Low-cost Options for Treating Faecal Sludges (FS) in Developing Countries – Challenges and Performance *

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Abstract

This article analyses and discusses the performances of low cost technology for treating faecal sludges (FS) in developing countries. The state of research shows two trends: where septic tanks are the predominant type of on-site sanitation (OSS) installations (like in many towns and cities in Latin America and Asia), septage is the only or predominant type of FS generated, and, the following pre-treatment options might prove suitable: constructed wetlands with solids loading rates (SLR) ≤ 250 kg TS/m^2/year, settling tanks/ponds (design based on solids accumulation rates and expected operation mode), or unplanted drying beds (SLR ≤ 200 kg TS/m^2/year). Pre-treatment will, in the majority of cases, have to be followed by processes catering for the polishing by algal or macrophytes ponds or by constructed wetlands, separately or in combination with municipal wastewater designed with the same rules as for domestic wastewater. In many African cities, highly concentrated and biochemically unstable sludges, such as those from unsewered public toilets or single-pit latrines occur in considerable proportions. Their high ammonia content (400-4,000 mg NH_4^+-N/L) inhibits algal growth in pond systems and might impair plant growth in constructed wetland. Appropriate low-cost treatment options for such FS need as yet to be developed.

Keywords

Faecal sludge, septage, stabilization ponds, constructed wetlands, drying beds

INTRODUCTION

Contrary to wastewater management, the development of strategies and treatment options adapted to the conditions prevailing in developing countries to cope with faecal sludges (FS) – the by-products of on-site sanitation installations - have long been neglected. In recent years though, an encouraging number of initiatives for improved FS management, including the devising of appropriate FS treatment schemes, have emerged, particularly so in several West African cities (Senegal, Mali, Ivory Coast, Burkina Faso, Ghana), in South East Asia (Nepal, Thailand, Vietnam) as well as in Latin America. These initiatives help urban dwellers and authorities to overcome the challenges posed by what might be designated the "urban shit drama" – the indiscriminate and uncontrolled disposal of faecal sludges into drains, canals, and onto open spaces, thereby creating a "faecal film" prevailing in urban areas and impairing public health, causing pollution and creating nose and eye sores.

The authors estimate that in the order of one third of the world population (approx. 2.4 billion urban dwellers) rely on on-site sanitation (OSS) installations, viz. unsewered family and public latrines and toilets, aqua privies and septic tanks. This situation is likely to last for decades to come, since city-wide sewered sanitation is neither affordable nor feasible for the majority of urban areas in

* Paper presented to the 9th International IWA Specialist Group Conference on Wetlands Systems for Water Pollution Control and to the 6th International IWA Specialist Group Conference on Waste Stabilisation Ponds, Avignon, France, 27 Sept. – 1 Oct., 2004.

developing countries. Using the figure of 1 L FS/cap/day as an average FS generation rate in urban areas (based on literature data and own investigations), in the order of 1,000 m^3 of FS should be collected and disposed of in a city of 1 million inhabitants. However, reported daily collection rates for cities much larger than this – e.g. Accra, Bangkok, and Hanoi – rarely exceed 300-500 m3. This indicates that huge quantities if not the major fractions of the FS generated are disposed of unrecorded and clandestinely within the urban settlement area. Among the many causes for this are the inadequacy of the FS collection and haulage systems; the non-affordability of mechanised pit emptying by the urban populace; the difficult-to access OSS installations for emptying vehicles; excessive haulage distances to designated disposal or treatment sites in large cities, and the lack of satellite treatment sites and low-cost treatment options at affordable haulage distances.

The treatment processes considered by the authors as potentially suitable for developing countries comprise:

- Solids-liquid separation:
- Settling/thickening tanks or ponds (non-mechanised, batch-operated)
- Unplanted drying beds
- Constructed wetlands
- Pond treatment of FS supernatants or percolates
- Combined composting ("co-composting") with organic solid waste
- Anaerobic digestion with biogas utilization

These options, with the exception of anaerobic digestion, have been experimented and investigated upon during ten years of collaborative field research with selected partners in Latin America, West Africa, and Asia.

The paper presents the basic features of the cited options and reports on their performance at pilot and field scale. The lessons learned and gaps-in-knowledge are discussed.

CHALLENGES IN TREATING FAECAL SLUDGES

The choice of an FS treatment option depends primarily on the characteristics of the sludges generated in a particular town or city and on the treatment objectives (agricultural reuse or landfilling of biosolids; discharge of treated liquids into receiving water bodies). Contrary to wastewater, FS characteristics vary widely within and between cities, based on the types of on-site sanitation installations in use and on the emptying practice. Sludges from septic tanks are biochemically more stable due to long storage periods than sludges from installations, which are emptied at only weeks' intervals (e.g. public toilet vaults). In cities like Bangkok, Hanoi, and Buenos Aires, e.g., septic tanks are the predominant form of OSS installations. When septic tanks are emptied, both the solids and liquid portions are usually pumped out. This renders septage more dilute than the pumpouts from unsewered public toilets or from pit latrines. Where soak pits are used for infiltrating the septic tank supernatants, they may have to be emptied, too, due to clogging. This contributes to diluting the FS collected in a particular settlement. In West Africa, an important fraction of the urban population relies on public toilets, which are usually highly frequented. In Kumasi (Ghana) e.g., a city of 1 million inhabitants, 40 % of the population rely on unsewered public toilets, which are emptied at weeks' frequencies. The sludges collected from these installations are biochemically unstable (high in BOD5) and exhibit high NH_4^+-N concentrations, as urine is disposed of with the faeces. The specific challenges in treating FS in developing countries as opposed to treating wastewater lie in the fact that contaminant concentrations in FS are by a factor of 10-100 higher than in municipal wastewater, and that appropriate, affordable, and enforceable discharge and reuse standards or guidelines pertaining to FS treatment are lacking. Table 1 lists FS characteristics as observed by the authors and their partners in selected cities in Africa and Asia. The fact that faecal sludges exhibit widely varying characteristics, calls for a careful selection of appropriate treatment options, notably for primary treatment. Primary treatment may encompass solids-liquid separation or biochemical stabilization if the FS is still rather fresh and has undergone but partial degradation during on-plot storage and prior to collection. Faecal and WWTP sludges may, in principle, be treated by the same type of modest-cost treatment options.

Table 1. FS characteristics in selected cities in developing countries (based on investigations conducted by SANDEC's field research partners)

Parameters	**Accra (Ghana)**	**Accra (Ghana)**	**Ouagadougou (Burkina Faso.)**	**Bangkok (Thailand)**	**Alcorta (Argentina)**
Type of FS	*Public toilet sludge*	*septage*	*Septage*	*septage mean (range)*	*septage mean (range)*
TS (mg/L)	52,500	12,000	19,000	15,350 (2,200 – 67,200)	(6,000 – 35,000 SS)
TVS (% of TS)	68	59	47	73	50 (VSS)
COD (mg/L)	49,000	7,800	13,500	15,700 (1,200 – 76,000)	4,200
BOD_5 (mg/L)	7,600	840	2,240	2,300 (600 – 5,500)	(750 – 2,600)
TN (mg/L)	---	---	2,100	1,100 (300 – 5,000)	190
NH_4-N (mg/L)	3,300	330	-	415 (120 – 1,200)	150

TREATMENT PERFORMANCE

Table 2 provides an overview on how selected treatment processes or process combinations are able to achieve reductions of selected contaminants or constituents.

Table 2. Overview of selected options and expected removal efficiencies for treating faecal sludges

Treatment process or option	**Design criteria**	**Treatment goal / achievable removal**		
		Solids-liquid separation	**Organic pollutants in liquid fraction**	**Parasites (helminth eggs)**
Settling / thickening tank	SAR*: 0.13 m^3/m^3 of raw FS HRT: ≥ 4 h S: 0.006 m^2/cap Accra	SS: 60-70 % COD: 30-50 %	To be treated for further improvement in ponds or constructed wetlands	Concentrated in the settled and floating solids
Settling / anaerobic pond	300-600g $BOD_5/m^3/d$ HRT: ≥ 15 days SAR: 0.02 m^3/m^3 (Rosario) and 0.13 m^3/m^3 (Accra)	BOD_5 > 60-70 %	filtered BOD_5 > 50 %	Concentrated in the settled and floating solids
Drying/dewatering beds	100-200 kg TS/m2/year 0.05 m^2/cap(Accra)	SS : 60-80 % COD: 70-90 % NH_4^+-N : 40-60 %	To be treated for further improvement in ponds or constructed wetlands	100 % retained on top of the filtering media
Constructed wetlands (planted drying beds)	≤ 250 kg TS/m^2/year SAR: 20 cm/year (Bangkok)	SS > 80 % SAR: 20 cm/year	To be treated for further improvement in ponds or constructed wetlands	100% retained on top of the filtering media
Facultative stabilization ponds	350 kg BOD_5/ha/d	Not for this purpose	> 60 % removal of BOD_5	Removed by settlement

**SAR : Solids Accumulation Rate*

Solids-liquid separation

Basic considerations. The separating of the solids and liquids, which make up FS, is the process-of-choice in FS treatment unless it is decided to co-treat FS in an existing or planned WWTP and if the FS loads are small compared to the flow of wastewater. Solids-liquid separation may be achieved through sedimentation and thickening in ponds or tanks or filtration and drying in sludge drying beds. Resulting from this are a solids and a liquid fraction. When treating sludges with intensive biochemical activities such as those collected from public toilets in West African cities, anaerobic digestion and solids-liquid separation take place in the same treatment unit. The biogas originating from the digestion process adheres to suspended solids that form a scum layer. As the tank is being loaded, the thickness of the scum and the settled solids layers increase while the interstitial, "clear" liquid layer is gradually reduced. The separated solids, will in most cases require further storage, dewatering, drying, or composting resulting in biosolids usable as a soil conditioner-cum-fertilizer. The liquid fraction will normally have to undergo polishing treatment to satisfy criteria for discharge into surface waters and/or to avoid groundwater pollution, where effluents are allowed to infiltrate.

Septage usually settles well (≤ 30-60 min under quiescent conditions). In contrast to this, fresh and biochemically active sludges do neither settle nor are they dewaterable e.g. on sludge drying beds. Hence, sedimentation tanks with hydraulic retention times (HRT) of but a few hours (≤ 4 h) can be used for solids-liquid separation of septage but not of unstable sludges. These have to be either admixed to septage at ratios, which enable quasi-discrete settling (septage: fresh sludge = 2-3 : 1 by volume) or be treated in a primary anaerobic/sedimentation pond, which provides ≥ 15 days HRT to allow for biochemical stabilization prior to sedimentation and solids thickening.

The choice of either sedimentation tanks or ponds, besides depending on the type of sludges to be treated, is also determined by the mode of operation envisaged and by the provisions, which will be made for handling the mass of solids to periodically be removed from these primary treatment units. Solids quantities produced in sedimentation/thickening tanks, which, in their low-cost version, will be non-mechanised and batch-operated, and operated in loading / consolidating cycles of weeks to a few months, will be much smaller than the mass of solids to be removed and handled from primary ponds. These have typical operating cycles of 6-12 months, unless measures are introduced, by which settled solids are evacuated at higher frequencies without stopping pond operations. Treatment plant operators might be overtaxed by having to deal with pond emptying, particularly in larger schemes, where large machinery such as front-end loaders would be required for days or weeks to cope with the solids mass. Moreover, land might be lacking for natural sun drying or for sludge drying beds having to treat such large quantities of thickened sludge within short periods of time.

Settling ponds. Suspended solids (SS) removal efficiencies of up to 96 % are achieved in two alternating, batch-operated septage sedimentation ponds in Alcorta, Argentina (Ingallinella *et al*., 2000). The concomitant solids accumulation rate amounts to 0.02 m^3/m^3 of raw FS. The quality of the septage pond effluent (COD =650 mg /L, BOD_5=150 mg /L, NH_4^+-N=104 mg /L) resembles that of the urban wastewater, allowing the combined treatment of the two liquids in a WSP system comprising a facultative and a maturation pond (Ingallinella *et al*., 2000). Septage deliveries to the pond in operation is suspended and the supernatant transferred to the parallel pond when the settled solids layer has reached 50 cm. The accumulated sludge is let to dewater until a TS concentration of 20-25 % and, hence, spadability is attained. This lasted up to 6 months under the temperate-subtropical climate prevailing in the particular area (400 km W of Buenos Aires). Bulking material such as grain husks, sawdust or woodchips could be used under such conditions to shorten the insitu storage and dewatering time. This type of settling pond is designed based on an assumed pond emptying frequency and on the known or expected solids accumulation rate.

Settling/thickening tanks. Twin, batch-operated, non-mechanised sedimentation/thickening tanks were put in use by the Accra (Ghana) Waste Management Department in 1989 to treat septage and public toilet sludges at mixing ratios of approx. 3:1. The tanks were intensively investigated upon by the Ghana Water Research Institute and SANDEC from 1994-97 (Heinss *et al*., 1998). Four distinct zones were observed to develop while FS loading was in progress: a lower bottom thickening zone with TS up to 140 g/L (14 %), an upper bottom zone with 60 g TS/L, a settled water zone with 3 – 4 g TS/L, and a scum layer containing up to 200 g TS/L. The settled solids accumulation rate was 0.16 m^3/m^3 of raw FS. SS removals ranged from 60-70 %. The average COD and SS contents in the tank effluents amounted to 3,000 mg/l and 1,000 mg/L, respectively.

Unplanted drying beds. Unplanted drying beds can be used for dewatering and drying of septage, septage/public toilet sludge mixtures at volumetric ratios > 2:1 and of primary pond sludges with initial TS content varying from 1.5 to more than 7%. Dewatering performance varies with the initial TS and TVS content and the applied loads. Pescod (1971), in conducting septage dewatering/drying experiments on yard-scale drying beds in Thailand found that 5 to 15 days of dewatering were necessary to reach a TS content of 25% with initial solids loading rates varying from 70 to 475 kg TS/m^2/year and a loading depth of 20 cm. In Ghana, a dewatered sludge with 40 % TS was obtained from a mixture of septage/public toilet sludge in 12 days with an initial solids loading rate of 200 TS/m^2/year and a loading depth of < 20 cm. With a solids loading rate of 130 TS/m^2/year, a sludge with 70% TS was obtained in 9 days and a reduction in the percolating liquid (compared to the raw sludge mixture) of 60% BOD_5 and 70 % COD was achieved (Strauss, 1996).

Planted dewatering/drying beds (constructed wetlands). Constructed wetlands have been successfully operated for treating Bangkok septage exhibiting 14,000-18,000 mg TS/L by the Asian Inst. of Technology (AIT) from 1997-2004. An optimum loading rate of 250 TS/m^2.year was established based on 6 years of field research with 3 pilot constructed wetland beds (Koottatep *et al*., 2002). The beds were planted with *Typha angustifolia* (narrow-leaved cattail). Each of them has a surface of 25 m^2 and was fed with 8 m^3 of septage once a week. Impounding of the percolate proved necessary to secure sufficient humidity for the cattails which developed wilting symptoms during dry seasons. 70-80% TS, 96-99% SS, and 95-98% tot. COD (TCOD) removals were achieved in the liquid fraction of the septage. TCOD removal was improved by impounding and so was N removal through denitrification. Ponding periods of 6 days were found optimum. The CW were able to accumulate 70 cm of sludge after 4 years of operation while maintaining their full permeability. The TS content of the dewatered sludge varied from 20-25 % in the uppermost layer (< 20 cm) to 30-30 % in the deeper layers. Under steady loading conditions, the percolate quality was constant. TCOD in the percolate amounted to 250-500 mg/L, TS to 1,500-4,000 mg/L and SS to 100-300 mg/L. Experiments with biochemically unstable and highly concentrated sludges as those from public toilets in West African cities could not be conducted to date.

Nitrogen removal

Settling tanks and ponds. Nitrogen removal in settling tanks is negligible due to the absence of nitrification under the fully anaerobic conditions. In pond schemes, N is mainly removed into the organic form by newly forming biomass that later settles and accumulates in the sediments. Additional losses may occur by ammonia (NH_3) volatilization if overall HRT are sufficiently long (weeks to months) and pH rises above 8 enabling the formation of NH_3 in the pH-dependant NH_4 / NH_3 equilibrium (Heinss *et al*., 1998).

Unplanted drying beds. Organic nitrogen is removed with the suspended solids retained on the bed surface (90-97%). NH_3-N is lost by volatilization and the removal efficiency varies with the local climatic conditions (wind, temperature, rain). Experiments from Ghana, conducted with different types of sludges, resulted in N removals of 35-70%.

Planted dewatering/drying beds (constructed wetlands). Nitrogen removal in constructed wetlands treating septage appears to be due mainly to the accumulation of organic-N in the dewatered sludge layers (55-60%). Additional sinks for TKN and (NH_4+NH_3) are due to ammonia volatilization, plant uptake and nitrification/denitrification and accounts for 15-35 %. Percolate concentrations of 100-200 mg TKN-N/L and 50-150 mg NH_4^+-N/L were observed at AIT's pilot scheme with initial concentrations of 1,000 and 350 mg N/L, respectively (Koottatep *et al*., 2002).

Polishing of supernatants and percolates

Although high removal efficiencies of nitrogen can be achieved in some of the above treatment processes, the effluent (or percolate) concentrations remain too high to allow a safe discharge into receiving water bodies. Where the possibility of recycling into agriculture exists, the salt content is often a limiting factor. Electric conductivities (EC) observed in the supernatants of the Accra (Ghana) sedimentation tanks ranged from 8 – 10 mS/cm. In contrast to this, salt tolerance limits of the most tolerable plants are 3 mS/cm. Percolates from AIT's constructed wetlands exhibited EC values of 2-5 mS/cm. In Ghana, pond systems have been developed to polish effluent of the settling/thickening tank pre-treatment units. Yet, algal growth was inhibited due to the excessive ammonia content caused by the highly concentrated public toilet sludges. These exhibit NH_4^+–N + NH_3-N levels of > 3,000 mg/L leading to NH_3–N levels in the FS liquids, which are beyond the toxicity limits of algae of 40-50 mg NH_3-N/L. In Kumasi, Ghana, where septage and public toilet sludges are collected at a volumetric ratio of 1:1, NH_3 volatilising from the newly established FS pond scheme causes eye irritation during hours of high temperature and during periods of insufficient winds. Ammonium concentrations in the public toilet sludges, high ambient high temperatures of >28 °C favour the release of obnoxious amounts of NH_3-N. COD and BOD_5 removals in a series of polishing ponds treating the sedimentation tanks effluents in the Accra FS treatment scheme was insignificant, even with several weeks HRT, as all ponds remained anaerobic (Strauss *et al*. 1997).

Where ammonia concentrations in raw septage were < 400 mg NH3+-N/L, pond treatment or a second stage of treatment in constructed wetlands was efficient in reducing N contents to < 15 mg NH_3^+-N/l and COD < 200 mg/L (Koottatep *et al*., 2002; Ingallinella *et al*., 2000). However, the high salt content prevents the use for irrigation.

CONCLUSIONS

The state of research in adapting low-cost technologies for treating faecal sludge in developing countries shows two trends.

Where septic tanks are the predominant type of on-site sanitation installations and, hence, septage is the only or predominant type of FS generated, treatment schemes might be devised which provide comprehensive treatment of the septage and its by-products (biosolids and liquids). Such schemes might comprise a pre-treatment stage such as constructed wetlands with solids loading rates (SLR) ≤ 250 kg TS/m^2/year, or settling tanks/ponds, or unplanted drying beds (SLR ≤ 200 kg TS/m^2/year) followed by a combination of polishing units (ponds, wetlands, or floating macrophytes-based systems) designed with the same rules as used for domestic wastewater treatment. Where WWTP exist, septage and wastewater treatment might be combined at the same site in a sound manner if FS collection and haulage conditions are conducive. Ideally, separate septage pre-treatment would be devised. The liquid fraction of the FS could be co-treated with the wastewater. Alternatively, FS pre-treatment schemes might be located at strategic, decentralized points near trunk sewers. Such satellite treatment plants could be conceived for solids-liquid separation and solids treatment to produce biosolids apt for agricultural use. The liquid fractions could be discharged into the trunk sewers. The second solution would allow to reducing FS haulage distances and cost.

In West African countries where wastewater treatment facilities are lacking or not performing properly (Koné *et al.*, 2004), co-treatment may not be a sound solution. As discussed in the above paragraphs, the highly concentrated, fresh, and biochemically unstable sludges collected from public toilets constitute a great challenge for treatment by low-cost technologies. Pond systems, although cheap, are likely to fail in those localities where high-strength sludges exhibiting excessive ammonia contents are being generated. Solutions might be sought in different domains: 1), in developing adequate treatment options, and 2), in seeking alternative on-site sanitation systems. The second option requires long-term planning and implementing strategies, since in many countries sizeable proportions of the urban dwellers would have to opt for and install alternative installations. Latrines or toilets allowing for the separate collection of faeces and urine constitute a possible option for reducing the excessive ammonia contents in FS from frequently emptied on-site sanitation installations. Socio-cultural and financial implications are considerable. To meet the treatment challenge, the authors consider anaerobic digestion-cum-biogas utilization for fresh and biochemically unstable sludges as a promising solution. To match local requirements, skills, and financial affordability, simple and robust reactors allowing for secure operations and needing but modest maintenance must be developed. Nitrification/denitrification of settling tank effluents or drying bed percolates in vertical-flow constructed wetlands or by infiltration/percolation might constitute suitable alternatives for reducing excessive ammonia levels. Both options warrant further field research.

ACKNOWLEDGEMENT

All field research carried out by SANDEC's partners in Latin America. Africa and Asia was co-financed by SDC, the Swiss Agency for Development and Cooperation.

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