Effect of influent COD and TN on ship sewage treatment by using an aerobic-anaerobic membrane bioreactor (O/A-MBR)

Kun Zhang 1, Yiquan Wang 1, Yuhang Cai 1, Peiqi Sun 1, Jianing Li 2, Gaoshuai Wang 2 and Yue Shi 1, 3, *

1 College of Power and Energy Engineering, Harbin Engineering University, Harbin 150001, China
2 Shanghai Waigaoqiao Shipbuilding CO., LTD. Research Dept., Shanghai 200120, China
3 Qingdao HEU Zhenghe Environment Protection Technology Co., LTD., Qingdao 26600, China

*Corresponding author e-mail: shiyue@hrbeu.edu.cn

Abstract. The implementation of the latest International Maritime Organization (IMO) emission standards places stringent requirements on ship domestic wastewater discharges. In this study, an aerobic-anaerobic membrane bioreactor (O/A-MBR) was used to investigate the effect of influent COD and TN on ship sewage treatment. The results show that the lower volume load will affect the growth of the organism, and then affect the removal efficiency of COD. The increase of volume load is beneficial to the removal of COD, but the relatively high load will affect the removal of TN. Throughout the process, the O/A-MBR reached high COD and TN removal efficiencies with average values of 87.46% and 85.83%, respectively, and the best volume load range is obtained based on this experiment. It indicates that the novel MBR leads to good pollutants degradation effort and has great potential in practical ship domestic sewage treatment.

1. Introduction

With the booming of the shipping industry, energy consumption and environment sustainability is getting much attention in the area [1-6]. Countries all around the world become more aware of the protection of marine environment. In particular, the emission standards of ship domestic sewage is becoming more strict, so that there is a great demand for developing novel ship domestic sewage treatment technologies for better treatment performances. Among various treatment technologies, membrane bioreactor (MBR), which combines membrane separation and biochemical treatment, exhibits significant advantages, such as perfect treatment effect and small processing volume. Membrane separation is the use of membranes to remove particles from sewage, and biological treatment refers to the use of microorganisms in sewage to remove carbon, nitrogen and phosphorus from sewage [7]. In our previous works, a novel aerobic anaerobic micro-sludge membrane bioreactor (O-AMSMBR) has been used for the removal of chemical oxygen demand (COD) and total nitrogen (TN) from ship sewage. The results show that the novel MBR achieved better COD and TN removal efficiencies [8,9]. The anaerobic micro-sludge membrane bioreactor (MBR) was further proved to have great potential for treating acidic or alkaline wastewater [10].
Former researches have indicated that many factors affect MBR removal efficiency [11-14]. Wang et al. [11] quantified the effects of seven operating parameters on domestic sewage treatment, and the results show that MLSS and temperature were the most important factors. Fallah et al. [13] reported that HRT is the most important factor for the MBR performance. Among many factors affecting MBR removal efficiency, influent COD and TN are considered to be important factor. However, the effect of influent COD and TN on the treatment of ship domestic sewage received little attention.

In this study, an aerobic-anaerobic membrane bioreactor (O/A-MBR) was used to treat marine domestic sewage under different influent COD and TN. Effluent COD, TN, $\text{NH}_4^+\text{-N}$, $\text{NO}_2^-\text{-N}$, $\text{NO}_3^-\text{-N}$, and sludge-related indicators were measured to address the removal characteristics of the process. In summary, the purpose of this study is to providing important references on the Effect of influent COD and TN on ship sewage treatment.

2. Materials and methods

2.1. Reactor configuration

The experiment was carried out in an O/A-MBR reactor, and the configuration is shown in Figure 1. The process consists of a water tank (100 L), an aerobic zone, a precipitation zone, an anaerobic zone and a membrane module. The aerobic zone, the precipitation zone and the anaerobic zone are made of polymethyl methacrylate. The influent flow was 100 L/d and the HRTs in the aerobic zone and the anaerobic zone were 8 h and 3 h, respectively.

![Figure 1. Schematic diagram of the O/A-MBR](image)

The biochemical zone has a built-in sedimentation tank, and the purpose is to separate the sludge and water mixtures in the biochemical zone. The concentrated sludge is returned to the biochemical zone, and the separated nitrifying liquid flows to the membrane zone via the pump. For the process, the influent was firstly pumped to the aerobic zone and the returned sludge is discharged directly into the same zone. The aerobic zone is equipped with 4 aeration strips for parallel aeration. The aeration volume is adjusted by a gas flow meter. The anaerobic zone has a mixer to suspend the sludge.

2.2. Sludge

Seed sludge comes from a urban wastewater treatment plant. The characteristics of the seed sludge were as follows: mixed liquor suspended solids (MLSS) 8000 mg/L, mixed liquor volatile suspended solid (MLVSS) 6150 mg/L, MLVSS/MLSS 0.78, and sludge volume (SV) 60%.
2.3. Reactor operation
The start and run of the reactor, the temperature was controlled at about 25 °C. While the start-up period was finished, the influent COD and TN were gradually increased from about 500 mg/L to 1600 mg/L and from about 40 mg/L to 130 mg/L, respectively. The reactor performances were evaluated by measuring important parameters, such as effluent COD, TN, NH$_4^+$-N, NO$_2^-$-N, NO$_3^-$-N, MLSS, and MLVSS.

2.4. Analysis methods
Collected water samples were filtered by 0.2 µm filter membrane, and the measurements of TN, NH$_4^+$-N, NO$_2^-$-N, and NO$_3^-$-N were based on standard methods. COD was analyzed by using the potassium dichromate method with a digester (DRB-200, Hach, China) and a spectrophotometer (DR6000, Hach, China). The sludge samples were also obtained for analyzing MLSS and MLVSS with standard methods.

3. Results and discussions

3.1. COD removal
For investigating the effect of influent COD, the influent COD increased in four phases from 500 mg/L to 800 mg/L, 1200 mg/L, and 1600 mg/L. The corresponding volume loads were 0.5, 0.8, 1.2, 1.6 kg/m$^3$·d. Figure 2 shows effluent COD and COD removal efficiency of the O/A MBR under different influent COD. The COD emission standard for ship sewage is 125 mg/L. For different periods of the process, the effluent COD all experienced initial increase and following decrease, and the effluent COD can meet the emission standard at the end of each phase. For the whole process, the average COD removal rate was 87.46%. However, the effluent COD was near the standard at the influent COD of 1600 mg/L, suggesting the high influent COD might lead to the effluent COD exceed the standard.

![Figure 2](image.png)

**Figure 2.** Effluent COD and COD removal efficiency of the O/A MBR under different influent COD.

3.2. Nitrogen removal
Figure 3 shows effluent NH$_4^+$-N (a), NO$_2^-$-N (b), NO$_3^-$-N (c) and TN (d) under different influent TN. With the increase of NH$_4^+$-N in the influent, the NH$_4^+$-N removal rate performed a trend of initial increase, following decrease and final stabilization. The NO$_2^-$-N in the effluent was relatively in low values in the first 8 days (about 1.5 mg/L), slightly increased to about 4 mg/L, and then sharply increased to around 9 mg/L. When the influent NH$_4^+$-N concentration reached about 130 mg/L, the NO$_2^-$-N begins to accumulate. The effluent NO$_3^-$-N concentrations kept increasing for the whole process, and the average effluent NO$_3^-$-N concentration from the first day to the 16th day is only 2 mg/L. For TN, the influent TN reached 136 mg/L in the 16th day, and the effluent TN was 32 mg/L. The TN emission standard for ship sewage is 20 mg/L, and the effluent TN concentration before the former 12 days is
within 8 mg/L. The results indicate that the influent TN should not exceed 100 mg/L to make sure the effluent TN meeting the requirement. For the whole process, the average TN removal rate was 85.83%.

![Figure 3](image)

**Figure 3.** Effluent NH$_4^+$-N (a), NO$_2^-$-N (b), NO$_3^-$-N (c) and TN (d) under different influent TN

3.3. MLSS and MLVSS

Figure 4 depicts MLSS and MLVSS values and MLVSS/MLSS ratios for the four phases. With the increase of influent COD and TN, the MLSS and MLVSS concentrations slightly increased which might be due to the biosynthesis of microbial consortium in sludge. The optimal MLVSS/MLSS ratio was found between 0.75 and 0.85. Within this range, microbial community was capable of biodegrading organic compounds efficiently.
4. Conclusion
In this study, an aerobic-anaerobic membrane bioreactor (O/A-MBR) was employed to investigate the effect of influent COD and TN on ship sewage treatment. Experimental results indicate that the O/A-MBR can work well at high influent COD and TN concentrations (under 1600 mg/L and 100 mg/L respectively). For the whole process, the average COD and TN removal efficiencies were 87.46% and 85.83%, respectively. The optimal MLVSS/MLSS ratio was between 0.75 and 0.85. In this experiment, the optimal volume loads were 0.8 and 1.2 kg/m$^3$·d. Under this condition, the COD and TN removal rates of the reactor remained high. Low volume load is not good for COD removal efficiency, but under relatively high load conditions, the removal efficiency of COD has been maintained at about 90%, and the removal efficiency of TN is less affected by the inlet volume load. In summary, the novel O/A-MBR resulted into good pollutants degradation effort and has great potential in the use of practical ship sewage treatment.

Acknowledgments
This work was financially supported by the National Key R&D Plan of China (2017YFC1404603), the Natural Science Foundation of China (Grant No. 51579049), the Natural Science Foundation of Heilongjiang Province (E2017020), and the Fundamental Research Funds for the Central Universities (HEUCFG201820).

References
[1] Ministry of Communications of the People’s Republic of China. Rules for preventing pollution of domestic sewage from ships.
[2] Jiang XQ, Lin AQ, Ma HL, Li XY, Li YY (2019) Minimizing the thermal bridge through the columns in a refrigeration room. Applied Thermal Engineering 165: 114565.
[3] Jiang XQ, Lin AQ, Malik A, Chang XY, Xu YY (2019) Numerical investigation on aerodynamic characteristics of exhaust passage with consideration of multi-factor components in a supercritical steam turbine. Applied Thermal Engineering 162: 114085.
[4] Lin AQ, Sun YG, Zhang H, Lin X, Yang L, Zheng Q (2018) Fluctuating characteristics of air-mist mixture flow with conjugate wall-film motion in a compressor of gas turbine. Applied Thermal Engineering 142: 779-792.
[5] G Lei, H Q Ren, L L Ding, F F Wang, X S Zhang. A full-scale biological treatment system application in the treated wastewater of pharmaceutical industrial park. Bioresource Technology, 2010, 101(15):5852–5861.
[6] Lin AQ, Zhou J, Fawzy H, Zhang H, Zheng Q (2019) Evaluation of mass injection cooling on flow and heat transfer characteristics for high-temperature inlet air in a MIPCC engine. International Journal of Heat and Mass Transfer 135: 620-630.
[7] Cai YH, Ben T, Zaidi AA, Shi Y, Zhang K, Lin AQ, Liu C (2019) Effect of pH on pollutants removal of ship sewage treatment in an innovative aerobicanaerobic micro-sludge MBR
system. Water Air Soil Poll 230: 163.

[8] Cai YH, Li X, Zaidi AA, Shi Y, Zhang K, Feng RZ, Lin AQ, Liu C (2019) Effect of hydraulic retention time on pollutants removal from real ship sewage treatment via a pilot-scale air-lift multilevel circulation membrane bioreactor. Chemosphere. 236: 124338.

[9] Cai YH, Ben T, Zaidi AA, Shi Y, Zhang K (2019) Nitrogen removal augmentation of ship sewage by an innovative aerobic-anaerobic micro-sludge MBR technology. Process Biochem 82: 123-134.

[10] Cai YH, Zaidi AA, Shi Y, Zhang K, Li X, Lin AQ (2019) Influence of salinity on biological treatment of ship domestic sewage using an air-lift multilevel circulation membrane reactor. Environmental Science and Pollution Research. (In press).

[11] Wang, Z., Chu, J., Song, Y., Cui, Y., Zhang, H., Zhao, X., Li, Z., Yao, J. "Influence of operating conditions on the efficiency of domestic wastewater treatment in membrane bioreactors", Desalination, 245(1), pp. 73–81, 2009.

[12] Han, H., Zhang, Y., Cui, C., Zheng, S. "Effect of COD level and HRT on microbial community in a yeast-predominant activated sludge system", Bioresource Technology, 101(10), pp. 3463–3465, 2010.

[13] Fallah, N., Bonakdarpour, B., Nasrnejad, B., Alavi Moghadam, M. R. "Long-term operation of submerged membrane bioreactor (MBR) for the treatment of synthetic wastewater containing styrene as volatile organic compound (VOC): Effect of hydraulic retention time (HRT)", Journal of Hazardous Materials, 178(1-3), pp. 718–724, 2010.

[14] Rodríguez, F. A., Reboleiro-Rivas, P., González-López, J., Hontoria, E., Poyatos, J. M. "Comparative study of the use of pure oxygen and air in the nitrification of a MBR system used for wastewater treatment", Bioresource Technology, 121, pp. 205–211, 2012.