^-$ ions were removed by ca. 7%–27%.

Nicolaidis and Vyrides [8] used a full-scale submerged MBR for laundry wastewater treatment. Parameters of industrial laundry wastewater tested by them were higher than in presented studies. In this research, raw laundry wastewater was a more concentrated effluent. Mean value of conductivity amounted to 2,249 µS cm^{-1}, turbidity 92 NTU and COD 317 mgO_2 dm^{-3}. Moreover, Kubota membrane type FS-75 with a cut of 0.4 µm was used. The effluent COD removal efficiency was greater than 70%, whereas in this study, the efficiency of COD removal reached >90%.

This reference study [8] has maintained the plant operational for a period of 288 d compared with 10 d in this study. Therefore, an additional pre-treatment step, such as filtration through microsieves, is recommended to enable longer testing periods.

4. Conclusions

In this study, the MBR process was applied for the industrial laundry wastewater treatment. The total efficiency of removal of anionic and non-ionic surfactants was in the range of 87%–95% and 94%–95%, respectively. The COD value decreased by 91%–93% and BOD by 99%, indicating high treatment efficiency. The disadvantage of the process was significant fouling of the used membrane. Despite the applied membrane operation sequence consisting of filtration, relaxation and back flush, after 1.5 week of operation the chemical membrane cleaning was necessary. Based on the membrane examination, it was concluded that the main factor responsible for the membrane fouling was the presence of fibers originating from the laundry. Therefore, an additional pre-treatment step, such as filtration through microsieves, was found to be necessary.

Acknowledgments

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