Design and Operation of MBR Type Sewage Treatment Plant at Lo Wu Correctional Institution, Hong Kong

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Abstract:
Lo Wu Correctional Institution (LWCI) is one of the female penal institutions managed by the Correctional Services Department (CSD) of the Government of the Hong Kong Special Administrative Region (HK Government of SAR). It comprises three prison facilities with two of them at medium security level and one at minimum security level respectively. The institution's accommodation capacity is 1,400 female adult prisoners. Having no public sewer available, a sewage treatment plant adopting Membrane Bioreactor (MBR) technology was built inside LWCI to handle sewage at designed average flow of 775 m^3/d. The MBR plant was designed with nitrification and denitrification process. It exhibits good performance in removal of organics, solids, nutrients, micro-organisms, etc. and operates satisfactorily in meeting stringent discharge license requirements stipulated by the Environmental Protection Department (EPD) of HK Government of SAR. This paper presents the experience in design and operation of this MBR plant.

Keywords: MBR, Lo Wu Correctional Institution

1. INTRODUCTION

LWCI is one of the female penal institutions managed by the Correctional Services Department of the HK Government of SAR. Its design accommodation capacity is 1,400 female adult prisoners. Having no public sewer available, a sewage treatment plant adopting MBR technology was built inside LWCI to handle the wastewater generated. Part of the treated effluent is recycled for toilet flushing within LWCI with the excess being discharged to the inland watercourse.

ATAL Engineering Limited (hereafter called ATAL) is the specialist sub-contractor responsible for the design and construction of the electrical and mechanical engineering works of the plant while the Drainage Services Department (DSD) of the HK Government of SAR is responsible for its operation and maintenance.

2. DESIGN CRITERIA AND CONSIDERATIONS

According to the "Design and Construction of the Redevelopment of LWCI - Second Stage Sewerage Impact Assessment Report" (hereafter called the SIA Report) issued in October 2007, the design population and the design flow for the plant are shown in Table 1 below:

Type	Design Population	Unit Flow Factors (m^3/person/d)	Sub-total Flow (m^3/d)
Inmates	1,680*	0.440	739.20
Prison Staff	506	0.060	30.36
Civilian Staff	48	0.060	2.88
Visitors	85	0.025	2.13
Average Dry Weather Flow (ADWF) (m^3/d)			**775**

** Population of Inmate should be 1,400 plus 20% design allowance*

Table 1 – Design Population and Design Flow

According to the SIA Report, the design loadings for the plant are shown in Table 2 below:

Type	Unit	Design Loading
Suspended Solids (SS)	kg/d	88.926
Biochemical Oxygen Demand (BOD_5)	kg/d	92.286
Chemical Oxygen Demand (COD)	kg/d	195.930
Total Kjeldahl Nitrogen (TKN)	kg/d	18.561
Ammonia Nitrogen (NH_3-N)	kg/d	10.956
Escherichia Coli (E. Coli)	count/d	9.6×10^{13}

Table 2 – Design Loadings

Based on the design flow and the design loadings in the SIA Report, the influent characteristics and the treated effluent quality for recycling are listed in Table 3 below:

	Flow (m^3/d)	BOD_5 (mg/L)	SS (mg/L)	TKN (mg/L)	NH_3-N (mg/L)	E. Coli (count/100mL)	TRC (mg/L)
Influent	775	119.1	114.7	23.9	14.1	1.22×10^7	N/A
Effluent	775	5.839	3.273	3.071	3.071	Non-Detected	1 - 2

Table 3 – Influent Characteristics and Effluent Quality

As the treated effluent may not be fully recycled, the excess effluent will be discharged to the local drainage system. In this case, the effluent must comply with the discharge standards at Deep Bay area, which require that the Total Residual Chlorine (TRC) level in the excess effluent should not be larger than 0.4 mg/L.

Wastewater from laundry and kitchen are assumed entering the plant on intermittent basis. After mixing with the wastewater from other sources at the equalization tank, the temperature of the wastewater will be less than 35℃. Also, the grease trap is designed to remove the majority of oil and grease in the wastewater generated from the kitchen.

A diurnal flow pattern is developed based on the activity schedule shown in Table 4 below:

Time	Activity
7:00 a.m.	Wake Up
8:00 a.m.	Breakfast
9:00 a.m. – 4:00 p.m.	Activities at Workshop including Lunch from 1:00 p.m. to 2:00 p.m.
5:00 p.m.	Dinner
8:00 p.m. – 10:00 p.m.	Shower at Dormitory

Table 4 – Activity Schedule

According to the "Guidelines for Design of Small Sewage Treatment Plants" published by the EPD and the diurnal flow pattern, the design peak flow is assumed to be four times of the ADWF. With the aid of the equalization tank, the MBR plant is therefore designed to handle three times of ADWF, that is 775 x 3 = 2,325 m^3/d.

3. TREATMENT PROCESS DESIGN

Coarse Screening

Wastewater from various buildings in LWCI will flow by gravity to the plant at a level of approximately +6.00 mPD. Solids of size larger than 20 mm will be screened out by the automatic raked coarse screens installed upstream of the equalization tank. The coarse screening is designed to protect the downstream mechanical equipment in the equalization tank.

Equalization Tank

The equalization tank is designed to smooth out peak flow and meet the design flow for two hours in accordance with the "Guidelines for Design of Small Sewage Treatment Plants" published by the EPD.

Fine Screening

The equalized wastewater is then further screened by the automatic fine screens. Solids of size over 2 mm will be screened out prior to the anoxic tank. The fine screening is designed to protect the downstream membrane module and aeration equipment.

Anoxic Tank

Screened wastewater flows to the anoxic tank and is mixed with the nitrate recycled from MBR tank and pre-aeration tank for denitrification. The design denitrification rate is 0.02 kg-N/kg-MLSS/d at 18℃.

Membrane Bioreactor

Mixed Liquor Suspended Solids (MLSS) from the anoxic tank is evenly distributed to two MBR tanks in which biological oxidation and nitrification takes place. Each MBR tank contains seven sets of fully submerged flat sheet type membrane modules and each membrane module has 200 nos. of membrane panels. The membrane modules comprises two sections – the top section containing membrane cartridges fixed into a stainless steel housing constructed with the lower section containing coarse bubble diffusers. The bubbles released by the lower diffuser section generate an upward sludge bubble flow over the membrane surface at a velocity of approximately 0.5 m/s. This bubble flow is able to minimize fouling and allow low pressure suction filtration of the treated effluent into the inner compartment of membrane cartridge and thence to the collecting manifold. The membrane nominal (maximum) and average pore sizes are approximate 0.4 microns and 0.2 microns respectively.

The MBR tank performs both functions of aerobic treatment and solids / liquid separation. The complete MBR system is able to operate at high MLSS concentration in the range 6,000 - 20,000 mg/L which features compact design and small footprint area, low sludge production rate due to long sludge age and strong resistance to shock pollutant loads. The micro-filtration performance of the flat sheet type membrane also produces permeate to disinfected quality. Sometimes pre-aeration is required if the air supply for air scouring is insufficient for biological treatment. As discussed above, the denitrification is performed in a separate anoxic compartment. Sludge is drawn off at a constant volume rate to maintain the MLSS at the optimum level according to the operational needs.

Design flux rates of 0.35 and 1.2 $m^3/m^2/d$ are used for sizing the average flow and design peak flow of the MBR system respectively.

Disinfection
In order to ensure pathogen-free for the recycled water, chlorination using sodium hypochlorite is adopted for disinfection followed by the de-chlorination.

4. PERFORMANCE OF THE PLANT

Compliance of EPD's Discharge License
Since taking-over of the plant from ATAL by DSD for operation in August 2011, the treated effluent quality has fully complied with EPD's Discharge License and the plant could demonstrate good performance in terms of effluent quality. The summary of the actual performance is listed in Table 5 below:

	SS (mg/L)	BOD_5 (mg/L)	Oil & Grease (mg/L)	Nitrate + Nitrite Nitrogen (mg/L)	NH_3-N (mg/L)	Surfactants (mg/L)	E. Coli (count/ 100mL)	TRC (mg/L)
Design (Influent)	114.7	119.1	-	-	14.1	-	1.22 x 10^7	-
Actual (Influent)	320	340	43	-	16	-	-	-
EPD's Requirements	60	40	20	40	10	10	100	0.4
Actual (Effluent)	<5	<5	<5	<2.5	<0.5	<2	40	<0.2

Table 5 – Influent Characteristics and Effluent Quality

Treatment Capacity

The average daily flow of the plant was about 64% of the design flow while the number of inmates was about 1,100 in September 2012. However, it is noticed that the BOD_5 strength was about three times of the design BOD_5 strength assumed for the influent, therefore the treatment capacity in term of kg-BOD_5 removed per day was 159 in average, which was approximate 1.79 times of the design treatment capacity.

5. OPERATION AND MAINTENANCE ISSUES

Concentration of MLSS

The concentration of MLSS in the MBR tanks is monitored by the MLSS sensors and controlled by the automatic desludge valves regularly. The concentration of MLSS can be maintained at about 10,000 to 12,000 mg/L and the average desludge rate is about 9 m^3/d which is corresponding to a sludge yield rate of 0.587 kg-SS/kg-BOD_5 removed.

Permeate Flux

The permeate pumps are controlled by variable speed drive to adjust the permeate flux to meet the demand. Based on the operation records, the flow of permeate pumps are always operated between 18 and 23 m^3/hr which are corresponding to flux rate at 0.192 to 0.246 m^3/m^2/d, lower than the design flux at 0.35 m^3/m^2/d.

Staffing Requirements

The plant is designed for unmanned operation. The plant incorporates the supervisory control and data acquisition (SCADA) system and the online sensors/instruments for the automatic control and remote monitoring of the plant. All signals and alarms are transmitted to the Regional Control Centre at Shek Wu Hui Sewage Treatment Works. However, appropriate level of manning is required for the satisfactorily operation and maintenance of the plant. In general, the overall staffing requirements of the plant are about 10 man-day per week.

Operation Activities

As the plant is almost fully automated, the on-site operation activities involving staffing requirements are minimal. The major manual operation activities of the plant are the waste disposal, sample collection as well as routine inspections. The general requirements of these operation activities are shown in Table 6 below:

Major Operation Activity	Frequency of Activity
Waste Disposal	6 times per week
Routine Inspection	6 times per week
Sample Collection	3 times per week

Table 6 – Operation Schedule

Maintenance Activities

One of the major maintenance activities is to clean the membranes as well as the effluent discharge pipelines with sight-glasses. Furthermore, the diffusers are required to clean for satisfactorily operation. The membranes are cleaned offline using sodium hypochlorite. The general requirements of these maintenance activities are shown in Table 7 below:

Major Maintenance Activity	Frequency of Activity
Membrane Cleansing	Once every 3 months
Discharge Pipeline Cleansing	Once every 1 month
Diffuser Cleansing	Once every 2 weeks

Table 7 – Maintenance Schedule

Major Breakdown

During the past 15 months of operation, no major breakdown was occurred. The system is very reliable.

Replacement of Membrane Panels

During the past 15 months of operation (by DSD) plus 15 months of process commissioning and trial run (by ATAL), 50 nos. of membrane panels were found damaged. The damage rate was approximate 0.7% per year. Investigation and consultation with the membrane supplier were conducted. It was believed that damages of the membranes were due to wear and tear arising from inflow of certain amount of food wastes to the sewage treatment plant with the influent during the process commissioning period.

6. TREATMENT COST

Electricity Cost

The electricity loading of the plant includes the aeration and the pumping systems. The electricity cost per unit flow was about 2.7 kWh/m^3. This comparatively high electricity consumption is mainly due to the additional electricity consumption for treating the excessive high BOD_5 concentration, which was three times higher than the design BOD_5 strength of the influent.

Chemical Cost

The membranes are cleaned offline using sodium hypochlorite. The annual consumption is about 3,300 kg. The chemical cost per unit flow is about HK$0.02/$m^3$.

Other Operation Costs

The other operation costs include the labour cost and the waste disposal cost. The cost per unit flow is about HK$2.6/$m^3$.

Replacement and Repair Cost

No major replacement or upgrading works has been carried out since the operation of the plant. In short, 50 nos. of membrane panels (out of 2,800) were replaced in 2012. The overall replacement and repair cost per unit flow is about HK$1.8/$m^3$.

Total Treatment Cost

The above breakdown of the operation and maintenance costs may not fully represent the actual treatment cost of the plant as the years of operation of the plant is relatively short. In addition, the generated sludge is not dewatered or treated locally. For initial reference, the estimated total treatment cost per unit flow of the plant in the first year of operation is between HK$6/$m^3$ and HK$8/$m^3$.

7. CONCLUSIONS

The wastewater generated from LWCI is currently treated by a flat sheet type MBR sewage treatment plant. MBR technology is the combination of activated sludge treatment technology and microfiltration/ultrafiltration technology for biological treatment of wastewater and separating the bio-solids from the effluent. The experience gained from the design and operation of this plant in LWCI indicates that MBR type sewage treatment plant performs well with regard to BOD_5 and SS removal, nutrients removal and effluent disinfection in reliable manner. Its effluent quality meets the design requirements reliably and is unaffected by operational problem, like sludge bulking or foaming commonly in existence in conventional type secondary sewage treatment plants. It is considered that the performance of MBR plants is reliable.

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