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A Novel Bio-film Wastewater Treatment System using Encapsulated Microbes

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The untreated or incomplete disposal of nitrogen pollutants in the wastewater can cause great harm to the environment. A large amount of ammonia-nitrogen (NH_3-N) will consume dissolved oxygen and cause eutrophication. The conventional wastewater treatment process in Malaysia is not efficient enough to remove the NH_3-N. Most of the sewage treatment plants (STPs) in Malaysia are open structures which occupy a large area and emit stench. The existing STPs are not suitable for construction in the compact urban areas and some of these STPs operation are costly. This study designs a novel biological water purification system using a bio-film reactor with encapsulated microbes that is known as Mass Bio System (MBS). The MBS had been used in the east of Asia to treat high concentration of NH_3-N in the industrial wastewater with high efficiency. MBS has not been reported to treat domestic wastewater. This paper reports the adaptability and verification of the new sewage treatment system based on MBS to treat domestic wastewater in Malaysia. The study will dynamically monitor the key parameters and compared with the conventional extended aeration (EA) process that is the most common STP applied in Malaysia using the same influent conditions. The aim is to verify that the MBS can treat the wastewater to meet the local emission standard where the water discharge shows the characteristics well below the discharge limits. The study showed that the average effluent and removal efficiency of NH_3-N was approximately 2 mg/L and 88.6 % (with maximum 99.7 % removal). All evaluated parameters in the MBS showed stability of effluent characteristics and met the requirements of Malaysian sewerage industry guidelines. MBS also offers the co-benefits of energy, and space saving than the conventional process. The process is recommended as an efficient sewage treatment system in Malaysia and other countries with similar climatic conditions.

1. Introduction

Many Malaysian rivers are suffering from sewage pollution (Ariffin and Sulaiman, 2015). Untreated or incomplete treatment of wastewater flowing into river or water body will cause eutrophication (Nixon, 1995). Scientists are making various innovations to reduce the environmental impact of waste, such as composting to produce fertilizers (Lim et al., 2017) and reduce carbon emissions (Kamyab et al., 2015), and also using palm oil wastewater for biodiesel productions (Kamyab et al., 2018). STPs also need to be improved more efficiently through technological innovation. Most of the STPs existing in Malaysia are inefficient and covers a large area, such as the sequencing batch reactor (SBR) or EA. Due to rapid urbanisation, the land resources are becoming more valuable, the requirements for the living environment has increased. High concentration of organic wastewater needs more efficient treatments, especially involving high concentration of NH_3-N. High NH_3-N in wastewater (NH_3-N > 500 mg/L), e.g., from food waste (Bong et al., 2018), chemical fertilizer (Savci, 2012), feed production (Botermans et al., 2010), and organic chemicals (Zheng et al., 2013) are the main sources of pungent smell. The existing open STPs in Malaysia pose negative impact (e.g., odour) to the surrounding environment. Wastewater with high ammonium concentration will lead to high emission of NH_3-N under high pH condition (Shao et al., 2017). It is a pressing need of introducing more advanced STP to adapt to the intensive urban ecology. This study reports a novel STP system, termed as Mass Bio System (MBS) as an improved STP that

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has been applied on industrial wastewater in East Asia. MBS has been proven to treat industrial wastewater with high NH_3-N with high removal efficiency (Tabassum et al., 2015). Tabassum et al. (2018) have compared the performance of MBS to the membrane aerated biofilm reactor (MBBR) for the industrial wastewater. There are limited studies reported regarding the efficiency of MBS in treating domestic wastewater. This study reports the application of a pilot-scale MBS project to treat domestic wastewater under the tropical climate in Malaysia. The performance of MBS was evaluated to meet the effluent discharge Standard A (STD A) by National Water Services Commission (SPAN) in Malaysian sewerage industry guidelines (SPAN, 2009). MBS was also assessed and proved to be more economical in term of energy consumption that could reduce carbon emissions.

2. Materials and methods

2.1 MBS system

The pilot-scale MBS system was situated at an existing STP managed by Indah Water Konsortium (IWK) in Kuala Lumpur, Malaysia. The MBS system is shown in Figure 1. The existing STP was operated using the conventional EA process and has a rated capacity of 17,000 population equivalent (PE). However, the STP was operated at 7,000 PE loading. The STP was fed via a collection sump (or pump sump), which was fixed with a bypass valve that routed 500 PE of the untreated wastewater to the MBS. The conveyor screening at the sump removes the larger solids and they were not fed into the MBS system. The system also experienced wet weather conditions where the influent might be diluted by the rain water.

Figure 1: The pilot-scale MBS installed next to the IWK STP

The MBS system is designed as a containerised wastewater treatment system comprising of primary treatment, secondary treatment, and tertiary treatment system (Figure 2). The primary treatment uses transfer pump and micro belt filter (DSWMLJ1500, TongHui, China) to remove grit, sand, and different kinds of foreign solid materials. The transfer pump (DDML, EBARA, Japan), comprises of two submersible pumps which are used one at a time, is used for transferring sewage from pump sump to the bed filter via a pipeline. It is placed in the pump sump close to the coarse and fine screen facilities. The secondary treatment consists of BioAX 1 and MBS 1. BioAX is an advanced aerobic system, which comprised of an efficient bio-membrane unit (Li et al., 2014). The BioAX consists of fixed-suspended filler and a microporous aeration system. More information on the BioAX was reported by Li et al. (2014) and its materials reported in Section 2.2. The fibrous filler is made of polypropylene and activated carbon. The rope packing is made of polyethylene and activated carbon. The fibrous filler is covered by the growing microbial film. The elastic fibre filler has light weight, stable physical and chemical properties. The fibre bundle floats in water and is not easily blocked. The aeration system adopts micro-pore aeration. The bubble diameter is about 1 mm. Its operation during the rise is relatively gentle, and the collision probability decreases, which greatly weakens the clustering effect and prolongs the residence time of the bubbles in the water. The BioAX showed a higher efficiency than the conventional activated sludge process in removing biochemical oxygen demand (BOD), chemical oxygen demand (COD), and NH_3-N in a shorter time for the industrial wastewater (Li et al., 2014). MBS contains pellets with functional bacteria including nitrifying and denitrifying bacteria that are put together with poison-free polymer at a proper ratio and installed inside the wet structure of polymer molecular chains by adding cross-linking agents (Tabassum et al., 2015). The tertiary system consists of MBS 2 and BioAX 2, which are the key unit to enhance the biodegradation rate for organic matter removal. The dissolved oxygen (DO) level and the hydraulic retention time (HRT) and the main design parameters for the MBS and BioAX are described in Table 1.

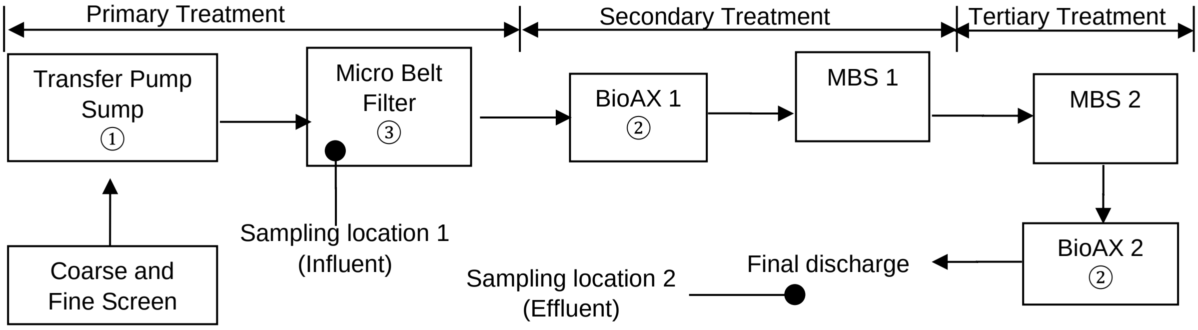

Figure 2: Process flow diagram of the MBS system

Table 1: The main design parameters of each unit (BioAX, MBS)

Item	Dimension (m) (L*W*H)	Effective Depth (m)	HRT (h)	Media Type (Tabassum et al., 2015)	Aeration Required	DO Level (mg/L)
BioAX 1	2.6*2.3*2.85	2.5	1.5 - 3	BioAX Packing Media	Yes	2 - 4
MBS 1	2.6*2.3*2.85	2.5	1.5 - 3	MBS	Yes	3 - 5
MBS 2	1.7*2.3*2.85	2.5	1 - 2	MBS	No	0.2 - 0.5
BioAX 2	1.7*2.3*2.85	2.5	1 - 2	BioAX Packing Media	Yes	2 - 4

In the BioAX 1 reactor, BOD, COD and NH_3-N will be biodegraded to low levels. The nitrification process, i.e., the conversion of ammonia to nitrite then to nitrate caused by the nitrifying bacteria takes place in MBS 1. The level of DO in MBS 1 shall be kept within a range between 3 - 5 mg/L. Similar to MBS 1, MBS 2 is a tank containing the same MBS pellets. The denitrification process happens in this tank due to the denitrifying bacteria embedded inside the MBS pellet that convert nitrate to nitrogen gas which will be released to the air. The DO level in MBS 2 shall be retained at a range between 0.2 - 0.5 mg/L to anoxic process to take place. BioAX 2 is the final step in the entire system that receives sewage from MBS 2 and is discharged as a treated effluent. It serves as an extra unit to further reducing the BOD.

2.2 MBS pellets

The pellets used in MBS 1 and 2 consist of suspended biological activated carbon granular carrier. They are cubical particles, with the side length of about 2 - 5 mm and the specific gravity is about 1.02 - 1.08. The main components of pellets are microbial liquid (nitrifying and denitrifying bacteria), bamboo powdered activated carbon (average size is about 100 µm) and waterborne polyurethane gel (average size is about 0.09 - 0.15 µm) (Tabassum et al., 2015).

2.3 Sampling procedures

The sampling was conducted on-site daily at sampling location 1 and 2 at regular intervals (Figure 2). The pH and temperature of the domestic sewage were recorded on-site using a portable pH meter (PHB-4, INESA, China). Other parameters were recorded based on the standard methods of American Public Health Association (APHA, 1998) as shown in Table 2. Each analysis was duplicated.

Table 2: The chemical analyses conducted on the sewage samples

Parameter	Units	Analysis method
Biochemical Oxygen Demand (BOD_5) at 20°C	mg/L	APHA 5210 B
Chemical Oxygen Demand (COD)	mg/L	APHA 5220 D
Total Suspended Solids (TSS)	mg/L	APHA 2540 D
Oil and Grease (O&G)	mg/L	APHA 5520 B
Ammoniacal Nitrogen (NH_3-N)	mg/L	APHA 4500 NH_3 - F

2.4 Power consumption for MBS system

Power consumption was recorded for the MBS daily at 08:30 a.m. on-site, based on a range of electrical equipment (Figure 2) as listed in Table 3.

Table 3: Main electrical equipment and components of the MBS

No. (refer Figure 2)	Equipment	Power Rated (kW)	Proposed Rated Power (kW/d)
①	Lifting Pump 1	1.50	28.80
②	Blower Motor	1.50	28.80
③	Belt Filter	0.75	14.40
	Dewatering motor	1.50	28.80
④	Air-conditioner, fans, lights & control system	1.00	8.00
Total		6.25	108.0

The power consumption of the MBS was calculated using Eq(1)：

$$P_{mbs} = P_r - P_{ac} \tag{1}$$

The power consumption for the existing IWK STP was calculated using Eq(2):

$$P_{iwk} = \frac{P_{rm}}{T} \tag{2}$$

The power consumption of MBS and the IWK STP (taking the IWK plant as basis) was compared using Eq(3):

$$\mathrm{ES} = \frac{P_{iwkd} - P_{mbsd}}{P_{iwkd}} \times 100\% \tag{3}$$

P_{mbs} = MBS Power consumption (kWh/d), P_r = Power reading (kWh/d), P_{ac} = Power consumption for air-conditioner and fan (kWh/d), P_{iwk} = Existing IWK STP power consumption (kWh/d), P_{rm} = Power reading (kWh/month), T = No. of days (d/month), ES = Energy Saving (%), P_{iwkd} = Existing IWK STP power consumption (kWh/PE·d), P_{mbsd} = MBS power consumption (kWh/PE·d), P_{iwkd} = Existing IWK STP power consumption (kWh/PE·d).

3. Results and discussion

3.1 The adaptability of MBS to meet the emission index of STD A

According to SPAN guideline (SPAN, 2009), all STPs shall be designed to produce the final effluents within the specified range for a range of parameters to be less than or equal to the design effluent values. Five primary parameters (BOD_5, COD, O&G, NH_3-N and TSS) were measured for the influent and effluent of the entire MBS (Figure 2). The results for the first four parameters are presented in Figure 3.

The BOD_5 reading for the influent was generally low and below 60 mg/L except for one occurrence where the value spiked to 90 mg/L (Figure 3a). This range shows the typical characteristics for Malaysia sewerage. The average BOD_5 characteristics of the effluent were below 10 mg/L where the highest readings were recorded at 16 mg/L. These values were well below the STD A discharge limit (< 20 mg/L). MBS was able to meet its design objective for BOD_5 removal of sewerage. The MBS showed the average BOD_5 removal efficiency of about 82.6 % with the highest limits of about 96.2 % removal.

For COD removal, the influent has the average level of 100 mg/L except for one occurrence where the value spiked to 478 mg/L (Figure 3b). This range represented the typical characteristics for Malaysia sewerage (SPAN, 2009). The average COD of the effluent were approximately 10 - 20 mg/L where the highest readings were recorded at 21 mg/L throughout the study period. Results in Figure 3b shows the stability and capability of MBS to remove COD at low or high loadings (spikes). The MBS showed the average COD removal of 86.4 % with the highest removal of 96.8 %. Figure 3c shows the average O&G of the effluent at approximately 1 mg/L. The MBS shows the O&G removal efficiency of about 90 - 100 %.

Figure 3d shows the average characteristics of effluent NH_3-N at approximately 2 mg/L. The typical removal efficiency of NH_3-N in the MBS was 88.6 % with the higher limits reaching 99.7 % removal. The trend also shows the normal stability of effluent NH_3-N characteristics throughout the study period where the overall trend remained horizontal.

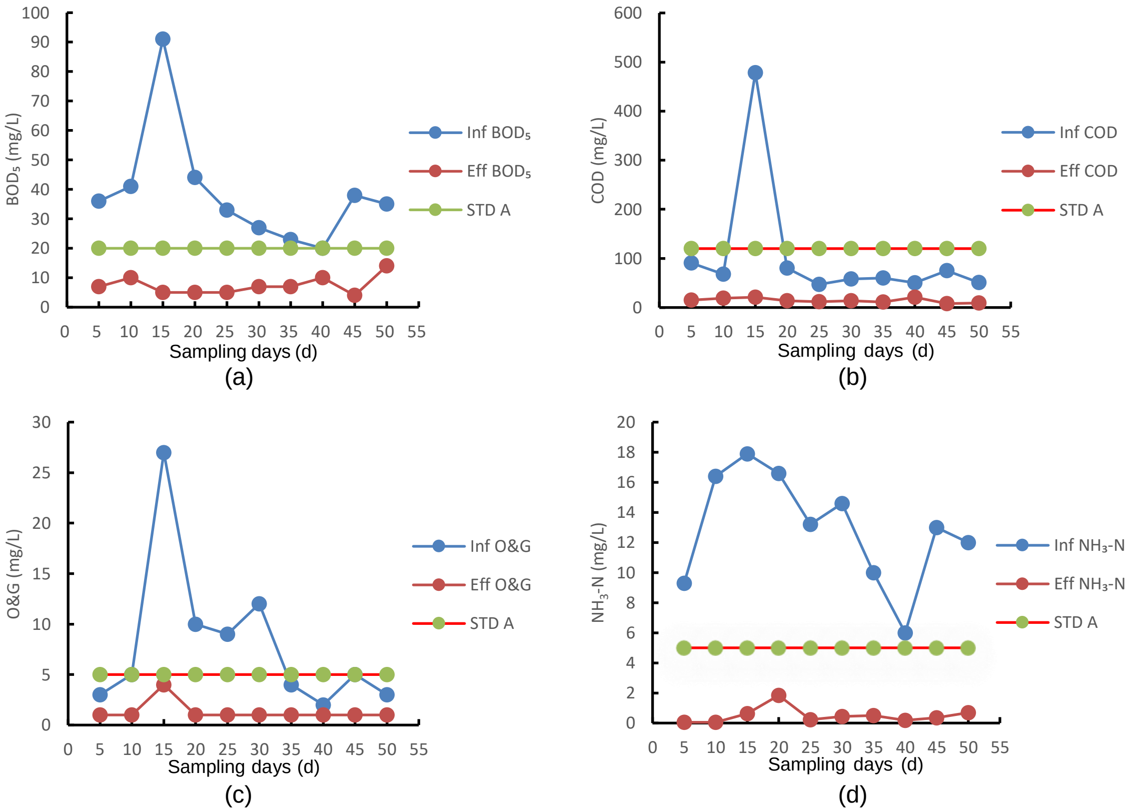

Figure 3: (a) Comparison of Influent and Effluent BOD_5 in MBS; (b) Comparison of Influent and Effluent COD in MBS; (c) Comparison of Influent and Effluent O&G in MBS; (d) Comparison of Influent and Effluent NH_3-N in MBS

The average characteristics of effluent TSS were generally below 5 mg/L, with the typical TSS removal efficiency 91.5 % with the higher removal limits reaching 97.9 %. The TSS was notably low in comparison to conventional treatment systems, typically at 20 - 40 mg/L.

In all cases, for all five parameters evaluated throughout the study period, the MBS shows the stability of effluent characteristics. The effluent discharge for all five parameters were within the limits of Malaysian domestic effluent STD A (SPAN, 2009) throughout the study period.

The temperature and pH readings for the influent showed normal values of the typical characteristics for Malaysia sewerage (Lee et al., 2013). These values may be affected by the external factors (e.g., rain or dry season). The pH readings of the effluent were stable at around 7.0. This pH range indicated the efficiency of the biological degradation of the MBS as the denitrification process is optimal at about pH 7.0 - 8.5 (Fang and Li, 2001). There was no apparent or unpleasant odour at the MBS site during the sampling period, even at near proximity throughout the study period.

3.2 The power consumption comparison of MBS and the existing IWK STP

The power consumption of the existing IWK STP (7,000 PE) was calculated to be 2,555 kWh/d which corresponded to 0.365 kWh/PE·d. The MBS (500 PE) power consumption was calculated to be 152 kWh/d which corresponded to 0.304 kWh/PE·d. The power savings for employing the MBS system is about 16.7 % as compared to the existing IWK STP as basis.

4. Conclusions

This study elucidated the effectiveness and adaptability of MBS to treat domestic wastewater. The MBS can meet the effluent discharge of NH_3-N based on STD A for the sewerage effluent under the tropical weather in Malaysia. The study has shown that the average effluent and the removal efficiency of NH_3-N was around 2 mg/L and 88.6 % (with higher limits reaching 99.7 % removal). The MBS also shows good stability and efficiency in removing the other major parameters of sewage and odour control. BOD_5, COD, O&G and TSS showed 96.2 %, 96.8 %, 100 % and 97.9 % maximum removal efficiency in MBS. MBS has saved up to 17 % of energy consumption as compared to the existing IWK STP using EA. The MBS assisted by the efficient pellets could enhance the efficiency of urban sewage treatment, as the design is more space- and energy- saving. Future studies could compare the economic feasibility of the MBS in terms of the capital, materials (e.g., pellets), operation and maintenance costs against the STP using EA with higher land cost. Some additional parameters such as total phosphorus and total organic carbon can also be evaluated as they are also found in the domestic wastewater.

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