Yannawa wastewater treatment plant (Bangkok, Thailand): design, construction and operation

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Abstract
Yannawa Wastewater Treatment plant (Phase 1) serves a population equivalent of 500,000 and is located on a restricted site within the city of Bangkok, Thailand. Secondary treatment is based on the CASS™ sequencing batch reactor (SBR) process and the plant is one of the largest multi-storey SBRs in the world. The limitation of available site area, the ground conditions and the characteristics of the wastewater to be treated set a series of challenges for the designers, contractors and commissioning and operational staff. This paper briefly describes the collection system, the process selection and the treatment streams of the wastewater treatment plant. The SBR secondary treatment plant is described in more detail. The problems that arose during commissioning and operation and the solutions made possible by the use of an SBR type of process are discussed. Details of plant performance during performance testing and during the first three years of plant operation are provided.

Keywords
Biological nutrient removal; CASS™; commissioning; construction; decanter; design; multi storey; operation; restricted site; sequencing batch reactor

Introduction

Project background
The Yannawa Wastewater Treatment Plant (now known as the Chong Nonsi Wastewater Treatment Plant) is the second in a series of large wastewater treatment facilities within the Bangkok area and serves a 30 km² drainage area. Local conditions set a number of challenges for the designers of both the collection system and the wastewater treatment plant. The site available for the wastewater treatment plant was owned by the client (Bangkok Metropolitan Administration (BMA)) but was less than 3 ha. Ground conditions are generally poor in the Bangkok area and as a result the treatment works is subject to land settlement and differential settlement between structures. Before completion of the project, wastewater discharged to local canals (khlongs) without treatment, therefore the lack of an integrated collection system prevented any detailed assessment of wastewater characteristics based on sampling programmes. Traffic congestion within Bangkok restricted the permissible hours of working on the wastewater collection system.

Design and construction

Collection system. Collection system costs accounted for over 60% of the contract value. Restrictions on daytime working along main roads meant that most main sewers were routed below the network of khlongs using trenchless methods. 51 km of sewers were provided, over 90% of which were laid using microtunnelling and pipe jacking methods. Ground conditions (soft clay) enabled pipe jacking of up to 200 m in each direction from jacking pits to receiving pits. Three sewage lift pumping stations were provided to avoid sewer depths greater than 15 m, which would have resulted in less advantageous ground conditions. Wastewater arrives at the treatment plant site via a 2.25 m diameter gravity sewer.
Treatment process selection. Factors in the selection of the process included:

- Limited land availability.
- Requirement to minimise environmental and visual impact.
- Flexibility to treat a range of influent wastewater concentrations.
- Nutrient removal final effluent requirement (see Table 2).

The secondary treatment process selected was based on sequencing batch reactor technology (using the CASS™ process variant), for the following reasons:

- Proven technology.
- Easily adaptable to a multistorey configuration.
- Easily constructed rectangular process units.
- Compatible with surrounding area.
- Capable of providing the required final effluent quality.

Wastewater treatment plant design conditions (Phase 1). The plant was designed to deal with influent conditions as specified in Table 1, and to achieve effluent quality as specified in Table 2.

Preliminary treatment units. An inlet pumping station was provided for all flows up to 500,000 m$^3$/day with seven submersible pumps, controlled on level in the pumping station wet well. All flows in excess of 500,000 m$^3$/day are transferred by gravity to a separate storm water pumping station. Flows from the inlet pumping station pass through two dynamic separators, operated as duty/assist. Inflows above a set point automatically bring the assist dynamic separator into use. Grit, sand and larger screenings are removed in the dynamic separators and transferred by the underflow pumps to underflow streams. Four underflow pumps are provided in total, two in each dynamic separator, operating as duty/assist according to increasing or decreasing flows. The remaining flow through each dynamic separator overflows into a band screen channel. Four underflow streams are provided, each stream being normally dedicated to an underflow pump. Each underflow stream consists of a fine drum screen with integral compacting screw conveyor, controlled on differential level, followed by a grit classifier equipped with two dewatering/conveyor screws. Screenings and grit removed in the underflow streams are transported to skips via belt conveyors. Two 5 mm band screens are provided to treat the overflow from the dynamic separators, one screen per separator. Screenings removed by the fine screens are dewatered in a screw compactor then discharged onto a belt conveyor and transferred to skips.

*Table 1* Specified influent conditions

<table>
<thead>
<tr>
<th>Units</th>
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<tbody>
<tr>
<td>Dry weather flow</td>
<td>m$^3$/day</td>
</tr>
<tr>
<td>Flow to full treatment</td>
<td>m$^3$/day</td>
</tr>
<tr>
<td>Maximum flow to preliminary treatment</td>
<td>m$^3$/day</td>
</tr>
<tr>
<td>Maximum flow to works</td>
<td>m$^3$/day</td>
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</tbody>
</table>

| BOD | mg/l | 20 |
| Suspended solids | mg/l | 30 |
| TKN | kg/d | 6,000 |
| NH$_3$-N | kg/d | 4,000 |
| Phosphorus | kg/d | 600 |

*Table 2* Specified final effluent quality

<table>
<thead>
<tr>
<th>Units</th>
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<tbody>
<tr>
<td>BOD</td>
<td>mg/l</td>
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<tr>
<td>Suspended solids</td>
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<tr>
<td>TKN</td>
<td>kg/d</td>
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<tr>
<td>NH$_3$-N</td>
<td>mg/l</td>
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<tr>
<td>Phosphorus</td>
<td>mg/l</td>
</tr>
<tr>
<td>Dissolved oxygen</td>
<td>mg/l</td>
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</table>

All as moving 30-day averages of daily flow weighted composite samples.
The dynamic separators, the underflow pumps, the underflow streams and the band screens together comprise the preliminary treatment units and are controlled according to the number of inlet pumps that are in operation. Flow from the band screen channels gravitates into a flow separation chamber from where flows in excess of 300,000 m³/day at Phase 1 are diverted to a river outfall by two actuated weir penstocks. Flow separation is controlled by level. Flows up to 300,000 m³/day at Phase 1 then pass into a pumping station, which delivers wastewater to the SBR secondary treatment units. This consists of a conventional four-way distribution chamber based on overflow weirs. Downstream of each overflow weir is a wet well which is dedicated to one floor of the four-storey sequencing batch reactor (SBR) plant. Each wet well is provided with duty/assist/assist submersible pumps and lifts the wastewater to a distribution manifold to ensure equal distribution into the six compartments on a floor of the plant, that make up a single SBR basin.

Secondary treatment. Secondary treatment to provide the final effluent quality described above is based on the CASS™ sequencing batch reactor process. The process is described in more detail below. The plant design is based on four basins. Owing to the limitations of site area availability, the basins are stacked one basin per floor in a four-storey configuration. Each basin is subdivided into six identical compartments, each 60 m long, 17.5 m wide and with a maximum depth to TWL of 4.7 m. Each compartment has a 16.5 m long decanter. Fully treated effluent is discharged via decanters and then flows to the Chao Phrya River through drop shafts, culverts and a final effluent cascade which ensures compliance with the minimum final effluent dissolved oxygen concentration.

Sludge treatment and odour control. Waste activated sludge (WAS) is removed periodically from the SBR compartments by dedicated WAS pumps under PLC control. One small submersible centrifugal pump is provided for this duty per compartment. Sludge is dewatered to a minimum 20% dry solids content by means of stacked belt thickener/belt press units with a single stage of polymer dosing upstream. Sludge stabilisation is by dosing with slaked lime powder. Foul air from anticipated sources of odour is collected by a system of ductwork and transferred to a chemical scrubbing system by a system of fans.

Secondary treatment – SBR description. Secondary treatment is based on an SBR process variant (CASS™ or Cyclic Activated Sludge System), which provides biological nutrient removal and is configured with an internal selector to control filamentous sludge bulking. A process cycle with aeration and non-aeration phases is used to provide aerobic, anoxic and anaerobic process conditions, which combined with aeration intensity, achieve denitrification and biological phosphorus removal where required.

The CASS™ process combines plug flow initial reaction conditions with a complete mix reactor configuration. Each reactor basin is divided by baffle walls into three volumes (zone 1 selector, zone 2 secondary aeration, and zone 3 main aeration). For nitrifying plants in North America or Europe treating normal domestic wastewater these zones are typically in the ratios 5%:10%:85%. Design operating mixed liquor concentration for the Yannawa plant was just over 3,000 mg/l, measured at maximum top water level. Return activated sludge (RAS) is continuously recycled from zone 3 to zone 1 to maintain the initial reaction conditions to remove readily degradable soluble BOD in the influent and encourage the growth of floc-forming organisms. One small submersible centrifugal pump is provided for this duty per compartment. The flow of RAS is determined only by the design loading rate in terms of kg influent BOD per kg of mixed liquor in the RAS and hence is much less than the flow of RAS in a conventional activated sludge plant.

The mechanisms of zone 1 and the internal sludge recycle mean that separate cycle
phases are no longer required to promote the selector and nitrogen and/or phosphorus removal regimes. As a result, the total cycle time can be reduced from a typical SBR cycle time of six hours to four hours when treating domestic wastewater. This permits:
• More batches treated per day
• Reduced hydraulic requirement per batch
• Potentially less total basin volume.

The captive contactor selector zone operates under anoxic and anaerobic reaction conditions. The complete mix nature of the reactor, particularly in zone 3, provides flow and load balancing and a tolerance to shock or toxic loadings. During normal operation, each basin is isolated from the inflow during decant, which helps prevent mixed liquor suspended solids washout during peak or wet weather hydraulic surges. The process operates with simple repeated time-based cycles as follows:
• Fill aerate (for biological reactions, two hours duration)
• Fill settle (for solids-liquid separation, one hour duration)
• Decant/idle (to remove treated effluent, one hour duration total)

For treating typical domestic wastewater influent concentrations, this constitutes a four-hour cycle which is then repeated. As with any sequencing batch process, varying the duration of the cycle phases offers considerable flexibility in terms of being able to adapt the process to suit changing influent conditions. Nitrification and denitrification can be achieved simultaneously by controlling the aeration intensity during the aerobic period to ensure anoxic conditions within the activated sludge flocs into which dissolved oxygen penetration is limited, with ammonia oxidation taking place externally to the flocs. The conditions within zone 1 of each basin also provide polishing denitrification, as well as rapid enzymatic transfer of influent soluble substrate as part of enhanced biological phosphorus removal.

CASS™ decanter
Treated effluent is removed from the basin after the settle period by a proprietary moving weir decanter or surface skimmer (see left). The weir trough of the decanter is situated above top water level for both aeration and settling sequences to prevent contamination and the accidental discharge of mixed liquor suspended solids. The decanter is controlled automatically by PLC. When operated during the decant phase of the cycle, the decanter is driven by a variable speed electromechanical actuator mechanism and a constant flow of clarified effluent is discharged from the reactor. When the pre-set designated bottom water level in the basin is reached, the decanter then returns to its parked position. The range of travel of the decanter is set by upper and lower position limit switches. The rest position of the decanter can be set at a position between designated top water level and the top of the reactor basin level to provide an emergency overflow. The decanter is fitted with a scum guard that excludes surface scum and other floating material.

Figure 1 CASS decanter
SBR aeration system and aeration control

The SBR aeration system selected uses fine bubble flexible membrane diffusers, consisting of thin, flexible discs made from soft synthetic rubber, supported by a circular baseplate. Air passages are created by forming minute holes in the membrane material. When the air is turned on, the membrane expands and each slot opens and passes a fine bubble stream. When the air is turned off, the membrane contracts and seals itself against the baseplate. In principle, the design of a fine bubble aeration system in an SBR process uses the same method as for a similar installation in a conventional activated sludge process. There is a significant body of literature which allows the performance of fine bubble systems to be predicted using widely accepted design methods in both conventional and sequencing batch activated sludge processes.

The design of the fine bubble aeration system and blower configuration typically allows for a turndown ratio of 3:1. Owing to the wide operational air flow per diffuser, this turndown ratio can be achieved without any penalty in terms of efficiency. The use of fine bubble aeration provides a gentle pattern of aeration which allows rapid initiation of good settlement conditions when the air flow is turned off. In a four-basin plant such as Yannawa, the cycle configuration would be as shown in Table 3 above. One set of blowers would be dedicated to basins 1 and 2 with a second set dedicated to basins 3 and 4. It can be seen that the flow of air alternates between basins 1 and 2 and also between basins 3 and 4, hence both blower sets operate continuously. Note also that one basin decants in each hour period, providing continuous outflow from the plant. Control of the aeration system requires one dissolved oxygen probe in each basin. The dissolved oxygen probe measures the dissolved oxygen concentration in the basin during the aerate phase of the cycle and the control PLC uses this signal to vary the blower output as necessary. As the start of the aerate phase follows settle and decant during which the process is not aerated, the initial dissolved oxygen concentration is always 0 mg/l. A graph of dissolved oxygen against time, starting at 0 mg/l and ending at 2–3.5 mg/l, is programmed into the PLC process control system. The actual dissolved oxygen concentration at any time is compared with this profile and the blower output adjusted accordingly.

Results

Yannawa operational experience – commissioning and performance testing. SBR process start up coincided with the wet season. As a result, during the early stages of plant operation, the influent organic load was low and influent dissolved oxygen concentration was relatively high. The average influent concentrations during start up are shown in Table 4.

As a result of the weak influent, mixed liquor build up within the basins was very slow. Importing sludge was considered and also addition of organic trade waste (“whisky slops”) to accelerate start up. Owing to lack of biological load, two compartments only were used to start up the process. Eventually the two compartments in use were operated using an extended cycle to maximise the utilisation of available BOD and hence the growth of mixed liquor organisms. Once mixed liquor had accumulated in two compartments, these were

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Four basin CASS cycle configuration</th>
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</thead>
<tbody>
<tr>
<td>Basin 1</td>
<td>Fill aerate</td>
</tr>
<tr>
<td>Basin 2</td>
<td>Fill settle</td>
</tr>
<tr>
<td>Basin 3</td>
<td>Fill aerate</td>
</tr>
<tr>
<td>Basin 4</td>
<td>Decant</td>
</tr>
</tbody>
</table>
used as a source of seed sludge for the rest of the plant. Although a degree of foaming is to be expected during start up of any activated sludge-based process, a high level of detergents present in the influent wastewater caused severe problems with foaming particularly wherever flow passed over a weir. Detergent usage is high in Bangkok with restaurants, street hawkers, etc., tending to wash under running water. The levels of foam resulted in the ultrasonic level measuring systems being adversely affected. Software changes were made to change the mode of control from measured level to number of inlet pumps running, where possible.

As the existing sewers were intercepted, significant quantities of inert silty material were drawn into the sewers through existing pipework, culverts and septic tanks. As a result, the influent suspended solids concentration has always been high in relation to BOD. The silty material in the influent is too fine to be removed in the grit removal stage of preliminary treatment and so passes through to the CASS™ process. This results in the process mixed liquor having a very high inert fraction, approximately 70%.

The performance test to determine plant acceptance by the client was carried out using three compartments in three basins operating on a 2 h 40 min cycle to suit a flow of around 100,000 m³/day. This configuration was chosen to concentrate organic load without exceeding the hydraulic capacity. For contractual reasons, the performance test was undertaken as soon at the CASS™ process was capable of producing a final effluent that complied with the specified final effluent quality. This was achieved before the CASS™ process was fully mature. Effluent quality during the performance test is shown in Table 5.

Alum was dosed throughout the test to assist P removal but was stopped at the end of the test since the required standard was being achieved without alum dosing. During the test, the intermediate pumping stations on the collection system were commissioned and brought on line. Flow into the works was an average of 106,000 m³/day. The odour control and sludge treatment systems were not operated during the performance test as recorded H₂S levels were generally very low although odour control fans were operated to ventilate plant and process areas for safety reasons. Owing to the need to accumulate mixed liquor within the process, no sludge was wasted from the process during the performance test. The blowers were operated on an on/off cycle at reduced speed to prevent over aeration. In the short term, it was not possible to utilise the normal method of blower control by dissolved oxygen profile because of high dissolved oxygen levels in the influent wastewater. Attempts to use the preferred method of control based on a preset DO profile resulted in insufficient mixing to keep the mixed liquor thoroughly mixed.

The plant passed its performance test and was accepted by the client. The plant was officially opened, on time and within budget, on 14 December 1999.

Table 5 Performance test final effluent data

<table>
<thead>
<tr>
<th>Units</th>
<th>Average</th>
<th>Maximum</th>
<th>Units</th>
<th>Average</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD</td>
<td>5.3</td>
<td>11.9</td>
<td>NH₃-N</td>
<td>4.4</td>
<td>6.7</td>
</tr>
<tr>
<td>Suspended solids</td>
<td>10.4</td>
<td>16.0</td>
<td>Phosphorus</td>
<td>0.6</td>
<td>1.7</td>
</tr>
<tr>
<td>TKN</td>
<td>6.1</td>
<td>8.9</td>
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</table>
Yannawa operational experience – post-performance test. On the collection system, the interceptor chambers were opened and this caused a gradual increase in flow but this was later balanced by a falling off as rain stopped completely. The influent BOD concentration slowly increased but nine compartments in service were still sufficient for the hydraulic and organic loads. Air blower run time (duty and assist units) was increased but the cycle remained at 2 h 40 min. Refinements continued to be made to the control system (for example, set point optimisation). Over a period of time as the collection system was developed, the influent BOD increased to over 100 mg/l and occasional spikes of suspended solids up to 300 mg/l were recorded, often at the start of the wet season as solids were flushed through the collection system. Illegal discharges may also contribute to short-term high solids loads. DWF is considered to be around 150,000 m³/day now that all interceptor chambers have been opened. Sludge build up was allowed to continue in the CASSTM compartments to find the optimum level for treatment. The mixed liquor concentration in the compartments was adjusted towards a target of 7,000–8,000 mg/l, taking into account the low volatile fraction of the mixed liquor.

At the start of the wet season following the performance test, additional compartments were brought on-line resulting in a CASSTM configuration of four basins, four compartments per basin. The process cycle time was adjusted to 3 h. During wet season conditions, average inlet BOD concentrations are approximately 50 mg/l and suspended solids average around 100 mg/l. Influent dissolved oxygen levels increase during the wet season and achieving denitrification is a problem as a result. Reducing the intensity of aeration in zone 2 has helped the effluent to remain within specification. Khlong operation has been a problem in the dry season since high water levels are maintained to prevent odour nuisance from the khlongs themselves. As a result, khlong water backflows into collection system and dilutes the sewage. Foam problems have all but disappeared but control is maintained in accordance with the number of inlet pumps running. Foam does reappear occasionally, particularly after a very heavy storm.

Sludge treatment by combined thickening/dewatering units was subject to a separate performance test. The specified requirement was for 20% minimum dry solids. 25–30% dry solids was achieved with nominal polymer dosing owing to the high inert content of the mixed liquor solids. The lime dosing plant was tested functionally and accepted. Odours from the plant even before odour treatment were generally negligible. The odour control system was commissioned and tested by injecting hydrogen sulphide into the inlet air. No odours were detectable at the site boundary and no complaints were received from the local residents.

Influent characteristics. Influent BOD concentrations are much lower than specified for the treatment works design (see Figure 2). Influent suspended solids concentrations are normally less than specified but occasional peak solids loads to over twice the specified concentration occur. These usually coincide with the start of the wet season when the collection system is flushed out by high flows.

Final effluent results. The first year of plant operation up to the end of year 2000 following take over by the client was the responsibility of the contractor. Subsequent plant operation was the responsibility of the BMA. The BMA’s preferred method of operation is to maximise the amount of mixed liquor solids within the CASSTM basins. This results in a prolonged sludge age and minimises the waste sludge for disposal. A highly mineralised waste sludge is also produced. Final effluent solids concentrations are within consent but relatively high (see Figure 3) as the basins are controlled to contain as much mixed liquor solids as possible. Note that, owing to the high inert fraction of the mixed liquor solids, the final effluent BOD concentration is generally less than 5 mg/l despite the relatively high solids content.
Conclusions

The SBR that was adopted as the basis of the plant design offered a highly competitive solution in terms of both capital and running costs. The process was shown to be free from odours, reliable, flexible and able to adapt to influent conditions considerably different from those specified. The SBR was able to accommodate operating mixed liquor levels which were well above the design maximum to compensate for the high inert fraction of the influent and to minimise sludge production. Recorded final effluent quality exceeded the requirements of the specification without the use of chemical dosing.

Acknowledgements

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References


