SOS - Management of Sludges from On-Site Sanitation

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Characteristics of Faecal Sludges and their Solids-Liquid Separation

Based on the Field Report Entitled "Sedimentation Tank Sludge Accumulation Study" Prepared by S.A. Larmie WRI (Dec. 1994)

Udo Heinss*, Seth A. Larmie** and Martin Strauss*

***EAWAG**	Swiss Federal Institute for Environmental Science & Technology
SANDEC	Dept. for Water and Sanitation in Developing Countries
****WRI / CSIR**	Water Research Institute Accra / Council of Scientific & Industrial Research, Ghana

This document is available from:

EAWAG/SANDEC
P.O. Box 611
CH-8600 Duebendorf, Switzerland

e-mail: Dallatorre@eawag.ch Phone +41-1-823 52 86 Fax +41-1-823 53 99

Photo on frontpage:
Staff from the WRI laboratory next to 2-meter cylinder which was used for settling experiments.

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Acronyms and Abbreviations

WRI	Water Research Institute Accra/Ghana
EAWAG	Swiss Federal Institute for Environmental Science & Technology, Zurich / Switzerland
SANDEC	Dept. of Water & Sanitation in Developing Countries (EAWAG)
FS	Faecal Sludge
FSTP	Faecal Sludge Treatment Plant
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
SS	Suspended Solids
TKN	Total Kjeldahl Nitrogen
TS	Total Solids
TVS	Total Volatile Solids

1. Raw sludge characteristics

1.1 Comparison of different raw sludge data

Table 1 shows results of different faecal sludge analyses carried out during the collaborative field research between SANDEC and its partners*. Also shown are the average of reported data from the United States (EPA 1984).

Table 1: Faecal sludge quality in different cities

	1 Accra Septage	Accra Public toilet Sludge	**2** Bangkok Septage	**3** Manila Septage	**4** US EPA Septage
COD	7,800	49,000	14,000	37,000	43,000
BOD	600 -1500	7,600		3,800	5,000
TS	11,900	52,500	16,000	72,000	38,800
TVS (%)	60	69	69	76	65
pH	7.6	7.9	7.7	7.3	6.9
COD/BOD	6-12	6.4		9.7	9
COD/TS	0.7	0.9	0.9	0.5	1.1
Helm.eggs no/l	4,000	25,000		5,700	

All units except pH and the ratios (COD/BOD, COD/TS) are in mg/l unless otherwise stated.

The data in column **1** are based on analyses of samples from over 60 septic tanks (3-5 m^3) and public toilets tanks. The average storage time prior to collection amounts to 1 year for septage and to 1.5 weeks for public toilet sludge. The data in column **2 and 3** are based on the analyses of about 15 samples each.

Faecal sludge quality can strongly differ from place to place as many factors influence the real sludge quality as well as the analysed quality. These are for the real quality, among others:

- Storage duration (weeks to years)
- Admixture to FS such as grease, organic waste from kitchen
- Temperature
- Performance of septic tank
- Tank emptying technology and pattern
- Common treatment of black and greywater

As the septage is very inhomogeneous, consisting of a liquid phase, settled and partly settled solids, scum and dissolved solids, representative sampling from septic tanks is

* **1**- Water Resource Institute Accra, Ghana (WRI), **2-** Asian Institute of Technology Bangkok, Thailand (AIT), **3**- University of the Philippines, Manila (UP)

very difficult. The development of a standardised sampling method appears nearly impossible as the conditions of sampling vary from place to place (different suction trucks, construction of the septic tank).

Raw sludge data for faecal sludges are more inhomogeneous than for wastewater and strongly vary from place to place. Only average values received from a statistically sufficient number of analyses may serve as a design basis for treatment plants. One example which illustrates the variability of septage samples: The average COD concentration of 75 septage samples in Accra amounted to 6,400 mg/l with the very high standard deviation of 6,200 mg/l.

1.2 BOD analyses

Knowledge of the right BOD concentration in FS is necessary to size treatment works, ponds in particular. The BOD analysis has been standardised for municipal wastewater as BOD_5. SANDEC has conducted special BOD monitoring for faecal sludge to find out, how the measured BOD concentration in FS depends on specific conditions under which the analysis is carried out.

Seeding

Faecal sludges are anaerobic. Hence, they contain no or only very few aerobic microorganisms. This led the authors to assume that the growth of aerobic bacteria is retarded. Therefore, septage and public toilet sludges were analysed with and without seeding. Two types of seeding material were used. The first type was biomass which was developed by continuously aerating a sample of water and small amounts of faecal sludge. Secondly, “Polyseed”, a broad spectrum of specialised bacteria serving as uniform seed population for BOD was applied.

Seeding did not significantly affect BOD.

Stirring

The method most commonly used in laboratories of low-income countries to determine BOD is the Winkler titration method. These laboratories usually lack stirring equipment, hence, Winkler bottles are incubated unstirred for 5 days.

Our investigations revealed that stirring has a significant effect on the BOD results. The BOD of stirred samples was 15 to 30 %, in some cases 40 %, higher than the BOD of the same unstirred sample. The difference appears higher in solid-rich samples and in samples with high BOD.

BOD decomposition curve

The course of the BOD decomposition curve for faecal sludge appears similar to the BOD curve of municipal wastewater. The measurements on septage point to differences of 10% to 30% between BOD_5 and BOD_{10}. This corresponds to the wastewater value. A retarded development of the BOD decomposition in the faecal sludge was not detectable.

$BOD_{filtered}$/ $BOD_{unfiltered}$

Whereas the share of non-dissolved BOD in wastewater amounts to around 50%, its share in faecal sludge is in the order of 5-20 % only. This underlines the low efficiency of solid/liquid separation processes for BOD elimination.

1.3 Settling/thickening tests

Settling tests can provide information about the settleability of a specific faecal sludge. Several tests for a spectrum of different septages should be carried out as individual septage samples may vary considerably in their settling characteristics.

Wall effects may disturb the results when trying to simulate settling in small (1 or 2-litre) cylinders. Standard Methods (1995) therefore suggests to equip cylinders with a stirring mechanism which allows to determine settling and thickening characteristic in a more reliable manner. The vessel is stirred with a low level of energy input. Disturbances can also occur through degasification in the cylinder, which is likely to happen when testing fresh anaerobic sludges.

WRI and SANDEC conducted numerous faecal sludge settling tests in Accra/Ghana. One litre cylinders as well as a cylinder of 2-meter height and 20 cm diameter were used.

The following variables serve to size batch operated settling/thickening tanks. Based on our experience they may be determined in an approximate manner through settling tests in 1-litre cylinders.

Minimum liquid retention time:

Figure 1 indicates that the solid/liquid separation process of the monitored septage is completed within a half-hour whereas the separation process of the mixture of septage and public toilet sludge lasts for about 1 hour (hindered settling due to the higher TS concentration). It was found that the results of settling tests in 1-litre cylinder and in a cylinder with 20 cm diameter are compatible.

Thickability

The thickability of faecal sludge was measured in laboratory scale (1-litre cylinder), pilot scale (settling column, 20 cm diameter and 2 metre height) and in full-scale sedimentation tanks (Achimota FS Treatment Plant (FSTP) in Accra/Ghana).

The SS concentration was determined in the settling tank in different depths and after different storage periods. Fig. 2 summarises the results for a tank at the Achimota FSTP. Maximum SS concentrations of over 180 g/l were measured at some points in the scum. Such a thick and deep sludge layer develops through flotation processes and drying caused by evaporation. Probably, continuous digestion processes in the fresh public sludges produce digester gas which cause sludge particles to float. When treating stored sludge such as septage the resulting scum layer will be shallower.

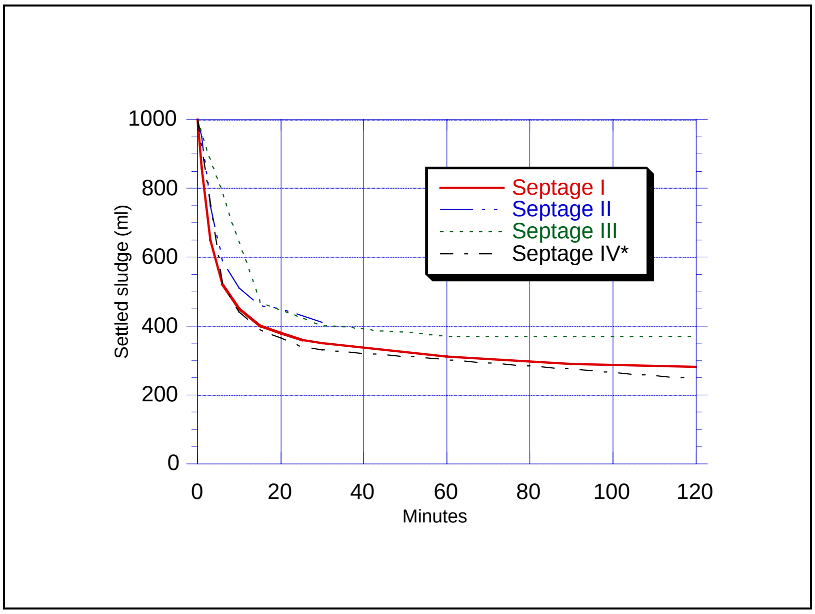

Fig. 1: Results of settling tests performed in 1-litre cylinders (septage I-III) and in a cylinder of 20 cm diameter and 2 m height (septage IV*)

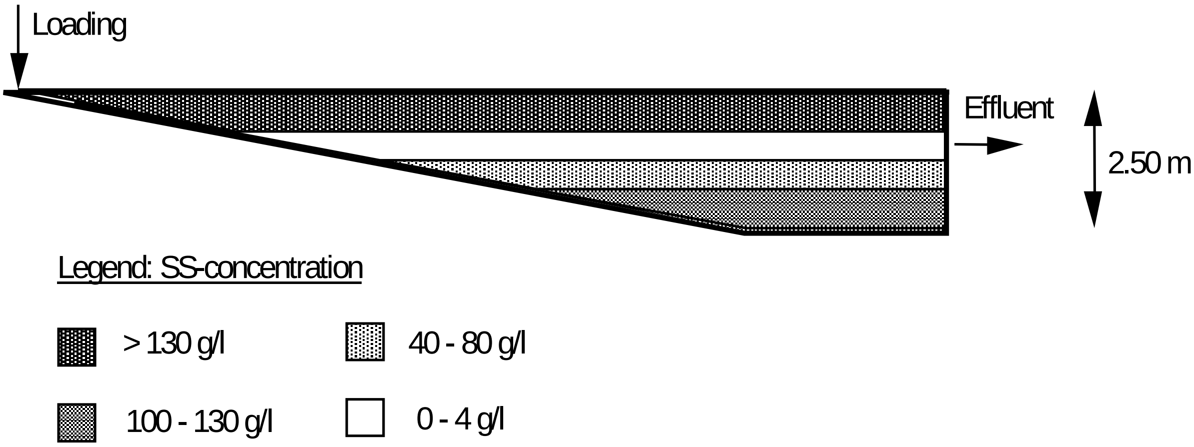

Fig. 2: Average SS concentration in a settling/ thickening tank after 4 weeks of operation and 1 week at rest (Achimota FSTP, Accra).

Beside SS concentrations in the full-scale tank, SS concentrations in settled sludge were also measured in 1-litre cylinders filled with a mixture of septage and public toilet sludge (SS = 15-20 g/l) which corresponded to the mixture treated in the settling/thickening tank. After 9 days when the settled sludge volume in the cylinder remained constant its SS concentration amounted to 60-85 g/l which is similar the SS concentration measured in the upper layer of settled solids in Fig. 2.

When testing septage (SS = 6 g/l) alone, the SS concentration in the settled solids amounted to 40-50 g/l. This result was found in tests with 1-litre cylinders as well as with the 2-metre cylinder.

The 2-metre cylinder was also used to test a faecal sludge mixture with 40 g/l TS. After 7 days a TS concentration of 100 g/l was measured in the settled and consolidated sludge.

The ratio between TS and SS is approximately 1 and 2 for public toilet sludge and septage, respectively. However in solids-rich sludge samples it is simpler to determine TS than SS since filtration of thick sludges is cumbersome and filterpaper is costly to procure.

Clear zone

Good correlation was obtained between the results measured in the full-scale sedimentation tank and in 1-litre cylinders. The maximum SS value of 4 g/l measured in the 1-litre cylinder experiments corresponded well with the average SS value found in the clear zone of the sedimentation tank. Since the settling in the cylinder happens without disturbance the average SS concentration in the clear water zone is lower than in the tank. Cylinder settling tests can provide the minimum possible SS effluent concentration in a sedimentation tank attained under optimum hydraulic conditions.

Sludge Volume Index (SVI)

The SVI is often used to characterise the settleability of a specific sludge. The SVI is also decisive for the admissible surface loading in continuously operated sedimentation tanks (ATV 1991). The SVI is affected by several factors. Hence it carries more validity as a relative rather as an absolute sludge settling information.

The SVI for septage in Accra/Ghana amounts to 40-80 ml/g. This value is substantially lower than for wastewater excess sludge (75-100 ml/g) and this points to a good sedimentation and thickening behaviour. The SVI is not used for sizing the batch operated settling/thickening tanks introduced in this paper.

2. Settling/Thickening Tanks: Results of Field Research and Recommendations for Design

2.1 The Twin Sedimentation Tanks at the FSTP in Accra/Ghana

The twin sedimentation tanks developed in Ghana by Annoh and Neff (1988) for the Achimota and other faecal sludge treatment plants are batch-operated and loaded by vacuum trucks at the shallow end. They serve as a pre-treatment for the downstream pond system. At an average daily loading of 150 m^3/d, the tank will be filled within two days and work from then on as sludge accumulator similarly to a septage tank. The settled sludge is stored and the supernatant flows from the tank into the following pond. An operating cycle lasts from four to eight weeks. Sludge loading is then transferred to a parallel tank. The settled and thickened sludge is removed at the latest point in time when the tank is due for a new operating cycle. The tanks, which are accessed by a ramp, are emptied by front-end-loaders. The sludge is co-composted with sawdust.

2.2 Process and Performance

Table 2 shows **mass balances** calculated for several variables across the thickening tanks operated at the Achimota FSTP. The values are based on analyses of the raw sludge, settling tank effluent concentration and raw sludge delivery rates. The following conclusions can be drawn:

- The mass balance in Table 2 shows important differences between the removal efficiencies for solids, COD and BOD. The decrease in solids obviously does not lead to a similar reduction in the COD and BOD concentrations. It can therefore be concluded that an important fraction of both COD and BOD is leaving the settling tank via the liquid phase. It is possible that insoluble complex compounds of COD are transformed by hydrolysis into simple soluble compounds. The COD : BOD ratio drops from an average of 9 in the inlet to 5.6 in the outlet. This is a sign that the organic constituents in the tank effluent are more easiliy biogradable than the ones in the raw sludge.
- The organic fraction (**VSS/SS**) increases from 60% in the raw sludge mixture to 70% in the settling tank effluent, indicating that mineral solids, mainly, are settled. Correspondingly the removal efficiency for SS (57%) differs from the one for VSS (48%).

Table 2: Mass balances across the sedimentation basin after four weeks of loading.

	Inlet [t]	Outlet [t]	Removal [%]
SS	91	39	57
VSS	52.4	27.4	48
BOD (unfiltered)	8.7	7.7	12
COD (unfiltered)	58	44	24
H. Eggs [number]	13,861	7,244	48

Fig. 3 illustrates the chronological development of the solids accumulation and **removal efficiency** over an operating period of nearly 4 weeks. Obviously, the removal efficiency is highly dependent on the accumulated solids in the tank. The following conclusions can be drawn:

- The period in which the tank can be operated without removing the separated solids is limited and determined by the sludge storage capacity of the basin. The settled and thickened sludge layers gradually expand in volume. This increasingly reduces the sedimentation area necessary to absorb the settled solids. Solids will be carried into the effluent at an increasing rate if the sedimentation area is reduced below a critical value at which a minimal stilling and hence solids separation can still proceed. Therefore, the proper sizing of the sludge storage volume and adherence to the loading cycles used in designing the plant are of utmost importance for a good functioning of the sedimentation basin.

- The desired removal efficiency determines the length of the loading/consolidation cycle (Fig.3).

- BOD and COD removal efficiencies drop more rapidly with time than solids removal efficiencies although the decrease in the COD clarification effect is less significant than that of BOD. The release of soluble organic constituents from the sludge into the liquid phase is probably the reason for this phenomenon.

- The COD/BOD ratio decreases through the transformation of non-biodegradable COD to biodegradable COD (with the concurrent increase in BOD).

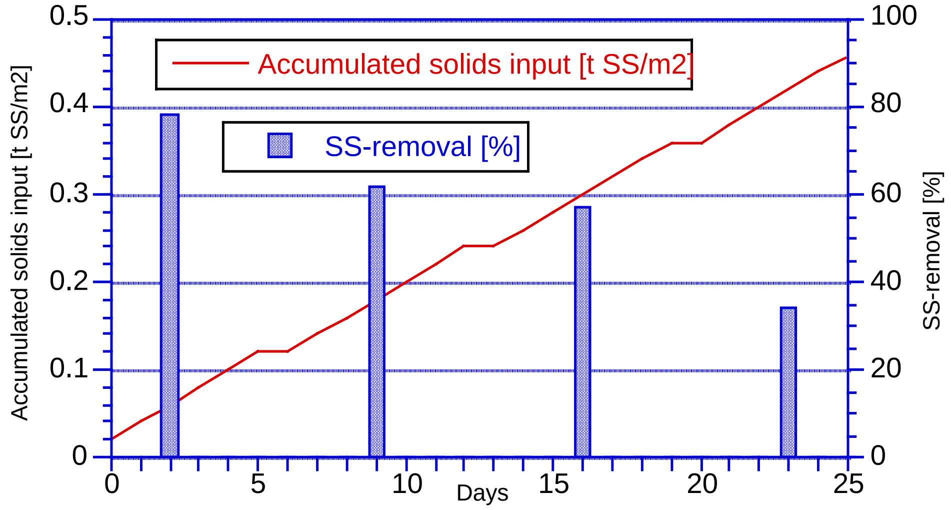

Fig. 3: Accumulated Solids Loading and Removal Efficiency in the Sedimentation/Thickening Tank as a Function of the Loading Duration

The following results were obtained from weekly **sludge profile** measurements. The SS concentrations in various tank depths and places along the tank were measured during 2 operation cycles measuring. One cycle included sludge loading, resting and sludge removal. The SS-profile of a tank after 4 weeks of operation is shown in Fig.2 above.

- A scum layer began to be formed during the first and second week of operation. By the 4th week of operation, this layer of sludge reached a thickness of 0.8 m and a solids concentration (SS) of 130-180 g/l.

- The solids concentration of the settled bottom sludge decreased from the 1st to the 2nd week of operation. It increased again to over 100 g/l during the 4th week . It appears that sludge thickening was negatively influenced by unfavourable hydraulic conditions.

- By the 2nd week, a clear water zone with solids concentrations under 4 g/l was produced which increased in thickness to approx. 0.3 m. This “clear water layer” altered its position horizontally. At the end of the loading process, the layer was found in the first half of the basin, i.e. close to the ramp, while concentrations of 15 g/l were measured in the vicinity of the outlet.

- The development of the sludge profiles indicates the formation of a hydraulic current. Probably, the density difference between the influent and the fluid in the tank causes a bottom current and a counterflow in the upper part of the tank. This phenomenon impairs the settling/thickening process.

- During the storage of the settled solids in the sedimentation tank digestion processes contribute to a further stabilisation of the sludge. Weekly analyses show that the organic fraction (VSS) in the settled sludge is reduced by 10 % in 4 weeks.

The following **are important conclusions** drawn from the evaluation of the sedimentation tank monitoring:

- Sedimentation/thickening appears to be particularly useful for solids removal from faecal sludges of the kind treated in Accra, Ghana, consisting of a mixture of septage and sludges from unsewered public toilets**.** It may substantially contribute to reducing the solids load on stabilisation ponds treating either faecal sludges or mixtures of wastewater and faecal sludges.

- It is assumed that higher solids removal efficiencies than currently observed may be achieved if the tank were designed to guarantee optimal hydraulic behaviour. Reducing the negative, hydraulic effects on sedimentation, as well as adapting the operation cycle of loading and removing settled solids to the available storage space would lead to a further increase in removal efficiency of the basin. (Chapter 2.3)

2.3. Design Recommendations for Improved Septage Sedimentation Tanks

Design Criteria

The main design criterion for batch operated sedimentation/thickening tanks is the storage space required to accommodate the settled and floating solids during the desired desludging interval. To calculate this space the sludge density attainable by thickening must be known. In Chapter 1.3 information is provided how sludge density concentrations can be estimated. Table 3 contains the results of measurements conducted in the full-scale sedimentation tank above described.

The publication on solids separation and pond treatment of faecal sludge by Heinss, Larmie and Strauss (1998) contains a design example for a sedimentation/thickening tank.

Table 3: Solids concentrations attained in full-scale settling-thickening tanks in Accra, Ghana (Larmie 1994)

Zone	Depth from the surface (m)	SS concentration (kg/m^3)
Scum	0 - 0.8	160
Clear zone	0.8 - 1.3	4
Separation and storage zone	1.3 - 1.8	60
Thickening zone	> 1.8	140

Tank Geometry

There exist well-established principles on how to configure settling tanks. The tank must be long and narrow to achieve an advantageous Froude (flow-mechanical comparative figure) and Reynolds (coefficient of flow stability - flow transition laminar/turbulent) numbers. The Froude number should be as high and the Reynolds number as low as possible. This requires a small hydraulic radius (flow cross-section divided by the wetted perimeter). Guidelines for rectangular tanks are given in ATV (1991). The ratio between the depth of water and the length of the tank should be 1:15 to 1:20. The length should be longer than 30 metres and the width from 4 to 10 metres.

Inlet and outlet configuration

The monitoring of the sedimentation tanks has revealed that hydraulic flow processes play an important role in sedimentation and thickening. These processes determine the quality of the outflow because they influence the position and clarity of the clear zone.

The shaping of the inlet should ensure that the kinetic and potential energy entering the tank during FS discharge is dissipated in the inlet area. Otherwise, this energy is transformed into hydraulic movement disturbing the sedimentation process and causing a circulation that will deteriorate the outflow. The following precautions will improve the hydraulic conditions at the inlet:

- Outflow interruption during the discharging of trucks and reopening it after calming down of the tank contents.
- Installation of a stilling grid
- Lowering the hose of the vacuum truck to a level just above the thickening zone during raw sludge discharge (at a depth of about 2 metres) or installing an inlet pipe fixed on the tank wall.
- Installation of other devices which dissipate the energy from the tanker discharge.

The concentration of solids in the effluent is dependent on the outlet arrangement. The following points should be noticed:

- The outlet must be placed in the clear-water zone under the scum and above the sludge storage zone. It could be advantageous to construct the outlet with an

adaptable and variable draw-off level in order to enable the adjusting to the varying depths of the clear-water zone.
- The outlet may be placed in the middle or in the last quarter of the tank rather than at its downstream end. This will contribute to minimising solids carry-over.
- For improved flow conditions, the outlet should extend over the entire width of the tank.

2. Literature

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