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TREATMENT OF SLUDGES FROM ON-SITE SANITATION – LOW-COST OPTIONS

M. Strauss*, S. A. Larmie** and U. Heinss*

** Department of Water & Sanitation in Developing Countries (SANDEC), Swiss Federal Institute for Environmental Science & Technology (EAWAG), Ueberlandstrasse 133, CH-8600 Duebendorf, Switzerland*
*** Water Research Institute (Council for Scientific & Industrial Research), Box M 32, Accra, Ghana*

ABSTRACT

An overview of the current literature-based knowledge regarding faecal sludge (FS) treatment along with the results and conclusions from own field research are presented. Issues for further faecal sludge treatment studies are also addressed. The article focuses firstly on the characteristics of the various types of faecal sludge. A set of variables is proposed for minimum faecal sludge determination and faecal sludge treatment plant (FSTP) design and control. Priority treatment options particularly relevant to developing and newly industrialising countries are listed. They include solids-liquid separation by settling/thickening processes, sludge dewatering and drying in drying lagoons or drying beds, stabilisation ponds, and co-composting with refuse or other bulking/organic material of high carbon content. The results of in-depth monitoring of a faecal sludge treatment plant in Accra, Ghana, are reported. The plant receives septage and public toilet sludge and comprises solids-liquid separation by settling/thickening followed by a series of four ponds for the treatment of the liquid fraction. The four ponds in series all function as anaerobic ponds. Facultative pond conditions do not develop. This appears to be due to the suppression of algal growth through high levels of ammonia (NH_3). Final effluent BOD is 300 mg/l as against 2,000 mg/l in the raw sludge mixture and 1,600 mg/l in the sedimentation tank effluent. © 1997 IAWQ. Published by Elsevier Science Ltd

KEYWORDS

Developing countries, faecal sludges, latrine sludges, on-site sanitation, ponds, septage, treatment

RATIONALE

The excreta of most urban dwellers in developing and newly industrialising countries is not disposed of by water-flush toilets and public sewerage systems but through on-site sanitation systems such as latrines, aqua privies and septic tanks. However, faecal sludge (FS) disposal is still an unresolved problem in many developing countries; i.e., the sludges are dumped untreated at the shortest possible distance, be it on open ground, into drainage ditches, into water courses, or into the sea. Growing urbanisation and the concurrent spreading of on-site sanitation systems lead to an increase in faecal sludge quantities to be disposed of. Septage and nightsoil are properly treated in treatment plants designed for this very purpose only in a few cases (e.g. in Ghana and Indonesia). In some countries (e.g. in Botswana, Tanzania, South Africa), faecal sludges are added to the urban wastewater stream for co-treatment in wastewater treatment plants, generally waste stabilisation ponds (WSP). These may easily become overloaded. In China, most of the approximately 30 million tons of sludges that are reportedly collected in the country's cities every year are used untreated in agriculture or aquaculture. Concern regarding the potential health impact has led Chinese authorities and research institutions to increasingly engage in research and development (R+D) for faecal sludge treatment (Ministry of Construction, P.R. China, 1993).

The fact that faecal sludges are usually disposed of untreated is mainly due to missing treatment options adapted to the socio-economic conditions of developing and newly industrialising countries. The treatment technology should be based on locally available and serviceable material and equipment that are simple to operate. EAWAG have therefore embarked on an R+D project concerned with faecal sludge treatment in developing countries. The project aims at producing guidelines on feasible treatment options; developing suitable methods for the assessment of faecal sludges and of faecal sludge treatment plants (FSTP); enhancing the expertise of institutions in developing countries for faecal waste monitoring and control. The project is in its field research phase, with EAWAG currently collaborating with partners in Ghana, Thailand, the Philippines, and China.

FAECAL SLUDGE QUANTITIES AND CHARACTERISTICS

The collected or collectable daily per capita faecal sludge quantities are dependent on the latrine or septic tank emptying practice itself; groundwater levels and infiltration, and soil absorption capacities. The per capita quantities, reported in the literature, vary widely. Figures for collected septage (= faecal sludge retained in septic tanks) can be as low as 0.3 l/cap·day and as high as 13 l/cap·day. Most of the reported values vary between 0.5 and 1 l/cap·day.

Similar to the figures for collected per capita quantities, faecal sludge characteristics vary greatly, too, and depend, among others, on the type of installation (e.g. septic tank, latrine or public toilet); the emptying frequency; the extent of stormwater or groundwater infiltration into latrine or septic tank vaults, and on user habits regarding domestic water use and domestic/personal hygiene.

Table 1 lists the characteristics of septage and faecal sludges collected from unsewered public toilets and pit latrines as reported from various sources. Thereby, a differentiation is made between high-strength sludges such as from unsewered public toilets, and low-strength sludges such as septage (the contents of septic tanks).

Table 1 Important Characteristics and Classification of Faecal Sludges

Item	High-strength	Low-strength	Sewage, for comparison
Example	Public toilet or bucket latrine sludge	Septage	Tropical sewage
Characteri-sation	Highly concentrated, mostly fresh FS; stored for days or weeks only	FS of low concentration; usually stored for several years	
COD	20, - 50,000 mg/l	< 10,000 mg/l	500 - 2,500 mg/l
COD : BOD	5:1 - 9:1	2:1 - 5:1	2:1
NH_4-N	2, - 5,000 mg/l	< 1,000 mg/l	30 - 70 mg/l
TS	≥ 3.5 %	< 3 %	< 1 %
Helm. eggs	20, - 60,000 /l	≤ 4,000/l	300 - 2,000 /l

VARIABLES FOR MINIMUM EVALUATION OF FAECAL SLUDGES AND FAECAL SLUDGE TREATMENT PLANTS

In most developing countries, analytical techniques for the assessment of waste characteristics and waste treatment plants are not routinely applied. One means of overcoming this, is to define selected variables and to develop related methods of analysis which are relatively low-cost and therefore suited for less industrialised countries. Such guidelines must include specifications for sample preparation, dilution, mixing, and homogenisation of faecal sludges.

In spite of its wide use in wastewater analysis and in the design of waste stabilisation ponds, BOD (biochemical oxygen demand) is little suited as a parameter for faecal sludge characterisation owing to difficulties in arriving at reliable results. FS samples have to be properly diluted, homogenised and seeded with aerobic bacteria capable of breaking down organic matter from human waste prior to starting the BOD determination. Samples which are not seeded may take a certain time until an aerobic biomass is sufficiently developed to consume oxygen. The resulting BOD values would consequently be too low. Most laboratories are, however, not equipped or may not have the routine to develop, maintain and use seeds of aerobic bacteria (e.g. from settled sewage). Further to this, BOD bottles should be stirred continuously over the entire five-day period of analysis, particularly when analysing sludges with high contents of suspended solids. Yet, related equipment is rarely available. Reported BOD data may therefore not be taken at their face values.

Where helminthic diseases are endemic, faecal sludges are likely to contain high loads of helminth eggs (mostly nematodes such as *Ascaris*) as illustrated in Table 1. Eggs then constitute the hygienic indicator of choice for untreated sludges, as well as for sludges and compost produced in the treatment process.

Table 2 contains the proposed minimum set of variables to assess untreated faecal sludges as well as liquids and sludges formed during faecal sludge treatment. Variables for faecal sludge treatment plant monitoring and control are also listed. Additional variables will have to be selected for more in-depth monitoring and to cover specific requirements.

Table 2 Minimum Set of Variables for FS and FSTP Assessment

Variables to be Assessed by Laboratory Analyses (Raw sludge and performance assessment)	**Variables to be Assessed by Field Measurements or Observations** (Process and operational control)
• TS (total solids = residue after evaporation at 103 °C) • Volume of settleable and floatable solids • Dewaterability and filterability tests (suitable tests still to be defined) • COD (chem. oxygen demand) (non-filtered and filtered) • BOD (biochemical oxygen demand) * • NH_4-N • Helminth eggs • Faecal coliforms	• Volume of settleable and floatable solids in 1 or 2-litre cylinders • DO (dissolved oxygen) • pH • Colour check for algal growth • Microscopic examination (e.g. for pond organisms) • Temperature (in thermophilic composting) • Settled sludge and scum thickness • Sludge thickness on drying beds • Weather data

* Only if samples can be properly treated and standard analytical techniques be adhered to

PROCESSES AND TECHNOLOGIES

Theoretical and Priority Options

Faecal sludge treatment options can be classified into options with and options without solids-liquid separation or, alternatively, into separate vs. co-treatment options. Co-treatment designates the joint treatment of septage or latrine sludges with municipal wastewater, wastewater treatment plant sludge, household/municipal solid waste or with organic residues such as sawdust or wood chips.

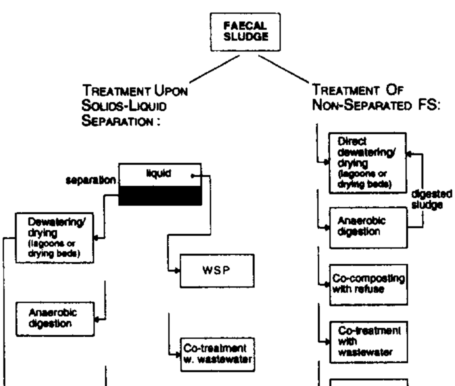

Fig.1 Theoretical options for treating faecal sludges

Fig. 1 shows some theoretical options for faecal sludge treatment. More sophisticated solutions have been excluded from the listing as they are not sustainable in most developing countries. We have chosen to conduct our field research first on those treatment options which appear particularly promising and for which we have found suitable partners and sites. They are solids-liquid separation (settling) and thickening; dewatering/drying on drying beds; stabilisation ponds, and co-composting with municipal solid waste.

Solids/Liquid Separation and Thickening in Settling-Thickening Units

The authors are not aware of any published literature on solids-liquid separation of faecal sludge by gravity settling and thickening (Fig. 2) although it might be a desirable treatment step in schemes comprising faecal sludge stabilisation ponds. Removal of settled sludge and scum in "manageable" portions from settling tanks at a frequency of once a week or every few weeks may operationally be more advantageous than having to remove much larger volumes of settled sludge from primary ponds once every year or every few years. Large volumes of sludge retained in ponds may not dry to consistencies amenable for removal by front-end loaders. If retained sludge is to be pumped in large quantities, intermediate storage basins would be required for operational flexibility prior to further treatment by for example drying beds or co-composting.

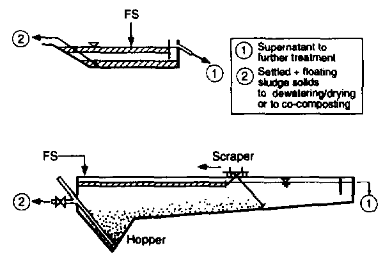

Fig. 2 Solids-liquid separation in settling / thickening tanks

Since 1989, parallel units of batch-operated settling/thickening tanks have been used in two septage treatment plants in Accra, Ghana. Results of field research conducted jointly with the Ghana Water Research Institute in 1994 are presented and discussed later in this article.

Owing to the fairly high degree of sophistication and high capital and repair costs, it is generally unfeasible to equip settling/thickening tanks with automated machinery for continuous sludge scraping and removal. Batch-operated settling tanks fitted with a ramp to allow emptying by front-end loaders appear to be a feasible solution. Semi-continuously-operated units with sludge removal by piped gravity draw-off may constitute an alternative option. They would require only a simple, hand or motor-driven scraping mechanism to periodically transport the settled sludge to the sludge hopper where it could thicken. Future field research on faecal sludge settling/thickening should address the operating patterns for batch and semi-continuously operated units; the tank geometry and hydraulics; solids accumulation rates, and thickening limits.

Sludge Drying Beds

Pescod (1971) and co-workers have carried out, under tropical conditions and parallel to drying lagoon experiments, bench-scale studies on drying bed treatment of septage at the Asian Institute of Technology, Bangkok. At ≤30 cm raw septage loading depths, a 7 - 27 days drying period in sludge drying beds was necessary to increase the solids content from ≤6.5 % to 25 %. Loading rates of 67 - 475 kg total solids (TS)/m^2·yr were applied during the experiments. Results from a first set of tests with pilot-scale drying beds

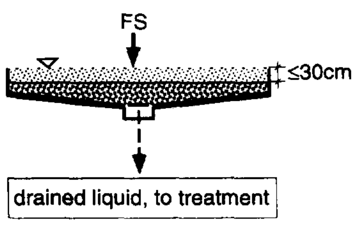

Fig. 3 Drying bed

in Accra, Ghana, with faecal sludges ranging in TS content from 1.6-6.7 %, tend to indicate that shovable consistencies (TS ≥ 20 %) may be attained within 10 days. Some public toilet sludges may take twice that time. Equivalent loading rates ranged from 130-330 TS/m^2·yr. In drying beds (Fig. 3), dewatering occurs both through drainage and evaporation, whereas drying lagoons allow for evaporation only. Drying lagoons must therefore be loaded at lower rates. Loading rates of ≤ 50 kg TS/m^2·yr may be used for drying lagoons in wet tropical climates provided the supernatant is decanted periodically (Pescod, 1971).

Dewaterability and filterability rates of untreated faecal sludges are likely to be lower than of stabilised sludges. Future field research on sludge drying bed treatment of various types of faecal sludges should focus on the dewaterability of untreated sludges as opposed to stabilised sludges; sludge loading and removal operations; bed loading rates vs. drying periods required to attain a desired dryness and hygienic quality.

Stabilisation Pond (Lagoon) Treatment (With or without prior Solids-Liquid Separation)

Waste stabilisation ponds for liquid and semi-liquid waste treatment (Fig. 4) are a potentially sustainable technology of increasing use world-wide. Substantial knowledge has been accumulated in recent decades as to the design and operation of waste stabilisation pond (WSP) schemes treating wastewater (McGarry and Pescod, 1970; Mara and Pearson 1986 and 1992).

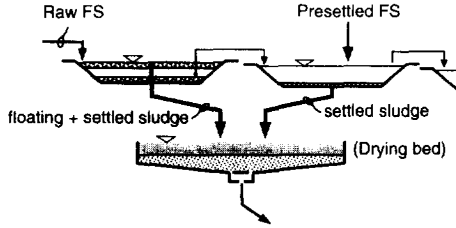

Fig. 4 Stabilisation (lagoon) treatment (with or without prior solids-liquid separation)

Waste stabilisation ponds treating municipal wastewater are often also used to treat faecal sludges. However, since WSP schemes are generally not designed for the additional faecal sludge load, facultative ponds may turn anoxic or anaerobic due to pond overloading. Algal growth will become impaired or completely suppressed, due mainly to excessive NH_3 concentrations produced under anaerobic conditions (see also the final chapter in this article regarding NH_3 toxicity). Only few investigations have been conducted to date in relation to the separate treatment of faecal sludges in WSP schemes.

WSP for separate treatment of faecal sludges are the option-of-choice in Indonesia (Ministry of Public Works, 1992) for treating septage and they are also used in Ghana (Collins, 1992), Benin and in Argentina. Lagoon treatment of septage (without wastewater admixture) is widely applied in the United States where 25 % of the population are served by septic tanks (U.S. EPA 1984). There, pond schemes usually consist of a primary pond for solids separation and partial degradation, followed by a secondary percolation/infiltration pond.

Naqibullah (1984) investigated the effect of co-treating septage with wastewater in a three-pond pilot scheme operated at the Asian Institute of Technology (AIT), Bangkok (one facultative pond followed by two maturation ponds run in series). Wastewater was co-mixed with a 0, 2, 10, and 20 % volume of septage. The total flow remained constant, meaning that the wastewater flow had to be reduced since faecal sludge was added. Algal biomass concentrations, determined by chlorophyll-a analysis, was highest at 10 % FS admixture. The dissolved oxygen (D.O.) concentrations in ponds 2 and 3 were also highest at this mixing ratio. This may be explained by the fact that the faecal sludge admixture causes a shift in nutrient ratios of the raw wastes entering the ponds. Carbon, nitrogen and phosphorus are thus made available to the bacteria breaking down the waste in ratios corresponding more closely to the C/N/P mix of the cells of these organisms than if wastewater alone is used. With 20 % faecal sludge addition, the D.O. levels dropped to 0 mg/l in all three ponds. A pH increase was observed in ponds 1 and 2 with 2 % and 10 % faecal sludge additions. Faecal coliform effluent concentrations were 10^2/100 ml at 0 and 2 % faecal sludge admixture. They increased to 10^3 and 10^4/100 ml at 10 and 20 % faecal sludge addition, respectively. This indicates that the pH increase favouring enteric bacteria die-off was probably compensated by the higher initial faecal coliform concentration and by the increased pond turbidity, causing a reduction in the lethal effect of the UV-light. Chemical oxygen demand (COD) removal efficiencies in the facultative pond were enhanced from about 50% to 80% by the addition of faecal sludge. This is an anticipated phenomenon as organic removal rates are generally proportional to the initial "food" concentration (first order kinetics). However, due to the higher COD concentrations in the influent, the effluent concentrations in pond 1 increased from 100 mg/l to 120 and 180 mg/l upon additions of 10 and 20 % faecal sludge, respectively.

Liu (1986) investigated the performance of a one-stage, pilot anaerobic pond treating septage from the AIT campus in Bangkok. Removal efficiencies for COD_{tot} amounted to approx. 80 % with one day retention time. At five days retention, efficiencies increased only insignificantly.

Even after removal of settleable solids in settling/thickening units, BOD and COD concentrations in the liquid fraction of faecal sludges are still several times higher than in normal wastewater. Pond schemes treating such liquids would thus have to comprise a series of several anaerobic ponds before concentrations and loading rates low enough for facultative pond conditions can be attained. McGarry and Pescod (1970) report about the treatment of tapioca starch waste having a 3,800 mg/l COD in a series of anaerobic ponds, each loaded with about 600 $g/m^3 \cdot day$. The authors recommend the use of the highest possible load in successive anaerobic ponds since it leads to successively smaller pond surfaces and to minimal land use. Pond pH decreases with increasing organic loading as a result of the inhibition of the slow-growing methanogenic bacteria which normally break down the acids formed the by acid-forming bacteria. When the organic load exceeds a certain limit odour formation and pH decrease become the critical variables in anaerobic pond design and operation. For tropical conditions, McGarry and Pescod (1970) consider pH 6.0 as the lowest possible limit below which the functioning of anaerobic ponds will be seriously impaired.

COD, BOD and faecal coliform removal kinetics, practical loading limits, and measures to prevent algal growth suppression in facultative ponds need to be further investigated for various types of faecal sludges.

Thermophilic Co-Composting of Faecal Sludges with Household/Municipal Refuse

Co-composting usually designates the combined composting of faecal or wastewater treatment sludges with household or municipal compostable refuse (Fig. 5). It is both a traditional process and a fairly recent "discovery" which is being tested in a few places. In a wider sense, it may also include the joint composting of sludges with other organic material such as sawdust, wood chips, bark, slaughterhouse or food processing waste. The material added to the sludge should enhance bulking for adequate air passage and create a 20-30 C/N ratio for optimum composting. C/N ratios in faecal sludges range from about two in fresh faeces to around 6 - 15 in septage. The moisture contents of the mixture to be composted should amount to 40-50 %. In China, India, Malaya, Singapore, and Nigeria, co-composting is reportedly being practised for several decades. Nightsoil is co-composted with either refuse and/or other organic/bulking material. The mixing ratios amount to 1/5 - 1/10 (sludge : added material) on a wet weight basis if undewatered sludge is used. With dewatered sludge or with wood chips, the faecal sludge proportions can be increased to as much as 1:1.5 (Scott 1952; Shuval et al. 1981; Obeng and Wright 1987).

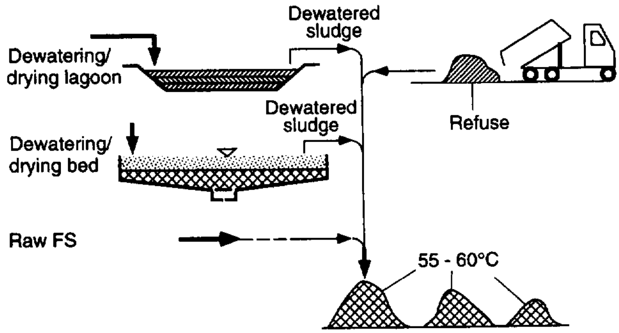

Fig. 5 Thermophilic co-composting of faecal sludges with household/municipal refuse

Rini near Grahamstown, South Africa, has recently started operation of a co-composting unit (La Trobe and Ross 1992) treating refuse and bucket latrine sludge from a community of 100,000. The nightsoil is pre-settled and then windrowed along with the unsieved refuse for a period of three weeks. The regular windrow temperatures amount to 55 °C. The Council for Scientific and Industrial Research of South Africa is presently conducting pilot investigations on the co-composting of latrine sludges with municipal solid waste. EAWAG is collaborating with municipal authorities and a research institution in Hubei Province, China, on similar field research projects. Since heavy metals may accumulate in the compost and in compost-treated soils if municipal wastes are co-composted with faecal sludges, future research should address this problem.

FULL-SCALE INVESTIGATIONS ON SOLIDS-LIQUID SEPARATION AND POND TREATMENT OF FAECAL SLUDGES IN ACCRA, GHANA

The Achimota faecal sludge treatment plant in Accra, Ghana, comprises two parallel batch-operated settling/thickening tanks (current minimum retention time = 3 hours) followed by four waste stabilisation ponds operated in series (overall retention time = about 30 days). One of the short sides of every settling unit is fitted with a ramp. This allows access and emptying by front-end loaders. The settling and floating solids, which are separated and thickened in the settling/thickening tanks, are windrow-composted with sawdust, an abundant waste product from timber mills. The supernatant liquid is further treated in a series of four waste stabilisation ponds. The plant was monitored and evaluated in 1993-94 (Larmie, 1994). During this period, the batch-operated *settling tanks* are loaded with septage containing 7 g SS/l and with public toilet sludge having 65 g SS/l at a volumetric ratio of 4:1. SS/TS ratios are 1:2 in septage and 1:1.2 in public toilet sludges. The SS and BOD concentrations in the raw sludge mixture amounted to 25 g/l and 2,000 mg/l, respectively. The solids surface loading averaged 40 kg $TS/m^2 \cdot d$. This loading rate is low compared with typical solids loading rates for sludge thickeners in sewage treatment plants (40-80 kg $TS/m^2 \cdot d$ for mixed primary and secondary sludge; 80-150 kg $TS/m^2 \cdot d$ for primary sludge). In-depth analysis of the settling/thickening tank performance yielded the following results with respect to solids accumulation and thickening during a four-week operating cycle: Four distinct zones were observed to develop; i.e., a lower bottom thickening zone with suspended solids concentrations of up to 140 g/l, an upper bottom zone with 60 g SS/l, a clear-water zone with 3 - 4g SS/l, and a scum layer containing up to 200 g SS/l (see Fig. 6). If the effluent draw-off is correctly located, this type of tank is capable of consistently retaining about 80 % of the SS from the type of septage and public toilet sludges collected in Accra. COD and BOD removal efficiencies amounted to 60 % at the beginning of the operating cycles but decreased to ≤ 20 % within 10 days of operation owing to inappropriate tank geometry and unfavourably located draw-offs. Effluent BOD averaged 1,600 mg/l over a 4-week loading cycle. Improvements in the tank geometry and draw installations could lead to relatively high removal efficiencies throughout the operating cycles. Helminth egg removals amounted to about 50 % on the average. Based on the observations made in this study and provided a minimum retention period of three hours is maintained in the clear-water zone for solids separation, available storage space for settled and thickened sludge emerges as the key design parameter. Fig. 6 proposes a faecal sludge settling/thickening tank of improved hydraulic design as well as suitable loading and effluent draw-off arrangements. The tank is also fitted with a ramp for front-end loader desludging.

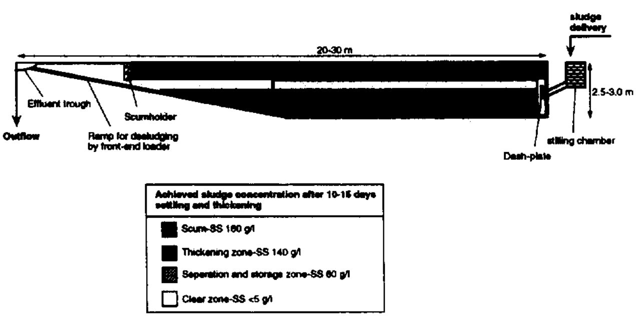

Fig. 6 Batch-operated settling / thickening tank with a ramp for front-end loader desludging

Pond monitoring data indicate that the four ponds which treat the supernatant from the settling/thickening tanks, all operate as anaerobic ponds. Although the volumetric BOD loading in the fourth pond amounted to about only 50 $g/m^3 \cdot d$ and was thus below normal anaerobic pond loading rates for tropical areas, there was no sign of algal growth nor dissolved oxygen on the pond surface. Inhibition of algal growth is probably due to ammonia (NH_3-N) toxicity. Ammonia is reported to be toxic to most algal species at levels ≥ 20-50 mg/l (Mara and Pearson, 1986). With the pH being close to 8, NH_3-N concentrations amounted to 120 mg/l in pond 1 and 80 mg/l in pond 4. Overall BOD reduction was in the order of 85 %, leaving a BOD of 300 mg/l in the effluent of the 4th pond. Most of the BOD removal was observed to take place in the first pond. The role of additional ponds is to reduce the pathogen load. Faecal coliforms were reduced from about 10^6 to 10^4/100 ml in the four ponds. This removal efficiency is much lower than the corresponding reductions in facultative and maturation ponds treating wastewater with similar retention times. Suppression of algal growth and the concurrent absence of pH rise with its lethal effects on enteric bacteria are the likely causes for impaired faecal coliform removal. Pond turbidity also prevents the penetration of UV light, another important pathogen die-off factor.

CONCLUSIONS

Faecal sludges exhibit 10-100 times higher concentrations than wastewater with respect to physico-chemical and biochemical characteristics. To treat faecal sludges, the same basic unit processes apply as for the treatment of wastewater and of sewage treatment plant sludge. The specific characteristics of faecal sludges and the fact that options must be developed which are sustainable in economically less advanced countries, however, call for the development of appropriate process combinations and design guidelines. There don't exist to date well-founded guidelines allowing a wider use of low to medium-cost treatment options for faecal sludges in so-called developing countries.

Waste stabilisation ponds constitute a suitable technology for faecal sludge treatment. Loading rate criteria, however, differ for most types of sludges as compared with wastewater. Further to this, separating off the solids in sedimentation /thickening units ahead of the ponds appears to be advisable in most cases. Ammonia toxicity for algae is a special difficulty when intending to induce facultative pond conditions for medium to high-strength faecal sludges. Solids-liquid separation and dewatering may also be achieved in sludge drying beds. Faecal sludges can be dried to shovable consistency within a period of one to two weeks. Co-composting appears to be a viable option, too, yet only scarce field data exist from engineered plants to date.

Given the still limited field experience with both pilot and full-scale faecal sludge treatment systems, more applied research is required to consolidate results obtained to date, to explore in detail the options considered sustainable, and to finally establish guidelines for the design and operation of faecal sludge treatment plants.

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