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Effects of high-strength faecal sludge in wastewater stabilization ponds: Port-au-Prince, Haiti

A.L. Martinsen, A. Kahler, V. Hill (USA) J.A. Darius & E. Petit, Haiti, R. Gelting (USA)

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At the request of the Haitian National Directorate for Potable Water and Sanitation (DINEPA), the Centers for Disease Control and Prevention (CDC) performed an evaluation of the Morne à Cabri wastewater stabilization pond (WSP) serving the Port-au-Prince metro area. In order to assess the performance of the facility, samples were taken from faecal sludge trucks entering the system to characterize influents and from each process unit to assess the reduction of BOD_5 (Biochemical Oxygen Demand) and other parameters. Although design expectations were met for BOD_5 removal, the system was overloaded with organics and solids, leading to quick sludge accumulation. More monitoring is required, and possible design modifications should be made to reduce the quantity of high-strength faecal sludge entering the system.

Introduction

Port-au-Prince, Haiti, home to more than two million people, remains one of the world's largest metro areas without a municipal sewer system (PAHO, 2012), and most residents rely on on-site sanitation facilities such as latrines, septic tanks, or cesspools. On-site sanitation facilities require regular emptying and disposal, especially in densely-populated urban areas such as Port-au-Prince where space is limited (WSP, 2014). For the purposes of this paper, we will refer to all waste emptied from on-site sanitation facilities as faecal sludge (Strande, 2014).

Prior to the 2010 Haiti earthquake, no waste disposal or treatment facilities existed in Port-au-Prince. Instead, faecal sludge taken from on-site facilities was often dumped into open canals or municipal solid waste dumps posing a potential health threat (Golder, 2013b). Although prior plans were in place, the 2010 earthquake and cholera epidemic sparked international investment in the National Directorate for Potable Water and Sanitation (known by its French acronym DINEPA) to accelerate construction of wastewater stabilization pond (WSP) facilities. The first facility to open was Morne à Cabri, located northeast of the capital city, and was completed in June of 2012 (Golder, 2013b).

WSPs were chosen as the most cost-effective treatment option in Haiti. They are ideal in tropical climates where sufficient land is available at close proximity to the service area, as a high level of pathogen removal and oxidation of organic matter is possible with low capital costs and limited operation and maintenance required (Kalbermatten, 1982 & Mara, 2004).

At the request of DINEPA, an initial performance evaluation of the Morne à Cabri wastewater treatment facility was conducted between March 2014 and September 2015 to determine if the facility was operating in accordance with its design, to better characterize the influent faecal sludge, and to assess the effect of high-strength faecal sludge on treatment. Although WSPs are generally ideal for tropical climates, there is little research on their performance in treating large amounts of high-strength faecal sludge, particularly from latrine waste. Preliminary research suggest that large doses of faecal sludge may present treatment challenges, such as fast sludge accumulation and high ammonia concentrations (Strande, 2014).

Design and operation of Morne à Cabri

The Morne à Cabri WSP facility incorporates three types of treatment units: anaerobic, facultative, and maturation ponds. Trucked faecal sludge (from septic tanks and latrines) is passed through grates to remove larger solids and enters the system into two parallel anaerobic ponds where the process of five-day biochemical oxygen demand (BOD_5) removal begins under anaerobic conditions. BOD_5 is the amount of dissolved oxygen consumed by microorgnanisms in the oxidation of organic matter in water (or wastewater or faecal sludge) over a five-day period (Bitton, 1999). Currently, there are no international standards on maximum BOD_5 discharged into a receiving water or for treatment facilities' effluent in general; however, this parameter serves as a good indicator of overall performance of the facility (Strande, 2014).

A layer of sludge is formed at the bottom of the anaerobic ponds, which must periodically be removed. Following the anaerobic ponds, the flow enters a facultative pond (Golder, 2013a). The facultative pond is shallower than the anaerobic ponds, which helps to promote the removal of BOD_5 by photosynthetic algae on the surface of the pond (Kalbermatten, 1982). It is in the anaerobic and facultative ponds where the majority of BOD_5 removal is designed to take place. Finally, the flow enters into a maturation pond, which is designed to enable additional removal of pathogens and nutrients as well as some further removal of BOD_5. Following these three main treatment steps, any overflow from the maturation pond flows through a monitoring basin and enters a constructed wetland designed to provide further wastewater treatment. There is no discharge from the facility at this time, as effluent is lost to seepage and evaporation (Golder, 2013a).

Typical untreated wastewater from municipal sewers has a BOD_5 in the range of 200-700 mg/L (Mara, 2004 & Renolds, 1996). In the absence of available data for typical faecal sludge in Port-au-Prince, a value of 1,500 mg/L BOD_5 was used in the design of the facility for influent. The estimated design flow into this facility was 500 m^3/day. The design estimated a 97% removal efficiency of BOD_5, which would result in a final BOD_5 of 45 mg/L.

At present, the facility receives faecal sludge that is emptied from latrines, septic tanks, and cesspools from households, hospitals, and government and UN facilities. Pumper trucks carry faecal sludge that has been emptied through hydraulic suction from septic tanks or latrines, when possible. Faecal sludge from latrines is often manually excavated by *bayakous*, sanitation workers who typically work at night in Port-au-Prince and other urban areas. Latrine waste excavated by *bayakous* is brought to the facility in 55-gallon barrels.

Methods

In order to assess the performance of the system as a whole and individual unit processes, grab samples were collected from barrels and trucks transporting faecal sludge to the facility, and from pipes between each unit process at the facility, and the monitoring basin when possible. Log data from DINEPA was used to estimate the volume of each type of waste discharged into the system. CDC staff were able to visit the facility on three occasions over a 21-month period between March 2014 and November 2015. On each sampling visit (three total), we collected one sample from each process step, as well as samples from trucks and barrels. The number of samples collected at each visit was limited to 11 total, due to the testing methods of BOD_5. All values of faecal sludge from barrels and trucks were used to calculate a geometric mean for influent characteristics. All other values from the ponds and effluent were used to provide a snapshot of the performance of the facility on that given day of the visit.

As BOD_5 was the main criteria used in the design of the Morne à Cabri facility, this was also the primary indicator used to assess its performance in this preliminary evaluation. Other parameters, such as chemical oxygen demand (COD), total suspended solids (TSS), total nitrogen (TN), total phosphorous (TP), Enterococcus (ENT), total coliforms (TC) and *E. coli* (EC) were also assessed. However, this discussion focuses on BOD_5, both because that was the main design parameter for the Morne à Cabri facility and due to results available at this time.

At each sampling location, approximately one liter of sample was collected, including one 250-mL bottle for BOD_5. All samples were kept chilled during handling. This 250-mL bottle was shipped to CDC headquarters in Atlanta, GA without preservation (but chilled) for BOD_5 testing.

Results

Estimating inputs into the facility

The system receives inputs from both pumper trucks (which pump faecal sludge from septic and holding tanks) and barrel trucks (in which *bayakous* manually collect faecal sludge from latrines and cesspools). Using data collected from DINEPA between September 2013 and March 2015, it is estimated that approximately 74% of inputs entering Morne à Cabri by volume come from pumper trucks and 26% from barrel trucks. The average daily flow into the system was calculated to be approximately 160 m^3/day. This is approximately one third of the design flow of 500 m^3/day.

The results of BOD_5 tests for the inputs, shown below in Table 1, were highly variable. The BOD_5 for the trucks was as low as 252 mg/L and as high as 40,000 mg/L for the faecal sludge from the latrine waste barrels. Due to the large range of values, the geometric mean of both the inputs from the pumper trucks and the barrel trucks was calculated to normalize the results, and the weighted average was calculated using the proportions of wastewater entering the system estimated above. The weighted average for BOD_5 entering the system was 4,310 mg/L, almost three times greater than the design value.

Table 1. BOD_5 test results

Type of input	BOD_5 (mg/L) range	BOD_5 (mg/L) geometric mean
Pumper trucks, n=8	252-2,260	581
Barrels, n=8	5,160-40,000	14,900
Weighted average		**4,310**

The estimated influent BOD_5 for the design was 1,500 mg/L (or 1,500 g/m^3) and the design flow into the ponds was 500 m^3/day. Based on the volume of both anaerobic ponds of 3,780 m^3, the design volumetric loading rate of BOD_5 is 198 g/m^3 day (Golder, 2013a) compared with 182 g/m^3 which was calculating using the weighted average, shown above in Table 1, and the average daily flow.

Reductions of BOD_5

Using the calculated weighted average of the inputs reported above, the reductions of BOD_5 were calculated for each cell and the system overall. Based on these calculations, the overall system approximately met the design expectation of 97% reduction of BOD_5, with a final effluent unfiltered BOD_5 of 77 mg/L in November 2014. There was no flow from the maturation pond in March 2014 or September 2015, so the final effluent could not be analyzed. Table 2 below shows the estimated reductions by unit process where possible. Reduction in the anaerobic pond was calculated relative to the weighted average for BOD_5 entering the system calculated above and in subsequent ponds relative to the previous process step. The geometric mean of effluents from the anaerobic ponds was used to calculate reduction in the facultative pond.

Discussion

While the volume of faecal sludge entering the Morne à Cabri WSP is less than a third of what it was originally designed for, the estimated volumetric loading rate of BOD_5 is approximately at capacity. This is primarily due to the high strength of the faecal waste from the latrine waste barrels. The range of values for BOD_5 found in the barrels was approximately 5,000 to almost 40,000 mg/L, which is much higher than previous literature would suggest. Although more sampling is required to confirm these results, this evaluation does suggest that the design value for BOD_5 in this facility and others receiving faecal sludge from latrines should be higher than the original value of 1,500 mg/L depending on the proportion of waste that comes from latrines.

The facility does appear to be performing approximately as designed according to the levels of BOD_5 reduction; however, the volumetric loading rate of BOD_5 implies that the facility is at capacity and would not be able to support a larger volume of faecal sludge, given the high strength of the latrine waste.

The accumulation of sludge at the Morne à Cabri has been a significant challenge, and emptying of the anaerobic ponds has been required multiple times. Not only can the sludge accumulation increase the

operation and maintenance challenges at the facility, but it may also it may decrease the effective treatment volume of the anaerobic ponds and therefore also decrease total retention time. According to the design, more BOD_5 reduction should take place in the facultative pond, whereas the maturation pond is used for clarification and nutrient and pathogen removal; however, the results from November 2014 show that the BOD_5 reduction in the maturation pond was lower than the anticipated design reduction, 56% actual compared with 70-85% design (Golder, 2013a). One possible explanation for lower performance in the facultative pond is the high ammonia content of faecal sludge. Facultative ponds rely on algal growth in their top layer to break down organic matter; yet, this may be inhibited by ammonia (Still, 2012).

Table 2. Results of BOD_5 and % reductions in BOD_5 at Morne à Cabri, March 2014 to September 2015

Sampling date	Sampling location	BOD_5 (mg/L)	% Reduction BOD_5
March 2014 (No flow in pipes between ponds. Samples taken from inside of ponds)	Anaerobic pond 1	1,482	66%
	Anaerobic pond 2	246	94%
	Facultative pond	508	16%
	Maturation pond	232	54%
	Overall		**95%**
November 2014 (All samples taken from effluent pipes of ponds)	Anaerobic pond 1	606	86%
	Anaerobic pond 2	2,094	53%
	Facultative pond	274.6	56%
	Maturation pond	77	72%
	Overall		**98%**
September 2015 (No flow from anaerobic pond 2 or from maturation pond. Other samples taken from effluent pipes of ponds. Overall reduction based on effluent from facultative pond)	Anaerobic pond 1	245	94%
	Facultative	47.4	--
	Overall		**99%**

Photograph 1. Private pumper truck disposing of faecal sludge at Morne à Cabri WSP, November 2014

Photograph 2. Accumulated sludge from anaerobic ponds and trash stored on site at Morne à Cabri WSP, November 2014

Conclusions and lessons learned

The topics of faecal sludge characterization and treatment of high-strength faecal sludge in traditional wastewater treatment facilities are not understood well. More research is needed to better characterize the strength of faecal sludge and to better understand how this high-strength waste affects treatment in wastewater stabilization ponds.

Although little research is available on the performance of WSPs for treating high-strength waste, there are several possible design modifications that should be further evaluated to improve performance at Morne à Cabri and other facilities in Haiti. Since solids are a major issue at the facility—both total suspended solids and trash from latrines—it is recommended that steps be taken to prevent solids overloading. Possible modifications to the existing facility include adjusting the grates to prevent larger solids from entering the system or utilizing the existing unused sludge drying beds for pretreatment of high strength faecal sludge. These changes may help to reduce the problem of BOD_5 and TSS overloading of the system; however, more evaluation would be necessary for implementing these changes, such as the amount of space required to accommodate the solids and whether composting is a viable option at Morne à Cabri. Ultimately, the faecal sludge solids diverted from the system would need to be disposed of somewhere, and at present, there is no long-term solution at the facility for the disposal of sludge solids that accumulate in the ponds.

Also important is the implementation of a plan to routinely monitor the performance of this facility. As this evaluation only took grab samples from one day and seasonality was not considered, it is important to build local laboratory capacity and begin performing regular analysis of key parameters to ensure that the facility is working properly. Additional parameters should also be assessed, including ammonia and sludge depth in the ponds. While the facility is not discharging into the environment at this time, more analysis would be necessary if effluent were to be discharged in the future to ensure that it doesn't pose health or environmental risks.

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Notes

[1] No data from JMP 2012 on what percentage of latrines were shared. Most recent data on shared latrines was from 2003, showing that approximately 19% of households used a shared latrine.

[2] The World Health Organization (WHO) does have effluent reuse standards for BOD_5, which depend on the intended reuse, such as fish farming, irrigation, or groundwater recharge. Because the Morne à Cabri facility does not discharge effluent, these standards would not be applicable at present.

Contact details

About the author: Andrea L. Martinsen has degrees in civil engineering and public health. She is a member of the Global WASH Team of the Emergency Response and Recovery Branch of CDC. Dr. Richard Gelting, Dr. Vincent Hill, and Amy Kahler also work at the CDC in Atlanta. Jean Allain Darius of Haiti is a civil engineer with CDC Haiti, and Edwige Petit is the director of sanitation at DINEPA in Haiti.

Andrea L. Martinsen
Centers for Disease Control and Prevention,
2500 Century Pkwy,
NE MS E-22, Atlanta, GA USA 30345.
Tel: 1 (404) 498-0235
Email: amartinsen@cdc.gov
www: http://www.cdc.gov/globalhealth/healthprotection/errb/