Proceedings of the 8th World Congress on Civil, Structural, and Environmental Engineering (CSEE'23)
Lisbon, Portugal – March 29 – 31, 2023
Paper ICEPTP 202
DOI: 10.11159/iceptp23.202

Performance of Membrane Biological Reactor for Tobacco Industrial Wastewater Treatment

Abdallah Alhajar, Sameer Al-Asheh*, Ahmad Aidan
Department of Chemical and Biological Engineering, American University of Sharjah, UAE
b00075877@alumni.aus.edu; sslasheh@aus.edu; aidan@aus.edu
*Corresponding author

Abstract **-** As technologies develop and populations grow, the demand for water sources increases. To keep up with such demand, innovative methods for water regeneration need to be explored. Amongst these methods is the utilization of Membrane Biological Reactors (MBRs) for wastewater treatment. MBRs combine conventional wastewater treatment technologies with a membrane, which enhances the purity of the effluent and eliminates the need for advanced treatment methods. By utilizing microfiltration or ultrafiltration, MBRs can achieve around 90% removal levels of chemical oxygen demand (COD). This work discusses membranes and factors that affect their performance. It also introduces MBRs, their significance, and the potential they offer for wastewater treatment. The study will be conducted experimentally on a lab-scale MBR to treat wastewater produced from molasses manufacturing exploring and optimizing MBRs operating parameters including influent pH, sludge concentration, and temperature. The study revealed that MBRs can effectively remove 80-90% of COD content in wastewater produced by the tobacco industry while operating at a pH of 6 – 8 with an HRT of 1 day. Additionally, they are highly desirable in treating tobacco wastewater at temperatures ranging between 20 to 40 ºC.

Keywords**:** MBR, membrane, wastewater, tobacco, HRT

1. Introduction

Water is the most crucial substance contributing to the existence of living organisms. It also plays a significant role in industrial operations. For instance, it is used to exchange heat in desired reactions, extract certain substances, yield products, and generate hydroelectricity. The applications of water are countless, which emphasize its importance. In fact, the demand for water has increased by 600% percent since 1918, which corresponds to a 1.8% incremental annual increase [1]. This could be traced back to the exponential population growth and industrial expansion to satisfy the current development requirements. Recently, 4600 km^3 of water has been in demand annually and it is expected to reach 6000 km^3 per annum by 2050; however, the greater concerns are associated with the availability of sources. With the current demand, the supply of water is close to a maximum, and yet there are about 1.9 billion people living in potentially severe water-scarce conditions. Due to the excessive consumption for industrial development and the coincident water pollution, it is expected that by 2050, 3.2 billion people will be endangered by water scarcity [1]. Thus, at this alarming rate, it is now more important than ever to develop and employ processes and techniques that can treat the wastewater, industrially or domestically produced, to supply freshwater that can meet the ginormous demand.

For decades, wastewater has been treated employing conventional methods [2]. In this scenario, raw sewage is pre-treated through screens to remove suspended such as rags, sticks, and debris. Then, the water undergoes primary treatment to remove suspended particles flocculation and sedimentation. Later, the effluent is introduced to secondary treatment to remove the present organic matter. Beyond this stage, the water is safe for discharge into water reservoir, or to be used for irrigation. If a higher level of purity is desired, the discharge can undergo tertiary treatment, which involves membrane technology such as reverse osmosis (RO) [3].

Although the conventional treatment method yields water with desired purity, it is slow and takes up large areas [2]. Therefore, it is of necessity to develop technologies capable of rapid and efficient for wastewater treatment while utilizing relatively small land space. Amongst these technologies are membrane biological reactors (MBRs), which involve submerged membranes that constrict the passage of contaminants present in wastewater [4] [5]. In essence, they replace the secondary treatment stage and eliminate the need for a tertiary stage as they validate microfiltration or ultrafiltration. In this case, as that of the conventional treatment, raw sewage undergoes pretreatment and primary treatment stages to remove suspended solids. Then the effluent is sent to an aeration tank to assist in the growth of the microorganisms producing activated sludge, which enhances the filtration process. Then, the effluent passes a membrane where the separation process takes place, achieving high levels of chemical oxygen demand (COD) and biological oxygen demand (BOD) removal.

Since the development of MBRs in 1969, numerous studies were conducted investigating their feasibility. Tadkaew et al. [6], investigated MBRs' ability to remove trace organics utilizing a submerged membrane within the bioreactor. A synthetic wastewater comprised of glucose, peptone, KH_2PO_4, $MgSO_2$, $FeSO_4$, and sodium acetate was used. 40 organic compounds were added employing pesticides, endocrine disrupting chemicals, steroid hormones, and pharmaceutically active chemicals. The experimental study revealed 85% - 98% removal efficiency of hydrophobic trace organic compounds whereas a removal efficiency below 20% was observed for hydrophilic trace organic compounds [6].

MBRs potential caught the pharmaceutical industry's attention. In a study conducted by Sipma et al. [7], MBRs capability of removing pharmaceuticals was compared to conventional activated sludge (CAS) systems. The study revealed that MBR has similar removal efficiency to CAS when it comes to easily removed pharmaceuticals such as ibuprofen. Additionally, it was shown that the removal of moderately or slightly removed pharmaceuticals was better in MBRs. Overall, MBRs showed better removal operations compared to CAS except for few chemicals such as sotalol and hydrochlorothiazide [7].

Tambosi et al. [8] tested MBRs performance for the removal of non-steroidal anti-inflammatory drugs (NSAIDs) and antibiotics. Utilizing a submerged membrane, their experiments revealed high removal efficiency of NSAIDs ranging between 86% to 100% with a sludge retention time (SRT) of 15 days. Meanwhile, antibiotics removal efficiency ranged between 55% to 86%. When the SRT was increased to 30 days, the treatment process resulted in the removal of 89% to 100% of NSAIDs while the antibiotics removal efficiency ranged between 64% to 94% [8].

In a study by Tan et al. [9], the performance of MBRs for the removal of microorganisms present in saline wastewater was reviewed. According to the study, the removal efficiencies of COD and ammoniacal nitrogen in a conventional MBR were 93% and near 100% respectively. In addition, the study suggests seeding the wastewater with halophilic microorganisms. The removal efficiencies of total organic carbon (TOC) and ammoniacal nitrogen were found to be 98% and 95% respectively. This is due to enhanced bioactivity provided by the microorganisms [9].

Membrane Biological Reactors (MBRs) provide a fast and reliable method for water regeneration [10] [11]. They offer a sustainable, low foot-print process that can produce water with high quality while discarding the need for large secondary clarifiers and disinfection processes [12]. MBRs combine the primary wastewater treatment stage with a membrane technology to achieve their desired product. Meanwhile, the only drawback that prevents decision makers from fully adopting MBRs is the membrane fouling, an essential issue in membrane applications [13] [14]. However, with the recent scientific developments and the better understanding of membrane preservation strategies, MBRs become a leading solution to an urgent crisis [15] [16] [17] [18]. Thus, the objectives of this study are to investigate MBRs effectiveness for industrial wastewater treatment; develop parameters that optimize MBRs performance; study the effects of membrane fouling on the effluent and explore optimum control strategies; and study the effect of altering operating conditions on the effluent.

2. Methodology

2.1. Apparatus

The MBR lab unit used in this work is designed by CERAFILTEC for short-term simple filtration purposes. It incorporates a ceramic membrane with an area of 0.01 m^2 and nominal pore size of 0.1 µm, a valveless rotary piston pump, an air diffuser, and an aeration tank. The unit operates automatically, with adjustable settings, via a control system designed using Siemens LOGO8 with TDE software. The control unit records the transmembrane pressure (TMP) changes with time. Additionally, the volumetric flowrate can be adjusted using the control panel by changing the frequency of the pump.

The operating conditions and the filtration specifications for this unit are as follows: medium temperature: 5 – 40ºC; ambient temperature: 5 – 40ºC; maximum recommended sludge concentration: 15 g/L; maximum relative humidity: 80%; 80%; maximum diameter of suspended solids inflow: 1 mm; type of pump: valveless rotary piston pump; CPF pump-head: head: FMI007; fuse rating: 2 x T800 mA/ 250 V (230 V_{AC}); speed range: 18 – 1800 rpm; 0 – 50 HZ; 0 – 100%; flow range: range: 0.002 – 10.8 L/ h; maximum differential pressure: 6.9 bar; power consumption: maximum 50 W; connections: polytetrafluoroethane (PTFE) tubes 1.6 mm (ID); 3.2 mm (OD); with 2 fittings UNF ¼-28 (male).

Meanwhile, the sludge utilized for the treatment process comprised of a mixture of 70% Pseudomonas bacteria and 30% Bacillus supplied under the commercial name RoeTech 302 [19]. The two main factors utilized for the selection of this specific mixture are their commercial feasibility and formulation that can degrade hydrocarbons and oils, which makes this selection favorable for industrial wastewater treatment.

2.2. Experimental Procedure

The wastewater sample, collected from a local Tobacco plant, consists of many suspended solids that might foul the membrane rapidly. Therefore, the sample underwent a pre-treatment stage before it is fed to the aeration tank of the MBR. This involved the following steps:

1. The wastewater sample will be introduced to a settling tank, for one day, to remove any suspended solids; hence, remove the major source of color.
2. Utilizing a dosing pump, the sample was then transferred into the MBR unit to initiate the treatment process.
3. The rotary piston pump sucked the sample across the membrane into the product tank.
4. Water analysis was carried out.
5. The previous steps were repeated under different conditions, and the performance was evaluated.

Figure 1 presents the piping and instrumentation diagram (P&ID) for the process mentioned above.

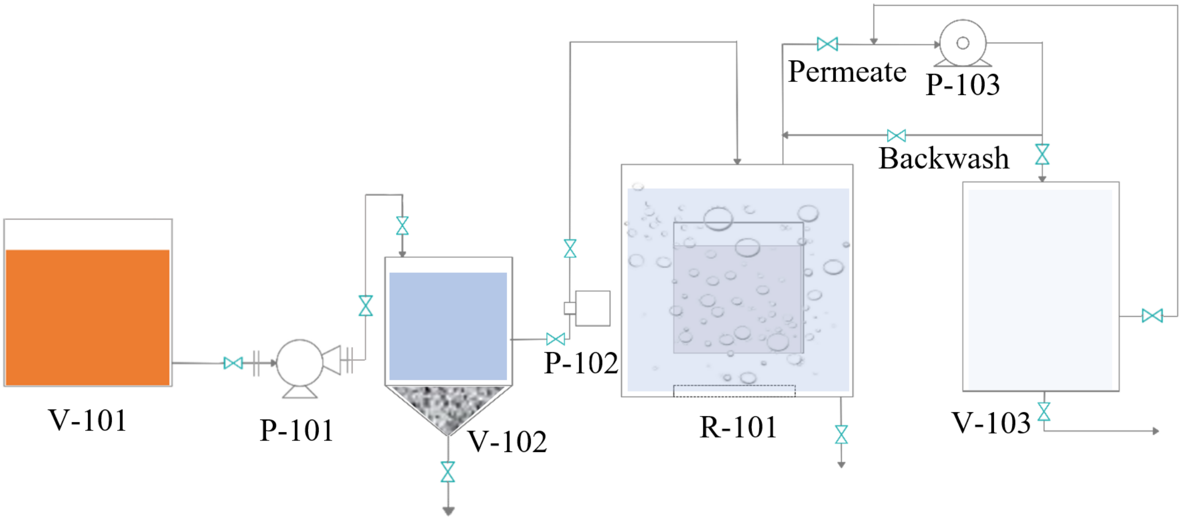

Fig 1: Process P&ID for the MBR apparatus. P-101: pump; P-102: dosing pump; P-103: suction pump; R-101: aerated biological reactor; V-101: storage tank; V-102: settling tank; V-103: storage tank.

.

2.3. Water Analysis

To ensure that the treatment process has achieved its objective, analyses were carried out on the effluent of the pre-treatment stage and the effluent of the MBR with emphasis on COD and TOC (Total Organic Carbon). COD was measured using Aqualytic PC Compact COD Vario Photometer utilizing Lovibond COD Vario Vials while the TOC was measured using Suez Innovox TOC AutoSampler.

2.4 Effect of Operating Parameters

After testing the MBR's ability to treat tobacco industrial wastewater, its effectiveness was evaluated for operation under different parameters including:

- Strength of wastewater: MBR's performance will be studied when the water sample is diluted.
- Contact time: the HRT will be manipulated to study its effect.
- pH: the wastewater sample acidity will be altered to reveal its influence.
- Membrane pore size: Different membrane ratings will be tested.
- Temperature: the sample will be heated and cooled to evaluate the technology's adaptation to different climates.

3. Results and Discussion

3.1 Effect of pH

The study of the effect of the pH was conducted on pH values of 5, 6, 7, 8, and 9 while the pH of 7 was taken as a reference state. The system operated at 20ºC while the wastewater was fed to the bioreactor with a concentrated sludge of 3000 ppm in a 1:1 ratio. A sample was collected and analyzed every 3 hours for a total operation of 12 hours. Then, a final sample at 24 hours was collected to conclude the experiment. Fig. 2 shows the effect of pH on COD and TOC removals at moderate range of pH, namely 5, 6, and 7. Within the first 3 hours, there has been a sharp decrease in the COD content for all pH values. As shown, the COD removal for the operation at a pH of 6 and 7 were comparable with values of 46.11% and 44.07%, respectively. Meanwhile, the operation at a pH of 6 resulted in a much lower COD removal of 23.70% within the first 3 hours. This can be caused by the low activity of the bacteria mixture at that pH.

During the following 6 hours, a steadier COD removal was observed for the operation at the pH of 6 and 7 whereas the operation at the pH of 5 showed an increase in the COD. This is due to the decrease in the microbial activity. In the following 3 hours, the COD resumes to decrease sharply achieving a COD removal of 20.19%, 74.26%, and 71.11% for the pH of 5, 6, and 7 respectively. After 24 hours of operation, the COD removal for the operation at pH of 5 is found to be 47.04%; 83.5% at pH of 6; and 88.15 at pH of 7. Ultimately, these findings indicate that the operation at a pH of 5 is not favorable for this system. Similarly, the TOC analysis revealed a similar trend to the COD analysis results as shown in Fig. 3. After operating for 24 hours, the TOC removal yielded values of 65.81%, 88.84%, and 90% for the operations at a pH of 5, 6, and 7 respectively.

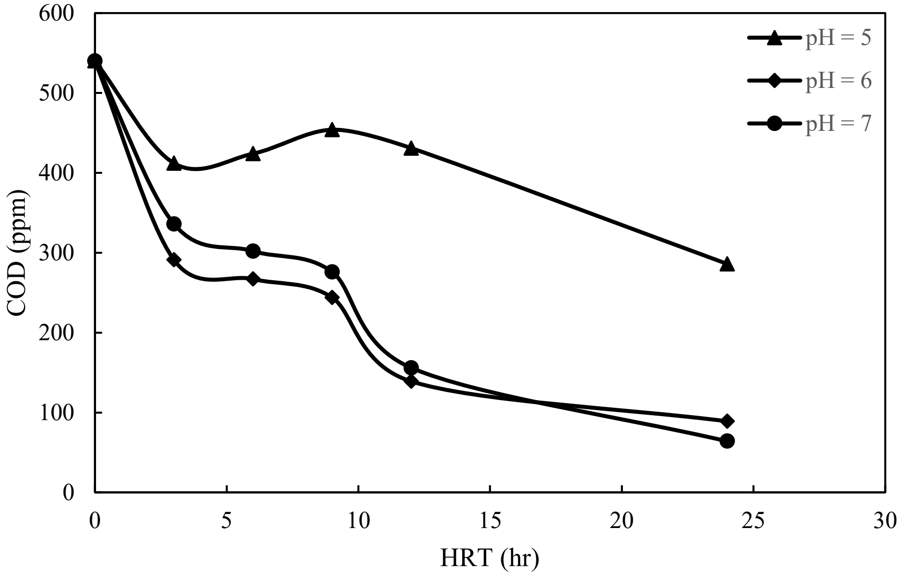

Fig. 2: Effect of pH, moderate range, on COD removal from tobacco wastewater at 20ºC and a sludge concentration of 3000 ppm.

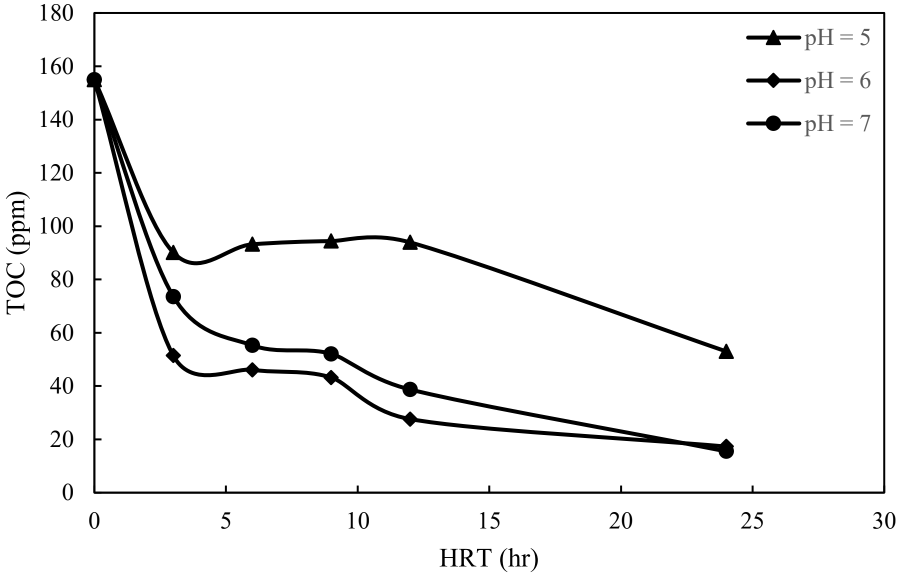

Fig. 3: Effect of pH, moderate range, on TOC removal from tobacco wastewater at 20ºC and a sludge concentration of 3000 ppm.

As for operating at high pH, the trend observed in the case of operating at a pH of 8 was similar to the case of pH of 6 and 7, which revealed a COD removal of 89.63% after 24 hours of operation. Meanwhile, operating at a pH of 9 revealed a COD removal of 72.96% after 24 hours. As for the TOC analysis, a similar trend for its removal has been observed yielding a TOC removal of 91.10% and 84.26% for operating at pH of 8 and 9, respectively, as shown in Fig. 5. Therefore, these results suggest that there is an operation window between pH of 6 and 8.

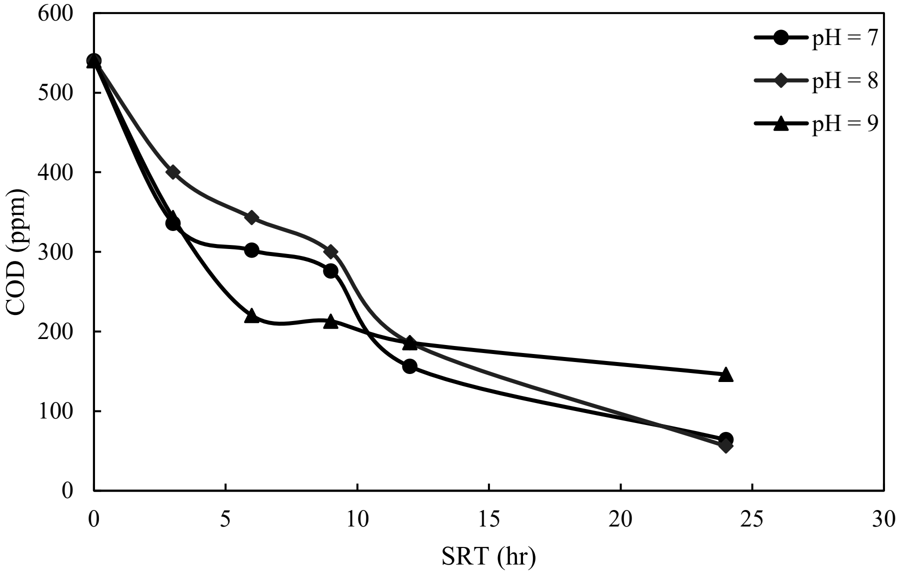

Fig. 4: Effect of pH, high range, on COD removal from tobacco wastewater at 20ºC and a concentration of sludge 3000 ppm.

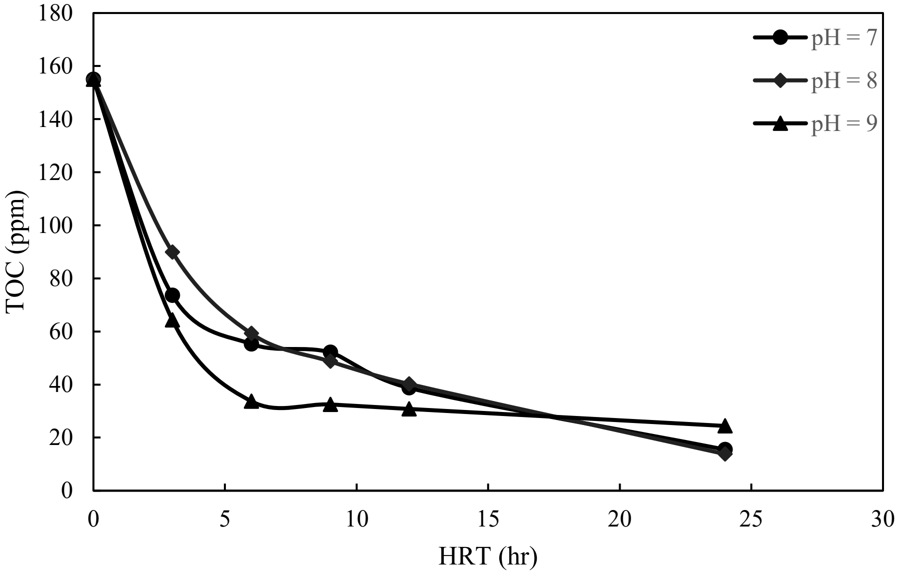

Fig. 5: Effect of pH, high range, on TOC removal from tobacco wastewater at 20°C and a sludge concentration of 3000 ppm.

Observing operating at pH of 6, 7, and 8, within the first 12 hours, the %COD removal is higher with lower pH; however, after 24 hours, the COD removal is greater at higher pH. This reveals an optimum operating condition with time. Therefore, the pH can be controlled to 6 for the first 12 hours. Then, it can be increased to 8 to increase the rate of COD removal.

The results obtained are consistent with what have been reported by Sanguanpak et al. [20]. In their study, they investigate the effect of operating pH on the biodegradation performance in MBRs for landfill leachate treatment. Ultimately, they revealed that the microbial activity was not affected while varying the pH between 6.5, 7.5, and 8.5. Meanwhile, as the mixed liquor pH decreased to 5.5 and below, the microbial activity has worsen revealing low %COD removal. Thus, low pH can interfere with the degradation mechanism of some bacterial species [21] [22] including Bacillus and Pseudomonas. Additionally, Bhattacharyya et al. [23] reported that heterotrophic bacteria favor the operation in pH in the range of 7.2 – 8.5 [24] [25].

3.2 Effect of Sludge Concentration

To observe the effect of sludge concentration on the treatment process, a 2000, 2500, 3000, 3500, and 4000 ppm concentrated sludge mixture was prepared and fed in a 1:1 volume ratio to the wastewater and set to a pH of 7 and a temperature of 20°C. In this experiment, the wastewater treated with the 3000 ppm sludge concentration is set as the reference. As shown in Fig. 6, the initial decrease in the COD was higher in the case of low concentrated sludge. This indicates that once the sludge concentration approaches 3000 ppm, the system becomes saturated with microbial organisms, which contributes into the increase in COD content due to insufficient levels of oxygen [26]. Ultimately, the COD removal is less over a period of 24 hours in comparison to the sample treated with 3000 ppm. This is shown in Fig. 6 where the COD removal yielded 59.62% and 80.37% for the cases of treating the wastewater with 2000 and 2500 ppm concentrated sludges respectively. These results can be put into perspective when compared to the 88.15% COD removal observed in the case treatment with 3000 ppm concentrated sludge. Thus, reducing the concentration of the sludge will extend the time required for treatment. Similar results were observed when the TOC sample was analyzed. The analysis revealed 74.13% and 88.55% TOC removal for the cases of treating the wastewater with 2000 and 2500 ppm concentrated sludges, respectively, in comparison to 90% TOC removal for the 3000 ppm concentrated sludge as shown in Fig. 7.

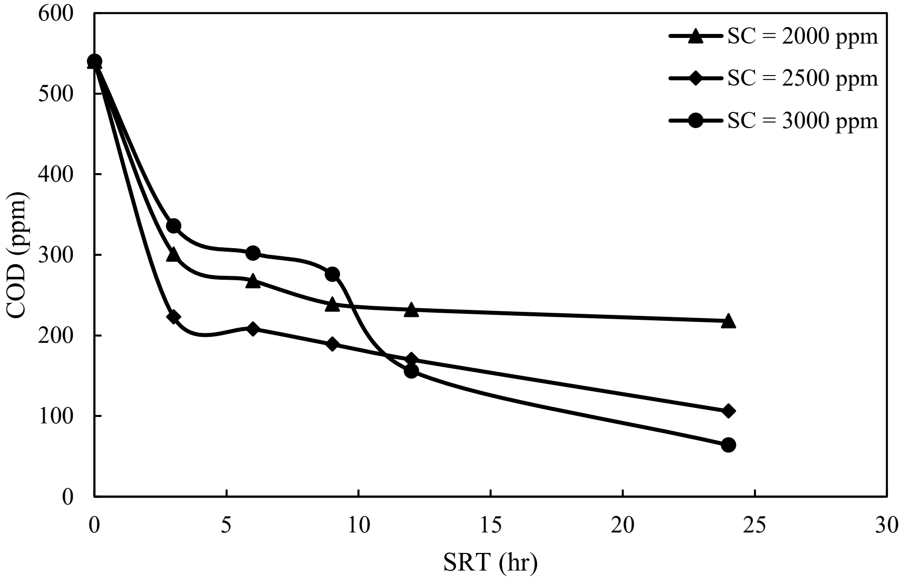

Fig. 6: Effect of sludge concentrations, 2000, 2500, and 3000 ppm, on COD removal from tobacco wastewater at 20°C and pH 7.

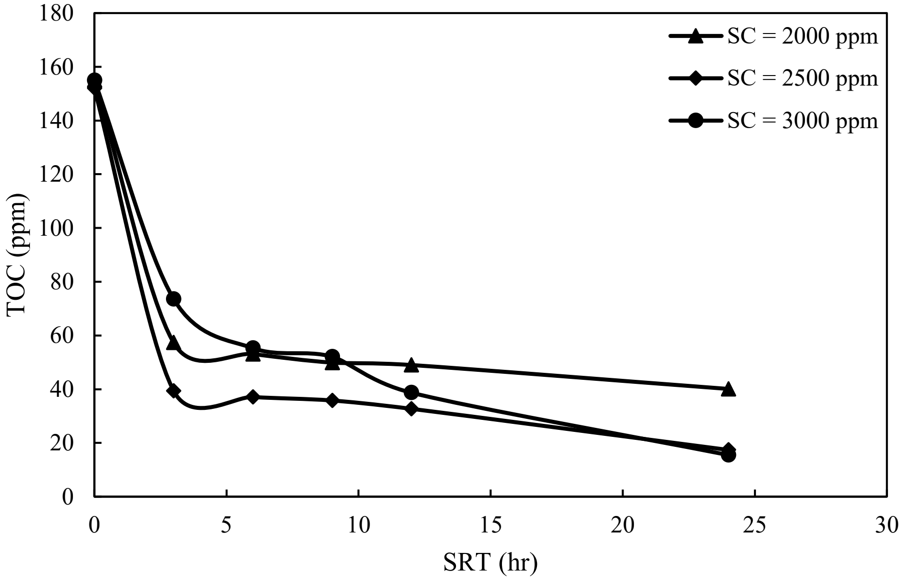

Figure 7: Effect of sludge concentrations, 2000, 2500, and 3000 ppm, on TOC removal from tobacco wastewater at 20°C and pH 7.

As for operating with higher sludge concentration, the results affirm the interference of sludge saturation on the COD content. As shown in Fig. 8, the initial decrease in COD content is lower than that of the low concentrated sludge operation. For the case of operating with a sludge concentration of 4000 ppm, the initial decrease in COD was relatively higher than the 2500 and 3000 ppm indicating fast consumption of COD content at high concentrations of sludge. However, the rate of COD removal decreases due to biomass deterioration as oxygen supply was lower than the required intake [26]. Comparing the operation at 3500 and 3000 ppm, it can be observed that a noticeable overlap in the performance exists. Nonetheless, the highest COD removal was observed for the 3000 ppm concentrated sludge in comparison to the samples operating at 3500 and 4000 ppm concentrated sludge that yielded 83.52% and 71.84% respectively as shown in Fig. 8. Similarly, the TOC analysis revealed a trend that is in accordance with the COD analysis revealing a TOC removal of 86.39% and 75.03% for operating with 3500 and 4000 ppm concentrated sludges respectively as shown in Fig. 9.

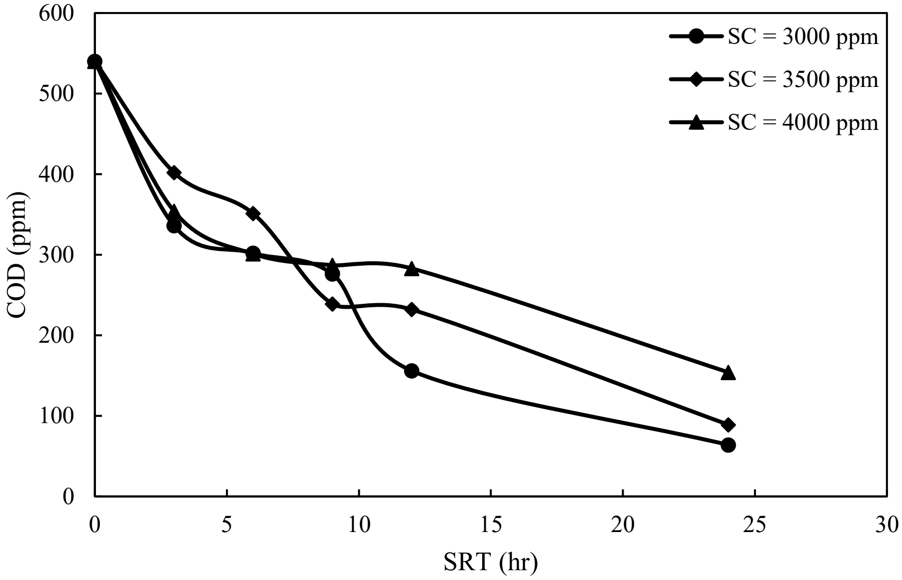

Fig. 8: Effect of sludge concentrations, 3000, 3500, 4000 ppm, on COD removal from tobacco wastewater at 20^{o}C and pH 7.

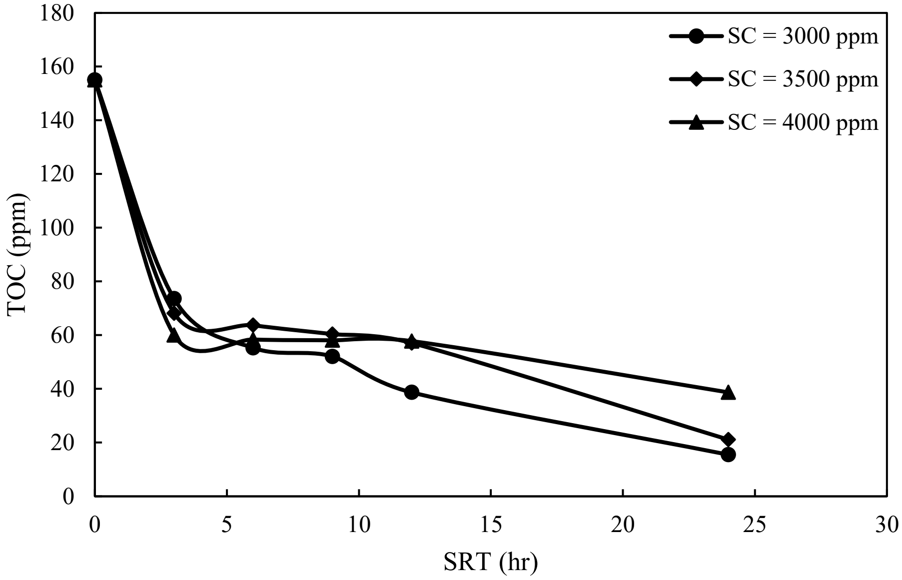

Figure 9: Effect of sludge concentrations, 3000, 3500, and 4000 ppm, on TOC removal from tobacco wastewater at 20^{o}C and pH 7.

In general, increasing the sludge concentration should enhance the treatment efficiency [27]. However, and as evidenced by the experiment, excessive sludge concentration can lead to elongate the treatment process to achieve the desired treatment. This can be attributed to the low oxygen levels supplied to the MBR that are required for aerobic degradation [26].

3.3 Effect of Temperature

To study the potential of the design to treat the wastewater at different climates, the temperature was varied to 30, 40, 40, and 50ºC. The wastewater was fed to the bioreactor with a concentrated sludge of 3000 ppm in a 1:1 ratio and set to a a pH of 7. As shown in Fig. 10, operating at 30 and 40ºC revealed almost identical COD removal compared to the operation operation at 20ºC within the first 5 hours. However, the removal rate has shown to be enhanced later on due to the enhanced kinetics of the system [28]. Observing the 50ºC operation, Fig. 10 reveals an increase in COD content, which indicates that the bacteria has deteriorated contributing into the increase. Therefore, the study reveals that this system can treat water in temperatures ranging between 20 and 40ºC. In climates that exceed such temperatures such as summer afternoons in the Arabian Peninsula, cooling measurements need to be taken into consideration.

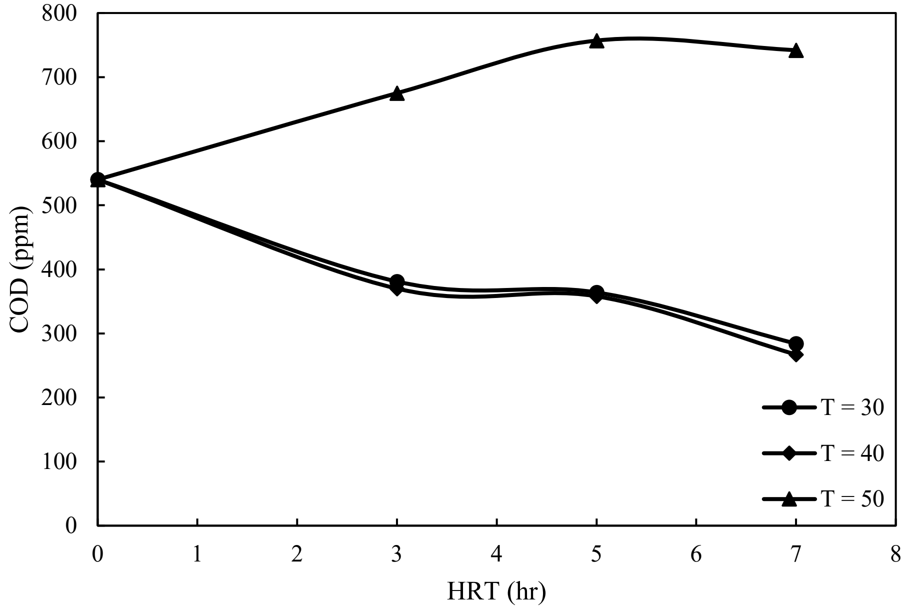

Fig. 10: Effect of temperature on COD removal from tobacco wastewater using 3000 ppm sludge concentration at pH 7.

4. Conclusions

Membrane bioreactor is capable of removing the COD and TOC contents of wastewater produced by the tobacco industry. It is considered a proposing technology compared to conventional wastewater treatment methods. The reduction in COD and TOC depends significantly on pH, concentration of biomass, and temperature. The effects of pH and biomass concentration is more pronounced that than that of temperature. In general, COD and TOC reductions increased with an in increased in pH and pH 8 found to be the optimum pH for this treatment process. Also, the increased biomass concentration resulted in higher COD and TOC reduction using MBR technology given that sufficient oxygen levels are supplied. The study reveals that this system can treat water in temperatures ranging between 20 and 40ºC while higher temperature resulted in higher COD and does not promise COD reduction by MBR.

Acknowledgements

The work in paper chapter was supported, in part, by Faculty Research Grant (FRG) from the American University of Sharjah. This work represents the opinions of the author(s) and does not mean to represent the position or opinions of the American University of Sharjah.

References

[1] A. Boretti and L. Rosa, “Reassessing the projections of the World Water Development,” *npj Clean Water,* 2019.

[2] G. Crini and E. Lichtfouse, “Advantages and disadvantages of techniques used for wastewater,” *Environmental Chemistry Letters,* no. 17, pp. 145-155, 2019.

[3] A. Alhajar, M. Tawalbeh, D. Arjomand, N. A. Rahman, H. Khan and A. Al-Othman, “Integrating forward osmosis into microbial fuel cells for wastewater treatment,” in *Integrated Environmental Technologies for Wastewater Treatment and Sustainable Development*, Elsevier, 2022, pp. 321-336.

[4] S. Judd, Industrial MBRs: Membrane Bioreactors for Industrial Wastewater Treatment, IWA Publishing, 2014.

[5] A. Achilli and R. Holloway, “Aerobic Membrane Bioreactor,” *Encyclopedia of Membranes,* 2014.

[6] N. Tadkaew, F. Hai, J. McDonald, S. Khan and L. Nghiem, “Removal of trace organics by MBR treatment: The role,” *Water Research,* vol. 45, pp. 2439-2451, 2011.

[7] J. Sipma, B. Osuna, N. Collado, H. Monclus, G. Ferrero, J. Comas and I. Rodriguez-Roda, “Comparison of removal of pharmaceuticals in MBR and activated sludge systems,” *Desalination,* vol. 250, no. 2, pp. 653-659, 2010.

[8] J. Tambosi, R. Sena, M. Favier, W. Gebhardt, H. Jose, H. Schrooder and R. Moreira, “Removal of pharmaceutical compounds in membrane bioreactors (MBR) applying submerged membranes,” *Desalination,* vol. 261, pp. 148-156, 2010.

[9] X. Tan, I. Acquah, H. Liu, W. Li and S. Tan, “A critical review on saline wastewater treatment by membrane,” *Chemosphere,* vol. 220, pp. 1150-1162, 2019.

[10] C. F. Galinha, S. Sanches and J. G. Crespo, “Membrane bioreactors,” in *Fundamental Modeling of Membrane Systems*, Elsevier, 2018, pp. 209-249.

[11] T. Melin, B. Jefferson, D. Bixio, C. Thoeye, W. De Wilde, J. De Koning, J. van der Graaf and T. Wintgen, “Membrane bioreactor technology for wastewater treatment and reuse,” *Desalination,* no. 187, pp. 271-282, 2006.

[12] K. Scott, Handbook of Industrial Membranes, Oxford: Elsevier Advanced Technology, 1995.

[13] S. Al-Asheh, M. Bagheri and A. Aidan, “Membrane bioreactor for wastewater treatment: A review,” *Case Studies in Chemical and Environmental Engineering,* vol. 4, 2021.

[14] Z. Wang, J. Ma, C. Tang, K. Kimura, Q. Wang and X. Han, “Membrane cleaning in membrane bioreactors: A review,” *Journal of Membrane Science,* vol. 468, pp. 276-307, 2014.

[15] A. Isma, A. Idris, R. Omar and P. Razreena, “Effects of SRT and HRT on Treatment Performance,” *International Journal of Chemical, Molecular, Nuclear, Materials and Metallurgical Engineering,* vol. 8, no. 6, pp. 488-492, 2014.

[16] Y.-P. Wang, X. Liu, W.-W. Li, F. Li, Y.-K. Wang, G.-P. Sheng, R. J. Zeng and H.-Q. Yu, “A microbial fuel cell–membrane bioreactor integrated system for cost-effective,” *Applied Energy,* vol. 98, pp. 230-235, 2012.

[17] W. Wu, X. Zhang, L. Qin, X. Li, Q. Meng, C. Shen and G. Zhang, “Enhanced MPBR with polyvinylpyrrolidone-graphene oxide/PVDF hollow fiber membrane for efficient ammonia nitrogen wastewater treatment and high-density Chlorella cultivation,” *Chemical Engineering Journal,* vol. 379, 2020.

[18] X. Wang, V. W. Chang and C. Y. Tang, “Osmotic membrane bioreactor (OMBR) technology for wastewater,” *Journal of Membrane Science,* vol. 504, pp. 113-132, 2016.

[19] Roebic Technology Inc., “RoeTech 302,” Roebic Technology Inc., [Online]. Available: http://www.roebictechnologyinc.com/roetech302.shtml. [Accessed 12 02 2022].

[20] S. Sanguanpak, C. Chiemchaisri, W. Chiemchaisri and K. Yamamoto, “Influence of operating pH on biodegradation performance and fouling propensity in membrane bioreactors for landfill leachate treatment,” *International Biodeterioration & Biodegradation,* vol. 102, pp. 64-72, 2015.

[21] D. D. Baldwin and C. E. Campbell, "Short-Term Effects of Low pH on the Microfauna of an Activated Sludge Wastewater Treatment System," *Water Quality Research Journal,* vol. 36, no. 3, pp. 519-535, 2001.

[22] J. Wu, Y. Zhuang, H. Li and X. Huang, "pH Adjusting to Reduce Fouling Propensity of Activated Sludge Mixed Liquor in Membrane Bioreactors," *Separation Science and Technology,* vol. 45, no. 7, pp. 890-895, 2010.

[23] A. Bhattacharyya, L. Liu, K. Lee and J. Miao, "Review of Biological Processes in a Membrane Bioreactor (MBR): Effects of Wastewater Characteristics and Operational Parameters on Biodegradation Efficiency When Treating Industrial Oily Wastewater," *Journal of Marine Science and Engineering 2022, Vol. 10, Page 1229,* vol. 10, no. 9, p. 1229, 2022.

[24] A. B. Al-Hawash, M. A. Dragh, S. Li, A. Alhujaily, H. A. Abbood, X. Zhang and F. Ma, "Principles of microbial degradation of," *The Egyptian Journal of Aquatic Research,* vol. 44, no. 2, pp. 71-76, 2018.

[25] J. Radjenović, M. Matošić, I. Mijatović, M. Petrović and D. Barceló, "Membrane bioreactor (MBR) as an advanced wastewater treatment technology," in *Emerging Contaminants from Industrial and Municipal Waste*, vol. 5, Berlin, Springer, 2008, pp. 37-101.

[26] C. M. Barreto, H. A. Garcia, C. M. Hooijmans, A. Herrera and D. Brdjanovic, "Assessing the performance of an MBR operated at high biomass concentrations," *International Biodeterioration and Biodegradation,* vol. 119, pp. 528-537, 2017.

[27] T. T. Nguyen, H. H. Ngo, W. Guo, J. Li and A. Listowski, "Effects of sludge concentrations and different sponge configurations on the performance of a sponge-submerged membrane bioreactor," *Applied Biochemistry and Biotechnology,* vol. 167, no. 6, pp. 1678-1687, 2012.

[28] R. M. Atlas, "Journal of Chemical Technology & Biotechnology," *Microbial hydrocarbon degradation—bioremediation of oil spills,* vol. 52, no. 2, pp. 149-156, 1991.