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Research Paper

A Case Study of Industrial MBR Process for Poultry Slaughterhouse Wastewater Treatment

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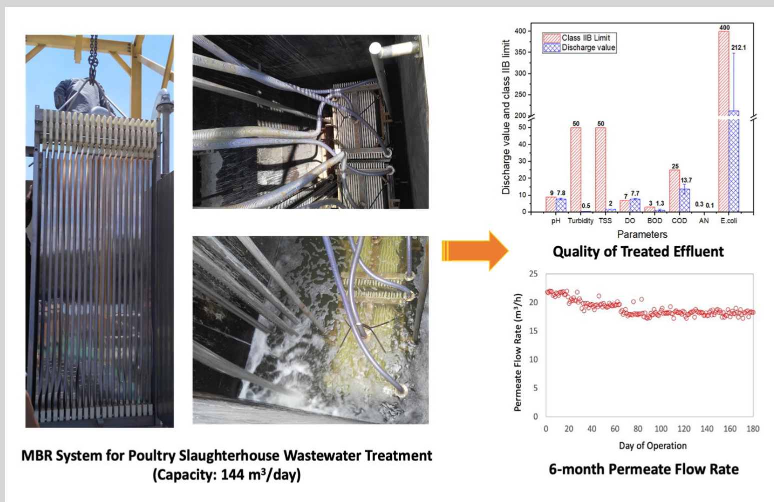
Highlights

- First large-scale implementation of MBR process in Malaysia for slaughtering house
- Effectiveness of MBR to produce effluent that meets the local standard
- Long-term monitoring of membrane flux performance for 6-month period

Graphical abstract



Abstract

The wastewater discharged from the poultry slaughterhouse always contains high levels of chemical oxygen demand (COD) and biochemical oxygen demand (BOD) and thus, it requires proper treatment to minimize its negative impacts on the receiving water bodies. In this work, we presented a local case study of the full-scale implementation of membrane bioreactor (MBR) process with capacity of 144 m^3/day to treat the poultry slaughterhouse wastewater. Over the 6-month monitoring period, our results showed that the permeate flow rate of the MBR process was relatively stable and only suffered from approximately 16% flux decline for the entire period with 8-h operation daily. Such flux deterioration is acceptable given the membrane was not subjected to any cleaning process. With respect to the separation efficiencies, the MBR process showed a very promising performance by meeting almost all of the parameters' limit of the National Water Quality Standards (Class IIB Limit), except for the dissolved oxygen (DO) that displayed slightly higher value than the maximum limit. A chemical cleaning process using sodium hydrochloride as agent was found to be effective to retrieve the permeate flow rate of the fouled membrane by 99%, indicating the deposited organic foulants were mainly reversible ones. The findings from this case study clearly demonstrated the potential of MBR process for treatment of poultry slaughterhouse wastewater and played an important role to minimize the negative impacts of discharged effluents on the environment.

1. Introduction

The technological progress of membrane bioreactors (MBRs) for wastewater treatment over the past decade has resulted in the rapid growth of its applications worldwide. Previously, MBRs are disregarded in favour of conventional biological treatment plants. However, the successful implementation of large-scale MBRs over the world for domestic sewage treatment [1-3] as well as industrial effluent treatment [4,5] had made the process being increasingly accepted as the technology of choice.

An analyst report indicated that the market of MBRs is currently experiencing a significant growth, and this growth is forecast to be sustained over the next decade. In 2018, the global MBRs market was reported to worth

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$1.9 billion and is estimated to double in 2023, reaching a value of $3.8 billion [6]. The growth indicates a compound annual growth rate (CAGR) of ~15%. As such, this segment is growing more speedily than the markets for other membrane systems such as reverse osmosis (RO) [7].

The MBR offers several unique features that make it distinctively advantageous over the conventional treatment technologies. These include smaller system footprint, less sludge production, reliability, lower energy demand and most importantly, high quality of treated water owing to its high separation efficiencies against pollutants [8]. Furthermore, the process of MBR is highly flexible and can be easily integrated with other processes such as RO technology [9] and chemical/electrochemical oxidation process [10] to achieve much better water quality. Nevertheless, the investment cost of large-scale MBR process is relatively higher in comparison to the conventional treatment process which restricts it from being widely implemented in most of the developing countries. It must be pointed out that recent studies have indicated that the high performance of MBR process could outweigh its capital cost which leads to the increase in large-scale construction of MBR process [11,12].

The increasing concern about the adverse impacts of the poorly treated effluent discharged into environmental as required by the stricter legislation have led many organisations to consider the excellence of installing an MBR system for their purposes. Currently, many countries demand higher water quality outputs compared to those that can be attained by conventional technologies.

Looking at the Malaysia's current scenario, there are in fact very limited use of MBR for the treatment of effluents discharged from the factory/industry. However, the local council in some states has made serious effort to start/implement MBR for wet markets to treat the effluent discharged from the slaughter farm. Currently, there are more than 1000 licensed chicken slaughterhouse sites (both large- and small-scale) in Malaysia and Johor is the state in Malaysia that has the highest number of slaughterhouse (>250) [13]. In order to treat the effluent produced, almost all of the local slaughterhouses employ conventional biological method which is simple and economic.

The main objective of this work is to evaluate the performance of a full-scale MBR process with capacity of 144 m^3/day for the treatment of poultry slaughterhouse wastewater. To the best of our understanding, this is the first MBR process in the country that is specifically designed to treat the poultry slaughterhouse wastewater. Long-term assessment on the MBR process was carried out in order to demonstrate the performance of membrane with respect to permeate flow rate stability and the removal efficiency. The treated effluent is targeted to comply with the National Water Quality Standards for Malaysia's Class IIB.

2. Experimental

2.1. Characteristics of poultry slaughterhouse wastewater

Table 1 presents the key parameter values of a poultry slaughterhouse wastewater discharged from a local wet market located in Kuala Lumpur, Malaysia. More specifically, it is a chicken slaughterhouse wastewater. The value of each parameter reported in this table is the average result of 4 measurements performed at different sampling time of the same day within 6-h period. As can be seen, this wastewater contained high levels of organic pollutants, resulting in high concentration of BOD_5 (>3000 mg/L) and COD (>7000 mg/L). Because of this, the DO value of the effluent was very low, i.e., 0.1 mg/L. In addition, AN and *E.coli* were also reported at high level, recording 330.8 mg/L and 6.8 MPN/100 mL, respectively. The bloods coming from the chicken during slaughtering and cleaning process are the main contributor to the high level of AN and *E.coli*. Figure 1 shows the sump inlet that is used to collect the wastewater from the slaughtering and cleaning process.

2.2. Wastewater treatment system

Figure 2 shows the entire flow chart of the treatment process that was designed to treat the slaughterhouse wastewater in order to ensure its discharge could meet the National Water Quality Standards for Malaysia, i.e., Class IIB [14]. The treatment process is designed to handle daily influent of up to 144 m^3/day and is operated daily for 8 hours, i.e., from 9 am to 5 pm. The wastewater was firstly subject to coagulation-flocculation process in which polyaluminium chloride (PAC) and polymer solution at dosing rate of 131 mL/min and 3,400 mL/min, respectively were introduced to the tank to promote the formation of larger floc. The floating floc was removed by skimming operation in dissolved air floatation (DAF) with injection of pressurized air whereas the treated effluent was then passed through a screen process with mesh size of 0.25 mm before going to aeration tank. Compressed air from a blower at flow rate of 8.8 m^3/min was supplied in 24/7 service to the tank to provide sufficient oxygen to the microorganism. After that, the effluent was treated in a MBR system in order to remove most of the organic pollutants from the water source. At this stage, the water is already of a good water quality (meeting the Class IIB limit). In order to further ensure that microorganisms are inactivated, an ultraviolet (UV) disinfection system (Model: SD15, Hanovia, China) was employed as the final stage as a further safety back-up to the MBR treatment before the treated effluent was finally discharged to the drainage system.

2.3. Membrane properties and membrane system

The MBR process as presented in Figure 3 is composed of braid-reinforced polyvinylidene fluoride (PVDF) hollow fiber membranes with total surface area of 1,400 m^2 and average pore size of 0.1 μm. The hollow fiber membranes in single module (Figure 3a) possess around 35-m^2 surface area and a total of 20 modules are required to form a single train. In this system, two membrane trains (Figure 3b) are used to treat the daily influent. During the treatment process, the entire membrane system is submerged in the water and the filtration is carried out in outside-in mode, i.e., the wastewater passes through the hollow fiber membrane and the permeate is collected in its lumen. The specific aeration demand per membrane area (SAD_m) is set at 7.54 $Nm^3/h.m^2$. The pure water permeability of the membrane is reported to be ~30 $L/m^2.h.kPa$ when it is tested under vacuum condition. A digital flow sensor (Model: Promag 10L, Endress+Hauser (M) Sdn Bhd, Malaysia) was installed at the point of discharge to continuously measure the permeate flow rate of the MBR process online during operation.

Table 1
Characteristics of chicken slaughterhouse wastewater.

Test Parameters	Batch 1	Batch 2	Batch 3	Batch 4	Average
Temperature (ºC)	30.5	33.1	32	31.2	31.7 (±1.1)
pH (-)	6.5	6.5	6.8	6.7	6.6 (±0.2)
Turbidity (NTU)	1140	1910	2720	1070	1710.0 (±773.4)
Total Suspended Solids (TSS) (mg/L)	750	930	1600	900	1045.0 (±378.3)
Dissolved Oxygen (DO) (mg/L)	0.03	0.05	0.04	0.2	0.1 (±0.08)
Biochemical Oxygen Demand (BOD_5) (mg/L)	3480	2340	3690	3240	3187.5 (±594.2
Chemical Oxygen Demand (COD) (mg/L)	7419	6161	7870	7161	7152.8 (±723.2)
Ammoniacal Nitrogen (AN) (mg/L)	264	256	420	383	330.8 (±83.1)
Escherichia Coli (MPN/100 mL)	4.5	9.1	5.5	8.1	6.8 (±2.2)
Conductivity (μS/cm)	1461	1776	2011	1870	1779.5 (±233.3)

Fig. 1. Sump inlet used to collect the wastewater from the slaughtering and cleaning process.

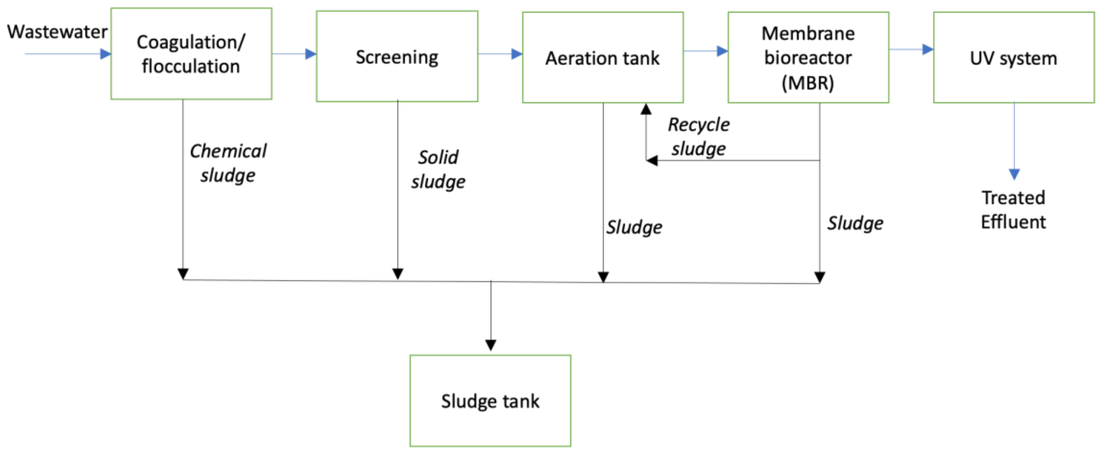

Fig. 2. Flow chart of wastewater treatment process.

2.4. Membrane cleaning process

Two different cleaning modes (i.e., cleaning-in-place (CIP) and washing/soaking) can be carried out for the fouled membranes to retrieve its water permeability. But in this case study, we only employed washing/soaking method to demonstrate the flux recovery of the membrane. The membrane was only washed after 6 months of operation. During the cleaning process, the MBR train was lifted up from the tank followed by washing using running tap water. The washing process was continued until all of the visible solid particles that were trapped among fibers were washed out from the module. After that, the entire membrane train was immersed in a washing basin composed of 300 mg/L sodium hydrochloride (NaOCl) and remained in the water for 24 h. Before the membrane train was transferred back to the MBR tank, it was rinsed with tap water to remove any chemical residues.

2.5. Water quality analysis

All of the water samples (raw wastewater and treated effluent) were analysed by a local laboratory that complies the ISO 17025, i.e., the international standard for testing and calibration laboratories. Each test parameter was evaluated using standard method and the difference between the raw and treated effluent was used to determine the rejection efficiency. The method used for each parameter is as follows: APHA 2550B (temperature), APHA 4500-H B (pH), APHA 2130B (turbidity), APHA 2540C (TSS), APHA 4500 O-C or G (DO), APHA 5210B & 4500OG (BOD_5), APHA 5220C (COD), APHA 4500NH_3-B&C (AN), APHA 9221F (*E. coli*) and APHA 2510B (conductivity).

3. Results and discussion

Figure 4 compares the permeate quality of the MBR process with the National Water Quality Standards' Class IIB Limit. As can be clearly seen, the MBR process that used PVDF membrane with average pore size of 0.1 µm was able to produce water with quality meeting almost all of the standards' limit, except the DO that displayed slightly higher value than the maximum limit. The values presented in this figure are the average data of the quality of permeate obtained from 10 measurements for a period of 2 months. As can be seen, the use of membrane was able to significantly reduce the turbidity and TSS value owing to its pore sizes that are much smaller than the particles existed in the wastewater. Compared to the high BOD_5 (>3000 mg/L) and COD (>7000 mg/L) level of the raw wastewater (see Table 1), the membrane technology was very effective to reduce the levels, recording as low as 1.3 mg/L and 13.7 mg/L, respectively. These achievements represented >99% removal rates. Our results are in good agreement with the work of Apatie [15] in which the efficiencies of MBR process in removing COD and BOD level of slaughterhouse wastewater were recorded at >95%. Furthermore, the AN and *E. coli* values of the permeate were also lower compared to the standards' limit, showing 0.1 mg/L and 212 MPN/100 mL, respectively.

Figure 5 presents the photographs of the water samples collected from different stages of the wastewater treatment process. Clearly, the MBR process was capable of producing treated effluent of good quality by removing most of the pollutants from the wastewater. Its water sample was crystal clear compared to the cloudy water collected from the aeration tank.

The permeate flow behaviour of the MBR process was also monitored for a period of 6 months without performing any cleaning and the results are shown in Figure 6. It has to be noted that the MRB process was operated for only 8 hours daily which followed the operation period of the slaughterhouse. From the figure, it can be clearly seen that the permeate flow rate remained quite stable for the first 20 days of operation before starting to experience gradual flux decline. Its initial water flow rate was recorded at 21.8 m^3/h while the flow rate at 50^{th} day, 100^{th} day and 180^{th} day was around 19.8 m^3/h, 18.6 m^3/h and 18.3 m^3/h, respectively. This revealed the membrane permeate flow rate was declined by approximately 16% over 180 days of operation. Such flux deterioration is acceptable given the membrane was not subjected to any cleaning process.

Figure 7 presents the photographs of the membranes before and after cleaning process. The fouled membrane module after being used for 6 months was first cleaned by running tap water to remove large flocs trapped within the fibers (near the potting area). It was followed by soaking it in the tank containing sodium hydrochloride. After 24-h soaking process, the MBR trains were returned to the MBR tank and continued the operation. Our results showed that the permeate flow rate of the MBR system could be retrieved by 99%, reaching 21.6 m^3/h. This clearly indicated the foulants deposited on the membrane surface were mainly reversible ones.

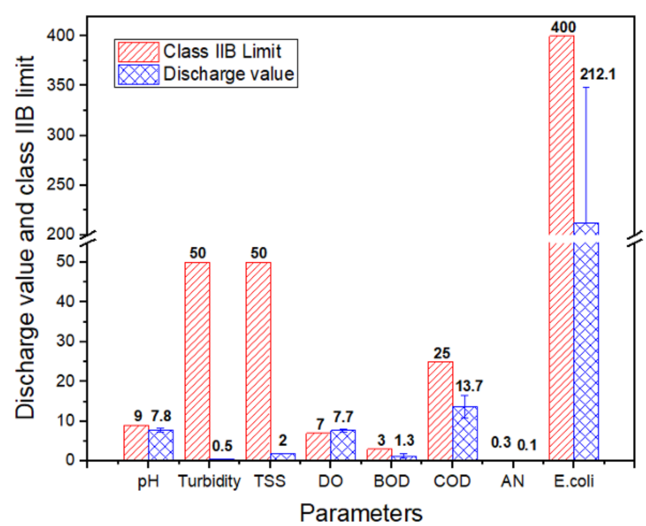

Fig. 4. Quality of effluent treated by MBR process with respect to several key parameters (Note 1: The value shown by each parameter in the figure is having the same unit as presented in Table 1. Note 2: Average of 10 measurements at different days).

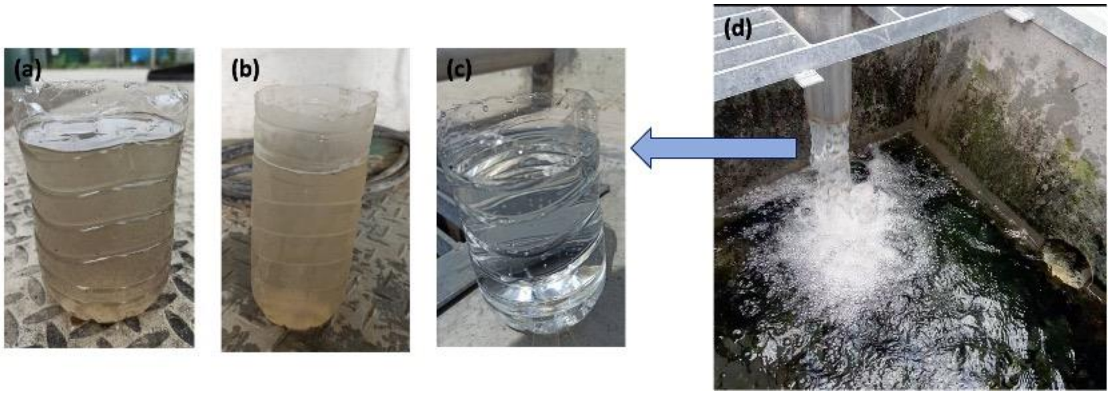

Fig. 5. Photographs of water samples at different stages, (a) influent, (b) after aeration tank and (c) after treated by MBR system and (d) point of discharge where water sample (c) was collected.

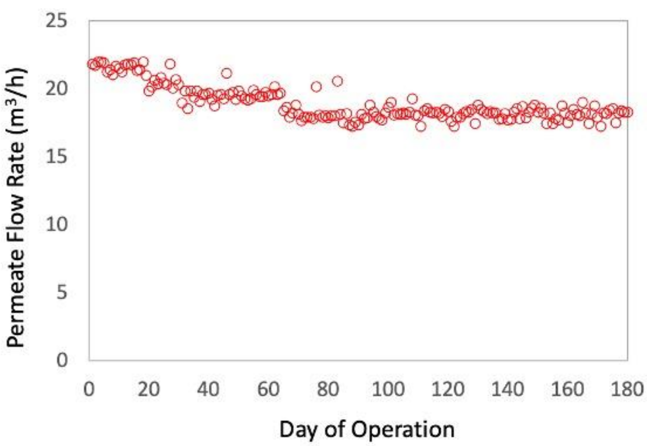

Fig. 6. Permeate flow rate of MBR system over 180-day operation.

4. Conclusions

In this work, we presented a local case study related to the employment of MBR process with capacity of 144 m^3/day to treat the wastewater discharged from a poultry slaughterhouse. The performance of the MBR process was very promising as it was able to produce the treated effluent that could meet almost all of the parameters' limit of the National Water Quality Standards (Class IIB Limit), except for the DO that displayed slightly higher value than the maximum limit. In terms of the stability of permeate flow rate, our results showed that the MBR process only experienced approximately 16% flux decline over 180 days of operation with 8-h operation daily. Such flux deterioration is acceptable given the membrane was not subjected to any cleaning process throughout the operation period. It was also found that the permeate flow rate of the fouled membranes could be retrieved by ~99% after a chemical cleaning process was conducted, indicating the deposited foulants deposited were mainly reversible ones. Our case study demonstrated the potential of MBR process for treatment of poultry slaughterhouse wastewater and played an important role to minimize the negative impacts of discharged effluents on the environment.

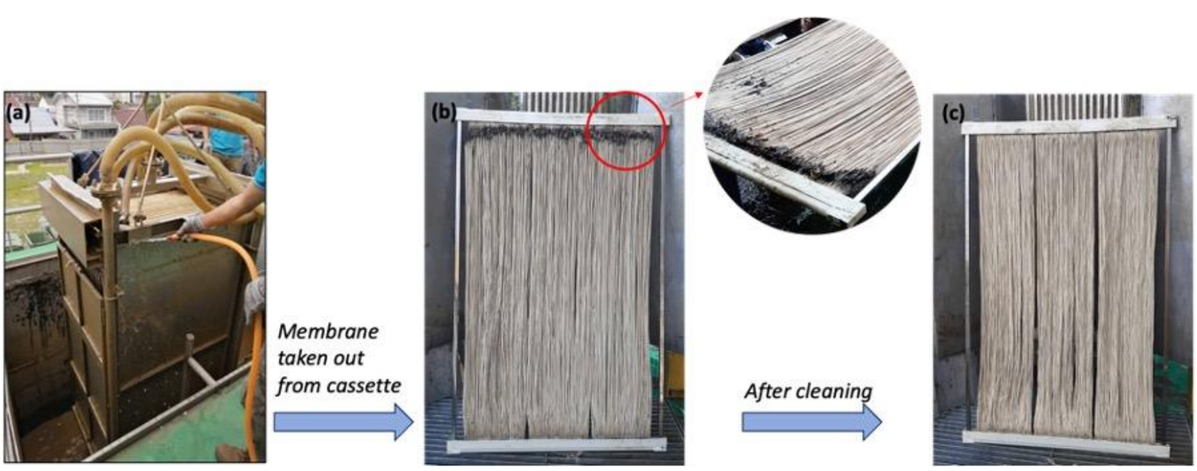

Fig. 7. Photographs of (a) the fouled hollow fiber membrane module in cassette and the membrane (b) before and (c) after cleaning process (Note: The red circle on the top part of the membrane module indicates the presence of foulants adhered onto membrane).

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