Egyptian Journal of Chemistry

http://ejchem.journals.ekb.eg/

Wastewater Remediation by Aerobic Membrane Bioreactor: Effect of Sludge Retention Time on Treatment Performance and Filtration Process

Aly Al-Sayed*, Fatma A. El-gohary

Water Pollution Research Department, National Research Centre, 33El-Bohouth St. (Former El-Tahrir St.), Dokki, P.O. 12622, Giza, Egypt

Abstract

In the present study, the effect of sludge retention time (SRT) on the performance of the membrane bioreactor (MBR) was investigated. For this purpose, an aerated activated sludge reactor equipped with submerged flat sheet membrane was operated at different SRT (10, 20, 30, and 60 days). The hydraulic retention time (HRT) and the organic loading rate (OLR) were kept constant at 7 h and 0.93 kg COD/m^3.d, respectively. The mixed liquor suspended solids ranged from 4.5–7 g/L. To avoid the impact of variations in the characteristics of real wastewater, the lab-scale reactor was fed using synthetic wastewater. Available results indicated that increasing the SRT from 10 to 60 days improved the performance of the system as reflected in the COD removal. Also, complete nitrification has been reported at 60 days SRT. Moreover, when the system was operated at SRT of 30 and 60 days, the biomass was in the form of small flocs which increased reactor performance due to a decline in mass transfer resistance.

Keywords: Wastewater remediation; membrane bioreactor (MBR); sludge retention time (SRT)

1. Introduction

Membrane bioreactors (MBRs), a highly effective wastewater treatment technology that combines membrane separation and biological treatment, have been successfully used for industrial as well as municipal wastewater treatment. MBRs offer a number of benefits compared to conventional activated sludge (CAS) treatment technology. The most important of which is the production of better permeate quality, free of suspended solids (SS), bacteria and viruses leading to direct reuse. Also, the absence of sedimentation tanks and the smaller bioreactor capacity reduces the footprint required by the treatment facility, which makes it an attractive technology when land is not available [1–4]. However, membrane fouling and membrane cleaning costs are still significant disadvantages for the widespread of MBRs [2, 5]. In terms of membrane filtration and fouling, transmembrane pressure (TMP) must be increased to maintain the water flux when fouling occurs. Even then, the membrane must be chemically cleaned after fouling or, in extreme cases, replaced. SRT is one of the most important operating parameters in the biological treatment systems [6]. Sludge retention time (SRT), has a substantial impact on sludge properties. Longer sludge retention time may provide better filterability, while shorter retention results in faster membrane fouling. This may be due to the amounts of soluble microbial products and extracellular polymeric substances (EPS) produced. In the course of operating an anoxic/anaerobic MBR at SRTs of 100, 60, and 20 days, **Ahmed et al.** found that membrane biofouling was significantly reduced by increasing SRT and that the concentration of bound EPS followed the same trend [7]. According to research results carried out by Ouyang and Liu using three laboratory-scale submerged MBRs, the highest membrane fouling rate was observed at SRT of 10 days. At the same time a reduction in the concentrations of soluble microbial

*Corresponding author e-mail: al.mohamed@nrc.sci.eg; alychemist@yahoo.com; (**Aly Al-Sayed**).
Received date 13 August 2023; revised date 26 October 2023; accepted date 08 November
DOI: 10.21608/EJCHEM.2023.229161.8425

products, polysaccharides, proteins, and total organic carbon in sludge supernatant has been reported [8]. Further, a submerged MBR may operate across a wide range of SRT, given that biomass separation is always effective in a submerged MBR and settleability is hardly a limiting concern. Therefore, to decrease the size of the reactor, very short SRTs have been tested [9]**.** Conversely, to maintain a high MLSS concentration while minimizing sludge production, total solid retention and very high SRTs are also now being explored [10, 11]. However, considerable options in operating conditions' impact on biomass systems and how they affect removal effectiveness and membrane fouling are still up for debate. Particularly, some investigations demonstrated a reduction in EPS concentration with increasing SRT [12, 13], but other studies demonstrated a precise reversal of this trend [14] or no discernible change in EPS [15, 16]. Likewise, recent research by **Wile'n et al.** demonstrated a correlation between the surface characteristics and the structure of biological flocs in AS and the chemical components of EPS. A relationship that can be greatly modified by operating conditions [17].

According to Xing et al., a bench-scale inclined-plate MBR operated at HRT of 6 h for 123 days without discharging any sludge successfully removed COD, NH_4-N, and TN with acceptable efficiencies. However, they also found that, without excessive sludge discharge, sludge may slowly build up in the reactor over time and reach unacceptable concentration levels in the aerobic tank. Consequently, it likely negatively affects the inclined plate function, treatment effectiveness, and operational performance [18]. Recent research has assessed how well conventional MBRs work while treating different wastewaters at varied HRTs [19]. For the treatment of digested sewage, Gao et al. investigated a lab-scale membrane-based process with an aerobic MBR and an anoxic tank at HRTs ranging from 8 to 2.5 h. According to their findings, shorter HRT improved NH_4-N and TN removal while accelerating membrane fouling, improving filtering resistance, and increasing fouling rate [20]. **Aida Isma et al.** examined the effects of various HRTs (12, 8, and 4 h) and sludge retention times (30, 15, and 4 d) on the functionality of a submerged MBR for the treatment of synthetic wastewater. They found that PO_4-P elimination was triggered by prolonged HRT. At the HRT of 12 h, the MBR with the longest SRT of 30 d improved PO_4-P, NH_4-N, and COD removal efficiencies and displayed reduced membrane fouling with the slowest TMP rise [21].

Similarly, Chan et al. reported good treatment performance with respect to biological phosphorous removal in systems operated at 20 ^oC and 5 days SRT, which reached up to 86% [22]. The data reported by Chan et al. showed significant reduction in the biological phosphorous removal with declining the operating temperature from 20 to 15 and then 10 °C as well as by increasing the SRT [22]. Also, microbial ecology and performance of enhanced biological phosphorous removal was assessed in a full-scale wastewater treatment plant by investigating impacts of various SRT (6-40 days). The results indicated great influence of SRT on the PAOs and GAOs on polyphosphate accumulating organisms and glycogen accumulating organisms and the authors recommend short SRT <10 days [23]. Even so, Wang reported possible excellent effluent quality with respect to organic carbon and phosphorous in biological wastewater treatment systems at extremely short SRT (1.5-4.5 days) [24]. On the other hand Operating lab-scale biological reactors for nutrients removal and treatment of synthetic wastewater was carried out using anaerobic-intermittent aeration at various SRT; 15, 20, and 30 days [6].The highest TP removal with 93% was recorded at 20 days SRT and the data indicated high phosphorus content and phosphate accumulating microorganisms in the waste sludge at higher SRT. The SRT was extended (35 days) to enhance biological phosphorous removal in anaerobic-anoxic-oxic SBR treating both real and synthetic municipal wastewater [25].

Babatsouli et al. tested the efficacy of an MBR pilot plant with 30, 20, and 15 day SRT at HRT of 24 and 19 h in treating industrial wastewater. They found a higher fouling rate and lower phosphate removal and denitrification at a shorter HRT of 19 h. Thus demonstrating the insufficient contact time between the wastewater and the polyphosphate-accumulating microbes and denitrifiers [26].

In light of that, this study aimed to establish an SRT criterion for the long-term operation of MBRs by examining the performance of a lab-scale MBR for the treatment of synthetic wastewater sludge characteristics at 10, 20, 30, and 60 days at a fixed HRT of 7 hours and an OLR of 0.93 kg COD/m^3.d. Additionally, this study's goal was to determine how varied SRTs affected membrane fouling behaviours.

2. Materials and methods

2.1. Membrane specifications

A schematic diagram of the lab-scale MBR system used for the present study is presented in Figure 1. The activated sludge reactor was equipped with a single flat sheet made of polyvinylidene fluoride (PVDF) with a nominal pore size of 0.1 µm, a total surface area of 0.1 m^2, and with advantages of high permeability and durability. The peristaltic pump was adjusted to: 10 min on/2 min off mode. TMP was constantly tracked with pressure gauge for its susceptibility to fouling throughout the process, and daily measurements of the permeate flow rate were obtained to ensure continuous flux.

2.2. Operation of the MBR system

The permeate flux was maintained at 11.4 $L/(h.m^2)$ for operation with a 7-hour HRT and an aeration rate of 4 L/min. The efficiency of the system using different SRTs (60, 30, 20, 10 days) was the controlling parameter. According to the overall biomass concentration (including suspended and attached growing biomass), the operating SRTs were managed by routinely discharging excess activated sludge.

2.3. Composition of synthetic wastewater

The lab-scale MBR was fed with synthetic wastewater prepared according to **Chen et al.** recipe [27] as follows **:** 230.0 mg/L glucose, 30.0 mg/L sodium acetate anhydrous, 118 mg/L NH_4Cl, 12 mg/L KH_2PO_4, 1.2 mg/L $CaCl_2$, 2.4 mg/L $MgCl_2.6H_2O$, 1.0 mg/L $FeCl_3.6H_2O$ and 0.03 mg/L $CoCl_2.6H_2O$ to tap water. The physico-chemical characteristics of the wastewater were: chemical oxygen demand (COD), ammonium nitrogen (NH_3-N), total Kjeldahl nitrogen (TKN) and total phosphorus (TP) were 270 ±16.8 mg/L, 25 ± 1.3 mg/L, 33 ± 2.6 mg/L and 3.5 ± 0.16 mg/L, respectively. To adjust the pH value of the synthetic wastewater within the range from 6.8 to 7.2, the required amount of $NaHCO_3$ was added.

2.4. Physico-chemical analysis

The impact of changing the SRT on the performance of the MBR has been evaluated by examining changes in the physical, chemical and microbiological characteristics of the feed and the permeate.

The measured parameters include: Mixed liquor volatile suspended solids (MLVSS), mixed liquor suspended solids (MLSS), total suspended solids (TSS), total phosphorus (TP), total Kjeldahl nitrogen (TKN), ammonium nitrogen (NH_4-N), and chemical oxygen demand (COD). All parameters were measured according to Standard Methods for the Examination of Water and Wastewater [28].

2.5. Calculations of membrane resistance fractions

The permeate flux (J) in $L/(h.m^2)$ was quantitatively determined employing eq. 1,

$$\mathbf{J=Q/A_m} \qquad \textbf{(1)}$$

here Q is the permeate flow rate (L/h) evaluated by measuring the collected effluent volume versus time, and A_m is the membrane surface area (m^2).

The total membrane resistance was calculated according to eq. 2 [29],

$$\mathbf{J=\Delta p/(\mu.R_t)} \qquad \textbf{(2)}$$

here ΔP is the Trans membrane pressure (N/m^2), μ is the effluent viscosity ($N.s/m^2$),

$$R_t = R_m + R_c + R_f \qquad \textbf{(3)}$$

here R_m; the initial membrane resistance, R_f; the total organic and inorganic fouling resistance, R_c; the sludge layer resistance coating membrane surface during filtration. R_m was determined by filtrating

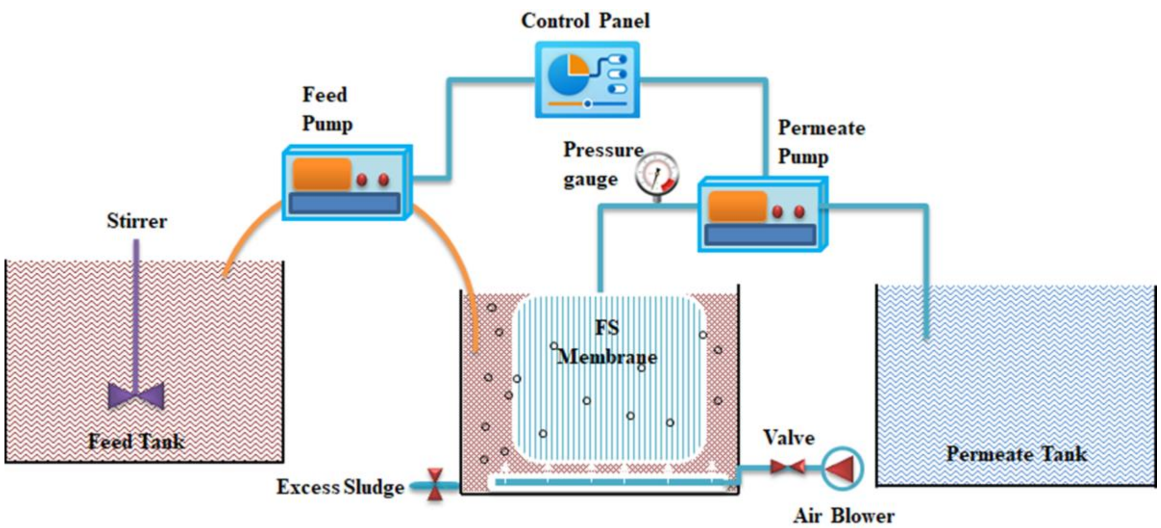

Figure 1 The schematic diagram of lab-scale MBR treatment system.

deionized water using the new membrane. The value of R_f was determined at the end of each run after removing the sludge layer [30].

3. Results and discussion

3.1. Performance of MBR under different conditions of SRT

3.1.1. COD removal

Based on the results of previous investigations, a HRT of 7h was selected for this study [30, 31]. Permeate flux was kept constant at 11.4 L/ m^2 h. COD loading rate was around 0.93 kg COD/m^3.d. SRT was varied throughout the operation of this study (174 days) from 10, 20, 30, and 60d, where the excess MLSS discharged per day were 800, 400, 266.6, and 133.3 mL, respectively.

Table 1 and Figures 2, 3, 4, 5, and 6 provide the average findings of the FS-MBR treatment efficiency in terms of the primary process parameters typically monitored at wastewater treatment. Regarding COD percentage removal, the obtained data indicated good performance for organic compounds removal. For all SRT, COD removal was more than 89%. These results are similar to those obtained by **K. Chen *et al.*, (2011) and W. Lee, Kang, and Shin (2003)** who concluded that COD and BOD removal values are not affected by changing the SRT within the range adopted in the present study [15, 27]. With the exception of the operation at SRT for 10 days, where COD treatment performance was only 89%, the concentration of the effluent of COD after the MBR operation ranged from 18.5 to 28.6 mg/L, corresponding to a removal efficiency of 90%–93% (Fig. 2). The reduction in COD removal could be attributed to the reduced biomass concentration (2.5 g/L). Using a pilot-scale submerged MBR for the treatment of high-strength industrial wastewater at 200-day SRT and 20 g/L of sludge solids, TOC and COD removal efficiencies of more than 98% and 99% were achieved [32]. Similar findings from other studies indicate that SRT has a prominent impact on the sludge's characteristics and that the longer SRT is, the more likely it is to reduce membrane fouling [12, 33]. Wan et al. found that the removal effectiveness of partial COD increased gradually from 89.56% to 95.48% with the increase in sludge concentration. Yet, the removal efficiency of total phenol and ammonia nitrogen did not change considerably. The system's ability to resist shock, toxicity, and the removal of refractory materials was enhanced by the rise in sludge concentration because, in practice, wastewater quality and treatment were more complex. However, when MLSS levels rise, the amount of oxygen needed in the aerobic tank and the viscosity of AS will increase. Since the oxygen transfer efficiency will decline as a result of the increased AS floc adhering to bubble surfaces, decreasing the oxygen contact area [34].

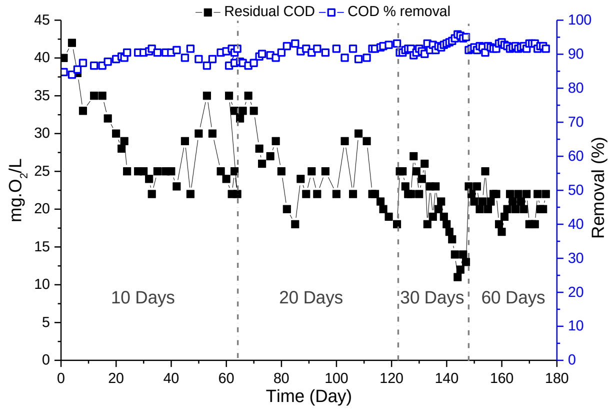

Figure 2 Variations of COD values in MBR permeate at 10, 20, 30, and 60 days SRT.

3.1.2. Nitrification and phosphorus removal

Table 1 Characteristics of the MBR influent and permeate at different SRT

Parameters	Unit	Influent	SRT							
			10d	R (%)	20d	R (%)	30d	R (%)	60 d	R (%)
PH	------	7.49±0.19	7.6±0.24	-----	7.8±0.24	------	7.7±0.16	------	8±0.14	----
COD	mg O_2/L	270±16.8	28.6±5.6	89.40741	25.7±5.2	90.4	18.5±5.3	93	20±2.3	92
NH_4-N	mg N/L	25±1.3	2.6±0.71	89.6	0±0.0	100	0	100	0	100
NO_3	mg N/L	0.2±0.17	15±2.5	-----	20.17±9.6	------	22.4±9.8	------	25±4.3	-----
TKN	mg N/L	29±2.6	6.5±2.2	80	5.7±2.1	82.7	4.2±3.8	86	5.5±2.6	83
TP	mg P/L	3.5±0.16	2.7±0.4	22	2.6±1.5	25.7	1.0±0.3	71	0.9±1.4	77

In the present investigation, except for ammonia at SRT of 10 d, which had an 89% removal effectiveness, the treated wastewater's ammonia and suspended particle concentrations were below detectable limits. Total nitrogen (TN) and/or total Kjeldahl nitrogen (TKN) in wastewater are two ways to express the amount of nitrogen present. TN includes nitrite and nitrate-based nitrogen in addition to TKN, whereas ammonia nitrogen and organic nitrogen make up TKN content [35]. As previously indicated, similar to other parameters, the maximum TKN removal efficiencies were attained at the SRT of 30 d. The average NO_3 concentrations in the permeate were 25±4.3, 22.4±9.8, 20.17±9.6, and 15±2.5 mg/L for the SRT intervals of 60 d to 10 d, respectively. Nitrite accumulation was found in the permeate for the MBR operation at SRT of 10 days in the range between 1.5 and 4.5 mg N/L, indicating a reduced nitrification efficiency over the first 20 days. However, over the next few days, the nitrification process' effectiveness ultimately improved, eradicating the buildup of nitrite in the permeate. It is well-established that nitrification performance is improved with higher SRTs since this gives the slow-growing nitrifiers in the system enough time to mature [36].

In the current study, the average TP concentrations in the permeate were 0.9 ± 1.4, 1 ± 0.3, 2.6 ± 1.5, and 2.7 ± 0.4 mg/L at SRTs of 60, 30, 20, and 10 d, respectively, with a corresponding removal efficiency of around 77, 71, 25.7, and 22%. Thus, phosphorus uptake increased by increasing SRT, which could be attributed to the increase in biomass [37].

Zahid and El-Shafai reported low phosphorous removal with 51-55% in MBR treating municipal wastewater at 26.3 days SRT and ORL of 1.65-1.84 g/L.d [38]. Similarly low biological phosphorous removal with between 17-37% from initial range of 5.06-6.5 mgP/L was reported in SBR treating municipal wastewater at 1.24-1.84 gCOD/L.d OLR [39]. To enhance phosphorous removal and mitigate membrane fouling in MBR, alum and ferric chloride have been used separately [40, 41].

3.2. *Impact of SRT on sludge biomass concentration*

The biomass concentrations in the MBR experienced a proportional increase as the SRT was increased, ranging from 4.5 to 6.5 g MLSS/L at SRT 10 to 60 day, (Figure 5). On the other hand, the MLVSS/MLSS ratio was in the range from 0.79 to 0.81 over the whole run, indicating a low accumulation of inorganic matter in the MBR at the different operating conditions. **Laera *et al.*** reported MLVSS/MLSS ratios above 0.75, at SRTs ranging between 20 and 80 days for municipal wastewater treatment [42]. According to **Fu *et al.*,** sludge accumulation up to 2.9, 6.9 and 11.63 g/L can be obtained when SRT are increased from 5 to 20 d, giving higher biomass growth rates [44].

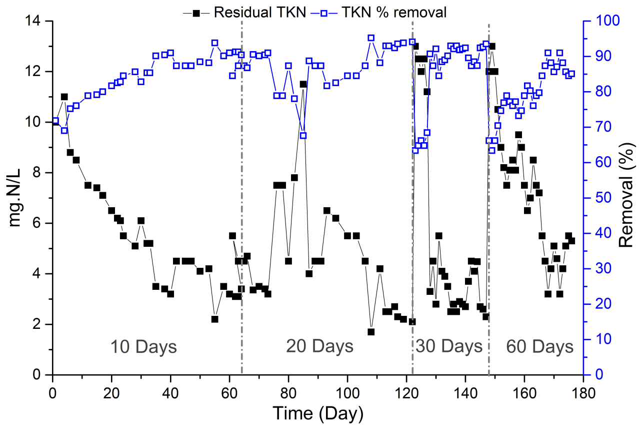

Figure 3 Variations of TKN in MBR permeate at 10, 20, 30, and 60 days SRT.

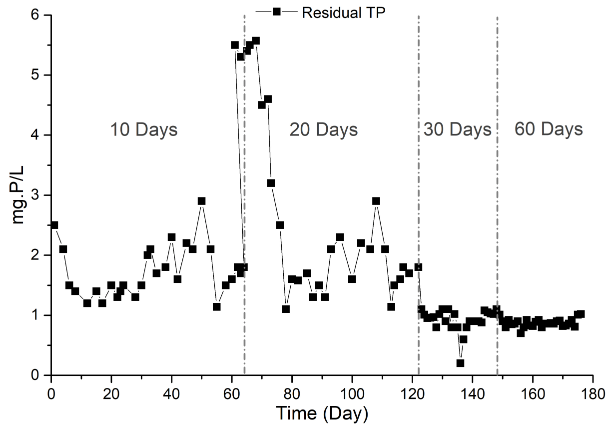

Figure 4 Variations of TP in MBR permeate at 10, 20, 30, and 60 days SRT.

According to previous publications, the biomass concentration, properties and the microbial community are impacted by SRT, HRS, and OLR [45, 46]. In the current study, Figure 6 shows that at SRT of 10 days, the MBR biomass was predominantly made up of scattered microorganisms and small, weak flocs, with significant quantities filamentous organisms. Thus, a shorter SRT resulted in smaller and weaker flocs. Ng and Hermanowicz found similar results when examining the performance and biomass characteristics of MBR operated at short SRTs ranging from 0.25 to 5 d with HRTs of 3 and 6 h. They observed that the MBR sludge was made up of a variety of short filamentous organisms and weak, tiny aggregates. The flocs in the shorter SRT were weaker and smaller. Additionally, they discovered that altering the F/M ratio, or SRT, boosted the amount of non-flocculating bacteria, which enhanced the removal of organic material [47].

3.3. The Impact of SRT on membrane fouling and filtration performance

In the current investigation, decreasing SRT from 60 to 10 days, increased total fouling resistance (R_t) from 0.38 x 10^{13} to 0.48 x 10^{13} m^{-1}. This might be a result of the system producing more colloidal substances as a consequence of the lower SRT and the pore-blocking effects of the colloidal organics on

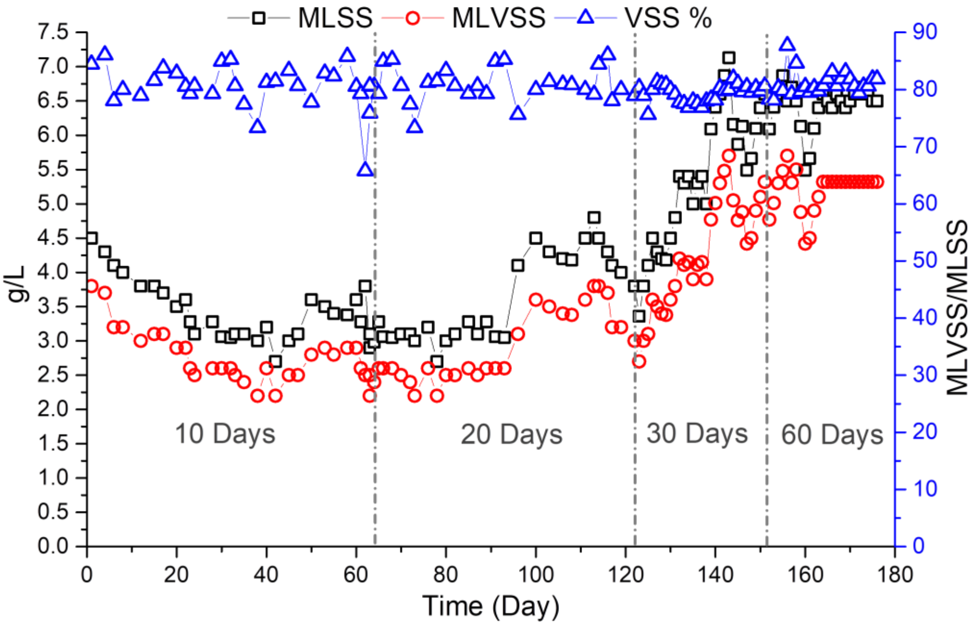

Figure 5 Sludge Growth (g/L) at Different SRT time.

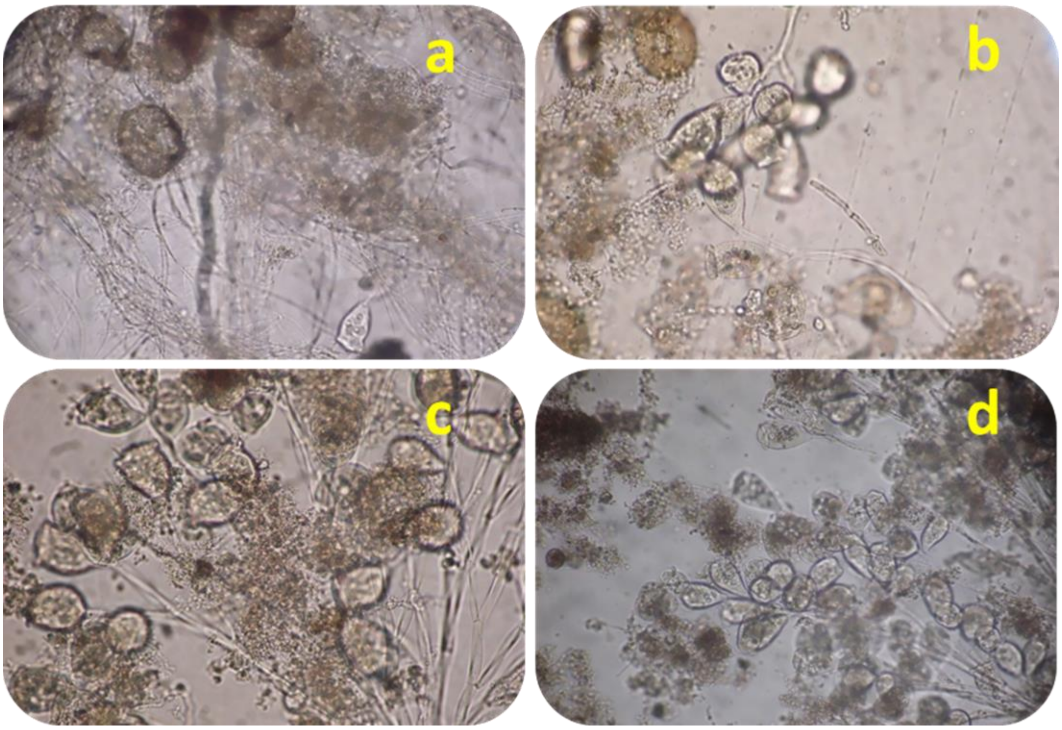

Figure 6 Biomass images of AS captured by optical microscope following SRT of 10 (a), 20 (b), 30 (c), and 60 days (d).

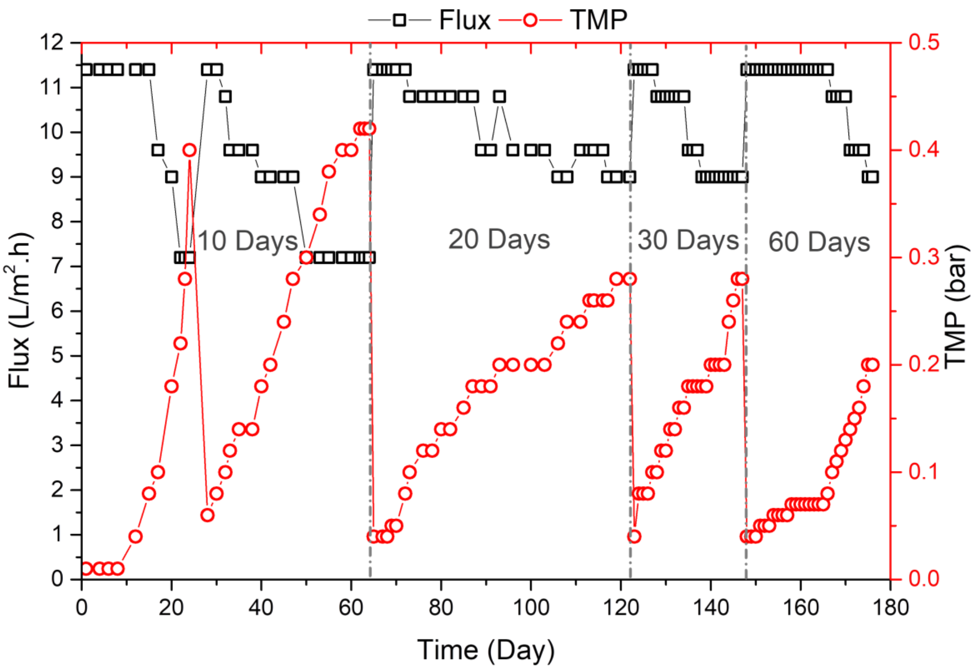

Figure 7 TMP and Flux Variation at different SRT time.

the membrane [48]. Other studies, however, observed that increasing SRT resulted in a decrease in the rate of membrane fouling [7, 8, 49–53].

3.4. Impact of SRT on Flux and TMP

Results presented in Figure 7, shows a gradual reduction of permeate flux and a gradual increase of TMP, in the four SRT investigated. At SRT of 10 days, the permeate flux was reduced from 11.4 to 7.2 L/m^2.h. At the same time, by the end of this run (at day 65), the TMP increased from 0.01 to 0.42 bar. Increasing the SRT to 20 and 30 days reduced the permeate flux from 11.4 to 9 L/m^2.h and increased the TMP from 0.04 to 0.28 bar. Further increase of SRT to 60 days led to a reduction of the permeate flux from 11.4 to 9 L/m^2.h and increased the TMP 0.04 to 0.2 bar. It is worth mentioning that before changing the SRT, the membrane was cleaned, following the manufacturer's guidelines to recover the permeate flux to the original value. In general, it can be concluded that increasing the SRT increases the TMP and reduces the permeate flux. This could be due to the increase in biomass concentration.

4. Conclusion

In the present study, increasing the SRT from 10 to 60 days slightly affect the organic matters removal as measured by COD values. Also, increasing SRT resulted in a better TP, TKN, and NO_3 removal performance. At the same time, a gradual increase in the biomass production ranging from 4.5 to 6.5 g MLSS/L has been reported. Corresponding MLVSS/MLSS ratio was in the range from 0.79 to 0.81 over the whole run, indicating a low accumulation of inorganic matter in the MBR at the different operating conditions. Microscopical examination of the biomass produced indicated that increasing the SRT improved sludge quality. At SRT of 10 days, the biomass produced was dominated by small flocs and filamentous organisms. The results also confirmed the correlation between SRT and membrane fouling. Increasing the SRT from 10 to 60 days increased permeate flux from 7.2 to 9 L/m^2.h L/m^2.h.and reduced the TMP from 0.42 to 0.2 bar. A result which is positive for reducing membrane fouling, consequently keeping a low operating cost.

5. Conflicts of interest

There are no conflicts to declare.

6. Funding sources

Partial financial support was received from National Research Centre, Egypt.

7. References

1. Hellal MS, Al-Sayed A, El-Liethy MA, Hassan GK (2021) Technologies for wastewater treatment and reuse in Egypt: Prospectives and future challenges. In: Handbook of Advanced Approaches Towards Pollution Prevention and Control. Elsevier, pp 275–310
2. Le-Clech P, Chen V, Fane TAG (2006) Fouling in membrane bioreactors used in wastewater treatment. J Memb Sci 284:17–53. https://doi.org/10.1016/j.memsci.2006.08.019
3. Meng F, Chae SR, Drews A, et al (2009) Recent advances in membrane bioreactors (MBRs): Membrane fouling and membrane material. Water Res. 43:1489–1512
4. Stephenson T, Jefferson B, Judd S, Brindle K (2000) Membrane Bioreactors for Wastewater Treatment. IWA publishing
5. Wang Q, Wang Z, Wu Z, et al (2012) Insights into membrane fouling of submerged membrane bioreactors by characterizing different fouling layers formed on membrane surfaces. Chem Eng J 179:169–177. https://doi.org/10.1016/j.cej.2011.10.074
6. Lee D, Kim M, Chung J (2007) Relationship between solid retention time and phosphorus removal in anaerobic-intermittent aeration process. J Biosci Bioeng 103:338–344. https://doi.org/10.1263/jbb.103.338
7. Ahmed Z, Cho J, Lim B-R, et al (2007) Effects of sludge retention time on membrane fouling and microbial community structure in a membrane bioreactor. J Memb Sci 287:211–218. https://doi.org/10.1016/j.memsci.2006.10.036
8. Ouyang K, Liu J (2009) Effect of sludge retention time on sludge characteristics and membrane fouling of membrane bioreactor. J Environ Sci 21:1329–1335. https://doi.org/10.1016/S1001-0742(08)62422-5
9. Gadkari J, Shrivastav A, Bhattacharya S (2021) Membrane bioreactors for wastewater treatment. In: Membrane-based Hybrid Processes for Wastewater Treatment. Elsevier, pp 423–443
10. Rosenberger S, Krüger U, Witzig R, et al (2002) Performance of a bioreactor with submerged membranes for aerobic treatment of municipal waste water. Water Res 36:413–420. https://doi.org/10.1016/S0043-1354(01)00223-8
11. Pollice A, Laera G, Blonda M (2004) Biomass growth and activity in a membrane bioreactor with complete sludge retention. Water Res 38:1799–1808. https://doi.org/10.1016/j.watres.2004.01.016
12. Chang IS, Lee CH (1998) Membrane filtration characteristics in membrane-coupled activated sludge system - The effect of physiological states of activated sludge on membrane fouling. Desalination 120:221–233. https://doi.org/10.1016/S0011-9164(98)00220-3
13. Cho J, Song KG, Yun H, et al (2005) Quantitative analysis of biological effect on membrane fouling in submerged membrane bioreactor. Water Sci Technol 51:9–18. https://doi.org/10.2166/wst.2005.0616
14. Ng HY, Hermanowicz SW (2005) Specific Resistance to Filtration of Biomass from Membrane Bioreactor Reactor and Activated Sludge: Effects of Exocellular Polymeric Substances and Dispersed Microorganisms. Water Environ Res 77:187–192. https://doi.org/10.2175/106143005x41753
15. Lee W, Kang S, Shin H (2003) Sludge characteristics and their contribution to microfiltration in submerged membrane bioreactors. J Memb Sci 216:217–227. https://doi.org/10.1016/S0376-7388(03)00073-5
16. Liao BQ, Allen DG, Droppo IG, et al (2001) Surface properties of sludge and their role in bioflocculation and settleability. Water Res 35:339–350. https://doi.org/10.1016/S0043-1354(00)00277-3
17. Wilén BM, Jin B, Lant P (2003) The influence of key chemical constituents in activated sludge on surface and flocculating properties. Water Res 37:2127–2139. https://doi.org/10.1016/S0043-1354(02)00629-2
18. Xing CH, Yamamoto K, Fukushi K (2006) Performance of an inclined-plate membrane bioreactor at zero excess sludge discharge. J Memb Sci 275:175–186. https://doi.org/10.1016/j.memsci.2005.09.016
19. Sari Erkan H, Çağlak A, Soysaloglu A, et al (2020) Performance evaluation of conventional membrane bioreactor and moving bed membrane bioreactor for synthetic textile wastewater treatment. J Water Process Eng 38:101631. https://doi.org/10.1016/j.jwpe.2020.101631
20. Gao D wen, Tao Y, An R (2012) Digested sewage treatment using membrane-based process at different hydraulic retention times. Desalination 286:187–192. https://doi.org/10.1016/j.desal.2011.11.020
21. Isma MIA, Idris A, Omar R, Razreena ARP (2014) Effects of SRT and HRT on Treatment Performance of MBR and Membrane Fouling. Int J Chem Mol Nucl Mater Metall Eng 8:488–492. https://doi.org/10.5281/ZENODO.1093004
22. Chan C, Guisasola A, Baeza JA (2020) Living on the edge: Prospects for enhanced biological phosphorus removal at low sludge retention time under different temperature scenarios. Chemosphere 258:127230.

https://doi.org/10.1016/j.chemosphere.2020.127230
23. Onnis-Hayden A, Majed N, Li Y, et al (2020) Impact of solid residence time (SRT) on functionally relevant microbial populations and performance in full-scale enhanced biological phosphorus removal (EBPR) systems. Water Environ Res 92:389–402. https://doi.org/10.1002/wer.1185
24. Lihui Wang by, Wang L, Wang Advisor L, Hongde Zhou P (2013) Use of Short SRT Biological Processes to Recover Energy and Phosphorus from Municipal Wastewater ABSTRACT Use of Short SRT Biological Processes to Recover Energy and Phosphorus from Municipal Wastewater. University of Guelph
25. Zhu Z, Zhang Y, Hu L, Li Y (2021) Phosphorus recovery from municipal wastewater with improvement of denitrifying phosphorus uptake based on a novel AAO-SBSPR process. Chem Eng J 417:127907. https://doi.org/10.1016/j.cej.2020.127907
26. Babatsouli P, Palogos I, Michalodimitraki E, et al (2015) Evaluation of a MBR pilot treating industrial wastewater with a high COD/N ratio. J Chem Technol Biotechnol 90:26–33. https://doi.org/10.1002/jctb.4364
27. Chen K, Wang X, Li X, et al (2011) Impacts of sludge retention time on the performance of submerged membrane bioreactor with the addition of calcium ion. Sep Purif Technol 82:148–155. https://doi.org/10.1016/j.seppur.2011.09.003
28. APHA (2005) Standard Methods for the Examination of Water and Wastewater. Stand Methods 541. https://doi.org/10.2105/AJPH.51.6.940-a
29. Lee EJ, An AKJ, Hadi P, Yan DYS (2016) Characterizing flat sheet membrane resistance fraction of chemically enhanced backflush. Chem Eng J 284:61–67. https://doi.org/10.1016/j.cej.2015.08.136
30. Al-Sayed A, El Senosy W, Alherrawy A, et al (2018) Membrane Bioreactor Technology for Wastewater Reclamation. Egypt J Chem 61:650–660. https://doi.org/10.21608/ejchem.2018.4128.1361
31. Al-Sayed A, Hellal MS, Al-Shemy MT, Hassan GK (2023) Performance evaluation of submerged membrane bioreactor for municipal wastewater treatment: Experimental study and model validation with GPS-X software simulator. Water Environ J 37:480–492. https://doi.org/10.1111/wej.12852
32. Hay CT, Sun DD, Khor SL, Leckie JO (2006) Effect of 200 days' sludge retention time on performance of a pilot scale submerged membrane bioreactor for high strength industrial wastewater treatment. Water Sci Technol 53:269–276. https://doi.org/10.2166/wst.2006.362
33. Ng HY, Hermanowicz SW (2005) Membrane bioreactor operation at short solids retention times: performance and biomass characteristics. Water Res 39:981–992. https://doi.org/10.1016/j.watres.2004.12.014
34. Wan N, Shi J, Zhou P, et al (2023) Efficiency of submerged ceramic flat membrane bioreactor in the treatment of coal chemical wastewater. J Water Process Eng 53:103638. https://doi.org/10.1016/j.jwpe.2023.103638
35. Deng Z, van Linden N, Guillen E, et al (2021) Recovery and applications of ammoniacal nitrogen from nitrogen-loaded residual streams: A review. J Environ Manage 295:113096. https://doi.org/10.1016/j.jenvman.2021.113096
36. Innocenti L, Bolzonella D, Pavan P, Cecchi F (2002) Effect of sludge age on the performance of a membrane bioreactor: Influence on nutrient and metals removal. Desalination 146:467–474. https://doi.org/10.1016/S0011-9164(02)00551-9
37. Zhang M, Leung KT, Lin H, Liao B (2021) Effects of solids retention time on the biological performance of a novel microalgal-bacterial membrane photobioreactor for industrial wastewater treatment. J Environ Chem Eng 9:105500. https://doi.org/10.1016/j.jece.2021.105500
38. Zahid WM, El-Shafai SA (2011) Use of cloth-media filter for membrane bioreactor treating municipal wastewater. Bioresour Technol 102:2193–2198. https://doi.org/10.1016/j.biortech.2010.09.116
39. Zahid WM, El-Qelish M, El-Shafai SA (2023) Effect of operating regime on the performance of biofilm reactor treating municipal wastewater. Int J Environ Sci Technol 20:8799–8812. https://doi.org/10.1007/s13762-022-04589-8
40. El-Shafai SA, El-Qelish M, Zahid WM (2023) Significance of Ferric Chloride Addition on the Treatment Performance of Cloth-Media MBR Treating Municipal Wastewater. Arab J Sci Eng 48:8723–8736. https://doi.org/10.1007/s13369-022-07373-5
41. Zahid WM, El-Shafai SA (2012) Impacts of alum addition on the treatment efficiency of cloth-media MBR. Desalination 301:53–58. https://doi.org/10.1016/j.desal.2012.06.010
42. Laera G, Pollice A, Saturno D, et al (2009) Influence of sludge retention time on biomass characteristics and cleaning requirements in a membrane bioreactor for municipal wastewater

treatment. Desalination 236:104–110. https://doi.org/10.1016/j.desal.2007.10.056

43. Deng L, Guo W, Ngo HH, et al (2016) Effects of hydraulic retention time and bioflocculant addition on membrane fouling in a sponge-submerged membrane bioreactor. Bioresour Technol 210:11–17. https://doi.org/10.1016/j.biortech.2016.01.056
44. Fu C, Yue X, Shi X, et al (2017) Membrane fouling between a membrane bioreactor and a moving bed membrane bioreactor: Effects of solids retention time. Chem Eng J 309:397–408. https://doi.org/10.1016/j.cej.2016.10.076
45. Mannina G, Capodici M, Cosenza A, et al (2018) The effect of the solids and hydraulic retention time on moving bed membrane bioreactor performance. J Clean Prod 170:1305–1315. https://doi.org/10.1016/j.jclepro.2017.09.200
46. Al-Sayed A, Hassan GK, Al-Shemy MT, El-gohary FA (2023) Effect of organic loading rates on the performance of membrane bioreactor for wastewater treatment behaviours, fouling, and economic cost. Sci Rep 13:15601. https://doi.org/10.1038/s41598-023-42876-7
47. Rosenberger S, Krüger U, Witzig R, et al (2002) Performance of a bioreactor with submerged membranes for aerobic treatment of municipal waste water. Water Res 36:413–420. https://doi.org/10.1016/S0043-1354(01)00223-8
48. Yilmaz T, Demir EK, Asik G, et al (2023) Effect of sludge retention time on the performance and sludge filtration characteristics of an aerobic membrane bioreactor treating textile wastewater. J Water Process Eng 51:103390. https://doi.org/10.1016/j.jwpe.2022.103390
49. Ng HY, Tan TW, Ong SL (2006) Membrane fouling of submerged membrane bioreactors: Impact of mean cell residence time and the contributing factors. Environ Sci Technol 40:2706–2713. https://doi.org/10.1021/es0516155
50. Al-Halbouni D, Traber J, Lyko S, et al (2008) Correlation of EPS content in activated sludge at different sludge retention times with membrane fouling phenomena. Water Res 42:1475–1488. https://doi.org/10.1016/j.watres.2007.10.026
51. Van den Broeck R, Van Dierdonck J, Nijskens P, et al (2012) The influence of solids retention time on activated sludge bioflocculation and membrane fouling in a membrane bioreactor (MBR). J Memb Sci 401–402:48–55. https://doi.org/10.1016/j.memsci.2012.01.028
52. Dong B, Jiang S (2009) Characteristics and behaviors of soluble microbial products in sequencing batch membrane bioreactors at various sludge retention times. Desalination 243:240–250. https://doi.org/10.1016/j.desal.2008.04.026
53. Hasani Zonoozi M, Alavi Moghaddam MR, Maknoon R (2015) Operation of integrated sequencing batch membrane bioreactor treating dye-containing wastewater at different SRTs: study of overall performance and fouling behavior. Environ Sci Pollut Res 22:5931–5942. https://doi.org/10.1007/s11356-014-3761-3