Treating faecal sludges in ponds

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Abstract Waste stabilisation ponds are a widely accepted and proven technology to treat wastewater. It is often stipulated (and also practised) that the design of ponds for faecal sludges (FS), septage in particular, should follow the same principles as for wastewater. Field research conducted by SANDEC and its partners at the Water Research Institute in Ghana, and information gathered from the scarce literature on FS treatment, however, has shown that design principles should be taken into consideration, which are specific to the treatment of FS. These principles depend on the type of FS to be treated and on the type of pond system envisaged. Issues dealt with in this article are the handling of FS solids; the role of anaerobic ponds in FS treatment; the anaerobic degradability of septage; and ammonia (NH_3–N) toxicity.

Keywords Ammonia toxicity; anaerobic ponds; facultative ponds; faecal sludge(s); septage

Faecal sludges – the magnitude of the problem

Compared to wastewater treatment technology, the development of sustainable options to treat faecal sludges (FS) has long been neglected. This is in spite of the fact that, depending on the city or town selected, from 65–100% of urban dwellers in Africa and Asia and some 20–50% of urban dwellers in Latin America are served by on-site sanitation systems. These comprise unsewered family and public toilets, aqua privies and septic tanks. The sludges accumulating in these installations are mechanically or manually collected and hauled to places of discharge or direct agricultural or aquacultural use. Only rarely are FS subjected to treatment. Where treatment systems exist, ponds form an important component. Design and operational guidance for FS treatment options and technologies likely to be sustainable in developing countries are still widely lacking.

Table 1 shows characteristics of faecal sludges sampled in Bangkok, Manila and Accra, along with average septage quality data from the U.S. (Heinss *et al.*, 1998). The strength of FS compared to wastewater is higher by several factors or even by an order of magnitude. Faecal sludges may be classified in two broad categories. One is sludges which are rather fresh and exhibit high concentrations of organics, ammonium and solids. They originate from non-flush or pour-flush public toilets and bucket latrines and may have been stored for a few days or weeks only prior to collection. The other category comprises sludges of relatively weak strength as the solids separated in the vaults or pits are normally collected along with flush and greywater retained in the tank. Moreover, these sludges have usually been stored for lengthy periods of time (from one to several years) and, hence, undergone biochemical stabilisation to a considerable extent. Septage normally falls into this category. It is important to assess in each case the characteristics of the FS or FS mixtures to be treated to be able to devise the appropriate type of treatment.

Faecal sludge and ponds

Table 2 lists the problem variables and their associated impacts on pond systems. They are then elaborated upon in the subsequent paragraphs. Information presented below was

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Table 1 Faecal sludge versus wastewater characteristics

		Bangkok septage* 90 samples	Manila septage* 15 samples	Accra septage* 60 samples	Accra public toilet sludge* 60 samples	U. S.** septage	Tropical sewage
COD_{total}	mg/l	16,900	37,000	7,800	49,000	43,000	500–2,500
$COD_{filt.}$	mg/l	–	–	230	5,300	–	–
COD/BOD		6.2	9.7	6–12	6.4	9	2:1 – 2.5:1
TKN	mg/l	830	2,800	–	–	700	–
NH_4–N	mg/l	340	–	330	3,300	160	30–70
TS	mg/l	18,600	72,000	11,900	52,500	38,800	< 10,000
TVS	%	72	76	60	69	65	–
Helm. eggs	no./l	4,000	5,700	4,000	25,000	–	300– 2,000

* Data generated during collaborative field research 1994–98 ** US-EPA, 1984

Table 2 Problem variables

Variable	Effects and expected problems
• TS	Relatively large bulks of accumulating solids; potential difficulties in pond performance unless solids are properly separated; potential difficulties in solids removal from deep ponds
• TVS; organic stability	Fresh, high-strength, as yet little digested FS requires stabilisation prior to solids–liquid separation. Septage is in many cases still conducive to further anaerobic stabilisation; its direct treatment in facultative ponds causes excessive land use
• NH_4 / NH_3	Ammonia toxicity in anaerobic and/or facultative ponds; process failure

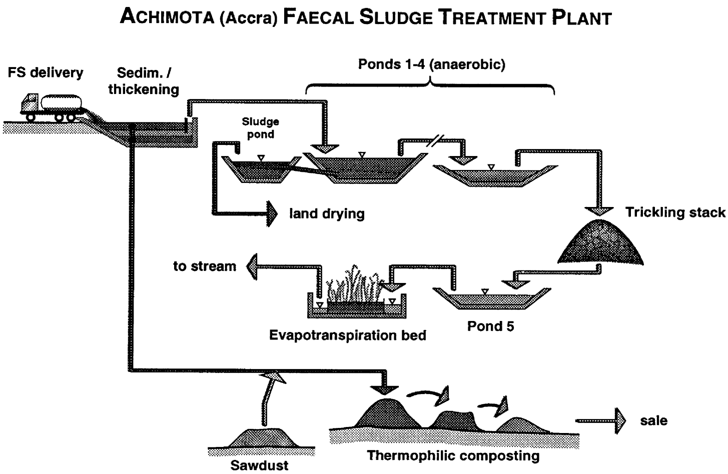

Figure 1 Schematic diagram of the achimota FSTP in Accra, Ghana

generated mainly through the monitoring campaigns conducted at the full-scale faecal sludge treatment plant (FSTP) of Achinota, Accra (Ghana) between 1994 and 1997.

Figure 1 is a functional sketch of the plant, which was commissioned in 1989. It receives 135 m^3/d of FS, of which 20–25% are high-strength public toilet sludge and 80–75% septage. Plant monitoring comprised the twin sedimentation tanks (t=1.7 days), and ponds no. 1–4 (operated in series; depths=1–0.6– 0.7–0.6 m; t=11–5–4–5 days).

The case of FS solids: their separation and handling

Faecal sludges typically exhibit total (TS) and suspended solids (SS) contents which are very high, compared to wastewater. When treating FS in ponds, be it separately or in conjunction with wastewater, settleable solids must be separated in primary treatment units in order to guarantee an undisturbed treatment of the liquid fraction. Process disturbance by improper design and operation for solids separation has been repeatedly observed (Hasler, 1995; Mara *et al.*, 1992). The settleability of FS can, as a first approach, be determined by settling tests in graduated cylinders at laboratory scale. Thereby, approximate information can be gained regarding the rate of settling and the density of the separated solids. The settleability of faecal sludges varies considerably depending on the type of sludge and specific location (U.S. EPA, 1984; Heinss *et al.*, 1998). Results from FS settling tests carried out in Accra, see Figure 2, have shown that Accra's septage, which has average TS contents of 12,000 mg/l (thereof, 60% volatile solids, TVS), exhibits good solids-liquid separability. Separation under quiescent conditions is complete within 60 minutes. This holds also for FS mixtures containing up to 25% by volume of fresh, undigested sludge from unsewered public toilets.

The rate of accumulation of settleable solids, hence, the required solids storage volume, is the decisive design criteria for preliminary settling/thickening units or for solids storage compartments in primary ponds. The specific volume occupied by separated solids may be assumed as 0.10–0.15 m^3/m^3 of raw FS, depending on FS composition and on the period allowed for solids consolidation and thickening.

Figure 3 shows the solids accumulation pattern in settling/thickening tanks operated in Accra and receiving a 3:1 mixture of septage and fresh, high-strength sludge. The batch-operated tanks have theoretical filling + consolidation (resting) cycles of 4+4 weeks. Four

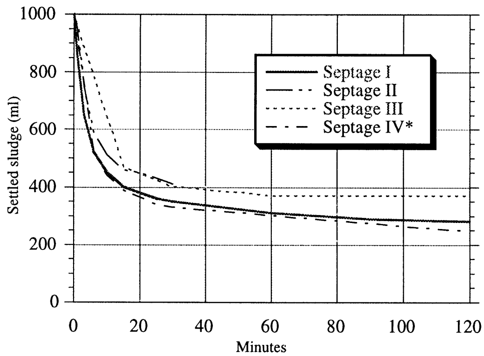

Figure 2 Results of settling tests performed in 1-litre cylinders (Septage I-III) and in a cylinder of 20 cm diameter and 2 m height (Septage IV*)

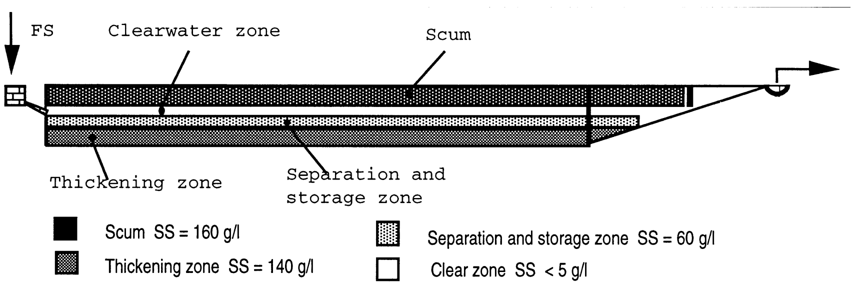

Figure 3 Batch-operated sedimentation/thickening tank with four distinct layers of Separated Solids (solids removal is by front-end loaders) (Heinss *et al.*, 1998)

zones characterised by distinct solids densities develop in the course of one cycle. Thickened solids densities range from 14% TS in the settled solids layer to 16% TS in the scum layer. The fairly thick scum layer is due to the share of undigested, high-strength sludges from unsewered public toilets and their associated intensive gas production causing buoyancy.

Batch-operated settling/thickening is, in most cases, the technology-of-choice in developing countries, as electro-mechanical installations for continuous sludge removal may not prove sustainable. Primary ponds may constitute an alternative to settling tanks where this proves feasible for reasons of land availability, construction cost and solids removal operations. Such ponds can be designed as deep ponds to comprise a compartment for solids accumulation, with pond emptying intervals of >1 year. However, the solids removal from the storage compartment may pose great technical difficulties, as high solids densities quite likely prevent gravity lifting under static pressure. Therefore, ponds of conventional depth requiring solids removal every 3–6 months constitute a more feasible option in most situations. Such ponds are currently being tested in Alcorta, Province of Rosario, Argentina, in a plant where septage and wastewater are co-treated in a pond system. Septage is thereby pretreated for solids-liquid separation and anaerobic stabilisation in two parallel, batch-operated ponds, the supernatant of which is co-treated with wastewater in a waste stabilisation pond system.

The handling of biosolids accumulated in pre-settling tanks or in shallow primary ponds is easier compared with deep primary ponds. Solids emptying intervals are relatively short – from weeks to a few months – and, hence, smaller volumes have to be removed and further treated at a time than when having to handle large bulks of biosolids accumulated in deep ponds over one or more years.

The case of organic stability: anaerobic ponds

Introduction

Given the frequently high organic strength of the faecal sludges, anaerobic ponds – with or without prior solids removal in separate settling units – are a feasible option for primary pond treatment in warm climates. Use of facultative ponds for raw faecal sludges may often not be possible due to the high ammonia levels hindering algal growth (see the section below on ammonia toxicity). Also, with the organic strength of faecal sludges being much higher than in wastewater, uneconomically large land requirements would result. FS, which largely or exclusively consist of fresh, high-strength sludge, are not conducive to solids separation. Primary treatment in anaerobic ponds might be the method-of-choice in developing countries to render such FS conducive to further treatment, i.e. solids-liquid separation and polishing of the liquid fraction.

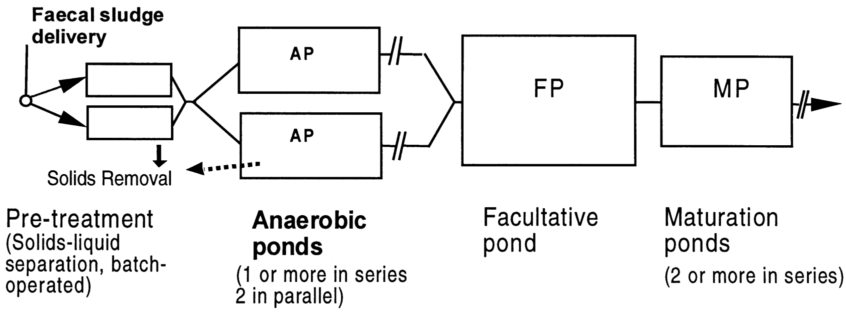

Figure 4 Schematic drawing of a WSP system treating low to medium-strength faecal sludges

Figure 4 shows a WSP system suitable to treat low to medium-strength faecal sludges. It comprises separate pre-treatment units for separate solids elimination followed by a series of one or more anaerobic ponds and a facultative pond. Maturation ponds will have to be added if the effluent is to be used for irrigation of vegetables consumed uncooked. Solids-liquid separation may alternatively be integrated in primary anaerobic ponds; yet, relatively short loading/resting cycles should be adhered to.

Anaerobic pond performance

The upper limit of the volumetric BOD loading rate for anaerobic ponds is determined by odour emissions and minimum pH threshold value at which methane formation as the second step in the anaerobic decomposition processes ceases to work. It is, however, not possible to establish a commonly valid maximum BOD loading rate for anaerobic ponds at which odours will not become a problem. Formation of odour is strongly dependent on the type of waste to be treated in the plant, notably its sulphate (SO_4) concentration and volumetric loading rate, respectively (Mara and Pearson, 1986). For high-strength waste such as FS, multi-stage pond systems comprising two or more anaerobic ponds in series each operated at a maximum BOD loading rate, will result in lowest land requirements (Uddin, 1970; McGarry and Pescod, 1970).

Figure 5 shows BOD removal and oxygen concentrations in the pond system of the Achimota FSTP during a 10-week monitoring campaign conducted in 1994. The plant was loaded with a 4:1 septage : high-strength FS mixture during this period. The Figure shows that considerable BOD removal did occur but it was entirely limited to the settling tanks (removal of settleable BOD) and the first, anaerobic pond. No further degradation, whether anaerobically or aerobically took place. Anaerobic conditions prevailed throughout the system, although ponds III-V were originally designed as facultative ponds. This can be attributed to ammonia (NH_3) toxicity for either methane-forming bacteria (hindering further anaerobic degradation) or for algae (hindering the development of facultative pond conditions).

Methanogenesis is the rate-limiting step in anaerobic metabolism. Products from the preceding acetogenesis reaction may accumulate and lead to a pH decrease. Optimum pH for methanogenesis amounts to 6.8–7.8. Based on various anaerobic digestion studies,

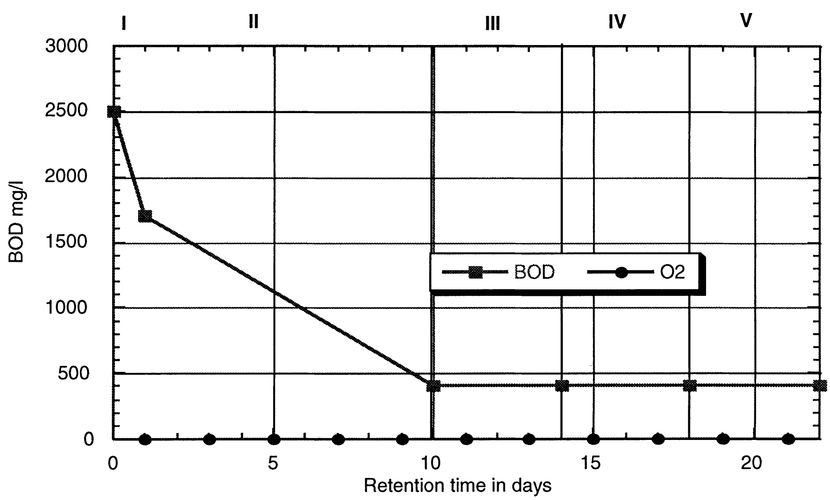

Figure 5 BOD and Oxygen in the Various Treatment Units of the Achimota FSTP in Accra/Ghana. I: Sedimentation/ Thickening Tank; II: Primary Pond; III, IV, V: Ponds Designed as Facultative but Operating as Anaerobic Units (Results of a 10-Week Study Conducted in early 1994)

McGarry and Pescod (1970) found that pH 6.0 probably constitutes the absolute, lowest limit for anaerobic ponds in the tropics when treating high-strength wastes. Determination of the maximum BOD loading rate beyond which pH is likely to drop below this threshold value is, therefore, important. A reason why anaerobic ponds treating FS might be loaded at higher rates than anaerobic ponds treating wastewater is the high alkalinity of FS imparted by the formation of ammonia bicarbonate (NH_4HCO_3) during the hydrolysis of urea (H_2NCONH_2). A high buffer capacity results. This acts as a safeguard against the drop in pH caused by the potential predominance of acid over methane-forming bacteria induced by excessive organic loading rates. Mara *et al.* (1992) suggest a safe volumetric BOD loading of 300 $g/m^3 \cdot d$ for anaerobic wastewater ponds at temperatures above 20ºC. A tolerance value of 400 $g/m^3 \cdot d$ is given at which odour emissions can still be avoided. More practical research is required to establish the maximum safe loading rates for wastes such as septage and septage/high-strength FS mixtures in warm climates.

Is septage conducive to anaerobic treatment ?

The question whether septage is conducive to anaerobic treatment and concurrent COD or BOD reduction is still open to debate. It would be reasonable to assume that, in a warm climate, septage is not or barely digestible as it has normally undergone extensive storage prior to collection. Mara *et al.* (1992) argue that anaerobic ponds might not be required as septage is already highly mineralised. Data on the content of total volatile solids (TVS) in septage, one measure indicating the anaerobic degradability, differ significantly. Mara and Sinnatamby (1986) observed bottom sludge of septage tanks having TVS of 40–50% at temperatures of 26–28.5ºC, hinting to a rather stable product. Strauss *et al.* (1997) published data for septage quality in tropical and temperate climates where the reported TVS values amount to about 60% of TS. This indicates that the particular septage samples were still rather unstable. The degree of mineralisation is not only dependent on temperature, but also on emptying frequency, sludge composition and on grease content. In many cases, septage is probably mineralised only partially during storage in the septage tank. Findings by the US EPA (1984) tend to support this assumption: anaerobic digestion of septage yielded TVS reductions of 30–47%.

Results obtained in recent investigations by SANDEC and its partners at a full-scale septage treatment plant in Thailand having unmixed, batch-operated, unsealed anaerobic digesters, and with lab-scale digestibility tests revealed that septage is anaerobically degradable to a varying degree (Puetbaiboon, 1999). This reflects the fact that individual truckloads of septage collected in cities usually exhibit widely varying biochemical stability. More experiments will be conducted to allow a safe quantification of the anaerobic degradability of septage based on gas production and its correlation to reductions in % TVS and soluble COD.

The case of ammonia toxicity: how does it affect pond systems?

Faecal sludges are high in ammonia (NH_3)

Ammonia (NH_4+NH_3–N) concentrations in faecal sludges range from ≥300 mg/l in septage to ≤5,000 mg/l in high-strength, rather fresh faecal sludges (Heinss *et al.*, 1998). NH_4 and NH_3 are in a temperature and pH dependent relationship. At 30ºC, NH_3 amounts to approximately 5% of (NH_4+NH_3–N) at pH 7.8, and 10% at pH 8.2. NH_3 is the potentially toxic component in anaerobic processes and in facultative ponds (inhibition of algal growth).

In the primary pond of the Achimota FSTP, average ammonium concentrations amounted to 1,000 mg NH_4–N/l during the monitoring campaigns conducted at the Achimota FSTP. Average maximum air temperatures amounted to 30ºC and average pH was 8. The corresponding NH_3–N level was 75 mg NH_3–N/l. The average (NH_4+NH_3)–N concentration in the pond 4 effluent was 700 mg/l. Natural NH_3 stripping, given a total retention period in ponds 1 through 4 of 25 days, may explain the loss. Mean NH_3–N levels in ponds 2–4 ranged between 50–70 mg/l.

Ammonia toxicity to methane-forming bacteria

No lab or field-scale investigations on the inhibiting effect of ammonia (NH_3) towards anaerobic bacteria have as yet been carried out with faecal sludges. Experiments conducted by Siegrist (1997) on the toxicity of NH_3–N for methane bacteria in digesters treating wastewater treatment plant sludge showed a 50% growth inhibition at NH_3–N/l concentrations of 25–30 mg/l. The question whether these can be transferred to anaerobic ponds remains to be examined.

Average NH_4–N concentrations of 1,100 mg/l were measured in pond 1 during a one-month monitoring cycle conducted in May 1997. BOD elimination in the first pond was then observed to be as low as 10%, but increased to 35% and 60%, respectively, in the secondary and tertiary ponds. This contrasts with the results of the first study shown in Figure 5 above. Anaerobic degradation was apparently shifted from the primary pond, in which excessive NH_3–N concentrations had an inhibitory effect, to the subsequent ponds where NH_4–N amounted to below 1,000 mg/l.

Ammonia toxicity to algae

No sign of measurable O_2 or algae growth could be observed during the investigative phases from 1994–1997 at the Achimota FSTP (see Figure 5 above). This indicates that all ponds were anaerobic, that facultative pond conditions did not develop, and that therefore no BOD elimination took place, although the surface loading rates ranged within permissible limits. These amount to 300–600 kg BOD/ha · day at temperatures of 30ºC depending on the empirical design model chosen (Mara *et al.*, 1992).

Excessive ammonia NH_3–N concentrations of 50–70 mg/l in ponds 2 through 4 were the likely cause for severely hindered algal growth. Kriens (1994) found that tolerance limits for *Chlorella vulgaris* and *Scendesmus obliquus* are 6 and 31 mg NH_3–N/l, respectively. These algae commonly form an important share of the algal biomass in facultative ponds. Some algal species are reportedly able to adapt to and withstand concentrations of up to 50 mg NH_3–N/l under specific conditions (Mara and Pearson, 1986).

Methods proposed to counteract the suppression of facultative pond conditions include intermittent surface or cascade aeration, lime dosing and recirculation, or a mixture thereof. Their aim would be to lower the ammonia concentrations and, hence, to eliminate NH_3 toxicity effects.

Summary and conclusions

Treatment technologies for faecal sludges

Treatment technologies such as continuously mixed anaerobic digesters with gas utilisation or chemically aided mechanical dewatering in centrifuges or filter presses, as are used for treating sludges in industrialised countries, prove unfeasible for the majority of situations in developing countries. Pond systems constitute one basic option to treat faecal sludges, as they tend to be associated with low investment and operating cost and do not require skilled labour (but skilled engineers!).

Solids separation

In treating FS, whether separately or in conjunction with wastewater, much larger relative volumes of separated solids accumulate in primary treatment units than when treating wastewater. The rate of accumulation of separated and consolidated (thickened) solids varies from 0.10–0.15 m^3 per m^3 of raw FS. The preferred technological options to achieve solids-liquid separation are non-mechanised, batch-operated settling tanks or ponds having short operating cycles with loading and resting periods of a few weeks to a few months only. This limits the volume of accumulated solids to be handled and further treated at a time.

Anaerobic ponds

Organic loading limits for anaerobic ponds treating FS have not been established yet, but the authors hypothesise that rates of up to 600–700 g $BOD/m^3 \cdot day$ might be tolerated in tropical climates as against 300–350 g $BOD/m^3 \cdot day$ for wastewater ponds. Field research is required to test this hypothesis, which is derived from the fact that the high organic N (protein) content of FS imparts high alkalinity to FS ponds through the formation of ammonia bicarbonate during protein hydrolysis.

Anaerobic degradability of septage

Although most septage has usually been stored for months or years prior to collection, it has become apparent that, in many cases, it is still conducive to anaerobic degradation. Treating septage in anaerobic ponds ahead of facultative pond treatment is likely to yield land savings.

Ammonia (NH_3 toxicity)

Anaerobic degradation of medium to high-strength FS can be impaired by toxicity due to high ammonia (NH_3) concentrations. NH_3–N threshold levels in the influent to anaerobic ponds in the tropics should not exceed 400–500 mg/l. The often high ammonia contents of FS may also lead to toxicity in facultative ponds, either impairing or preventing the growth of algae. The respective threshold level in facultative pond influents is 400 mg NH_3–N/l. Suggested but as yet untested countermeasures to reduce ammonia and its toxicity effects are intermittent surface aeration at the inlet section of facultative ponds treating FS; cascade aeration of the pond influent; pond effluent recirculation; lime addition, or a combination thereof.

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