The effect of HRT on the treatment of domestic wastewater by MBR

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Abstract

In this study, the effect of applying different hydraulic retention times (HRTs) was investigated for a lab-scale membrane bioreactor (MBR) treating domestic wastewater. The submerged flat-type ultrafiltration MBR was operated under three different decreasing HRTs (9.6, 7.7 and 6.2 h) corresponding to three different operating periods to examine its efficiency in removing organic content and nutrients from domestic wastewater. The membrane module flux was equal to 16, 20 and 24 L m^{-2} h^{-1}, respectively, during the three examined periods. The chemical oxygen demand (COD) decreased from 99.5 to 96.4% with the flux increase from 16 to 20 L m^{-2} h^{-1} (i.e. HRT decrease from 9.6 to 7.7 h). The bacteria performing nitrification were mostly affected by the HRT change: the ammonium (NH_4-N) removal dropped from 99.6% (HRT=9.6 h) to 67.2% (HRT=7.7 h). With the flux adjusted to 24 L m^{-2} h^{-1} (i.e. lowest HRT=6.2 h), the COD and NH_4-N removals were 93.4% and 46.3%, respectively. The phosphates (PO_4-P) removal was 80.5%, 30.3% and 17% during periods 1, 2 and 3, respectively. In terms of COD removal efficiency, the treated effluent met the Turkish limits for discharge to the environment during all the examined periods. The system performance was sufficient in terms of NH_4-N removal for periods 1 (HRT=9.6 h) and 2 (HRT=7.7 h). However, applying the operating conditions of period 2 (i.e. keeping the HRT decreased at 7.7 h) requires additional post-treatment (e.g. low-cost chemical precipitation) to enhance PO_4-P removal.

Keywords: Membrane bioreactor, hydraulic retention time, membrane flux, organic content, nitrogen, phosphorus

Nomenclature

CAS	Conventional Activated Sludge
COD	Chemical Oxygen Demand
DO	Dissoled Oxygen
HRT	Hydraulic Retention Time
MBR	Membrane Bioreactor
MLSS	Mixed Liquor Suspended Solids
ORP	Oxidation-Reduction Potential
SRT	Sludge Retention Time

TN	Total Nitrogen
TSS	Total Suspended Solids

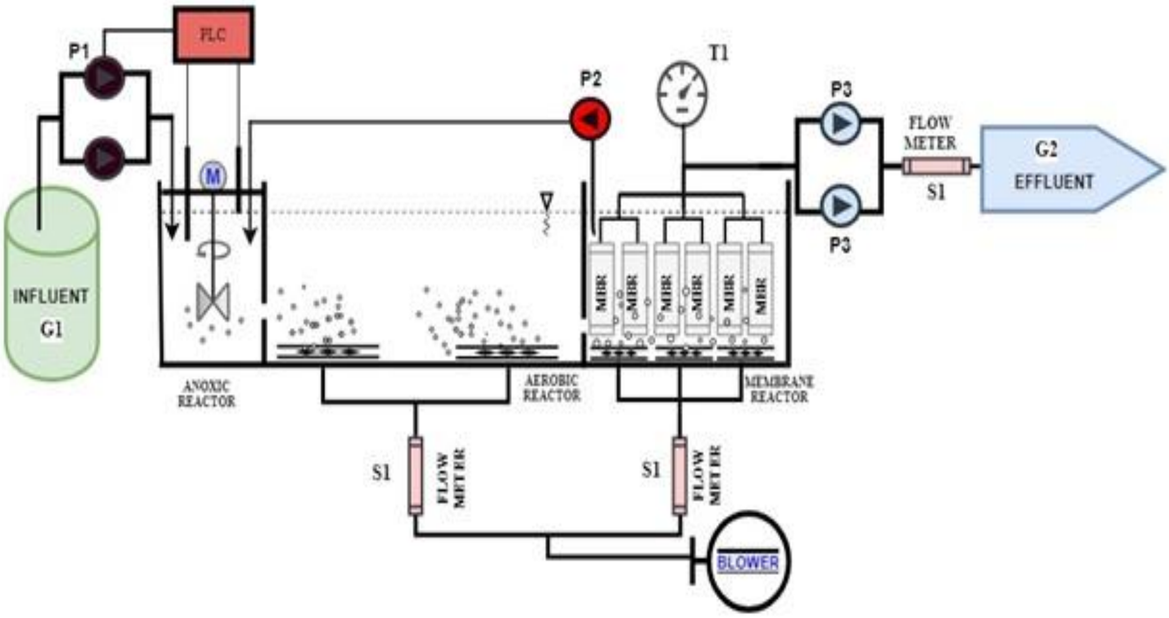
1. Introduction

Water is the most significant source of life: all living things need water to perform their vital activities [1]. With the increasing population and industrialization worldwide, clean potable water resources are continuously decreasing and the requirements for fresh water rise day by day throughout the world [2]. Hence, the removal of pollutants from wastewater is an environmental issue of the utmost importance. There is a variety of macro- and micro-pollutants such as detergents, pesticides, endocrine disruptor compounds and heavy metals that generate pollution in water [3-4]. However, organic matter and nutrients such as nitrogen and phosphorus also require removal from wastewaters since they cause oxygen consumption and eutrophication in the receiving environments [5]. The Conventional Activated Sludge (CAS) systems are widely used in the treatment of domestic and industrial wastewater for the removal of organic matter, nitrogen and phosphorus [6]. Nevertheless, they are highly sensitive to fluctuations in the organic and volumetric loads. In such cases, a frequent choice is to increase the biomass amount to boost the treatment efficiency of the system. However, this is likely to cause sludge settleability problems in the clarifier unit. Membrane Bioreactors (MBRs) are suspended growth activated sludge processes that perform filtration through membranes [7-8]. While the treatment and solid-liquid separation in the CAS systems occur in separate tanks, the MBR systems do so in a single tank. Because of the recent rapid development in the membrane technology and the resulting reduction of production costs, the MBRs have become cost-competitive and are now widely applied both for drinking water and wastewater treatment purposes [9-10]. Their advantages over the CAS systems also include the possibility to attain high solid retention times (SRTs) due to high mixed liquor suspended solids (MLSS) concentrations in the tank. Moreover, they generate significantly less amount of sludge that needs to be disposed of. It has also been noted that the nitrification process is more successful and less impacted by ambient conditions at higher SRTs. Similarly, the microorganisms that biodegrade synthetic organic compounds work more effectively under higher SRTs. Furthermore, the higher MLSS concentrations within the MBR tanks allow operation under increased organic and hydraulic loadings and resistance to shock loads [11-15]. However, membrane fouling is still the main challenge; it must be minimized to avoid a poor MBR performance [16]. Fouling is a complex phenomenon that involves adsorption, accumulation, and/or precipitation of organic and inorganic substances on the membrane surface under various operational conditions [17]. Operation at very low HRT may result in low removal of nutrients and organic carbon due to the short contact time between the wastewater and the biomass. The continuous HRT decrease has been associated with the limited or problematic growth of bacteria. The latter is attributed to insufficient time for the active biomass to perform satisfactory substrate degradation [18-20]. MBR studies have demonstrated that the high growth of bacterial populations performing substrate degradation or the optimal carbon oxygen demand (COD) removal combined with a satisfying energy production were achieved after applying a minimal required HRT [21-23]. Moreover, the decrease of HRT can result in higher membrane fouling rate in MBR [24-26]. Lower HRT requires higher membrane fluxes to be maintained, fact which can accelerate membrane fouling. The above findings show the importance of testing different HRTs for the optimization of the system's performance. In this study, the effect of decreasing HRTs (9.6, 7.7 and 6.2 h) corresponding to three different operating periods was examined for a lab-scale MBR treating domestic wastewater.

2. Material and Methods

2.1 The Experimental Set-up

In the current study, the removal of COD, nitrogen (NH_4-N) and phosphorus (PO_4-P) in a lab-scale submerged flat-type ultrafiltration MBR system was examined. The MBR unit was installed at the Ataturk University Campus (Erzurum, Turkey). Wastewater for MBR system was drawn from a storm drain by a submersible pump controlled by a level sensor relay. The MBR system operation started with a biomass inoculum of approximately 2.5 g TSS L^{-1} taken from conventional activated sludge. The Total Suspended Solids (TSS) concentration increased up to 11.5 g TSS L^{-1} while the MBR system was working. The MBR system is schematically shown in Fig. 1.



P1: feed pump	P3: vacuum pump
M: mechanical stirrer	S1: flow meter
P2: retun pump	T1: pressure gauge
G1: influent	G2: effluent

Figure 1. Process diagram of the lab-scale submerged flat-type ultrafiltration MBR implemented in the current study.

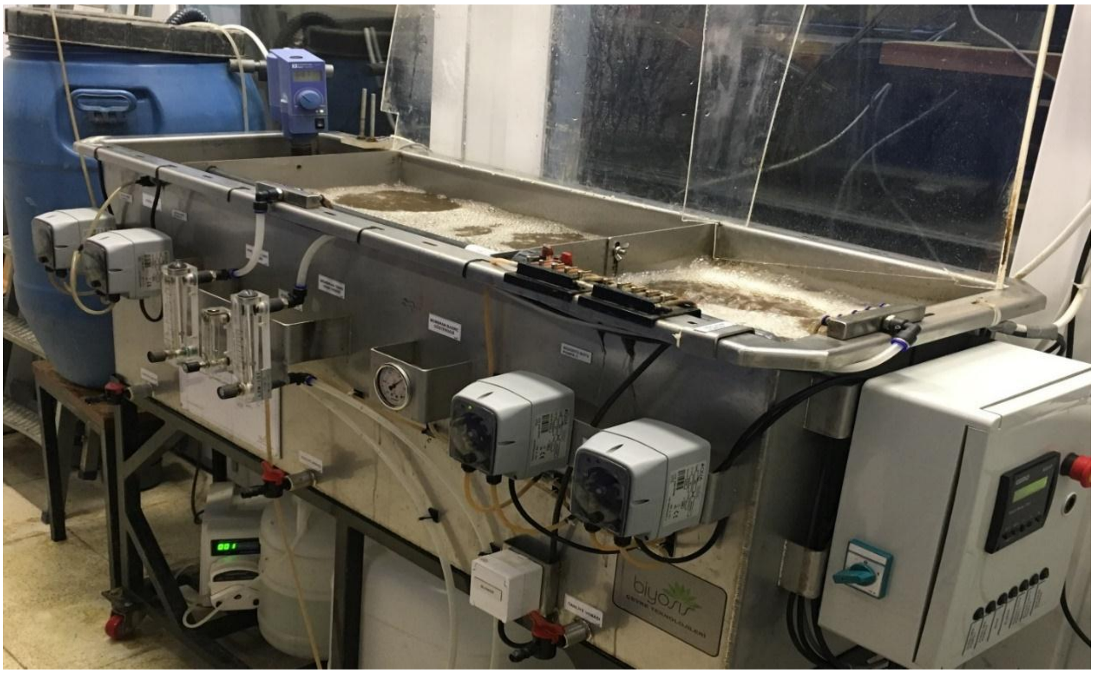


Figure 2. The lab-scale submerged flat-type ultrafiltration MBR treatment system used in the present study.

The lab-scale submerged flat-type ultrafiltration MBR treatment system used in the present study is given in Fig. 1. The tank was divided into 3 sections to enable water flow from the bottom. Wastewater from the influent tank was pumped by the (P1) peristaltic pumps into the first (anoxic) compartment where mixing occurred using the (M) mechanical stirrer. The second section (aerobic) was aerated via a diffuser (blower). In the third compartment, the membranes were installed; they were aerated with same diffuser (blower). The aeration level in the membrane and aerobic sections was controlled by flowmeters. 10 units of flat-sheet Polyethersulfone (PES) membranes with a pore size of 0.038 μm were placed in the 40-L membrane compartment for solid-liquid separation. The total area of each membrane unit was 0.84 m^2. In each operating period, the membrane module was cleaned using 500 mg Cl_2 L^{-1} hypochlorite. The transmembrane pressure was continuously controlled by a pressure gauge (T1). In addition, there was a peristaltic pump (P2) for the return from the membrane section to the anoxic compartment. Three different membrane fluxes (i.e. 16, 20 and 24 L m^{-2} h^{-1} for periods 1, 2 and 3, respectively) were applied in the MBR section using a vacuum pump (P3).

2.2 Wastewater Characteristics and Operating Conditions

Table 1 shows the wastewater composition and the operating conditions during the experimental study. Table 2 presents the average values of operational parameters in the anoxic and aerobic sections.

Table 1. Wastewater characteristics and operating conditions of the lab-scale MBR used during the experiments.

Parameter	Unit	Value
COD	[mg L^{-1}]	198 - 245
BOD	[mg L^{-1}]	95-175
NH_4-N	[mg L^{-1}]	22.2-28.1
PO_4-P	[mg L^{-1}]	5.7-8.5
NO_3-N	[mg L^{-1}]	<0.5
MLSS	[g L^{-1}]	11-11.5
SRT	[d]	∞
HRT	[h]	9.6 (period 1), 7.7 (period 2), 6.2 (period 3)
flux	[L m^{-2} h^{-1}]	16 (period 1), 20 (period 2), 24 (period 3)

Table 2. Average values of the operational parameters in the anoxic and aerobic compartments.

Parameter	Unit	Anoxic section	Aerobic section
Dissolved Oxygen	[mg L^{-1}]	0.10-0.21	4.10-5.20
pH	-	7.61	7.53
ORP	[mV]	-1.1, -1.6	247
Temperature	[°C]	16	17

2.3 Sampling and Analytical Methods

Samples were taken 3 times per week from the inlet, anoxic, aerobic, membrane and effluent sections. The samples were analyzed using a Merck Pharo 300 spectroquant Spectrophotometer in terms of COD, NH_4-N and PO_4-P content. All samples were filtered to remove solids through Whatman membranes (0.45 μm) and the filtrate was measured photometrically for its NH_4-N and PO_4-P content. The COD analysis was conducted according to the 5220C Standard Method. The MLSS and TSS were estimated according to the 2540B Standard Method. The dissolved oxygen (DO) concentration, oxidation-reduction potential (ORP) and pH were measured in all sections using specific probes (WTW LF340). NH_4-N and PO_4-P analyses were carried out by Merck kits (NH_4-N with no: 14752 and PO_4-P with no: 14842).

3. Results and Discussion

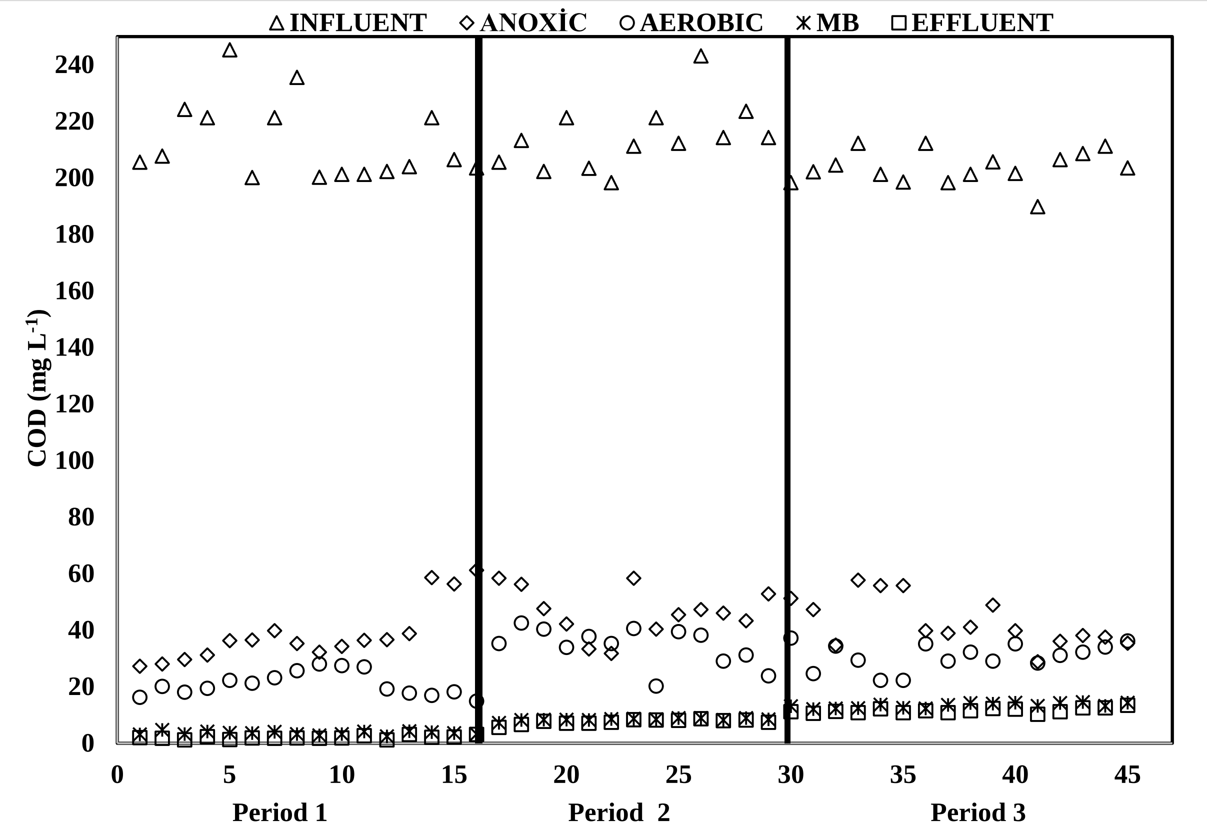


Figure 3.1 COD removal in the three different operating periods (period 1: HRT=9.6 h, period 2: HRT=7.7 h, and period 3: HRT=6.2 h).

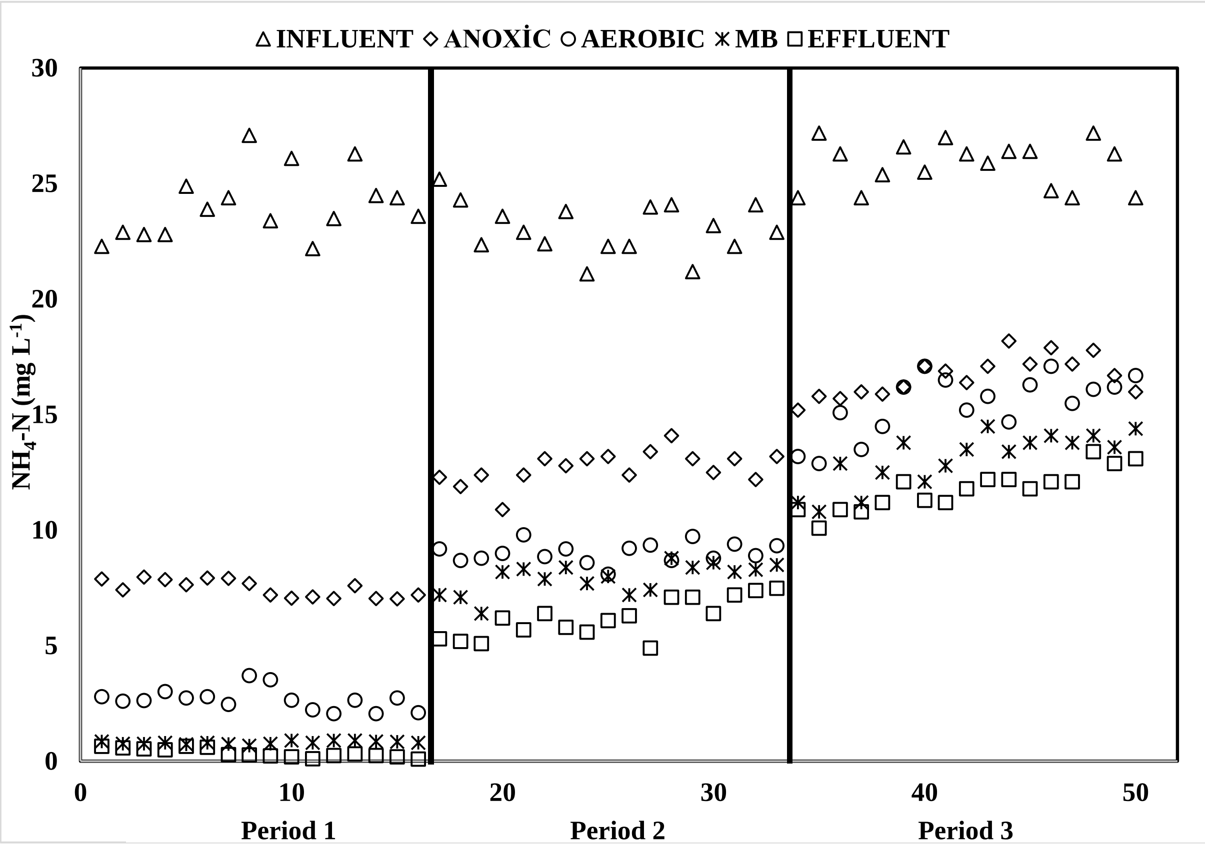


Figure 3.2 NH_4-N removal in the three different operating periods (period 1: HRT=9.6 h, period 2: HRT=7.7 h, and period 3: HRT=6.2 h).

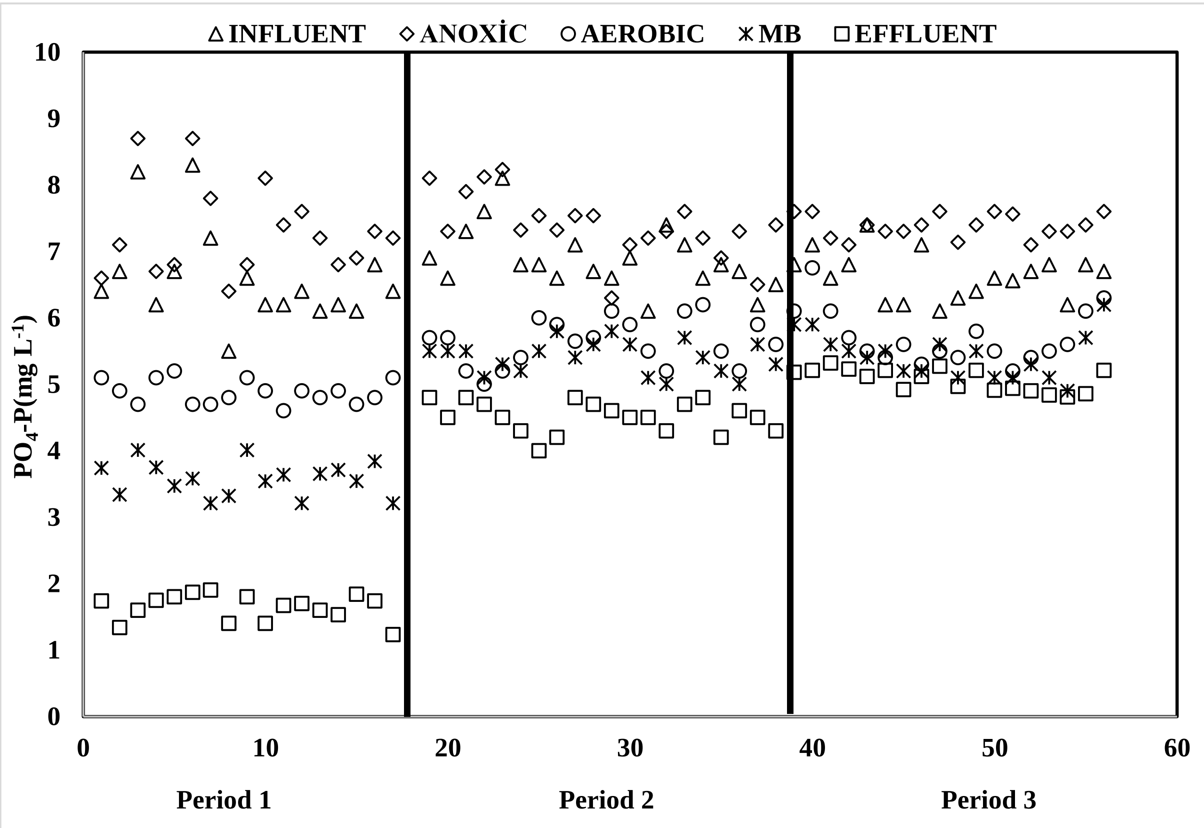


Figure 3.3 PO_4-P removal in the three different operating periods (period 1: HRT=9.6 h, period 2: HRT=7.7 h, and period 3: HRT=6.2 h).

The membrane flux increase from 16 to 20 L m^{-2} h^{-1} caused a respective decrease in the HRT from 9.9 to 7.7 h (period 1 to period 2). As shown in Fig. 3.1, 3.2 and 3.3 the removal of COD, NH_4-N and PO_4-P decreased from 99.5 to 96.4%, from 99.6 to 67.2%, and from 80.5 to 30.3%, respectively. The COD, NH_4-N and PO_4-P concentrations in the effluent increased from 1.2 to 8.4 mg L^{-1}, 0.1 to 7.5mg L^{-1}, and 1.2 to 4.8 mg L^{-1}, respectively. Increasing further the membrane flux to 24 L m^{-2} h^{-1} (i.e. period 3: HRT=6.2 h) resulted in decreasing the COD removal at 93.4%. The NH_4-N and PO_4-P removals dropped at 46.3% and 17%, respectively, meaning that the average NH_4-N and PO_4-P concentrations in the effluent increased from 7.5 to 13.4 mg L^{-1} and from 4.8 to 5.3 mg L^{-1}, respectively.

Similar results were obtained in other research studies that examined the effect of HRT on the performance of bioprocesses applied for wastewater treatment. Wang et al. [27] operated a lab-scale external-submerged anaerobic MBR for the treatment of bamboo industry wastewater at HRT ranging from 2 to 10 d; the COD removal ranged from 80% (HRT=2 d) to 93% (HRT=10 d). Longer contact time between the biomass and the substrate was obtained at the highest examined HRT, thus enabling enhanced substrate degradation. In another study, Ng et al. [28] investigated the COD removal operating a lab-scale MBR treating high-salinity pharmaceutical wastewater. The COD removal was 68% at HRT=60 h (flux=1.46 L m^{-2} h^{-1}) and slightly less (61%) at HRT=40 h (flux=2.19 L m^{-2} h^{-1}). At the lower HRT, the increased membrane flux and MLSS concentration led to faster membrane fouling and, thus, to poorer process performance. Song et al. [29] explored the effect of HRT decrease on the total nitrogen (TN) removal of a pilot-scale sequencing anoxic/anaerobic membrane bioreactor for municipal wastewater treatment. By decreasing the HRT from 9.4 h to 6.5 h, TN removal gradually dropped from 73% to 65%. A lower HRT along with a decreased SRT (from 80 to 50 d) lowered the nitrifying bacteria concentration, thus leading to incomplete nitrification. Low HRTs can be tested with the view to avoiding reactor oversizing and, subsequently, reducing the overall cost. However, HRT decrease is desirable only if it does not compromise on nitrification-denitrification. Furthermore, Mouthon-Bello and Zhou [30] implemented a lab-scale MBR for municipal wastewater treatment. Raising the HRT from 6 to 8 h resulted in increasing PO_4-P removal from 89 to 98%. In this case, high PO_4-P removal was expected as a result of the low influent soluble PO_4-P content (i.e. 1±0.3 mg L^{-1}). Under these favorable conditions, the HRT increase provided adequate time for the effective PO_4-P removal in the system. Taking all the above into account, it can be concluded that HRT optimization is a key factor for the achievement of satisfying COD and nutrient removal.

In the current study, the emphasis was put on the optimization of the HRT parameter within lab-scale MBR system treating domestic wastewater. As discussed in the Introduction section, concluding to an optimal HRT is important in order to ensure sufficient substrate degradation, maintain a MLSS concentration that does not aggravate membrane fouling [30-33] and avoid system oversizing. In this work, the minimal applied HRT respecting the Turkish legislation limits concerning the COD and NH_4-N removal was 7.7 h (period 2). Effective PO_4-P removal was noted only during the 1st period (i.e. highest HRT=9.9 h). The addition of a cost-effective post-treatment step (e.g. chemical precipitation), though, can enhance the PO4-P removal and, simultaneously, allow keeping the HRT equal to 7.7 h.

4. Conclusions

(1) This study examined the efficiency of a lab-scale MBR treating domestic wastewater at 3 different HRTs (9.9, 7.7 and 6.2 h). The system operated in an anoxic/aerobic mode followed by a last section of submerged flat-type MBR. The system's removal efficiency was:

- 99.5%, 96.4% and 93.4% of in terms of COD,
- 99.6%, 67.2% and 46.3% in terms of NH_4-N and
- 80.5%, 30.3% and 17% in terms of PO_4-P

for periods 1 (HRT=9.9 h), 2 (HRT=7.7 h) and 3 (HRT=6.2 h), respectively.

(2) In terms of COD, the treated effluent from the MBR system met the Turkish limits for discharge to the environment during all the examined periods. The system performance was sufficient in terms of NH_4-N removal for periods 1 and 2, but only in period 1 in terms of PO_4-P. However, the addition of a low-cost post-treatment (i.e. chemical precipitation) can enhance PO_4-P removal and allow keeping the HRT=7.7 h.

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References

[1] Baten, R., Stummeyer, K.: How sustainable can desalination be? Desalin. Water Treat. 51(1-3), 44-52 (2013).

[2] Benotti, M.J., Trenholm, R.A., Vanderford, B.J., Holady, J.C., Stanford, B.D., Snyder, S.A.: Pharmaceuticals and endocrine disrupting compounds in US drinking water. Environ. Sci. Technol. 43 (3), 597-603 (2008).

[3] Changa, J.S., Changa, C.Y., Chen, A.C., Erdei, L., Vigneswaran, S.: Long-term operation of submerged membrane bioreactor for the treatment of high strength acrylonitrile-butadiene-styrene (ABS) wastewater: effect of hydraulic retention time. Desalination. 191(1), 45-51 (2006).

[4] Denga, l., Guo, W., Ngo, H.H., Zhang, J., Liang, S., Xia, S., Zhang, Z., Li, J.: A comparison study on membrane fouling in a sponge-submerged membrane bioreactor and a conventional membrane bioreactor. Bioresour. Technol. 165, 69-74 (2014).

[5] Drews, A.: Membrane fouling in membrane bioreactors - characterisation, contradictions, cause and cures. J. Memb. Sci. 363(1-2), 1-28 (2010).

[6] Gao, F., Peng, Y.Y., Li, C., Cui, W., Yang, Z.H., Zeng, G.M.: Coupled nutrient removal from secondary effluent and algal biomass production in membrane photobioreactor (MPBR): Effect of HRT and long-term operation. Chem. Eng. J. 335, 169-175 (2018).

[7] Kang, G.D., Cao, Y.M. : Development of antifouling reverse osmosis membranes for water treatment: a review. Water Res. 46(3), 584-600 (2012).

[8] Le-Clech, P., Chen, V., Fane, T.A.G.: Fouling in membrane bioreactors used in wastewater treatment. J. Memb. Sci. 284(1), 17-53 (2006).

[9] Lin, H., Gao, W., Meng, F., Liao, B.Q., Leung, K.T., Zhao, L., Chen, J., Hong, H.: Membrane bioreactors for industrial wastewater treatment: a critical review. Crit. Rev. Environ. Sci. Technol. 42(7), 677-740 (2012).

[10] Mansouri, J., Harrisson, S., Chen, V.: Strategies for controlling biofouling in membrane filtration systems: challenges and opportunities. J. Mater. Chem. 20(22), 4567-4586 (2010).

[11] Melin, T., Jefferson, B., Bixio, D., Thoeye, C., De Wilde, W., De Koning, J., van der Graaf, J., Wintgens, T.: Membrane bioreactor technology for wastewater treatment and reuse. Desalination. 187(1), 271-282 (2006).

[12] Mutamim, N.S.A., Noor, Z.Z., Hassan. M.A.A., Olsson, G.: Application of membrane bioreactor technology in treating high strength industrial wastewater: a performance review. Desalination. 305, 1-11 (2012).

[13] Saqib, J., Aljundi, I.H.: Membrane fouling and modification using surface treatment and layer-by-layer assembly of polyelectrolytes: state-of-the-art review. J. Water Process Eng. 11, 68-87 (2016).

[14] Scholz, M.: Chapter 15 - Activated Sludge Processes. In: Scholz, M. (eds.) Wetlands for Water Pollution Control (Second Edition), pp. 91-105. Elsevier, London (2016).

[15] Schoumans, O.F., Bouraoui, F., Kabbe, C., Oenema, O., van Dijk, K.C.: Phosphorus management in Europe in a changing world. Ambio. 44(2), 180-192 (2015).

[16] She, Q., Wang, R., Fane, A.G., Tang, C.Y.: Membrane fouling in osmotically driven membrane processes: a review. J. Memb. Sci.499, 201-233 (2016).

[17] Skouteris, G., Hermosilla, D., López, P., Negro, C., Blanco, A.: Anaerobic membrane bioreactors for wastewater treatment: A review. Chem. Eng. J. 198, 138-148 (2012).

[18] Badiei, M., Jahim, J.M., Anuar, N., Sheikh Abdullah, S.R.: Effect of hydraulic retention time on biohydrogen production from palm oil mill effluent in anaerobic sequencing batch reactor. Int. J. Hydrogen Energy. 36, 5912-5919 (2011).

[19] Sin, S.N., Chua, H., Lo, W., Yu, P.H.F.: Effects of trace levels of copper, chromium, and zinc ions on the performance of activated sludge. Appl. Biochem. Biotechnol. 84-86, 487-500 (2000).

[20] Kargi, F., Uygur, A.: Hydraulic residence time effects in biological nutrient removal using five-step sequencing batch reactor. Enzyme Microb. Technol. 35, 167-172 (2004).

[21] Boonnorat, J., Techkarnjanaruk, S., Honda, R., Prachanurak, P.: Effects of hydraulic retention time and carbon to nitrogen ratio on micro-pollutant biodegradation in membrane bioreactor for leachate treatment. Bioresource Technol. 219, 53-63 (2016).

[22] Win, T.T., Kim, H., Cho, K., Song, K.G., Park, J.: Monitoring the microbial community shift throughout the shock changes of hydraulic retention time in an anaerobic moving bed membrane bioreactor. Bioresource Technol. 202, 125-132 (2016).

[23] Poh, P.E., Chong, M.F.: Upflow anaerobic sludge blanket-hollow centered packed bed (UASB-HCPB) reactor for thermophilic palm oil mill effluent (POME) treatment. Biomass Bioenerg. 67, 231-242 (2014).

[24] Bayat, M., Mehrnia, M.R., Hosseinzadeh, M., Sheikh-Sofla, R.: Petrochemical wastewater treatment and reuse by MBR: A pilot study for ethylene oxide/ethylene glycol and olefin units. J. Ind. Eng. Chem. 25, 265-271 (2016).

[25] Deng, L., Guo, W., Ngo, H.H., Du, B., Wei, Q., Tran, N.H., Nguyen, N.C., Chen, S.S., Li, J.: Effects of hydraulic retention time and bioflocculant addition on membrane fouling in a sponge-submerged membrane bioreactor. Bioresour. Technol. 210, 11-17 (2015).

[26] Xue, J., Zhang, Y., Liu, Y., Gamal El-Din, M.: Effects of ozone pretreatment and operating conditions on membrane fouling behaviors of an anoxic-aerobic membrane bioreactor for oil sands process-affected water (OSPW) treatment. Water Res. 105, 444-455 (2016).

[27] Wang, W., Yang, Q., Zheng, S., Wu, D.: Anaerobic membrane bioreactor (AnMBR) for bamboo industry wastewater treatment. Bioresource Technol. 149, 292-300 (2013).

[28] Ng, K.K., Shi, X., Ong, S.L., Lin, C.F., Ng, H.Y.: An innovative of aerobic bio-entrapped salt marsh sediment membrane reactor for the treatment of high-saline pharmaceutical wastewater. Chem. Eng. J., 295, 317-325 (2016).

[29] Song, K.G., Cho, J., Cho, K.W., Kim, S.D., Ahn, K.H.: Characteristics of simultaneous nitrogen and phosphorus removal in a pilot-scale sequencing anoxic/anaerobic membrane bioreactor at various conditions. Desalination. 250, 801-804 (2010).

[30] Mouthon-Bello, J., Zhou, H.: Performance of a submerged membrane bioreactor system for biological nutrient removal. Water Environ. Res. 78, 538-547 (2006).

[31] Huang, Z., Ong, S.L., Ng, H.Y.: Submerged anaerobic membrane bioreactor for low-strength wastewater treatment: Effect of HRT and SRT on treatment performance and membrane fouling. Water Res. 45, 705-713 (2011).

[32] Scheumann, R., Kraume, M.: Influence of hydraulic retention time on the operation of a submerged membrane sequencing batch reactor (SM-SBR) for the treatment of greywater. Desalination. 246, 444-451 (2009).

[33] Chu, L.B., Yang, F.L., Zhang, X.W.: Anaerobic treatment of domestic wastewater in a membrane-coupled expended granular sludge bed (EGSB) reactor under moderate to low temperature. Process Biochem. 40, 1063-1070 (2005).