Experience in Using Flat Sheet Type Membrane Bioreactor for Sewage Treatment Works on Lamma Island

Dr. Oliver Au-Yeung(1), Mr. K. M. Chau(2), Mr. Nelson Hong(3), Mr. Neil Wong(4)

(1) Associate Director, URS/Scott Wilson, 38th Floor, Metroplaza Tower 1, 223 Hing Fong Road, Kwai Fong, Hong Kong, China; oliver.auyeung@scottwilson.com.hk; Direct +852 24103714

(2) Chief Engineer, Drainage Services Department (HKSAR), 5th Floor, Western Magistracy, 2A Pok Fu Lam Road, Hong Kong, China; henrykmchau@dsd.gov.hk; Direct +852 21593400

(3) Associate Director, ATAL Engineering Ltd, 17th Floor, Java Commercial Centre, 128 Java Road, North Point, Hong Kong, China; nelsonhong@atal.com.hk; Direct +852 25618278

(4) Senior Resident Engineer, Scott Wilson CDM JV; neil.mk.wong@scottwilson.com.hk;

ABSTRACT

Lamma Island is one of the outlying islands with limited flat land and has fish culture zones in its nearby waters. There is currently no centralised sewage treatment process; sewage is treated by individual house owners by primitive soak-away methods. In order to meet the future development demand and improve the water quality of the nearby waters, modernization of the sewerage and sewage treatment systems in the two main residential areas, Yung Shue Wan (YSW) and Sok Kwu Wan (SKW), is in dire need. Two secondary sewage treatment works (STWs) that have adopted membrane bioreactor (MBR) technology to handle peak flow of 8,550 m³/day and 4,290 m³/day in YSW and SKW, respectively, are now under construction. The flat sheet type membrane bioreactor plants exhibit good performance in the removal of BOD, TSS and nutrients; effluent disinfection; and reliable operation.

This paper presents the MBR technology adopted for the treatment process.

1. INTRODUCTION

The project entitled “Construction of Sewage Treatment Works at Yung Shue Wan and Sok Kwu Wan” was commissioned by the Drainage Services Department (DSD) of the Government of the Hong Kong Special Administrative Region to provide two secondary STWs at YSW and SKW on Lamma Island. It is the first time that DSD has used MBR technology in medium size STWs for a residential district. The project has been procured using the conventional Engineer-design and Contractor-build approach - with Scott Wilson CDM Joint Venture as the Engineer for the project. Leader Civil Engineering Corporation Ltd was selected as the main Contractor, with ATAL Engineering Ltd as its specialist contractor for E&M installation for the STWs. The construction works commenced in May 2010 and the STWs are scheduled for commissioning in mid 2013.
2. BACKGROUND

2.1 Background on Lamma Sewage Treatment Works

In 1993, the Environmental Protection Department (EPD) undertook the Outlying Islands Sewerage Master Plan (SMP) Study and recommended sewage collection, treatment and disposal works to be implemented at YSW and SKW on Lamma Island. EPD then commissioned DSD to implement a project to build village sewerage systems, sewage treatment plants, pumping stations and submarine outfalls in these two main residential areas on the island to allow enforcement of sewage collection in villages to proceed, with the intent of improving the water quality in its coastal waters. Both YSW and SKW are rural village areas with limited flat land available. They are crowded with visitors during weekends and holidays. Therefore, in addition to the reliability for handling substantial sewage flows, the new STWs should also be compact enough to fit in the small pieces of allocated land. The appearance of the new STWs need to be carefully designed such that they can blend into the surrounding environment. The view of the future YSW STW is shown in Figure 1 below.

![Figure 1 – Future Yung Shue Wan Sewage Treatment Works](image-url)
2.2 Background on Membrane Bioreactor

Since the commissioning of the first full scale flat sheet type MBR municipal sewage treatment plant in early 1998, there have been thousands of MBR plants constructed worldwide. MBR technology has been widely used for sewage treatment and recycling applications. Also with the continuous technological advances developed by membrane manufacturers and technology providers, there has been breakthroughs in the aspects of membrane service life, anti-fouling performance, energy saving and flux rate, as well as a reduction in operation, maintenance and pre-treatment requirements. These developments drive the MBR technology, transforming it from a new and risky process to a proven, state-of-the-art and reliable technology.

MBR in fact is the combination of activated sludge treatment process together with microfiltration/ultrafiltration for separating the bio-solids from the effluent. In submerged membrane design, both biological treatment and microfiltration are carried out in the same reactor which features very compact reactor design. Two families of membrane systems, namely the flat sheet type MBR system and the hollow fibre type MBR system, have been developed and put into full scale operation in municipal sewage treatment plants since 1998.

A number of full scale type MBR municipal sewage treatment plants have been constructed and put into operation in Hong Kong since 2005. The largest municipal MBR sewage treatment plant in operation in Hong Kong is the sewage treatment plant at Lo Wu Correctional Institution. This flat sheet type MBR plant is designed to handle wastewater collected from Lo Wu Correctional Institution at average dry weather flow (ADWF) of 775 m$^3$/day and design hydraulic capacity of 2,325 m$^3$/day with nitrification and denitrification incorporated. The two flat sheet type MBR STWs under construction on Lamma Island have a design peak flow in wet weather of 4,290 m$^3$/day and 8,550 m$^3$/day, respectively, and they are designed to perform total nitrogen removal. The MBR plants currently in operation at Tai Lam Correctional Institution and Airport Island in Hong Kong feature reliable effluent quality unaffected by operational problems, fully automatic and unmanned operations, simplest operation and maintenance efforts and low damage rate of membrane cartridge over the past 5-year operation period.
3. MEMBRANE BIOREACTOR TREATMENT FOR LAMMA ISLAND SEWAGE TREATMENT WORKS

In the two STWs currently under construction on Lamma Island, it has been confirmed to adopt Kubota’s submerged flat sheet type MBR technology. These two STWs are designed to meet the following design criteria:

Table 1 – Design Flows of Yung Shue Wan and Sok Kwu Wan Sewage Treatment Works

<table>
<thead>
<tr>
<th>Sewage Treatment Works</th>
<th>ADWF (m$^3$/d)</th>
<th>Wet Weather Peak Flow (m$^3$/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yung Shue Wan</td>
<td>2,850</td>
<td>8,550</td>
</tr>
<tr>
<td>Sok Kwu Wan</td>
<td>1,430</td>
<td>4,290</td>
</tr>
</tbody>
</table>

Table 2 – Design Loads of Yung Shue Wan and Sok Kwu Wan Sewage Treatment Works

<table>
<thead>
<tr>
<th>Design Cases</th>
<th>Flow (m$^3$/d)</th>
<th>SS (mg/L)</th>
<th>BOD (mg/L)</th>
<th>TKN (mg/L)</th>
<th>NH3-N (mg/L)</th>
<th>E.coli (count/100mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>At Weekday</td>
<td>2,280</td>
<td>152</td>
<td>210</td>
<td>33</td>
<td>19</td>
<td>1.5E+07</td>
</tr>
<tr>
<td>At Weekend</td>
<td>2,850</td>
<td>129</td>
<td>215</td>
<td>33</td>
<td>19</td>
<td>1.4E+07</td>
</tr>
<tr>
<td>At Peak Flow</td>
<td>11,400</td>
<td>82</td>
<td>144</td>
<td>22</td>
<td>13</td>
<td>9.6E+06</td>
</tr>
<tr>
<td>At Initial Influent Variant</td>
<td>912</td>
<td>380</td>
<td>525</td>
<td>83</td>
<td>48</td>
<td>3.8E+07</td>
</tr>
<tr>
<td>At Interim Influent Variant</td>
<td>1,520</td>
<td>228</td>
<td>315</td>
<td>50</td>
<td>29</td>
<td>2.3E+07</td>
</tr>
</tbody>
</table>
Table 3 – Effluent Standard for Yung Shue Wan and Sok Kwu Wan Sewage Treatment Works

<table>
<thead>
<tr>
<th>Location</th>
<th>Parameter</th>
<th>Effluent Standard for Sewage within Design Flow and Load to be achieved on 95%ile basis</th>
<th>Effluent Standard for Sewage within Design Flow and Load never to be exceeded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yung Shue Wan Sewage Treatment Works</td>
<td>Flow (m³/day)</td>
<td>N/A</td>
<td>8,550</td>
</tr>
<tr>
<td></td>
<td>SS (mg/L)</td>
<td>30</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>BOD5 (mg/L)</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Ammonia Nitrogen (mg/L)</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>TIN (mg/L)</td>
<td>12</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>E.Coli (counts /100mL)</td>
<td>1500</td>
<td>100*</td>
</tr>
<tr>
<td>Sok Kwu Wan Sewage Treatment Works</td>
<td>Flow (m³/day)</td>
<td>N/A</td>
<td>4,290</td>
</tr>
<tr>
<td></td>
<td>SS (mg/L)</td>
<td>30</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>BOD5 (mg/L)</td>
<td>20</td>
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<td>E.Coli (counts /100mL)</td>
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<td>100*</td>
</tr>
</tbody>
</table>

Note
The figures marked with “*” stand for effluent standard of E.Coli in a sample for the sewage within design flow and load to be achieved on a Monthly Geometric Mean basis.

3.1 Pre-treatment
The pre-treatment for both STWs includes coarse screening, flow balancing, grit removal and fine screening.

3.1.1 Coarse Screening
Coarse screening is purposely designed for providing mechanical protection of the pumping equipment in the downstream flow balancing tanks. Bar spacing of coarse screen usually depends on the solid handling capability of the downstream sewage pumps. In both STWs, the bar spacing is 20 mm.

3.1.2 Flow Balancing
Flow balancing tanks are designed for smoothing out the diurnal peak flow. In both STWs, the diurnal peak is four times of the hourly ADWF and the MBR reactor is designed to handle the design peak flow - three times of the ADWF. Therefore the flow balancing tanks in this case are designed to smooth out the difference equivalent to hourly ADWF for two hours.

3.1.3 Grit Removal
Given that membrane is vulnerable to attack from abrasive materials, vortex chamber type grit
removal unit is designed at the upstream of the MBR system. Generally, properly designed aerated grit chamber and vortex chamber can perform the required functions.

### 3.1.4 Oil and Grease Removal
As the wastewater generated from seafood restaurants at YSW and SKW would contain certain amount of oil and grease, therefore aerated type oil and grease removal equipment is designed at both STWs. Usually if the biodegradable oil and grease content is less than 15% of the BOD content, oil and grease removal equipment is not required for pretreatment of flat sheet type MBR system.

### 3.1.5 Fine Screening
Fine screening is important for any kind of MBR system. The recommended fine screen for Kubota’s flat sheet type membrane is 1 to 2 mm mechanically raked bar screen or 3 mm two dimensional (perforated) screens. In both STWs, mechanical raked bar screen with 2 mm bar spacing is designed at the upstream of the MBR system.

### 3.2 Membrane Bioreactor
The MBR systems in both STWs will perform biological treatment and solids / liquid separation. A submerge system of Kubota’s flat sheet type membrane is used for the MBR reactors.

#### 3.2.1 BOD and TSS Removal Performance
The Kubota membrane has physical nominal pore size of 0.4 microns, which is in the overlapping range of micro-filtration and ultra-filtration. When the biological culture is developed, a dynamic membrane in jelly form is formed over the entire membrane surface by the bubble flow effect. This dynamic membrane offers varying pore sizes to match different flux rate conditions. The actual pore size of this dynamic membrane is simply controlled by the permeate pump flow rate and can be down to 0.01 microns. Therefore the flat sheet type membrane also exhibits excellent TSS removal and disinfection performance. The treated effluent will be less than 1 mg/L TSS and can achieve 6 log bacteria removal.

Due to the extreme low TSS in effluent, the flat sheet type MBR system also exhibits very good BOD removal performance. The BOD content of treated effluent in a pilot test carried out at Sai Kung STW was on average below 3 mg/L. Therefore in the process design of MBR system for both STWs, the BOD content in the effluent is expected to be well below 5 mg/L.

The design MLSS concentration is based on 12,000 mg/L, however flat sheet type MBR system can operate at MLSS concentration from 6,000 mg/L to 20,000 mg/L. The actual
MLSS concentration is a mass balance result of the pollutant loadings in the influent and the substances leaving the reactor. Hence the reactor volume is significantly smaller than the conventional suspended growth biological treatment unit. Based on the experience in Hong Kong’s sewage treatment plants, the biological reactor volume is only one-third of that required for conventional suspended growth bioreactor operating at MLSS concentration in the range of 2,500 to 4,000 mg/L.

### 3.2.2 Total Nitrogen Removal Performance

Nitrification takes place in the MBR/aeration tank whilst denitrification occurs in the anoxic zone. According to the results of pilot study carried out in Sai Kung STW, if flat sheet type MBR system operates at the design conditions, i.e. design average flow and dissolved oxygen concentration (DO) at around 1 to 1.5 mg/L at aeration zones, the average total nitrogen (TN) in effluent was 3.4 to 4.3 mg/L. However, the design of aeration capacity is based on the pollutant loadings at peak flow conditions in order to maintain the design dissolved oxygen level. The Sai Kung pilot test results also indicated that the nitrogen removal performance in summer time (average TN = 3.4 mg/L and average NH4-N < 0.1 mg/L in September) is significantly better than that in winter time (average TN = 4.3 mg/L and average NH4-N = 0.7 mg/L in February). Therefore the process design should also consider the influent characteristics with nitrification and denitrification rates at winter time. Details of the pilot test results are shown in Figures 2 and 3 below.

![Figure 2 – MBR Pilot Test at Sai Kung STW - Influent and Effluent Nitrogen](image-url)
3.2.3 Sludge Age and Sludge Yield
The Sludge Retention Time (SRT) for MBR plant with total nitrogen removal is around 30 to 45 days depending on the incoming pollutant loadings and actual MLSS concentration. In this SRT range the excess sludge production rate is around 0.3 Kg TSS / Kg COD removed. In general, longer sludge age results in lower excess sludge production rate.

3.2.4 Flux Rate
Design flux rate of 0.6 m/day usually is used for sizing the design peak flow - three times of the ADWF. Flow balancing tank is designed to smooth out the excessive diurnal peak flow for two hours.

3.2.5 Anti-fouling Performance
Flat sheet type membrane exhibits good antifouling performance. The required membrane cleaning measure is on-line chemical cleaning at 3 to 4 months interval. The chemical cleaning usually takes one to two hours to complete. The chemical required for removing organic fouling is 0.5 % hypochlorite solution.

3.2.6 Energy Consumption
The energy consumption of the whole STW, including pre-treatment, biological treatment and sludge treatment, is expected to be around 2.3 kwh/m$^3$ while the energy consumption of the biological treatment only is expected to be in the range of 1.1 to 1.3 Kwh/m$^3$.

3.2.7 Membrane Service Life
A study on membrane failure rate of all Kubota's flat sheet type MBR plants in Europe reflected that the average annual membrane failure rate is 0.475 % calculated over an eight-year period. The low failure rate of flat sheet type membrane is due to the robust
design of membrane cartridge and each damaged membrane cartridge can be replaced individually. There has been so far no report on membrane cartridge failure in Hong Kong’s MBR plants with Kubota flat sheet type membrane installed.

4. CONCLUSION
The two new Sewage Treatment Works at Yung Shue Wan and Sok Kwu Wan on Lamma Island with their peak capacities of 8,550 m$^3$/day and 4,290 m$^3$/day, respectively, have been designed to use flat sheet type MBR treatment process. It is the first time that DSD has used MBR technology in medium size STWs for a residential district. MBR is the combination of activated sludge treatment together with microfiltration/ultrafiltration for separating the bio-solids from the effluent. Such a system performs well with regard to BOD and TSS removal, nutrients removal and effluent disinfection. Its operation is reliable, with effluent quality unaffected by operational problems, like sludge bulking and foaming.
Reference


