An Investigation in the Effectiveness and Optimisation of Smart ponds for Sludge Management

Raveena Maria Raju

Anas Ghadouani and Liah Coggins
Civil, Environmental and Mining Engineering
The University of Western Australia

Beatrice Yong and Andrew Chua
CEED Client: Water Corporation

Abstract

Advanced Facultative Ponds or "Smart" Ponds are wastewater stabilisation ponds that combine the advantages of facultative and anaerobic ponds. Incomplete understanding of sludge deposition, accumulation patterns and the effect of pond hydraulics on sludge accumulation, means sludge management in smart ponds can be improved. The objective of this project is to enhance understanding of the various factors affecting sludge accumulation rates and patterns, enabling analysis of the problems hindering online desludging of smart ponds and identification of the actions needed to resolve them. From a series of site inspections and experiments, it was found that the poor flow characteristics of settled anaerobic sludge and the pond hydraulics may be the reasons for difficulties in desludging rather than the suspected phenomenon of rat-holing. CFD modelling is being undertaken to improve understanding of the pond hydraulics. The modelling results will guide recommendations for improving the efficiency of sludge management in smart ponds.

1. Introduction

Advanced facultative ponds or smart ponds are wastewater stabilisation ponds that consist of a conventional facultative pond with a deeper anaerobic pit engineered to its bottom. These ponds facilitate aerobic and anaerobic digestion in a single system, eliminating the need for separate systems, and thereby saving land area. The influent wastewater is fed into the bottom anaerobic pit, which are designed taking into consideration the solids sedimentation rates and the digestion rates, to ensure that only the non-organic component of the raw influent settles down in the pit. The settled solids and anaerobic bacteria are constantly disturbed by the evolution of biogas bubbles, causing a rise and fall of solids within the pit. This creates an anaerobic layer through which wastewater has to flow. The gases produced from anaerobic digestion are oxidised in the upper aerobic section, avoiding odour problems. The depth of the anaerobic pits eliminates any chance of oxygen inhibiting the fermentation process. As a result, smart ponds facilitate methane fermentation more efficiently than simple facultative ponds (Green, et al., 1996).

1.1 Previous Investigation in Smart Ponds

A smart pond (Pond A) in the southwest of Western Australia was chosen as the primary study site. The smart pond is the primary treatment system of the Wastewater Treatment Plant (WWTP), with a total treatment capacity of approximately 13,300 m^3. The design depth of the pond is 7 m, with 5 m for the anaerobic section and 2 m for the facultative section. The design influent velocity of the pond is around 0.6-1 m/s. The inlet and sludge withdrawal pipes are positioned at the bottom of the pond. The pipe configuration is shown in Figure 1. Desludging attempts at Pond A have led to the withdrawal of diluted sludge which was far from the expected thick consistency of digested sludge. Suspecting that inlet 1 might be disrupting the flow of sludge during desludging, inlet 1 was shut for a short period. The pond was desludged after a few months, but there was no significant change in the flow.

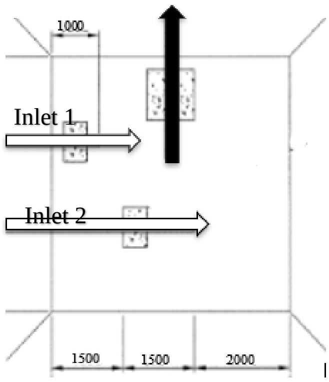


Figure 1 Inlet pipes (white) and sludge withdrawal (black) pipe configuration at a height of 0.5m from bottom of the smart pond (Water Corporation, 2017).

Two other smart ponds (B and C) of different pipe configurations and geometry, in the north west of Western Australia were also assessed, to understand the effect of inlet and sludge pipe positions on efficiency of sludge withdrawal and flow patterns. Successful desludging has been recorded at Pond B. The overall objectives of this study are to analyse the different bio-physiochemical factors affecting sludge settling rates and patterns, investigate the occurrence of rat-holing and assess the pond hydraulics through detailed CFD modelling to suggest reccomendations for efficient sludge management.

2. Methods

2.1 Sludge Profiling

To quantify the sludge present in the pond and determine its spatial distribution, sonar profiling was done using a remote-control boat developed by UWA in collaboration with Water Corporation. The boat was operated at a low constant speed of 2-4 km/hr (Coggins, et al., 2017). Care was taken to turn off the aerators at least half an hour prior to the profiling, to ensure dissipation of air/gas bubbles in the water column that may affect the results. Sludge profiling using a sludge judge was carried out to validate the sonar profiling data, and identify any stratification in sludge layers, or variations in turbidity and concentrations in the water column. The high-resolution bathymetric data obtained from sonar profiling was plotted using the Sludge Pro software. Since Sludge Pro does not take into account the unique geometry of smart ponds, volume corrections were added wherever necessary to obtain the actual sludge volumes.

2.3 Sampling and Anaysis

Wastewater samples from the inlet, outlet and various points in the pond were analysed to determine Chemical Oxygen Demand (COD), Total Nitrogen (TN), pH and Suspended Solids

(SS). The removal efficiency of each parameter was determined and compared with previous reports to identify any variations in the trend. While the sludge judge test was carried out, sludge samples from seven sampling points (see Figure 2) of the pond were also collected and tested for percentage total solids. The dissolved oxygen (DO) and Oxygen Reduction Potential (ORP) were also measured at various depths to identify anaerobic conditions or dead zones.

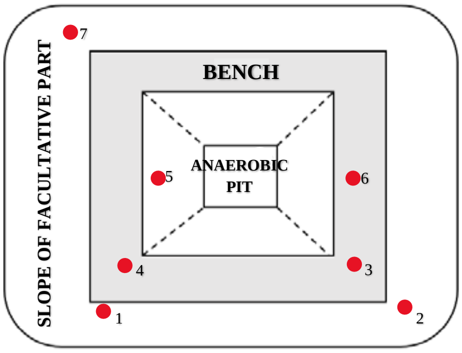


Figure 2 Sludge samples collected from six sampling points.

2.4 Temperature Profiling

To identify any stratification peculiarities in the pond and obtain spatial data to calibrate the 3D model, temperature profiling was carried out along the depth of the pond. This was done using the YSI 5239 Dissolved Oxygen probe to monitor the temperature. The probe was initially suspended at 7m (at centre of the pond) and pulled back by 1m, to log the temperature at each 1m interval. The sludge withdrawal pipe was flushed for 5 minutes and the temperature of the discharge was measured. The ambient temperature was also recorded.

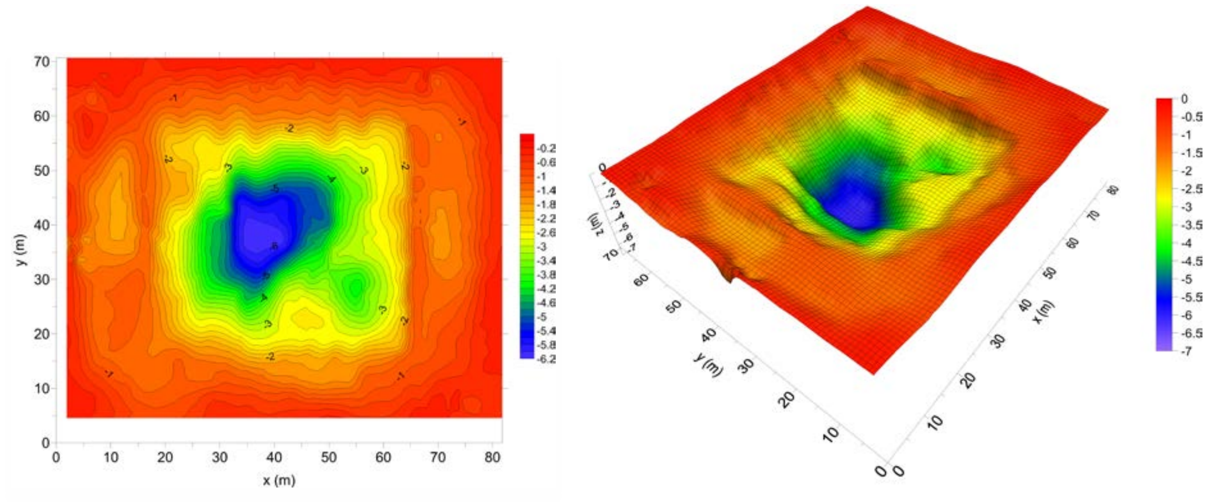
2.5 Modelling

To attain a deeper understanding of the pond hydraulics on sludge settling patterns, the data collected from site were input into the CFD software Flow 3D, to generate a 3D hydrodynamic model. Flow 3D was chosen as it has an inbuilt sludge settling model which will help ascertain the effect of flow dynamics on sludge settling rates. The 3D model still needs to be calibrated in order to achieve reliable results.

3. Results and Discussion

3.1 Sludge Profiling

The bathymetric data collected by the sonar boat were plotted to produce a sludge profile of the pond. Since the Sludge Pro software does not take into account the geometry of the pond, volume corrections were made where necessary, to give the actual sludge and water volume of the pond. From the results of sonar profiling (see Figure 3) it was determined that about 22 percent (Table 1) of the pond was filled with sludge, which is about 2785m^3 of sludge. Assuming a sludge accumulation rate of 0.04m^3/person/year (Mara, 2004) and an average regional population of 6000 (Australian Bureau of Statistics, 2016), approximately 240 m^3 of sludge is expected to accumulate each year. As the pond has not been desludged since it was put into operation, multiplying by the years of operation (12) yields an expected total sludge volume in the pond of 2800 m^3, which compares well with the measured volume of 2783 m^3.

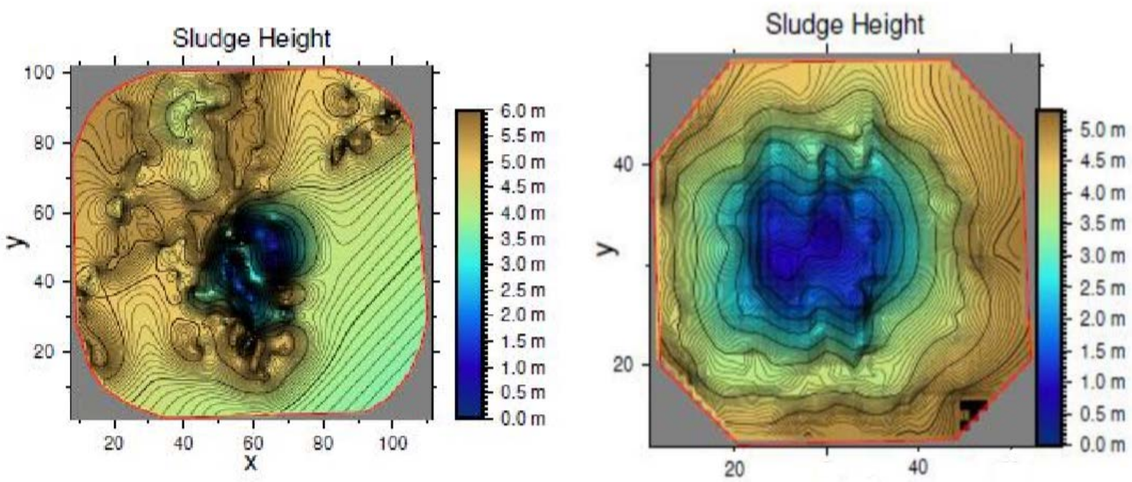


(a) **(b)**

Figure 3 (a) 2D and (b) 3D contour plots of water depth (depth from water surface till top of sludge) in the profiled Smart pond A. The colour scales indicate the water depth from the surface in metres.

Depth (m)	Total Volume (m^3)	Water Volume (m^3)	Sludge Volume (m^3)	Sludge Infill (%)
7	12,448.34	9665	2783.34	22.36

Table 1 Corrected total, water and sludge volumes from the volume results computed by Sludge Pro Software



(i) (ii)

Figure 4 Contour plots of Sludge distribution in Smart pond (i) pond B and (ii) pond C

In Figure 3 it is evident that a significant quantity of the sludge lies in the facultative portion of pond A, with greater accumulation at the corners. The sludge accumulation in the anaerobic pit was lower than expected, especially at the bottom near the inlet and sludge withdrawal pipes, with a sludge height of only 0.5-0.7m. Pond B and Pond C (Figure 4) show similar patterns, with sludge infill of 38% and 25% respectively. Comparing the sludge profiles with the pipe configurations, a ‘no to little sludge zone’ was observed around the inlets, contradicting the idea that most settling occurs near the pipe. This can be attributed to the pond hydraulics being affected by the pipe configuration, which can be further investigated through CFD modelling.

3.2 On- Pond Sampling on Pond A

COD, TN, TP and SS concentrations in the influent and effluent samples were fairly consistent with previous analysis records and no peculiarities were observed. Table 2 shows the %TS of the seven sludge samples collected from the pond. It can be observed that the total solids content from all the sampling points fell within 1.2-3%. A higher solids content was observed for the sludge samples retreived from the SW corner of the bench (sampling point 4), SE Corner of pond (sampling point 2) and NW corner of the pond (sampling point 7). The sludge samples were highly viscous and odorous. The DO readings by these sampling points were nearly zero with highly negative ORP values, indicating anaerobic digestion. Stratification of sludge was also observed in the sludge judge column at sampling point 6, where the top suspended sludge layer was fluffy in appearance while the bottom settled sludge layer was thick and highly viscous. Considering that the solids content of the sludge retrieved from the bench regions to be greater than 2%, the settled sludge in the deeper sections of the pond may be highly anaerobic with high solids content and poor flow characteristics. Sewage sludge with a solids content of 2-8% is generally viscous and anaerobic in nature, and could impose problems while desludging, as illustrated in Figure 5 (Watson, 1999).

Sampling Point	%TS
1	1.7
2	2.1
3	1.5
4	2.6
5	1.73
6 (top suspended layer)	1.22
6 (bottom settled layer)	1.9
7	2.9

Table 2 Corrected total, water and sludge volumes from the volume results computed by Sludge Pro Software

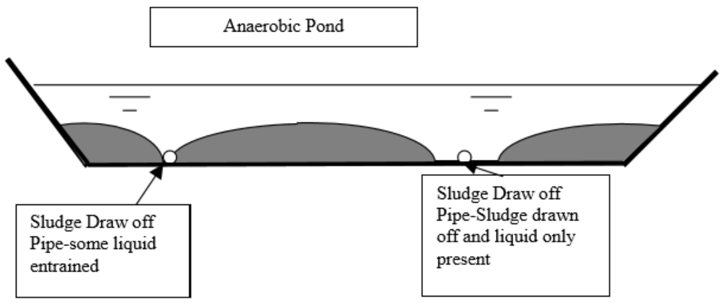


Figure 5 Typical Sludge Draw-Off Problems from Anaerobic Ponds (Watson, 1999)

3.3 Temperature Profiling

The temperature profiles of all three ponds showed a similar trend. The temperature decreased gradually over the first 1m and was fairly stable over the next 2-3m. The temperature increased slightly towards the bottom of the pond. This increase in the temperature could be a result of the probe coming in contact with the sludge layer at the bottom of the pond. In Pond A, the mouth of the sludge withdrawal pipe lies in the ‘no to little sludge zone’ near both inlets. This fact coupled with the highly viscous nature of the sludge could potentially be the reason for no solids being drawn out via the sludge pipe. This could also mean that there may not be any rat-holing occurring when flushing the sludge pipe, and it could be just the supernatant wastewater being drawn out of the sludge pipe. In short, the problem hindering desludging in pond A may not be ratholing but the highly viscous nature of the sludge. In contrast, the sludge pipe of Pond B is placed outside the ‘no to little sludge zone’, which could possibly be the reason why desludging pond B has been successful.

4. Conclusions and Future Work

Sonar sludge profiling in smart pond has revealed uneven deposition of sludge within the pond, with a larger quantity of sludge accumulating in the facultative portion. The difficulties encountered in desludging Pond A could potentially be due to the lack of sufficient transport momentum to draw out the highly viscous sludge. To study the effect of inlet 1 on sludge accumulation in Pond A, inlet 2 was turned off on the 9th of August, for a period of 4 months. The sludge withdrawal pipe will be opened after this period to see if there are any significant changes in the discharge. The transportation of sludge from the deep pit to the facultative portion is facilitated by the pond hydraulics. This will be further studied by detailed CFD modelling using Flow 3D. A 2D model using Mike 21 will also be built to compare and validate the flow results from both models. Methods to prevent transportation of sludge from the lower pit to the upper facultative portion, such as, the provision of a suitable nylon mesh at the top of the anaerobic pit, could be a potential area for future research.

5. Acknowledgements

A special thanks to my mentor, Beatrice Yong and Andrew Chua from the Water Corporation for being a constant source of unconditional support and inspiration. It was an honour to work with such experienced professionals from the water industry. I would like to offer my deepest gratitude to Anas Ghadouani and Liah Coggins from the University of Western Australia for always giving me direction and guidance to get through this project.

6. References

Coggins, L. X., Ghisalberti, M. & Ghadouani, A., 2017. Sludge accumulation and distribution impact the hydraulic performance in waste stabilisation ponds. Water Research, pp. 354-365.

Green, F. B., Bernstone, L. S., Lundquist, T. J. & Oswald, W. J., 1996. Advanced Integrated Wastewater Pond Systems for Nitrogen Removal. Water Science and Technology, pp. 207-217.

Mara, D., 2004. Domestic Wastewater Treatment in Developing Countries. 2nd ed. London: Earthscan.

Watson, M., 1999. Continuous anaerobic pond desludging, North Sydney: Meat and Livestock Australia Limited