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# Design of Sewage Treatment Plants for High-Density Urban Reclamation Land

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The success of any coastal reclamation project depends strongly on a sound planning and design practices. Due to the land use limitations, sewage treatment plant (STP) of the reclamation land should be fully studied to save land and reduce its adverse effects on the environment. This research focuses on the selection of biological treatment process for a novel STP, as various pollutants of the sewage can be effectively removed via the biological process. The paper presents a design of the STP implemented in Johor as an example, to achieve the goal of 'zero discharge' in the reclaimed wetland. The domestic sewage is treated, recycled and reused in the artificial wetland as an ecological green water to achieve Class IIB standard (effluent quality). The novel STP design comprised of the Immobilized Aerobic Biofilm (BioAX) and Mass Bio System (MBS) was compared against the conventional Sequencing Batch Reactor (SBR) process. Combination BioAX + MBS process is advantageous due to significantly less land needed, lower power consumption and lower sludge generation. The system was demonstrated as a viable process to treat the sewage wastewater in the reclamation land to meet Class IIB discharge at a lower environmental footprint, saving up to 50 % of the area.

## 1. Introduction

The population connected to wastewater collection and treatment has increased due to rapid urbanisation, more restrictive standards on the quality of water effluents have been introduced (Gude, 2015). The design of a sewage treatment plant (STP) should meet the criteria of minimum land use and enhanced treatment efficiency in the coastal reclamation land and urban area of high population.

Various studies and innovations have been reported to reduce the environmental impact of waste, such as composting to produce fertilisers (Lim et al., 2017) and reduce carbon emissions (Kamyab et al., 2015). Similarly in waste water treatment, STPs also need to be improved more efficiently through technological innovation, such as developing a mechanism to remove high ammonia concentration (Xie et al., 2017).

This paper presents a novel STP designed for a high-density urban reclamation land in Johor, Malaysia. Malaysian Department of Environment (DOE) governs the treatment and discharge of wastewater in the reclamation land, the requirement is set at Class IIB (suitable for body-contract recreational usage). The case study is located at the estuary of Johor Strait, a coverage of 13.13 $km^2$ of land will be materialised through sea reclamation on the Malaysian side adjacent to Singapore waterway. The available land in Malaysia is very limited and the cost of land is high, particularly in the urban areas (Kaparawi and Abdul Latif, 1996). The land reclamation project aims to build a new residential city that is green and environmentally friendly and reflects a future city model. The design of highly efficient STP with space saving has become one of the important research topics.

The novel STP design comprised of the combination units of Immobilized Aerobic Biofilm (BioAX) and Mass Bio System (MBS). The novel STP was compared against the conventional Sequencing Batch Reactor (SBR) process based on aerated sludge. The novel STP is designed to handle the sewage of 17,100 PE (population equivalent), providing a valuable reference case for the design of any STP system deemed fit for a reclamation land with high density in the urban area.

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## 2. Materials and methods

### 2.1 Design requirements for STP

The novel STP is located in an urban high-density reclamation land in Johor. The STP must be hidden in the proposed landscape green park to avoid negative perception by the public. The source of sewage, treatment scale and water quality are as follows:

a) Source of sewage: domestic sewage from public facilities such as residential buildings and shops;
b) Treatment scale: 17,100 PE (sewage treatment capacity is about 3,850 $m^3$/d);
c) Water treatment standard: The water quality standard after treatment should achieve Class IIB standard as specified in Table 1.

*Table 1: The typical influent and effluent values and standard of Malaysian STP*

| Parameter | Unit | Raw Sewage | National Water Quality Standards for Malaysia | | | | |
|---|---|---|---|---|---|---|---|
| | | | CLASS I | CLASS IIA | CLASS IIB | CLASS III | CLASS IV |
| pH value | - | - | 6.5-8.5 | 6.0-9.0 | 6.0-9.0 | 5.0-9.0 | 5.0-9.0 |
| Temperature | °C | - | - | Normal ±2 | - | Normal ±2 | - |
| Biochemical Oxygen Demand, $BOD_5$ at 20°C | mg/l | 250 | 1 | 3 | 3 | 6 | 12 |
| Chemical Oxygen Demand, COD | mg/l | 500 | 10 | 25 | 25 | 50 | 100 |
| Suspended Solid, SS | mg/l | 300 | 25 | 50 | 50 | 150 | 300 |
| Ammoniacal Nitrogen ($NH_3$-N) | mg/l | 30 | 0.1 | 0.3 | 0.3 | 0.9 | 2.7 |
| Nitrate Nitrogen, $NO_3$-N | mg/l | 50 | Natural levels | 7 | 7 | - | 5 |
| Oil and Grease (O&G) | mg/l | 50 | Natural levels | Natural levels | No sheen | No sheen | No sheen |
| Total Phosphorus (TP) | mg/l | 10 | Natural levels | 0.2 | 0.2 | 0.1 | - |
| Turbidity | Nephelometric turbidity unit (NTU) | - | 5 | 50 | 50 | - | - |
| Faecal Coliform | - | - | - | - | - | - | - |
| Chlorine, $Cl_2$ residual | mg/l | | - | - | - | - | - |

The design of the proposed STP in the reclaimed land has considered the following requirements: -

a) Comply with Malaysia's "Code for Design of Urban Sewage Treatment Plants" and relevant regulations and requirements of National Water Services Commission (SPAN, 2009) and the Malaysian Environmental Quality Act 1974 (DOE, 2009);
b) Advanced treatment technology, less land occupation, low energy consumption, simple maintenance and management, and low production of secondary pollutants (sludge, etc.);
c) The STP adopts a semi-underground design; the STP is covered with soil for green coverage;
d) The treated water is connected to the artificial landscape wetland to further purify the treated sewage and reservoir and beautify the environment;
e) All sewage treatment tanks are connected with the odour collection pipeline.

### 2.2 Comparison and analysis of biology treatment process

Biological treatment is the heart of the STP. It is the processes where the dissolved and non-settleable organic material remained in the sewage that would be removed by the micro-organisms. The STP in Malaysia generally employs the activated sludge treatment process (Suja et al., 2015). Sequential Batch Reactor (SBR) is the upgraded version of activated sludge process; the novel STP developed in this study is compared against the SBR. SBR process is considered relatively robust, cost-effective and efficient under Malaysia conditions (Al-Shididi et al., 2003). As a fill and draw or batch process, the biological nutrient removal is carried out in one

reactor, where the final sedimentation tank and return activated sludge pumping are not required. However, the drawback of SBR are the long hydraulic retention time (HRT) (18 h), contributing to a higher footprint. The sludge production is higher and not able to be continuously discharged and will affect the efficiency of the tertiary treatment.
Extended aeration (EA) activated sludge process (Özdemir et al., 2014) is easy to interface with the tertiary treatment, but it requires more space. The bio-contact oxidation process (Li et al., 2012) and the rotating biological contactor (RBC) process (Hassard et al., 2015) are biofilm-based sewage treatments which could offer a higher treatment efficiency. Compared with the activated sludge process, the advantage of the biofilm-based sewage treatment plant is that the sludge production is low. However, the operation of the plant needs to be halted and the aeration tank need to be emptied during maintenance. Both processes are not considered for this project.
In recent years, biological aerated filter (BAF) (Biplob et al., 2012) and moving bed biofilm reactor (MBBR) (McQuarrie and Boltz, 2011) have been introduced to overcome the drawbacks of the activated sludge and RBC. BAF and MBBR are highly efficient sewage treatment processes. An improved version of BAF technology, termed as BioAX has been reported by Tabassum et al. (2018a). BioAX effectively solved the clogging problem. BioAX is an efficient biofilm-based technology which allows treated water to reach Class IIB for water reuse. It is capable of handling a higher volumetric organic loading compared to the conventional activated sludge process. BioAX does not have the returned sludge as the activated sludge process. BioAX substantially reduces the sludge quantity and reduces the cost. BioAX plants also reduce the land area occupied by the STP. Figure 1 shows the section view of the BioAX aeration tank.

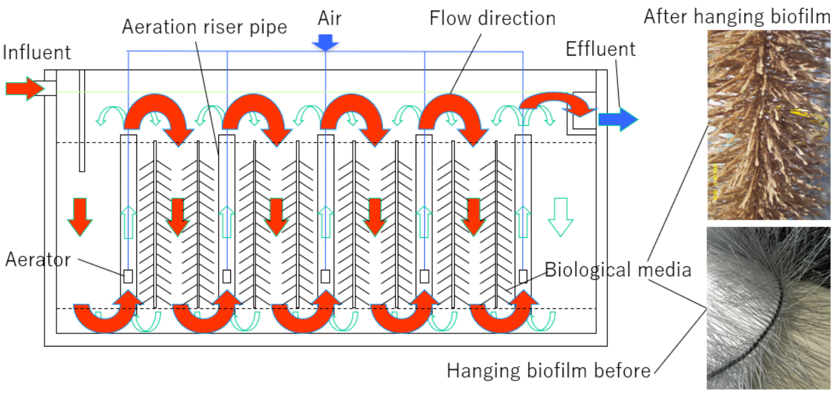


*Figure 1: Section View of BioAX aeration tank*

The packing is a brush-like shape, made of polypropylene with nano-activated carbon, having the advantages of fast biofilm formation, larger porosity and minimum clog issue. The low resistance diffuser is installed in the centre of the aeration riser pipe at 4.5 m below the water surface; the centre spacing of the aeration riser pipes is 1.4 m with its inner diameter is 0.25-0.3 m, the lower edge is 0.3 m from the bottom of the tank and the upper edge is 1-1.5 m below the surface of the water. The centre spacing of packing is 0.2 m. The length of both the packing and aeration pipes are similar. The air provided by the roots blower passes through the air distribution pipe from the upper tank to the diffuser. Diffuser can be serviced and maintained by lifting up from the aeration tank. The maintenance personnel do not require to go down the tank for maintenance work.
The BioAX aeration tank is a rectangular tank, i.e. length to width ratio (L/W) of more than 5, maximum water depth of about 4-8 m. The treated sewage flows in from the front of the aeration tank and flows out from the end. In the aeration tank, the aeration pipe riser continuously elevates the water below the packing to the top of the packing and completed the oxygenation process. The microorganisms on the surface of the packing continue to degrade the pollutants during this process.
The concentration of organic pollutants (COD or BOD) gradually decreases from the front to the end of the BioAX aeration tank. The dominant microorganisms on the surface of the front packing are composed of degrading bacteria, and the latter part of packing is composed of protozoan and metazoans.
The sewage treatment process is completed and the amount of the sludge produced is greatly reduced. It has been proven that the amount of the sludge produced by the BioAX aeration tank is only about 5 % of that in the activated sludge tank. There is no blockage of packing in the BioAX aeration tank. When the aeration diffuser is damaged, it does not need to be stopped for maintenance, and the treatment efficiency is high. The HRT is less than 9 h, which is less than 50 % of the SBR process (HRT = 18 h). Figure 2 shows the carriers of the bio-film in the MBBR aeration tank.

*Figure 2: Carriers of the biofilm in the MBBR aeration tank*

The carrier is made of polyvinyl chloride (PVC) resin which is relatively low cost. The disadvantage of this carrier is that the biofilm is formed slowly and floats easily on the surface of the aeration tank, causing the outlet to be blocked.

To overcome the shortcomings of the biofilm carriers in the current MBBR aeration tank (Figure 3), another biofilm carrier known as MBS (Tabassum et al., 2018b) has been developed. MBS consists of a suspended biological activated carbon granular carrier, in cubic particle with average 3 mm side length (Figure 3). It is composed of microbial liquid, bamboo powdered activated carbon and waterborne polyurethane gel. The improved MBBR tank with the MBS carrier was developed and known as MBS technology.

The structure of the MBS technology aeration tank is obviously different from the conventional MBBR aeration tank. In the conventional MBBR aeration tank, the direction of the outlet is the same as the flow of the aeration tank. However, in the MBS aeration tank, the water flow direction is perpendicular with the outlet of the tank.

The treatment process of BioAX and MBS and an inclined tube sedimentation tanks has been validated for treating domestic sewage plant in Kuala Lumpur for a year to provide the water quality as stated in Table 1 (Class IIB) except for Nitrate ($NO_3$) and Phosphorus (P) (UPUM, 2016).

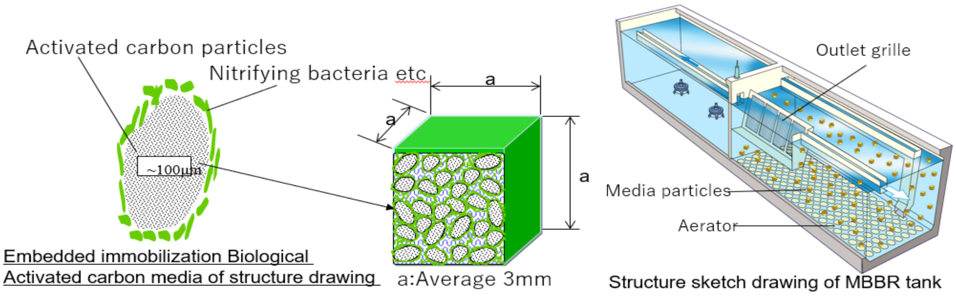


*Figure 3: Structure and MBS carrier of the improved MBBR aeration tank (MBS technology)*

### 2.4 Comparison and analysis of tertiary treatment processes

Tertiary treatment process will achieve the Class IIB standard as tabulated in Table 1.

Tertiary treatment is associated with the requirements to further reduce or remove pollutants beyond the levels achieved by the secondary treatment processes. The purpose of the tertiary treatment is to further remove the remaining COD, $BOD_5$, $NH_3$-N, $NO_3$-N and TP in the biologically treated water, as well as the odour, turbidity and colour. Bacteria, viruses and parasites, which are harmful to public health, are also removed.

The granular activated carbon adsorption filter and Ultraviolet (UV) disinfection are adopted as the tertiary treatment processes. The granular activated carbon adsorption filter has good filtration and adsorption functions, which can remove turbidity and almost all dissolved pollutants in water (COD, $BOD_5$, $NH_3$-N, $NO_3$-N, TP, odour and colour). Due to the highly adsorbent nature and porous surface area of granular activated carbon, these filters have a good capacity for contaminant removal. UV disinfection is a common disinfection method in STP.

The artificial wetlands are an integral part of the STP planned for this project. It serves to further purify the treated water and as a source of green water to beautify the environment.

## 3. Results and discussion

### 3.1 The novel design of the STP

Figure 4 shows the overall flow diagram of the novel STP. After removing the large particles through the primary screen, the sewage is raised to a higher elevation at the pumping stations to the belt microfilter for further screening. The sewage enters the balancing tank for equalising the sewage flow. Going through the combined tank of BioAX and MBS, the organic pollutants and ammonia nitrogen are removed. The suspended solids in the sewage are removed through the inclined tube sedimentation tank before going to the tertiary treatment stage. The treated water is stored in the constructed wetland that can be reused and recycled for irrigation purposes.

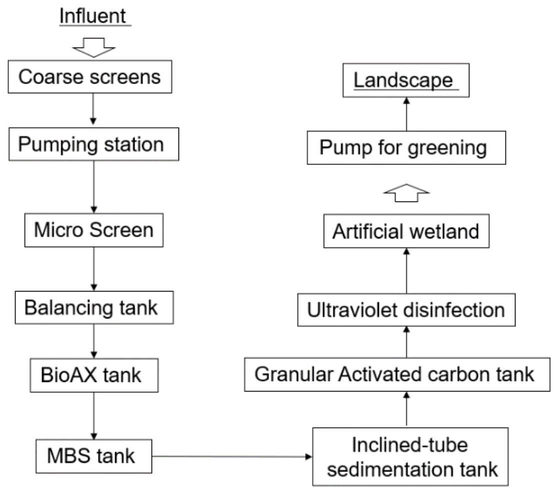


*Figure 4: Flow chart of the combination units of BioAX and MBS process*

### 3.2 Space Footprint Comparison of the STPs

Tables 3 and 4 showed the comparison of the space footprint of the combination units of BioAX and MBS treatment process against the conventional SBR process.

For the STP designed in this study (PE of 17,100 and average sewage treatment capacity of 160.3 $m^3/h$), for 1 t of sewage treated, the SBR technology takes up 6.82 $m^2$ of space footprint, which is 2.37 times larger than the combination of BioAX and MBS. The combination technology only takes up an area of 0.03 $m^2$ per PE, a saving of up to 50% of the area required by the SBR (0.06 $m^2$ per PE).

*Table 3: Design parameters of the combination of BioAX and MBS process*

| Item | HRT | Surface loading | Effective Volume | Depth of Water | Area |
|---|---|---|---|---|---|
| | (h) | (m/h) | ($m^3$) | (m) | ($m^2$) |
| BioAX tank | 9 | - | 1442.7 | 5 | 288.54 |
| MBS tank | 2 | - | 320.6 | 5 | 64.12 |
| Inclined-tube sedimentation tank | - | 2 | - | - | 80.15 |
| Activated carbon tank | - | 6 | - | - | 26.72 |
| Total amount | | | | | 459.53 |

*Table 4: Design parameters of SBR process*

| Item | HRT | Surface loading | Effective Volume | Depth of Water | Area |
|---|---|---|---|---|---|
| | (h) | (m/h) | ($m^3$) | (m) | ($m^2$) |
| SBR tank | 18 | - | 2,885.4 | 3.3 | 874.36 |
| Relay tank | 3 | - | 480.9 | 2.5 | 192.36 |
| Activated carbon tank | - | 6 | - | - | 26.72 |
| Total amount | | | | | 1,093.44 |

From the above comparative analysis, the combination technology of BioAX and MBS technology is proposed as a more efficient STP to treat wastewater in the urban reclaimed land where space saving and high efficiency are of utmost concern.

## 4. Conclusions

Based on the STP designed for the project as implemented in the urban area of a reclaimed land in Johor, the combination technology of BioAX and MBS process serves as a more superior design over the conventional SBR process to achieve the effluent quality of Class IIB for water reuse purposes.

The combination of BioAX and MBS technology has offered a higher treatment efficiency with smaller space footprint over the SBR technology, saving up to 50 % of the area. It also offers the advantages of energy saving, reduced sludge production, maintenance and management, and biological treatment processes over the SBR. This novel STP design is highly recommended for sewage treatment in the reclaimed land and in the highly populated urban area where land is scarce and expensive.

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