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Performance of an ultrafiltration membrane bioreactor (UF-MBR) in wastewater treatment

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ABSTRACT

This work presents the performance of an ultrafiltration membrane bioreactor (UF-MBR) system used as a means of removing pollution from domestic wastewater. Considering the technical performances of the process under different operational conditions, influence of hydraulic retention time (HRT), aeration rate and transmembrane pressure were observed. The evaluation of permeate quality, calculated by the removal efficiencies for various water quality indicators: chemical oxygen demand, biological oxygen demand, total suspended solids, total nitrogen (TN) and total phosphorous (TP). The best results obtained on the system (pressure $p = 1.27$ bar), HRT (15 h) showed removal efficiencies up to 90% in terms of organic compounds removal, 100% in terms of suspended solids presence and up to 80% reduction of TN and TP. The overall results suggest that the performance of the UF-MBR are likely to impact on the operation and maintenance of the system. However, the MBR process might be successfully applied as a treatment for the removal of pollution from domestic wastewater.

Keywords: Domestic wastewater treatment; Ultrafiltration membrane bioreactor; Hydraulic retention time; Aeration rate; Pollution removal

1. Introduction

Water is extremely essential for the survival of all living organisms. Like many other developing countries, Morocco is also regarded as a water-stressed country, and it is likely to have a water scarcity in the near future [1]. The quality and quantity of fresh water is deteriorated by the discharge of untreated municipal wastewater, and according to a recent report, only 12% of the urban wastewater is treated in municipal treatment plants [2]. Therefore, the interest for wastewater treatment increases in step and the reuse has become an environmentally and economically viable option [3].

Diverse technologies have been introduced for the treatment of municipal, domestic and industrial wastewater [4]. For example, the integrated anaerobic–aerobic sequencing batch reactor system is a suitable technology for treatment of high concentrations of organic matter in domestic and industrial wastewater treatment [5]. Also, the conventional activated sludge processes (ASP) are often used for municipal and domestic wastewater purification, showing high organic matter removal efficiency [6]. Nevertheless, the treatment efficiency of these processes is usually limited by the difficulties in separating suspended solids [7]. To overcome this problem, one of the most promising technologies for wastewater treatment and reuse are membrane separation systems combining with other technologies [8]. Among these technologies, the Membrane bioreactors (MBR), which integrate biological degradation of waste products with membrane filtration, ensuring effective removal of organic contaminants and nutrients from wastewater [9].

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In recent years, MBR technology has grown up to become state-of-the-art in municipal wastewater treatment [10]. During the operation of a MBR system, several factors must be taken into account. Hydraulic retention time (HRT), sludge retention time (SRT), biomass concentration, oxygen supply ratio, transmembrane pressure (TMP) and permeation flux [11]. The HRT is a fundamental operating parameter that determines reactor performances in MBR systems [8]. HRT correlated not only to the treatment efficiency of the MBR systems, but also to the characteristics of biomass in an activated sludge system and affect the operational cost [12]. Furthermore, dissolved oxygen is one of the most critical factors to the aerobic biological wastewater treatment process, which can be adjusted by controlling aeration rate. However, an optimal aeration sequence and duration when cyclic aeration mode is used can improve the treatment effectiveness [13]. The aeration not only provides oxygen to the biomass, but also maintains the solids in suspension in the activated sludge process [14]. These offer to MBR significant advantages compared to conventional ASP. Among these advantages: compactness, high removal ratios for most contaminants, less sludge production and a flexible operation mode attributed to the separation of SRT and HRT [15,16]. The main objective of the present study was to investigate the performance of MBR process combined with ultrafiltration (UF) membrane to treat domestic wastewater. Attention was paid to its efficiency of organic and nutrients removal, and particularly to the impact of operational parameters, such as the influence of HRT, aeration rate and TMP on effluent quality.

2. Materials and methods

2.1. MBR configuration and operation

The MBR system used consists of three parts; an anoxic tank (20 L, Plexiglas) connected to a biological reactor (40 L, Plexiglas) coupled to an external membrane. A schematic of the MBR is shown in Fig. 1. The feed flow was regulated with two level sensors to maintain a constant working volume of liquid in the reactor. A peristaltic pump controlled by these levels feeds the pilot in wastewater from a storage tank. A sequenced aeration was done by four diffusers placed at the bottom of the aeration reactor, providing the necessary oxygen for good treatment. The aeration cycles were fixed by the oxygen transmitters to control the air blowing. Two levels of aeration flow rates were used: a low flow rate just to maintain the mixing at 300 NL h^{-1} and a high flow rate for intensive air scouring at 700 NL h^{-1}. In this study, the bioreactor was operated at different HRTs (7, 10, 12, and 15 h) to investigate the effect of varying detention time on MBR performances.

The UF membrane employed in the study is ceramic tubular (Membralox®) allowing the separation of the treated effluent and the purifying biomass, it is placed outside the bioreactor. The characteristics of the membranes are listed in Table 1. Ceramic UF membranes are by far widely used through physical removal of particles from liquid in the size range of 0.01–0.1 μm, because of their potential advantages including chemical and thermal stability, physical strength,

Table 1
Characteristics of the membrane

Membrane material	Ceramic
Module	Tubular
Provider	Pall Exekia
Membrane area	0.45 m^2
Cut off	15 kD
Membrane length	1,178 cm
Diameter of the channels	6 mm
Transmembrane pressure (TMP)	0.05–1.35 bar

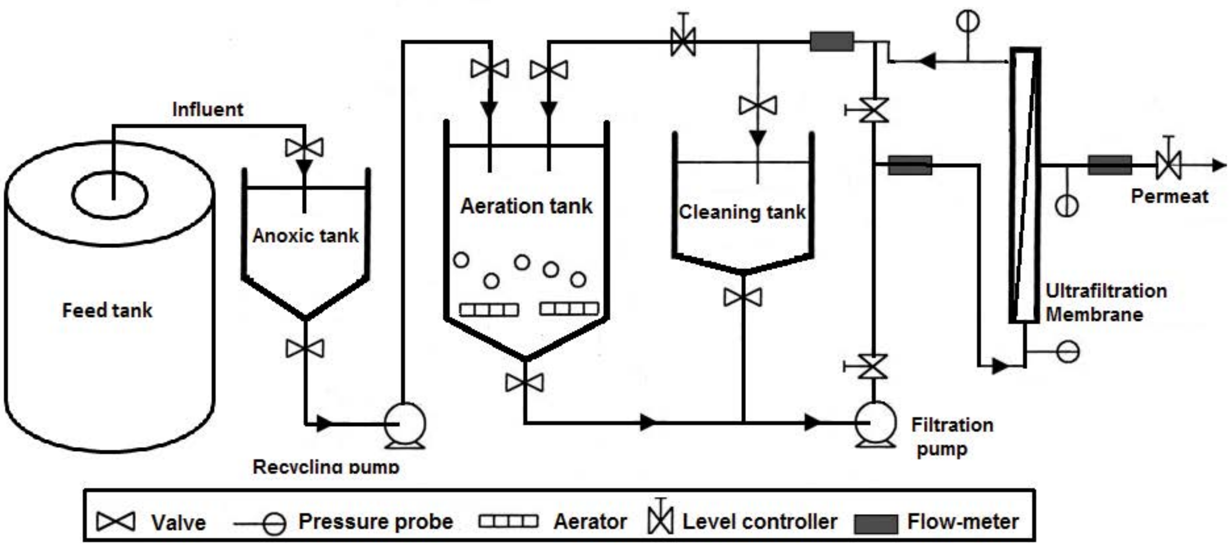

Fig. 1. Flow diagram for the ultrafiltration MBR system.

and a longer operational life [17]. The pressure is measured by means of pressure sensors and pressure gauges placed at the outlet of the recirculation pump just before the membrane module is inlet, at the outlet of the membrane module and in the permeate collecting circuit. The system was operated at different TMP (0.05–1.35 bar).

The membrane was cleaned after each use following the manufacturers' recommendation. However, the membrane filtration unit was disconnected from the bioreactor before starting the chemical cleaning of the membranes. Prior to this cleaning exercise, the membrane modules were rinsed two to three times with tap water for the removal of the sludge layer and solid particles deposited on the membrane surface. Then, citric acid solution and alkali solution were prepared and put in the cleaning tank, each solution recirculated through the membrane for about 20 min [18].

2.2. Inoculum and supply of wastewater

The reactor was inoculated with 15 L of aerobic sludge from a wastewater treatment plant located in National Office of Electricity and Drinking Water in Rabat. The concentration of activated sludge into the MBR were in the range of 3–10 g L^{-1} of total suspended solids (TSS). In fact, the physicochemical and microbiological characteristics of the activated sludge were typical of the conventional ASP. Then, the reactor was fed with domestic wastewater, their characteristics were within the standard limits of World Health Organization (WHO) and United States Environmental Protection Agency (US-EPA) [19,20]. Thus, TSS (350–414 mg L^{-1}), 5 d biochemical oxygen demand (BOD_5) (217–497 mg L^{-1}), and chemical oxygen demand (COD) (527–745 mg L^{-1}) deviated considerably from their prescribed limits, indicating a high level of contamination. Parameters of the domestic wastewater are listed in Table 2. However, the wastewater used characteristics can represent the medium-strength urban wastewater seen in Morocco and in most cities around the world [21,22].

2.3. Analytical methods

Samples of wastewater were taken before and at the end of each treatment cycle. They were collected periodically and analyzed for various physical and chemical parameters. Quality parameters such as TSS, 5 d BOD_5 and nitrate (NO_3^-) were determined in accordance with Standard Methods [22,23]. These parameters were measured every day. While, COD, total nitrogen and total phosphorous (TP) were measured with reagent kits (HACH DR4000, USA) twice per week [23]. The HRT was calculated based on the influent flow rate and size of the aeration tank. The aeration rate was measured using the flow meter.

3. Results and discussion

3.1. The effect of HRT on removal efficiency

Fig. 2 shows the evolution of COD, BOD_5 and TSS concentrations in permeate as a function of HRT. The results showed that the concentration of COD decreases in the permeate according to the HRT; achieve 11 mg L^{-1} during 15 h of the HRT. In the same way, the concentration of BOD_5 decreases to 11, 7, 5, and 3 mg L^{-1} respectively for HRT of 7, 10, 12, and 15 h. Furthermore, a reduction in the concentration of TSS was recorded in the permeate, reaching respectively 5, 3, 1, and 0 mg L^{-1} for the TRH 7, 10, 12, and 15 h. Thus, the results showed that the high HRT (15 h) gives a better reduction of the concentrations of the TSS, the BOD_5 and the COD. These results comply with Moroccan Rejection Standards (Table 2).

The influence of HRT variation is shown in Fig. 3. The removal efficiency of COD in the permeate was 98% at 15 h of HRT. However, when the reactor was operated under the lowest HRT (7 h), an increase in the concentration of COD was registered. This behavior may be a consequence of the inability of the solids separator to retain the sludge and the decrease in contact time between the microorganisms and the substrate, allowing part of the incoming COD to leave the reactor without proper treatment [21]. Furthermore, according to Wang et al. [24], this could also be a consequence of the increase in shear forces inside the reactor which causes microorganisms stress. The elimination rate of TSS was 100% and the BOD_5 removal was higher than 98% at 15 h of HRT. These results are consistent with the results reported by Bornare et al. [25] in their study, they confirmed that a sufficient HRT is required to ensure the process effectiveness. In this study, it needed to be more than 15 h.

Table 2
Influent wastewater characteristics

Parameter	Influent concentration	Rejection standards*
TSS, mg L^{-1}	350–414	150
COD, mg L^{-1}	527–745	250
BOD_5, mg L^{-1}	217–497	120
Temperature, °C	21.5	<30
pH value	7.6	5.5–9.5
Conductivity, μS cm^{-1}	1,220	2,700
TN, mg L^{-1}	45.5–60	40
TP, mg L^{-1}	9.2–7.5	15

*Moroccan pollution standards: specific limits for domestic discharge.

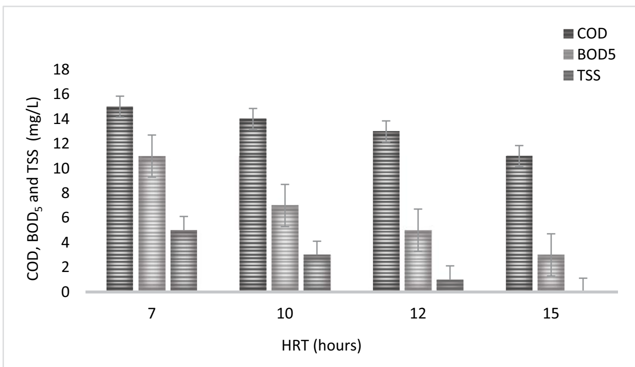

Fig. 2. Concentrations of COD, BOD_5, and TSS in the permeate as a function of HRT.

Results from recent reports indicate that HRT for MBRs are typically 4–20 h. On most domestic wastes this is an enough time to allow for the oxidation of organic material [26]. Viero et al. [27] reported that the recommended HRT for aerobic activated sludge is approximately 10 h; however, 15 h are preferred. At this HRT, all parameters are significantly lower. This also shows good pollutant removal efficiencies and short start-up period for reactor operating.

3.2. Influence of aeration rate

Aeration flow is also one of the main factors influencing the pollution effectiveness removal. To compare performance, three aeration rates (300, 500, and 700 NL h^{-1}) were operated (Fig. 4). The removal efficiency of BOD_5 and COD is higher than 97% for both rates 300 and 500 NL h^{-1}, and for the rate 700 NL h^{-1} it is 92%. In the same way, the removal efficiency of the TSS is 99% for the 300 and 500 NL h^{-1} aeration rates, for the 700 NL h^{-1} flow rate it is 97%. The results showed that the lower aeration rate gave a better reduction of TSS, COD, and BOD_5 concentrations. The increase in aeration rates does not pose a risk to the treatment of pollution, but it leads to an increase in the energy consumption of the process. Lorain et al. [28] in a similar study showed that optimized MBR aeration could operate at a low aeration rate of 300 NL h^{-1}, they also concluded that sequencing aeration could reduce the aeration demand. Other authors have confirmed that sequenced aeration is advantageous in reducing both pollution and energy consumption [29]. For pollution degradation, microorganisms had to receive the appropriate amount of oxygen to meet their specific demands [30]. In addition, as an initial approach, it is important to explore how much air can be saved by reducing the total aeration rate.

3.3. Nitrogen removal efficiency

In order to evaluate the nitrogen removal efficiency of each compartment of MBR process, NH_4^+–N and NO_3^-–N concentrations in the different tanks were analyzed (Fig. 5). The average NH_4^+–N concentration was 31 and 7 mg L^{-1} at the outlet of anoxic phase and aerobic phase, respectively. The average concentration of NO_3^-–N was 15 mg L^{-1} during the anoxic phase, lower than 47 mg L^{-1} in the aerobic phase. Hence, nitrification was observed in anoxic and aerobic reactors with a nitrate concentration of 53 mg L^{-1} and a residual ammonia nitrogen concentration below 3.7 mg L^{-1}. After aerobic tank, the nitrification process was almost finished. Furthermore, 2.5 mg L^{-1} (~72%) of phosphorus was removed by bacterial uptake during the anoxic phase and the overall *P*-removal was reduced to the end of cycle. The mean value of TP elimination at the outlet of membrane treatment is 1.6 mg L^{-1} (~82%). A significant decrease of TP concentration was recorded within the UF-MBR. Radjenović et al. [30] reported that, there is an increasing interest for the application of MBR as a technology for phosphorus recycling. However, MBR offers two major advantages in the elimination of phosphorus: complete removal of all particles and prevents the phosphate release that occurs under anoxic conditions. Much researches had confirmed that MBR is a highly viable wastewater treatment technology regarding nitrification-denitrification and phosphorus removal. With optimized design and operating parameters it warrants high effluent quality in terms of ammonia, nitrates, and phosphors present in wastewater [31,32].

3.4. Influence of TMP

One of the most important aspects related to the treatment of domestic effluents are the organic loads, reflected in the

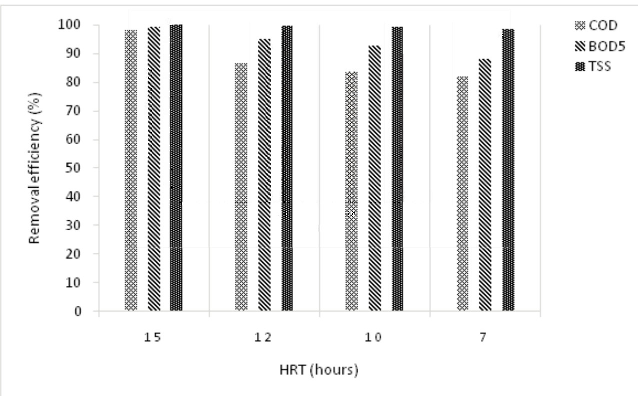

Fig. 3. COD, BOD_5, and TSS removal efficiency as a function of HRT.

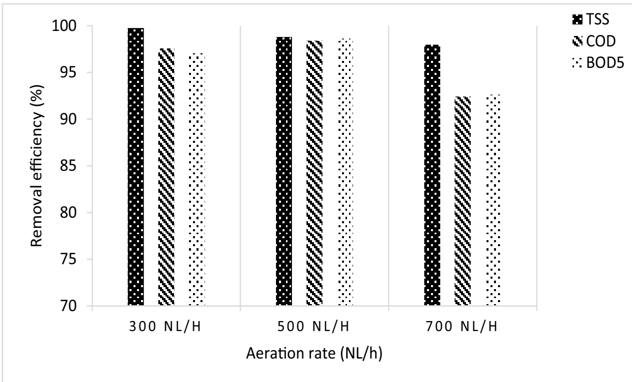

Fig. 4. Influence of aeration rate on the removal efficiencies.

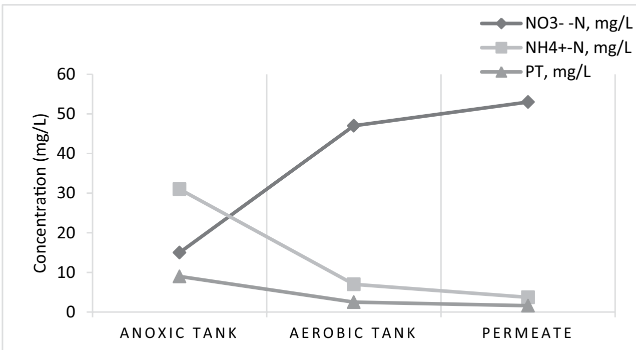

Fig. 5. Nutriment compounds concentration in the anoxic, aerobic and permeate.

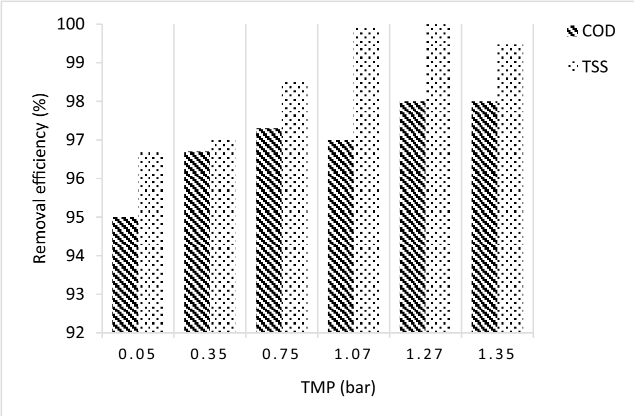

Fig. 6. Influence of TMP on the removal efficiencies.

values of COD and TSS indicators. Under these circumstances, the operating parameters of the UF process play an important role. The results displayed in Fig. 6, indicate that the removal efficiency expressed as COD (95% to 98%) content varies with pressure between 0.35 and 1.27 bar. In the same way, the removal efficiency expressed as TSS register a constant profile (99%) as a function of pressure, approx. 1.37 bar. Thus, a constant removal of these pollution parameters is noticed, regardless of the input concentration. This removal rate is associated with the separation capacity of the solids filtration membrane by physical methods. Solids greater than 0.04 micron, the pore size of the membrane, will not penetrate the membrane [32,33].

4. Conclusion

This study was focused on evaluating how HRT and aeration influence on MBR performance by analysing the results of a lab-scale experiment. The reactor coupled with an external UF membrane was operated under different HRTs (7, 10, 12, and 15 h). MBR system with higher HRT seemed to be more efficient in removing TSS, COD, and BOD_5. Removal efficiencies up to 100%, 99%, and 98% respectively where achieved. In the same way, the results shown that the optimized MBR aeration could be permitted to work with a very low aeration flow rate of 300 NL h^{-1}, thus, low aeration rate is advantageous to reduce pollution from wastewater. However, aeration is a key point for MBR operation because the choice of aeration strategy is important in the treatment process. Moreover, high removal efficiencies were obtained for both Ammonia and phosphorus. The results presented showed the feasibility of anoxic/aerobic reactor coupled with UF membrane for domestic wastewater treatment. The separation step on porous membranes has confirmed the importance of membrane selectivity to ensure a high quality of the treated water irrespective of the quality of the supernatant of the biological suspension. MBR technology is widely accepted today as the key technology for wastewater treatment and reuse.

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