SOS - Management of Sludges from On-Site Sanitation

EAWAG/SANDEC
January 1999

# Co-treatment of Faecal Sludge and Wastewater in Tropical Climates

Udo Heinss and Martin Strauss

**EAWAG** Swiss Federal Institute for Environmental Science & Technology

**SANDEC** Dept. for Water and Sanitation in Developing Countries

# Contents



## Acronyms and Abbreviations

| | |
|---|---|
| EAWAG | Swiss Federal Institute for Environmental Science & Technology, Zurich |
| SANDEC | Dept. of Water & Sanitation in Developing Countries (EAWAG) |
| UNR/CIS | Universidad Nacional de Rosario, Argentina / Centro de Ingeneria Sanitaria |
| EPA | Environmental Protection Agency (USA) |
| ATV | German Association for the Water Environment |
| FS | Faecal Sludge |
| STP | Sewage Treatment Plant |
| WSP | Waste Stabilization Ponds |
| BOD | Biochemical Oxygen Demand |
| COD | Chemical Oxygen Demand |
| $NH_4$ | Ammonium |
| $NH_3$ | Ammonia |

## Summary

Faecal sludges (**FS**) collected from on-site sanitation systems (septic tanks, aqua privies, latrines and unsewered public toilets) in many urban areas of developing countries are often disposed of untreated. This is due, mainly, to the lack of sustainable sludge management strategies and sludge treatment options. Where wastewater treatment facilities are available, the combined treatment of FS and wastewater may be a feasible option. Specific design rules have, however, to be observed.

This article provides operational and design guidance for the co-treatment of faecal sludge in waste stabilisation ponds and in activated sludge sewage treatment plants. Problems, which may arise when highly concentrated faecal sludges are not properly included in the design of the co-treatment system, are also discussed.

For co-treatment in waste stabilisation ponds, FS solids should first be separated by sedimentation or in sludge drying beds. The high ammonia content, especially in fresh faecal sludges, can inhibit algae growth in the facultative ponds. Therefore, when calculating the permissible additional faecal sludge load, ammonia is a relevant design parameter besides BOD.

A methodology for calculating the permissible FS load in activated sludge plants is presented. It takes into consideration the varying characteristics of different faecal sludges.


## 1. Introduction

Availability of sewerage systems in tropical cities is usually confined to central districts. Municipal wastewater treatment plants only exist in a few places. In most cities, large sections are unsewered and on-site sanitation systems are used. Where STP exist or are being planned for, municipalities may choose to co-treat the faecal sludge collected from on-site sanitation systems. Often, plant operational problems and deteriorated removal efficiencies arise due to high BOD, TS and $NH_4$ concentrations typical of faecal sludges. The hygienic quality of the effluent (helminth eggs, faecal coliforms) may also be impaired. Various biological wastewater treatment plant processes are affected by FS overloading.

In tropical countries where sewage treatment systems are in use, waste stabilisation ponds (WSP) and activated sludge plants are the usually chosen option. Experience with the co-treatment of FS in WSP shows that numerous problems may arise (Mara 1992; Naqibullah 1984; Hasler 1995; Heinss et al. 1998). This article deals with the most relevant problems and provides suggestions on how they might be solved to ensure a reliable operation of WSP systems receiving FS.

ATV (1985) and EPA (1984) have published guidelines for the co-treatment of FS in activated sludge treatment plants in temperate climates. The formulae and diagrams which were developed by ATV and EPA to determine the allowable rate of septage addition are based on a standard value for BOD concentrations in faecal sludge (5,000 and 7,000 mg/l, respectively). However, the quality of FS in many cities of tropical countries varies greatly, particularly where the faecal sludge is composed of a mixture of septage and highly concentrated sludges from latrines or from unsewered public toilets.

# 2. Co-treatment of Faecal Sludge and Wastewater in Waste Stabilisation Ponds

## 2.1 Problems encountered treating FS in ponds

Fig. 1 shows a WSP system co-treating FS and wastewater. It should, ideally, contain a pre-treatment unit for FS.

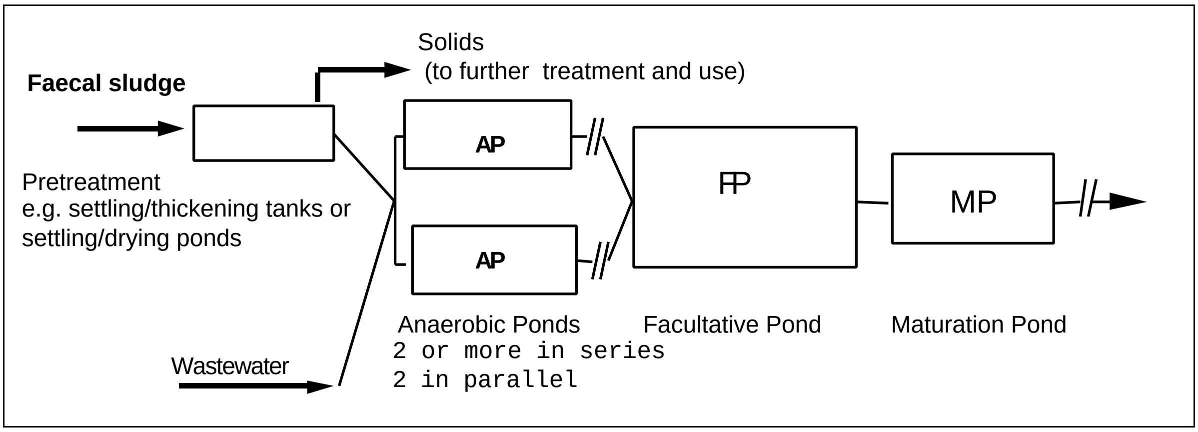



**Fig. 1: Layout of a waste stabilisation pond system receiving faecal sludge**

In Heinss et al. (1998), a number of problems are discussed which may arise when treating faecal sludge in waste stabilisation pond systems (see Fig. 1):

- Excessive organic (BOD) loading rates may lead to overloading of the anaerobic and facultative ponds. This overloading causes odour problems and prevents the development of aerobic conditions in the facultative pond.

- Ponds may fill up with sludge at undesirably fast rates due to the high solids content of FS.

- Fresh, undigested excreta and FS contain high $NH_4$ concentrations. These may impair or even prevent the development of algae in facultative ponds.

Preventive measures, such as the addition of a solids separation step ahead of the first pond, and the consideration of a maximum admissible FS load can avoid the aforementioned problems.

## 2.2 Organic loading rates

In existing WSP schemes treating wastewater, the permissible additional FS load is dependent on the base load exerted already by the wastewater. For newly designed WSP systems, the combined organic load (BOD;COD) of both FS and wastewater has to be taken into account.

Naqibullah (1984) investigated the combined treatment of septage and wastewater in three pilot stabilisation ponds in series (facultative pond followed by two aerobic ponds) at temperatures >25 ? C. The facultative pond was initially loaded with wastewater at a rate of 180 kg BOD/ha·d, only. This rate is low, given the prevailing temperatures of 25 ? C which would allow for rates of up to 350 kg BOD/ha·d (Mara et al. 1992). Addition of faecal sludge at a wastewater : FS ratio of 10:1 enhanced algae growth in the underloaded facultative pond. However, as the septage quantity was further increased to 20 %, the dissolved oxygen in the facultative pond and also in the two following aerobic ponds dropped to zero. At this FS ratio, the facultative pond loading amounted to 650 kg/ha·d. This is considerably higher than the above-cited loading limit.

### 2.3 Ammonia toxicity in facultative ponds

Ammonia ($NH_3$) is toxic to both bacteria and algae when occurring at excessive concentrations. Therefore, its threshold concentration in the facultative pond is an additional limiting factor to the permissible additional FS load.

Ammonia ($NH_3$) levels and hence toxicity to algae is strongly dependent on pH and temperature. The ammonium ($NH_4$)/ ammonia ($NH_3$) equilibrium moves towards higher $NH_3$ levels with increasing pH and temperature. According to Abeliovich and Azov (1976), the upper limit for undisturbed algae photosynthesis in the presence of ammonia is pH 7.9. Based on the findings of different authors (US-EPA 1985, Kriens 1994), a maximum permissible $NH_3$-N concentration of 20 mg/l can be regarded as safe. Assuming that $NH_3$ amounts to 5 % of $NH_{4,}$ the permissible $NH_4$-N influent concentration of the wastewater/FS mixture amounts to 400 mg/l.

In tropical climates, ammonia ($NH_3$) normally makes up 2-6% of the ammonium ($NH_4$) concentration in facultative ponds (T= 25-28 °C; pH= 7.5-8). Ammonia concentrations may increase as a result of pH raise to ? ? ? ? due to algal $CO_2$ consumption during mid-day and afternoon hours. This effect may be counteracted by nitrification enabled by algal oxygen production, hence leading to a lowering of pH. Mara and Pearson (1986), however, concluded in their studies on nitrogen cycling in WSP that nitrification plays a minor role in nitrogen transformation occurring in WSP. At pH 8.5 and ambient temperatures of 25-28 °C, e.g., as much as 15-18 % of $NH_3/NH_4$ will be in the form of $NH_3$.

Pond ammonia concentrations may also be reduced through stripping, a process which depends on pH, temperature, pond depth, and retention time. At 15 days retention time, the maximum rate of $NH_3$ stripping amounts to 10% and 30% at pH 8 and 8.5, respectively.

Faecal sludges which have been stored over an extended period, e.g. septage, usually exhibit $NH_4$-N concentrations of ? ? 400 mg/l. Fresh FS from unsewered low or zero flush toilets may contain $NH_4$-N concentrations of 5,000 mg/l which would lead to an algae growth inhibition if excessive quantities were admixed. Based on ammonia toxicity considerations, a determination of the maximum permissible FS volume to be co-treated with 1,000 $m^3$ wastewater in a primary facultative pond is exemplified in Box 1.

**Box 1**

**Calculation of the faecal sludge volume which can be co-treated with wastewater in facultative ponds based on ammonia toxicity considerations [1)]**

The $NH_4$-N concentrations of faecal sludge and sewage amount to 2,000 mg/l and 40 mg/l, respectively. How much FS can be co-treated with 1,000 $m^3$ of sewage in a primary facultative pond in tropical climates?
**Prerequisite:** To prevent the inhibition of algae growth, $NH_4$-N concentrations in the pond influent should not exceed 400 mg/l.
The maximum FS volume which may be co-treated with 1000 $m^3$ of wastewater is calculated as follows:

$Q_{FS}$ = **Error!**= 225 $m^3$

| | |
|---|---|
| FS | - Faecal sludge |
| $c_{FS}$ | - NH4-N concentration [mg/l] in faecal sludge |
| $c_S$ | - $NH_4$-N concentration in sewage |
| $Q_{FS}$ | - Faecal sludge flow |
| $Q_S$ | - Sewage flow |

The resulting maximum FS flow which can be co-treated amounts to 225 $m^3$.

**1)** It is assumed for this example that BOD loading is not a critical design factor.

## 2.4 Solids Accumulation

The high solids concentrations found in most faecal sludge, require pre-treatment of FS by solids-liquid separation, e.g. in batch operated settling/thickening tanks. This will prevent problems from occurring when having to handle large quantities of settled sludge from large primary ponds at intervals of one or more years. Sedimentation tanks and sludge drying beds may be suitable to offer appropriate low-cost options for solids separation. Based on field research conducted in Accra/Ghana (Larmie 1994+1995), Table 1 provides design recommendations for the two methods.

Sedimentation/thickening tanks require a much smaller surface area to treat a given volume of faecal sludge than sludge drying beds. However, the sludge removed from sludge drying beds and stored to obtain a sufficient helminth egg inactivation can be used directly in agriculture on account of its high TS content and improved hygienic quality.

**Table 1: Comparison of Two Methods of Faecal Sludge Solids-Liquid Separation**

| | Max. Attainable TS (%) | Assumed Loading Cycle | TS Loading kg TS/$m^2$yr | Required Area* $m^2$ /cap. |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| Sedimentation/ Thickening Tank | ? ? 14 | 8-week cycle<br>(4 weeks loading<br>+ 4 weeks resting;<br>6 cycles per year)<br>with 2 parallel settling tanks | 1,200 | 0.006 |
| Sludge Drying Bed (unplanted) | ? 70 | 10-day cycle<br>(loading, drying, removing)<br>36 cycles per year | 100-200 | 0.05 |
| *Assumed parameters:<br>Daily per capita faecal sludge quantity: 1 l/cap d<br>TS conc. of the faecal sludge: 20 g/l | | | | |

The settled and floating sludge removed from sedimentation tanks requires further treatment by e.g. dewatering/drying on drying beds or by composting. Since the organic and solids loads in the percolating water of drying beds are significantly lower than in the effluent of sedimentation/thickening tanks, they require less polishing treatment. Selection of the "best" process is determined by practical aspects related to sludge removal operations, dewatering and settling characteristics of a specific FS, as well as required surface area and degree of additional treatment to achieve the desired effluent and sludge quality.

Primary ponds receiving both FS and wastewater may theoretically also constitute a suitable treatment option if they are designed to receive the extra solids load from faecal sludges and if they are built to offer easy desludging (e.g. access for front-end loaders and availability of mixing material like sawdust). Experience with ponds located in developing countries and co-treating wastewater and FS show, however, that desludging of primary ponds does not often work well. The reason of that are high costs, technical and logistic difficulties and large space requirements for dewatering or drying huge quantities of sludge removed in bulk from the ponds.

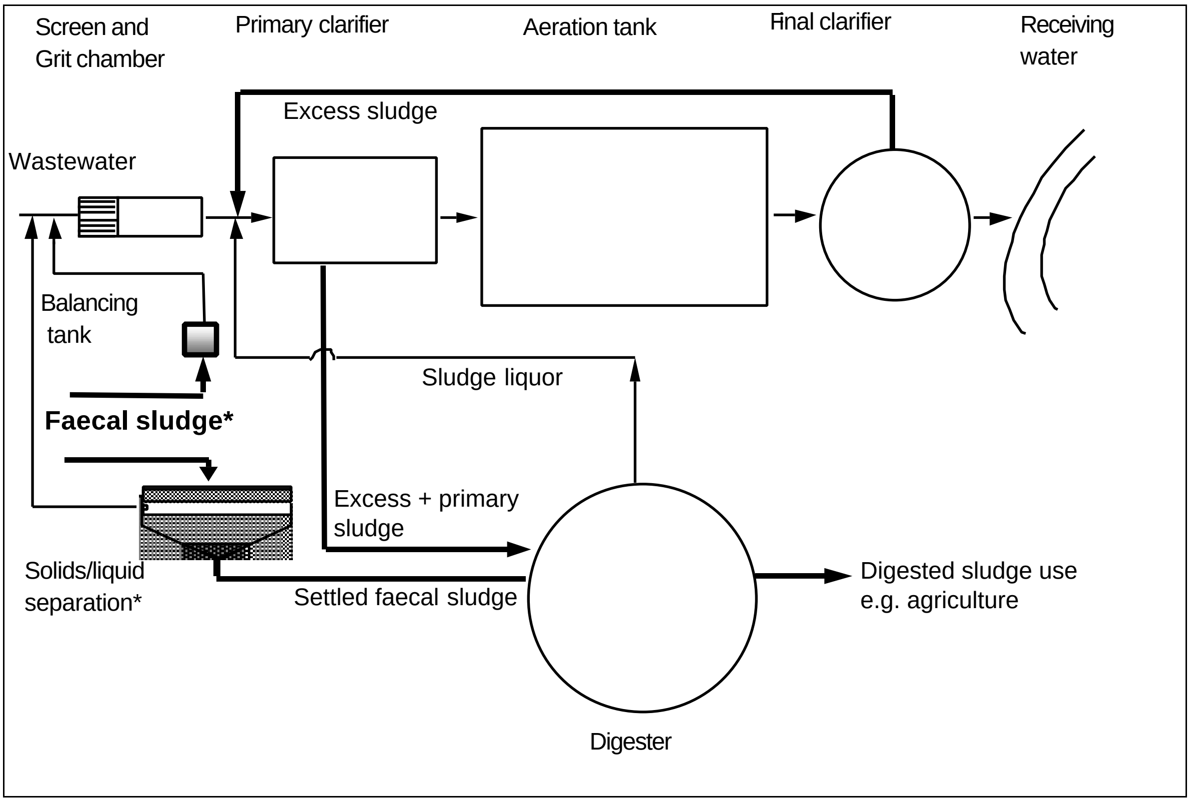
A sensible option for FS pre-treatment may consist in providing solids-liquid separation in batch-operated ponds. Design and operations should be selected such as to optimise separated solids accumulation, dewatering and emptying. A scheme of this kind has recently been implemented in Alcorta, Prov. of Santa Fee, Argentina. It will be intensively monitored under a collaborative field research agreement between Universidad National de Rosario / Centro de Ingeniera sanitaria and EAWAG/SANDEC in the years 1998-2000.

# 3. Co-treatment of Faecal Sludge and Wastewater in Activated Sludge Plants

## 3.1 Addition of Faecal Sludge Upstream from the Aeration Tank

### *3.1.1 General view*

Fig.2 presents a schematic diagram of a conventional, activated sludge plant and provides two alternatives for faecal sludge addition to the flow of wastewater. If the added faecal sludge: wastewater ratio is high, solids/liquid separation options as described above in Chpt.2 may be applied.




*The choice for one of these two options is dependant on the specific design of the wastewater treatment plant, and on the quantity and type of faecal sludge to be treated.

**Fig.2: Co-treatment of Faecal Sludge and Wastewater (schematic)**

### *3.1.2 Primary Treatment Process*

According to ATV (1985), two conditions must be met if FS is to be co-treated with wastewater:

- FS should be diluted with the wastewater at least 20 times.
- The capacity of a sewage treatment plant should be designed for at least 600 kg BOD/d to avoid unstable treatment performance (equivalent to about 13,300 inhabitants, assuming 45 g BOD/cap•d).

The installation of a receiving station for faecal sludge with a storage / balancing tank is recommended to prevent both hydraulic and organic shock loads if the vacuum tankers would empty their contents directly into the primary treatment unit. The FS receiving and storage station facilitates faecal sludge addition to the main treatment units at periods when wastewater flows are low (usually at night). Alternatively, it allows for a sludge addition at constant rates or at rates proportional to the sewage flow. The volume of the storage unit should hold 1-2 daily faecal sludge loads (ATV 1985).

Resch (1982) showed that intermittent FS loading in activated sludge pilot plants is inappropriate compared to continuous loading when co-treating faecal sludges. Overall BOD elimination dropped by about 20-30% during intermittent FS loading.

The FS should be screened and degritted separately or added to the wastewater flow upstream from the screen and grit chamber. Where activated sludge units are not preceded by primary clarifiers (e.g. in extended aeration plants), FS should be pre-treated for solids separation prior to activated sludge treatment. This leads to important savings in aeration energy as the BOD elimination rates in sedimentation tanks amount to over 50 %. Opinions differ with regard to the treatability of FS in sedimentation units. EPA (1984) reports that raw septage has poor settling characteristics. However, treatment of septage in combination with raw sewage in primary clarifiers showed acceptable suspended solids and BOD removals. In contrast to this, ATV (1985) notes that FS generally settles well. Its settling properties, however, deteriorate upon thorough mixing with wastewater. In Accra/Ghana, good results were obtained with pre-treating faecal sludge in sedimentation/thickening tanks (Heinss et al. 1998). Settling experiments are obviously necessary to determine the settling characteristic of a specific FS or FS/wastewater mixture (Heinss and Strauss 1998).

Problems like decreased oxygen transfer in the aeration unit, inhibition of microbiological activity and settling properties in subsequent clarifiers may arise from excessive grease contents in some of the faecal sludges. EPA (1984) recommends that the combined septage/sewage influent to primary clarifiers should not exceed 300 mg/l grease to avoid the aforementioned problems. Furthermore, the installation of skimming mechanisms to handle additional grease may become necessary.

### *3.1.3 Activated Sludge Process*

The presence of sufficient excess aeration capacity to treat the additional faecal sludge load is the first prerequisite for successful FS co-treatment in sewage treatment plants. Pre-treating sludge by settling and/or anaerobic treatment leads to lower organic loading, and thus, to a lower additional oxygen requirement in the aeration unit. Untreated faecal sludge with its high TS content may also impair the composition of the activated sludge biomass by inducing changes in the ratio of the organic and inorganic content, as well as in the concentration of the active cell mass. The flow of unsettled septage added to an activated sludge plant must, therefore, be limited only.

The following impacts have been observed and reported in treatment plants overloaded with faecal sludge:

- Decrease in $O_2$ content in aeration units
- Odour and foaming problems in aeration units
- Scum build-up in clarifiers
- A brownish-yellowish colouring of the effluent

In activated sludge plants, which are already in existence, the permissible faecal sludge delivery rate is dependent on the available free design capacity. Consequently, treatment plants operating at their design load are unable to receive any faecal sludge without the installation of additional aeration capacity.

Determination of the permissible FS feeding rate may not be based on the free BOD capacity alone. Apart from the BOD load, the performance of the sewage treatment plant is influenced by the increased suspended solids load (increased load in the final clarifier), changes in sludge composition in the aeration tank, and other factors (e.g. grease). Further assessments of co-treatment plants are necessary to quantify the impact of these factors.

Based on field research data from Rezek and Cooper (1980), an empirical safety factor for the determination of the permissible FS load can be established. This factor takes into account the above-described impacts of the FS (besides its BOD content) on the performance of the sewage treatment plant. To calculate the equalised permissible feeding rate for FS, the BOD load of the FS has to multiplied by a factor 2 for plants with primary treatment, and by a factor 2.5 for plants without primary treatment. This procedure, presented in Box 2, serves as an approximation to determine the allowable FS feeding rate. Additionally, the local conditions and the special type of sewage treatment plant play a decisive role in the determination of this rate.

Faecal sludge often contains very high ammonia concentrations. In tropical climates with temperatures between 28 and 30 °C, nitrification may occur inevitably. Even in highly loaded sewage treatment plants, with organic loading rates of up to 1-1.5 kg BOD/$m^3$·d and a sludge age of not more than two days, nitrification is likely to occur. Orth and Bahre (1995) claim that the oxygen consumed by nitrification should be included in the design of the aeration system even if the treatment objective is not nitrification. Siegrist (1996), however, observed that nitrification was suppressed if oxygen levels were kept below 0.5 mg/l. No additional oxygen is thus consumed. Nitrates formed at low concentrations, are denitrified in anaerobic zones of the aeration unit and the oxygen is re-supplied. We suggest that the supplementary oxygen requirement for nitrification should only be taken into account if nitrification is in fact required to protect the receiving water, i.e. to avoid fish toxicity by ammonia and to minimise eutrophication (see Box 2, case c).

**Box 2**

**Calculation of the permissible FS feeding rate**
(At an already existing activated sludge plant)

85,000 inhabitants are currently connected to a wastewater treatment plant designed for 100,000 population equivalents (p.e.).
The daily per capita $BOD_5$ load amounts to 45 g.

**a)** How much faecal sludge (FS) pre-treated in a primary settling tank may be added to the treatment plant? The FS exhibits the following composition:
80 % septage: $BOD_5$ = 6 g/l, $NH_4$-N = 0.3 g/l
20 % public toilet sludge: $BOD_5$ = 12 g/l, $NH_4$-N = 3.5 g/l

**b)** How much FS with equivalent BOD and $NH_4$ concentrations as in a) may be added to this treatment plant without pre-sedimentation?

**c)** How much FS may be added to a treatment plant with a primary treatment step and requiring 70 % nitrification?

**1. Calculation of the free BOD capacity**

Design capacity: 100,000 population equivalent
Daily per capita BOD: 45 g
Present capacity used: 85,000 population equivalent
Free BOD capacity: 675 kg BOD/d

**2. Determination of the FS loading pattern**

The permissible FS loading pattern is dependent on the design capacity of the treatment plant (ATV 1985):

At < 3,000 kg BOD/day
- Equalisation of the added septage flow in a retention basin

At 3,000 - 6,000 kg BOD/day
- Up to 10-15 % of the daily maximum FS flow ($m^3$) may be added hourly without balancing; however, the operation of the plant has to be monitored to recognise possible problems.

At > 6,000 kg BOD/day
- Up to 15 % of the daily maximum quantity ($m^3$) may be added hourly. Operation might essentially be problem-free.

In this example, the design capacity amounts to 4,500 kg BOD/d. Therefore, 10-15 % of the daily maximum FS flow may be received hourly without balancing

**3. Determination of the average BOD and nitrogen concentration in the faecal sludge mixture**

$c_{BOD}$ = **Error!**= 7.2 g/l

$c_{BOD\ settled}$ = 3.6 g/l (assuming 50 % BOD elimination by settling)

$c_N$ = **Error!**= 0.94 g/l

**4. Determination of the faecal sludge addition rate**

**a)** Treatment plant comprising pre-sedimentation of FS

$BOD_{FS}$ equivalent [kg/m$^3$] = a • $c_{BOD\ settled}$

2 • 3.6 kg BOD/m$^3$ = 7.2 kg/m$^3$
where:
a - an empirically determined factor accounting for the impact of faecal sludge on the activated sludge system (besides its BOD content).
=2 for activated-sludge treatment plants with primary treatment
=2.5 for activated-sludge treatment plants without primary treatment

Permissible feeding rate:
**Error!**= **Error!**= 94 m$^3$/d

**b)** Treatment plant without pre-sedimentation of FS

2.5 • 7.2 kg BOD/m$^3$ = 18 kg/m$^3$ ($BOD_{FS}$ equivalent)

Permissible feeding rate:
**Error!**= 37.5 m$^3$/d

**c)** Treatment plant with nitrification

Calculation of the free aeration capacity for a treatment plant comprising nitrification and pre-sedimentation step

Design capacity: 100,000 p.e.
Daily per capita BOD: 45 g
Daily per capita N: 10 g
4,500 kg $O_2$/d and 3,010 kg $O_2$/d (4.3 kg $O_2$/kg N) are required for BOD elimination and nitrification (70%), respectively.
Design aeration capacity: 7,510 kg $O_2$/d
Present capacity used: 85,000 population equivalent corresponding to 6,384 kg $O_2$/d
Free capacity = 1126 kg $O_2$/d

BOD equivalent of FS [kg/m$^3$] = a • $c_{BOD}$ + 4.3 x $c_{NH4}$

= 2 • 3.6 g/l + 4.3 x 0.7$^*$ x 0.94 g/l
= 10 kg/m$^3$

($^*$the factor 0.7 corresponds to a required nitrification of 70 %)

Permissible feeding rate:

**Error!**= 113 m$^3$/d

The STP in case c) is designed for BOD removal and nitrification. Therefore, the design aeration capacity and consequently also the free capacity are higher than for the plants in case a) and b). This results in a higher permissible FS feeding rate for case c).

## 3.2 Addition of Faecal Sludge to the Sewage Sludge Stream

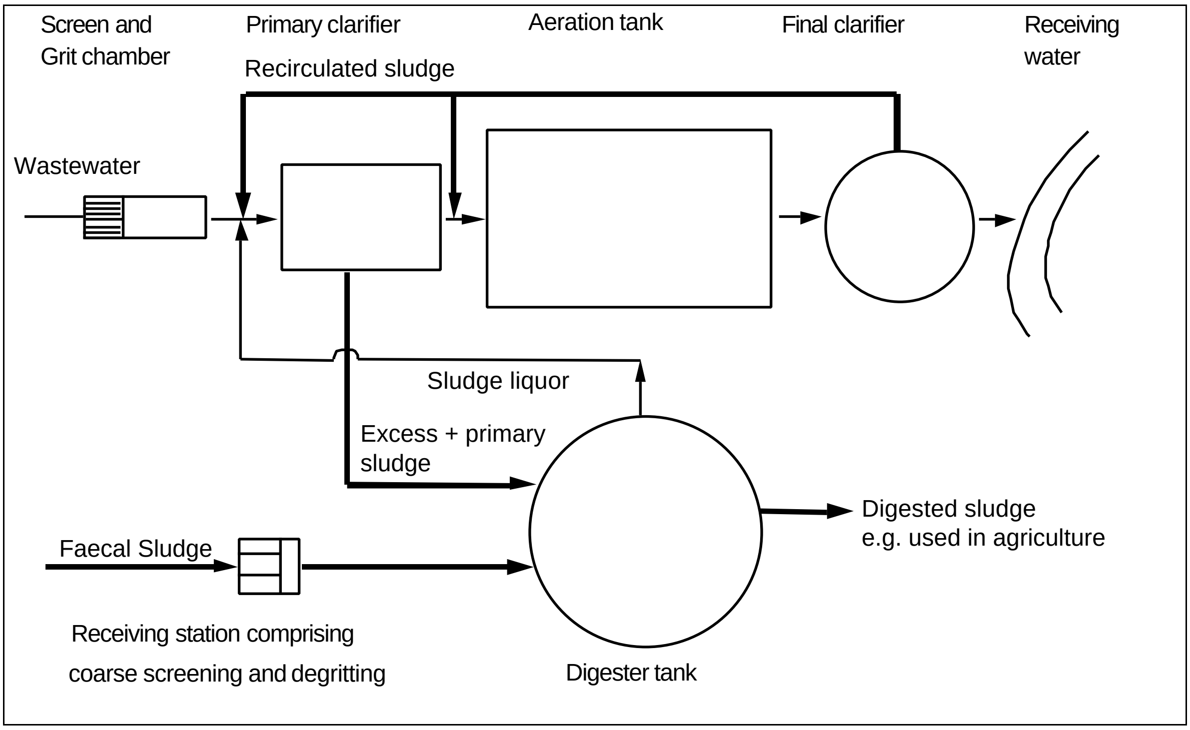



**Fig. 3: Anaerobic Co-treatment of Sewage and Faecal Sludge**

The schematic diagram in Fig. 3 shows one possible option to co-treat sewage sludge and FS. Bischofsberger et.al. (1987) describe co-treatment of the two types of sludges by mesophilic and thermophilic digestion, as well as by aerobic thermophilic treatment. The process principles, although developed and primarily applied in temperate climate so far, are equally applicable in tropical countries. Higher temperatures may simplify anaerobic processes; less external heat support is required. An overview of important design considerations is provided below.

Co-treatment through mesophilic sludge digestion (30-35°C) has frequently been described. FS may be added directly to the digester after screening. The digestion process is reportedly not impaired by the faecal sludge if the daily raw sludge feeding rate, including FS, is not greater than 1/20th of the digester volume (ATV 1985). Bischofsberger et.al.(1987) report about digester operation where the added sludge amounts to 50 % of FS. It appears that FS co-treatment in mesophilic digestion usually does not pose any problems. The permissible organic loading of the digester is dependent on the operating conditions. EPA (1984) recommends a total loading rate of 0.5-1.6 kg VSS/$m^3$·d. Higher loading (? 3 kg VSS/$m^3$·d) is possible if the digester is heated and the sludge kept in circulation. The additional organic load in sludge liquor originating from the digested FS into the activated sludge tank must be taken into consideration. 1.5 kg BOD loading per $m^3$ digested FS with a BOD of around 7 kg/$m^3$ (ATV 1985) may be assumed as a safe estimate. The value has to be increased if more concentrated FS is treated.

A $NH_4$ concentration of ? 2g/l causes inhibition of methane bacteria.? Therefore, only a limited amount of fresh toilet sludge with high ammonia concentration? (2-5 g/l) may be added to the digester.

Varying results have been reported on co-treatment of faecal sludge in thermophilic digesters (49-52 °C). Garber reported in Bischofsberger et.al.(1987) that a higher gas yield, improved dewatering characteristics and an improved susceptibility of the sludge towards desinfection may be attained as compared to mesophilic digestion. Other experiments, however, could not confirm these findings. While a higher gas yield was attained, dewatering did not improve when compared with the mesophilic process. Furthermore, thermophilic digesters are more difficult to operate than mesophilic digesters. Thermophilic reactors are more susceptible to small temperature variations. Maintenance of such plants is also more intensive and, hence, more costly than of mesophilic digesters.

## 4. References

Abeliovich A. and Azov Y.(1976).*Toxicity of Ammonia to Algae in Sewage Oxidation Ponds.* Applied and Environmental Microbiology, June 1976, p. 801-806

ATV (1985). *Treatment and Disposal of Sludge from Small Sewage Treatment Plants* . Gesellschaft zur Förderung der Abwassertechnik e.V. (GFA), St. Augustin.

Bischofsberger W., Resch H., Baumgart P. (1987). *Schlämme aus Hauskläranlagen*. ("Sludges from individual sewage treatment plants"). Berichte aus Wassergütewirtschaft und Gesundheitsingenieurwesen Nr. 48, Technische Universität München. In German.

Hasler N. (1995). *Étude des Performances de la Station d'Épuration Sibeau à Cotonou et Propositions d'Extension.* École Polytechnique Fédérale de Lausanne. Unpublished, in French.

Heinss U., Larmie S.A., Strauss, M. (1998). *Solids Separation and Pond Systems for the Treatment of Faecal Sludges in the Tropics.* EAWAG/SANDEC. SANDEC Report No.5/98 Second Edition.

Heinss U. and Strauss M. (1999). *Characteristics of Faecal Sludge and Solid-Liquid Separation.* EAWAG/SANDEC.

Kriens M. (1994). *Grenzen der Belastbarkeit von aquatischen Oekosystemen mit Stickstoff*. EAWAG Report. EAWAG Duebendorf, Switzerland. In German.

Larmie, S. A. (1994). *Sedimentation Tank Sludge Accumulation Study*. Project report No. 2. Water Resources Research Institute (CSIR), Accra, Ghana. Unpublished document. December.

Larmie, S. A. (1995). *Faecal Sludge Drying Bed Study*. Water Resources Research Institute (CSIR), Accra, Ghana. Interim project reports Nos. 1 and 2. Unpublished documents. October and December.

Mara, D. D. and Pearson, H. (1986). *Artificial Freshwater Environment: Waste Stabilisation Ponds*. In: Biotechnology (Rehm and Reeds, eds.). VCH Verlagsgesellschaft, Weinheim, Germany.

Mara D.D., Alabaster G.P., Pearson H.W., Mills S.W. (1992). *Waste Stabilisation Ponds.* Leeds: Lagoon Technology International Ltd..

Naqibullah (1984). *Combined Treatment of Septage in Waste Stabilization Ponds.* AIT Thesis No. EV-84-9, Bangkok, Thailand.

Orth and Bahre (1995). *Auswirkungen unterschiedlicher klimatischer und sozio-oekonomischer Bedingungen auf die Abwasserbehandlung.* ("Influence of different climatic and socioeconomic conditions on wastewater treatment") Proceedings: Fortbildung von Ingenieuren und Naturwissenschaftlern aus und fuer Entwicklungslaender. ATV, Hennef In German.

Resch H. (1982). *Vorschläge für die Behandlung von Schlämmen aus Hauskläranlagen*. Berichte aus Wassergütewirtschaft und Gesundheitsingenieurwesen Nr. 38, Technische Universität München, (in German).

Rezek J.W. and Cooper (1980). *Septage Management*. U.S. EPA Report No.600/8-80-032.

Siegrist H.R. (1996). Personal communication.

U.S. EPA (1984). Handbook: *Septage Treatment and Disposal*. EPA 625/6-84-009, U.S. Environmental Protection Agency, Center for Environmental Research Information, Cincinnati, Ohio.

U.S. EPA (1985). *Ambient water quality criteria for ammonia*. EPA 440/5-85-001, U.S. Environmental Protection Agency, Office of Water Regulations and Standards, Washington, D.C.