Literature review on co-treatment of fecal sludge at sewage treatment plants

Characteristics of Fecal Sludge

The quality of fecal sludge from septic tanks has been characterized by various researchers. The following figures present the quality reported by different researchers.

The quality of fecal sludge varies significantly depending on the geographical and site variabilities, as well as the source and method of sludge handling. The FS quality indicators reported by different researchers indicate that FS sampled in many parts of the world, including samples from India (Chennai) is not of the quality reported by the USEPA for the US conditions. The pollution load from FS is considerably lesser in the samples analyzed by researchers, as presented in the following table.

The design for FS handling and treatment will need to incorporate detailed characterization of the FS to be treated on site and its impact on any existing sewage treatment plant (STP).

	The World Bank (2016) - 5 Districts in Dhaka		Bassan et al (2013)						Kone etal (2004)				Rashed et al (2006)	USEPA (1999)	Pradeep etal (n.d.)	Ligy etal (2016)		Ingallinella (2002)
Parameter	**1**[1]	**2**[2]	**3**[3]	**4**[4]	**5**[5]	**6**[6]	**7**[7]	**8**[8]	**9**[9]	**10**[10]	**11**[11]	**12**[12]	**13**[13]		**14**[14]	**15**[15]	**16**[16]	**17**[17]
Total solids (mg/L)	19,420 to 57,272	12,778 to 72,694	8,984	11,820	19,000	,900	14,000	4,500	52,500	12,000	15,350	6,000 - 35,000	3,095	1,132 to 130,475	42,395	2185	3,555	
Suspended Solids (mg/L)	17,868 to 55,484	10,852 to 70,896	7,077										3,068	310 - 93,378		712	1103	5943
COD (mg/L)	300 to 672	480 to 687	7,607	10,725	13,500	7,800	15,700	7,100	49,000	7,800	15,700	4,200	1,243	1,500 to 703,000	59,745	905	1,460	4,243
BOD (mg/L)	118 to 306	266 to 447	1,237		2,240				7,600	840	2,300	750 - 2,600	434	440 to 78,600				754
COD:BOD Ratio	2.01 to 2.54	1.65 to 1.93	7										3					
NH4 - Nitrogen (mg/L)	20 to 1,100	130 to 1,900							3,300	330	415	150	91	3 to 116	1,323	16	32	146
Total nitrogen (mg/L)	30 to 10,700	200 to 1,400			2,100						1,100	190	150	66 to 1,060		94	58	191
Total Phosphorus (mg/L)	170 to 900	120 to 200											13	20 to 760	1,001	77	54	28
Total Volatile Solids (% of TS)			57	48	47	59	NA	70	68	59	73	50	2706	353 - 71,402	15,223	1414	1541	

[1] From Manual emptying
[2] From Mechanical emptying
[3] From FS from septic tanks
[4] Ouagadougou (From discharging trucks)
[5] From Ouagadougou (From septic tanks)
[6] Accra (From Septic tanks)
[7] Dakar (From discharging trucks)
[8] Dakar (from treatment plant receiving channel)
[9] Accra (Ghana) Public Toilet Sludge
[10] Accra (Ghana) (Septage)
[11] Bangkok (Thailand)
[12] Alcorta (Argentina) (Septage)
[13] Albireh Septage
[14] Devanahalli
[15] Chennai - Summer
[16] Chennai - Winter
[17] Argentina

Planning and Design of fecal sludge treatment at STPs

Several researchers have developed guidelines to help design and operationalize co-treatment of FS at sewage treatment plants. The following table summarizes the guidance documents and literature available to help determine safe FS loading rates and design a co-treatment system.

S.No	Study / Document	Aspects covered under the guidance				Reference
		OSS emptying	**FS characterization**	**Decanting Stations**	**Co-treatment at STPs**	
1	Septage Management in Urban India			Theoretical guidance on components of decanting facility at STP	Provides guidance on co-treatment and estimating permissible load at STPs based on existing capacity utilization and technology.	MoUD (2013)
2	Fecal Sludge Management in Developing Countries: A Planning Manual			**Guidance on siting a decanting / disposal location for FS:** The design must avoid high transport costs for delivering sludge to the facility. **Safe collection:** Appropriate incentive systems should make sure that all collected fecal sludge reaches the plant.	**Siting treatment facility: "**When choosing the treatment sites, it is very important to take into account the resistance or acceptance of the population neighboring the site or the access roads. Possible negotiations for compensation measures should be held early in the plan. It is important to include surface for possible extensions of the plant and for buffer zones when purchasing or reserving land for sludge treatment. **Safe loading of FS:** "It is necessary to verify if the STP has sufficient capacity to treat the additional pollution load from FS. The most critical parameter is usually suspended solids (SS). Other design parameters are COD, BOD5, NH4-N. **Co-treatment of liquids with sewage:** Effluents from primary FS treatment can be treated together with sewage if a sewage treatment plant is existing or planned. The primary treatment mainly eliminates the suspended solids and the STP can then treat much higher volumes of liquid effluent than of raw FS. This option can be considered when there is existing or planned a sewage treatment plant, and when its capacity is not sufficient to treat raw FS. It is necessary to verify if the STP has sufficient capacity to treat the additional pollution load from pre-treated FS. The greatest part of suspended	SANDEC (2002)

S.No	Study / Document	Aspects covered under the guidance				Reference
		OSS emptying	**FS characterization**	**Decanting Stations**	**Co-treatment at STPs**	
					solids will be removed in primary treatment. The critical parameters will therefore be BOD5 and COD, further important are remaining SS and NH4-N.	
3	Solids Separation and Pond Systems For the Treatment of Faecal Sludges In the Tropics Lessons Learnt and Recommendations for Preliminary Design		Human Excreta: Per Capita Quantities, Characteristics, Classification and Comparison of FS, Heavy Metal Concentrations in Septage		Three critical variables should be considered when planning to co-treat wastewater and faecal sludge, viz. organic loading rate, solids load and ammonium/ammonia nitrogen concentration. Recommendation for Solids-Liquid Separation Prior to Pond Treatment, design guidelines for settling / thickening. Additional detailed guidance from this reference is included in **Annex 1.**	SANDEC (1998)
4	Decentralized Systems Technology Fact Sheet Septage Treatment/ Disposal		Typical FS characteristics for domestic septage		Discusses septage addition at: 1. To Upstream Sewer Manhole: When septage is added to a sewer upstream of the wastewater treatment plant, substantial dilution of septage occurs prior to it reaching the wastewater treatment plant. This method is only feasible with large sewers and treatment plants. It is economical due to the very simple receiving station design. F7However, there is the potential for grit and debris to accumulate in the sewer and for odor problems near the manhole 2. To Plant Headworks: Septage can be added to sewage immediately upstream of the screening and grit removal processes. This method, like the one mentioned above, is economical because of the very simple receiving station design. It also allows the wastewater treatment plant staff to have control of the septage discharge. 3. To Sludge Handling Process: This method reduces the	USEPA (1999)

S.No	Study / Document	Aspects covered under the guidance				Reference
		OSS emptying	**FS characterization**	**Decanting Stations**	**Co-treatment at STPs**	
					loading to liquid stream processes, and it eliminates the potential for affecting effluent quality. However, there could be an adverse effect on the sludge treatment processes such as dewatering. Adding septage to the sludge handling process may also cause clogging of the pipes and increase wear on the pumps if the septage is not screened and degritted in the receiving station. 4.To Both Liquid Stream and Sludge Handling Processes: Septage can also be pretreated to separate liquid and solid fractions, which are then processed accordingly. This provides more concentrated sludge for processing and reduces the organic loading to liquid stream processes and the hydraulic loading to sludge processes. Increased operations are required for septage pretreatment at the receiving station.	
5	Septage Management: A Practitioner's Guide				Guidance on 1. Septage directly mixed with sewage 2. Septage treated with the sludge of an STP. **Key considerations for septage directly mixed with sewage:** **a)** The quality, and not just the quantity, of the sludge, must be evaluated. b) It must be ascertained beforehand whether the septage and sludge contain any toxic chemicals that can destroy biological communities. The presence of trash, grit, and trade and industrial sludge can be toxic and impact biological processes. c) Consistent compliance of STPs might be an issue **Septage co-treated with STP sludge:** This is a better option because most STPs have land for sludge drying and	Rohilla et al (2017)

S.No	Study / Document	Aspects covered under the guidance				Reference
		OSS emptying	FS characterization	Decanting Stations	Co-treatment at STPs	
					dewatering. Sludge dewatering sites needs to be improved a bit by designing proper sludge drying beds. Geobags to dewater the septage or sludge can be developed as an alternative option to sludge drying bed. The liquid fraction from sludge or septage can be directed to the STPs. This is a much better option than directly mixing septage into the liquid stream of STPs. Septage, after dewatering, and sludge from STPs can be treated together through co-composting, pyrolysis etc. This solution is feasible only in STPs in the vicinity of the target city, otherwise, sludge transportation cost will be prohibitive.	
6	USEPA Guide To Septage Treatment and Disposal	Guidance on septic tank emptying: Types of pumps, procedures for emptying (including precautions), transportation requirements	Typical FS characteristics for domestic septage	Examples of septage receiving stations (typical design), record keeping requirements, example of septage and sludge manifest, O&M checklist,	See Figure on different approaches and advantages / disadvantages of each. Potential impacts of septage addition: 1. Increasing volume of screenings and grit requiring disposal 2. Increased odor emissions 3. Scum accumulation in clarifiers 4. Increased organic loading to biological processes 5. Increased loadings to sludge handling processes 6. Increased sludge volumes 7. increases housekeeping requirements Guidance on odor control approaches (operational and physico-chemical)	USEPA (1994)
7	Co-treatment of Faecal Sludge and		"The formulae and diagrams which were		Includes operational and design guidance for the co-treatment of faecal sludge in waste stabilisation ponds and in activated sludge sewage treatment plants.	SANDEC (1999)

S.No	Study / Document	Aspects covered under the guidance				Reference
		OSS emptying	**FS characterization**	**Decanting Stations**	**Co-treatment at STPs**	
	Wastewater in Tropical Climates		developed by USEPA to determine the allowable rate of septage addition are based on a standard value for BOD concentrations in faecal sludge (7,000 mg/l). 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."		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. Additional detailed guidance from this reference is included in **Annex 1.**	

S.No	Study / Document	Aspects covered under the guidance				Reference
		OSS emptying	**FS characterization**	**Decanting Stations**	**Co-treatment at STPs**	
8	Faecal Sludge Management Systems Approach for Implementation and Operation		Includes detailed guidance on FS characterization, and the impact of different water quality parameters on treatability and co-treatment performance. **Use of FS quality parameters in design:** The researchers recommend using COD over BOD to measure organic matter. Advantages of COD over BOD5 include: (i) a rapid analysis (e.g. hours as opposed to 5 days), (ii) more detailed and useful information	Types of transfer stations, siting considerations for transfer stations, hazards in handling FS at transfer stations,	Detailed guidance from this reference is included in **Annex 1.**	Strauss et al (2014)

S.No	Study / Document	Aspects covered under the guidance				Reference
		OSS emptying	**FS characterization**	**Decanting Stations**	**Co-treatment at STPs**	
			including all degradable and undegradable organics, and (iii) the potential for the organics balance to be closed (on a COD basis). Of the two COD analytical determination methods, the dichromate method is preferred, as the permanganate method does not fully oxidise all organic compounds			
	Treating Faecal Sludges in Ponds	FS characteristics			Effect of FS TS, VSS, and Ammonia on WSP performance. When treating FS in ponds, be it separately or in conjunction with wastewater, settleable solids must be separated in primary treatment units in order to guarantee an undisturbed treatment of the liquid fraction. Process disturbance by improper design and operation for solids separation has been repeatedly observed The rate of accumulation of settleable solids, hence, the	Strauss et al (2000)

S.No	Study / Document	Aspects covered under the guidance				Reference
		OSS emptying	FS characterization	Decanting Stations	Co-treatment at STPs	
					required solids storage volume, is the decisive design criteria for preliminary settling/thickening units or for solids storage compartments in primary ponds. Batch-operated settling/thickening is, in most cases, the technology-of-choice in developing countries, as electro-mechanical installations for continuous sludge removal may not prove sustainable. Primary ponds may constitute an alternative to settling tanks where this proves feasible for reasons of land availability, construction cost and solids removal operations. Such ponds can be designed as deep ponds to comprise a compartment for solids accumulation, with pond emptying intervals of > 1 year. However, the solids removal from the storage compartment may pose great technical difficulties. The handling of biosolids accumulated in pre-settling tanks or in shallow primary ponds is easier compared with deep primary ponds. The authors hypothesise that rates of up to 600-700 g BOD/m3·day might be tolerated in tropical climate as against 300-350 g BOD/m3·day for wastewater ponds. Although most septage has usually been stored for months or years prior to collection, it has become apparent that, in many cases, it is still conducive to anaerobic degradation. Anaerobic degradation of medium to high-strength FS can be impaired by toxicity due to high ammonia (NH_3) concentrations. NH_3-N threshold levels in the influent to	

S.No	Study / Document	Aspects covered under the guidance				Reference
		OSS emptying	**FS characterization**	**Decanting Stations**	**Co-treatment at STPs**	
					anaerobic ponds in the tropics should not exceed 400-500 mg/l.	

Fecal sludge co-treatment experience

Table X summarizes examples of fecal sludge co-treatment at a sewage treatment plant (STP) from different countries. There is limited information available on the practice of co-treatment, and lesser still on the specific experience and design / operation details from sites where the practice of co-treatment is occurring. Anecdotal information on FS treatment at STPs is available and summarized in the following table.

S.No	Study / Document	Country / Region	Description of co-treatment experience	Level of detail available
1	Regional Siting Of Fecal Sludge Treatment Facilities: St. Elizabeth, Jamaica, Ana Martha Fernandes[18]	Jamaica	Brief reference to practice of co-treatment at 2 existing STPs in St. Elizabeth, Jamaica, however this practice has not been continued due to prohibitive cost of transportation	Brief mention of practice
2	A Review Of Fecal Sludge Management In 12 Cities[19]	Santa Cruz, Bolivia	The private operators transport the FS to a water and sanitation cooperative run (SAGUAPAC) treatment plant. 60% of the waste emptied is transported to treatment but the balance is dumped illegally in the environment. The treatment efficiency is understood to be good and 100% of the sludge delivered is treated and discharged. Only 9% of FS generated from OSS is treated. This cooperative receives and treats sludge from 25 sludge collection services (10,000 m3 / month).	Reference to the practice, and share of FS in the city that is treated at WWTP
3	A Review Of Fecal Sludge Management In 12 Cities[20]	Managua, Nicaragua	50% of the mechanically emptied FS is transported to the water and sanitation provider’s (ENACAL) WWTW. The balance is discharged illegally.	Reference to the practice, and share of FS in the city that is treated at WWTP

[18] Fernandes (2005).
[19] "WSP (2013); Furlong (2017)"
[20] WSP (2013)

S.No	Study / Document	Country / Region	Description of co-treatment experience	Level of detail available
			Six of the 10 known collection companies discharge their fecal sludge at the wastewater treatment plant. Nicaragua's national drinking water and sanitation enterprise, ENACAL, charges them US$0.30/m3. The collection companies generate a monthly sludge volume of 863.51m^3 and fees amounting to US$3,165.16 (ENACAL 2011). These figures suggest that the plant's capacity for the treatment of sludge is probably greater than what it receives.	
4	A Review Of Fecal Sludge Management In 12 Cities[21]	Maputo, Mozambique	Dumping of FS in Infulene WWTW is permitted; this is operated by Municipality but operates at only 50% efficiency.	Reference to the practice, and share of FS in the city that is treated at WWTP
5	A Review Of Fecal Sludge Management In 12 Cities[22]	Kampala, Uganda	Dumping of FS in Bugolobi WWTW is permitted; this is operated by NWSC; efficiency is estimated to be 75% (nominal). Faecal sludge that is removed from the plot through manual or mechanical means is disposed of at designated wastewater treatment plants. Operators need a license to transport faecal sludge, but this is seldom enforced	Reference to the practice, and share of FS in the city that is treated at WWTP
6	Faecal Sludge Management In Botswana: A Review Of Current Practices And Policies Using The Case Of Gaborone	Botswana, Gaberone	The FS sludge from pit latrines is treated with municipal wastewater at the Gaborone Wastewater Treatment plant, 10 km northeast of Gaborone City. Due to limited methods of treatment and disposal of FS from pit latrines, sludge management	Reference to the practice and challenges

[21] "WSP (2013); WSP(2012)"
[22] "WSP (2013); WRC (2015)"

S.No	Study / Document	Country / Region	Description of co-treatment experience	Level of detail available
	Low Income Areas[23]		has become an integral part of the wastewater treatment plants across the country (FS is mixed with sewage at the inlet to the STP).	
7	The Status Of Faecal Sludge Management In Eight Southern And East African Countries[24]	South Africa	Vacuum tanks usually dispose of faecal sludge at the municipal wastewater treatment plants. In a number of municipalities, these plants struggle to meet regulatory requirements. In the urban areas of South Africa, faecal sludge is usually added to the wastewater stream where it is subject to co-treatment in wastewater treatment plants, as well as waste stabilisation ponds	Plant configuration, size of units, removal efficiencies at each stage of treatment
8	Cotreatment of sewage and septage in waste stabilization ponds	Alcorta, Argentina	System of two waste stabilization ponds in series was put into operation in the town of Alcorta. Both wastewater and septage were cotreated in a pond stabilization system with two ponds in series. The vacuum trucks discharge directly into the first pond. Due to high contents of solids of septage, the primary pond had reduced its capacity by half. Construction of two septage ponds was undertaken to address this issue.	
9	Domestic Septage Characteristics and Cotreatment Impacts on Albireh Wastewater Treatment Plant Efficiency	Albireh, Palestine	The study modeled the impact of FS after detailed characterization using a modeling software Albireh city has a central public sewer network of a modified combined system, where part of the collected stormwater is mechanically treated at AWWTP	

[23] Odirile etal (2018)
[24] "WRC (2015); WRC (2012)"

S.No	Study / Document	Country / Region	Description of co-treatment experience	Level of detail available
			site in the stormwater tank. Samples were collected from different septage haulers delivering septage from different places in Albireh at different times. ANAwin was used to simulate the impact of septage increment (%) on the unit operation design of the aeration tank including structural and biological design parameters at variable temperatures	
10	FSM Handbook	South Africa	Two activated sludge WWTPs located in eThekwini, South Africa were receiving low volumes of FS from pit latrines. experienced serious operational problems caused by the high loads of organics, nitrogen compounds and suspended solids	
11	FSM Handbook	Saint Marten, Netherlands Antilles	On the island of Saint Marten, wastewater and septic tank sludge were discharged into the existing Illidge Road WWTP. The plant consisted of an Imhoff tank, buffer tank, secondary settling tank and sludge drying beds. The plant capacity was considerably exceeded by the wastewater flow rate (of at least 65 m3/h) and the high FS volumes that in a typical working day accounted for an equivalent of about 175 m3/day. During retrofit to a Modified	

S.No	Study / Document	Country / Region	Description of co-treatment experience	Level of detail available
			Bardenpho (A2O) process design, different scenarios were evaluated through mathematical modelling.	
12	FSM Handbook	Manila, Philippines	Activated sludge systems have recently been chosen in the Philippines as the main biological treatment process for FS treatment. Manila Water's FS operations with septic tank sludge currently utilise a FS treatment with activated sludge in the Manila South septage treatment plant. The plant is able to treat up to 814 m3 per day of FS.	

The following table summarizes the challenges observed and approaches adopted at sites that were co-treating FS at STPs.

S.No	Study / Document	Country / Region	Challenges	Year of study	Reference
1	Regional Siting of Fecal Sludge Treatment Facilities: St. Elizabeth, Jamaica, Ana Martha Fernandes	Jamaica	Cost of transportation by trucks was prohibitive	2005	Fernandes (2005).
2	A Review of Fecal Sludge Management in 12 Cities	Santa Cruz, Bolivia		2013; 2017	WSP (2013) Furlong (2017)
3	A Review of Fecal Sludge Management in 12 Cities	Managua, Nicaragua		2013	WSP (2013)
4	A Review of Fecal Sludge Management in 12 Cities	Maputo, Mozambique		2013	WSP (2013) WSP(2012)
5	A Review of Fecal Sludge	Kampala, Uganda	Most of the wastewater treatment plants are designed	2013	WSP (2013)

S.No	Study / Document	Country / Region	Challenges	Year of study	Reference
	Management in 12 Cities		for wastewater treatment and not faecal sludge. Overloading of plants has been reported at some of the plants		WRC (2015)
6	Faecal Sludge Management in Botswana: A Review of Current Practices and Policies Using the Case of Gaborone Low Income Areas	Botswana, Gaberone	indiscriminate practice of co-treatment has caused the wastewater treatment plant to malfunction due solids over load.		Odirile etal (2018)
7	The Status Of Faecal Sludge Management In Eight Southern And East African Countries	South Africa	Part of the problem might be the vacuum tanks that discharge their sludge into the inlet structure of the wastewater treatment plant. This might cause shock loads. There seems to be little experience regarding the treatment process and there are no established strategies to deal with problems. The mechanism of WWT plant failure is not clearly understood. In one case, the removal of secondary solids from the works was limited by the number of truckloads of solids arising from secondary sludge from the plant that could be removed in a month, in terms of operating costs, and the willingness of the receiving landfill to accept the material. Thus when large volumes of fairly dry pit sludge were added to the works, with relatively little addition of biodegradable material, the solids report fairly soon as secondary sludge. The sludge could not be removed at an accelerated rate, and thus	2015	WRC (2015) WRC (2012)

S.No	Study / Document	Country / Region	Challenges	Year of study	Reference
			was retained in the system for an extended period. It was clearly a case of taking one solids problem and making it into another solids problem. Secondly, the very high load of nitrogen added to the works appeared to inhibit or otherwise deactivate the nitrification capacity of the works, and in this particular case, it took the works several months to recover. Thus while co-treatment in a conventional WWTP seems a convenient disposal route, it is not a sustainable or successful one.		
8	Co-treatment of sewage and septage in waste stabilization ponds	Alcorta, Argentina	Without pre-treatment, the solids loading from FS greatly impacted the available volume in the stabilization ponds, and impacted plant performance. The great difference in total solids between septage and sewage makes it necessary to pretreat the septage before its discharge into conventional treatment. Addition of a sludge pre-treatment unit (sedimentation ponds) helped achieve an effluent that was similar in quality to domestic sewage, and could be co-treated in WSPs.	1998	Ingallinella (2002)
9	Domestic Septage Characteristics and Co-treatment Impacts on Albireh Wastewater Treatment Plant Efficiency	Albireh, Palestine	FS co-treatment exerted additional energy consumption due to additional oxygen demand in the oxidation ditches for the biological processes. The daily average energy costs for septage treatment was calculated at US$ 410 per day.		Ingallinella (2002).

S.No	Study / Document	Country / Region	Challenges	Year of study	Reference
			The modeling indicated: 1. An increase in the aeration capacity (8-49%) must be achieved to cope with additional loads of both organic carbon and nitrogen; otherwise deficient oxygenation will lead to build-up of nitrite, less nitrification capacity and might cause sludge foaming/bulking. 2. 5-30% of septage addition implies overloading of the system and lead to 7-51% additional volume in the aeration tank. 3. Continuous co-treatment of septage will dramatically affect the issue of non-compliance related to COD and nitrogen.		
10	FSM Handbook	South Africa	A complete inactivation of the nitrification process was observed in one of the plants, which took several months to recover. The researchers suggested that this was a result of the excessive nitrogen load discharged into the plant and that the aeration capacity was exceeded as a consequence of the high loads discharged At the other plant under study, the high solids overloading made it practically impossible to remove the excess sludge generated as it was equal to the sludge volume produced in a month. Sludge removal was limited by the number of truckloads that could be removed, increasing associated operational costs and even the	2012	Strauss et al (2014)

S.No	Study / Document	Country / Region	Challenges	Year of study	Reference
			willingness of the receiving landfill to accept the material.		
11	FSM Handbook	Saint Marten, Netherlands Antilles	Higher concentrations of unbiodegradable compounds and low biodegradability of organics in FS hindered compliance with the effluent limits. Due to the loads of unbiodegradadable particulate organic matter and unbiodegradable soluble organic nitrogen from the digested FS, the modeling study suggested that the proposed plant would only be able to comply with most of the discharge limits when the FS volumes comprise of no more than 2.8% of the influent. However, as a consequence of the high nitrogen load and slow biodegradability of biodegradable organics, the study also speculated that the nitrogen limits will probably not be met at the new plant.		Strauss et al (2014)
12	FSM Handbook	Manila, Philippines	Currently, the plant handles about 40-50% of its maximum capacity, indicating that there is still room for growth. In addition, the septage management system of the Baliwag water district has decided to build a septage treatment plant that utilises a sequencing batch reactor as a secondary treatment process.		Strauss et al (2014)

S.No	Study / Document	Country / Region	Challenges	Year of study	Reference
			These experiences indicate that co-treatment of FS in aerobic biological systems can be feasible and satisfactory if the design is adequate to cope with the FS influent, there is adequate operator capacity and competence, and an appropriate management scheme is implemented.		

References:

Bassan et al (2013). Characterization of faecal sludge during dry and rainy seasons in Ouagadougou, Burkina Faso, M. Bassan, T. Tchonda, L. Yiougo, H. Zoellig, I. Mahamane, M. Mbéguéré, and L. Strande, 36th WEDC International Conference, Nakuru, Kenya, 2013

Fernandes (2005). Regional Siting of Fecal Sludge Treatment Facilities: St. Elizabeth, Jamaica, Ana Martha Fernandes, Tufts University, 2005

Furlong (2017). SFD Promotion Initiative Santa Cruz, Bolivia, Claire Furlong, 2017

Ingallinella (2002). Cotreatment of sewage and septage in waste stabilization ponds. A.M. Ingallinella, G. Sanguinetti, R.G. Fernández, M. Strauss and A. Montangero, Water Science and Technology Vol 45 No 1 pp 9–15 © IWA Publishing 2002

Kone and Strauss (2004). Low-cost Options for Treating Faecal Sludges (FS) in Developing Countries – Challenges and Performance, 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

Krithika etal (2016). Spatio-temporal variation of septage characteristics of a semi-arid metropolitan city in a developing country, D. Krithika, Anu Rachel Thomas, Gomathy R. Iyer, Martin Kranert, Ligy Philip, Environ Sci Pollut Res DOI 10.1007/s11356-016-8336-z, 2016

MoUD (2013). Septage Management in Urban India, Ministry of Urban Development, 2013

Odirile etal (2018). Faecal Sludge Management in Botswana: A Review of Current Practices and Policies Using the Case of Gaborone Low Income Areas, Phillimon T. Odirile, Innocent Thukwi, Ontiretse Dintwa, Bontle Mbongwe, Journal of Environmental Protection, 2018, 9, 122-139

Pradeep etal (n.d.). Characteristics of Faecal Sludge generated from Onsite Systems located in Devanahalli, Rohini Pradeep, Sarani.S, Susmita. S, Presentation at FSM 4 Conference

Rashed et al (2006). Domestic Septage Characteristics and Cotreatment Impacts on Albireh Wastewater Treatment Plant Efficiency,RashedM.Y. A/-Sa'edand TaghreedM. Hithnawi , Dirasat, EngineeringSciences,Volume33,No.2, 2006

Rohilla et al (2017). Septage Management: A Practitioner's Guide, Suresh Kumar Rohilla, Bhitush Luthra, Amrita Bhatnagar, Mahreen Matto and Uday Bhonde, Centre for Science and Environment, New Delhi, 2017

SANDEC (1998). Solids Separation and Pond Systems for the Treatment of Faecal Sludges In the Tropics Lessons Learnt and Recommendations for Preliminary Design, SANDEC Report No. 05/98, June 1998

SANDEC (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, 1999

SANDEC (2002). Fecal Sludge Management in Developing Countries: A Plannng Manual, Florian Klingel , Agnès Montangero, Doulaye Koné, and Martin Strauss, 1st Edition , April 2002, Swiss Federal Institute for Environmental Science and Technology Department for Water and Sanitation in Developing Countries

Strande et al (2014). Faecal Sludge Management, Systems Approach for Implementation and Operation, Linda Strande, Mariska Ronteltap, Damir Brdjanovic, IWA Publishing, 2014

Strauss and Montangero (n.d). Feacal Sludge Management Review of Practices, Problems and Initiatives, Martin Strauss and Agnes Montangero, EAWAG/SANDEC

Strauss et al (2000). Treating faecal sludges in ponds. Strauss, M., Larmie, S. A., Heinss, U., & Montangero, A. Water Science and Technology, 42(10), 283-290

Strauss et al(2002). Fecal Sludge Management in Developing Countries: A planning manual, Florian Klingel , Agnès Montangero, Doulaye Koné, and Martin Strauss, 1 s t E d i t i o n , Swiss Federal Institute for Environmental Science and Technology, Department for Water and Sanitation in Developing Countries, A p r i l 2 0 0 2.

The World Bank (2016). Fecal Sludge Management: Diagnostics for Service Delivery in Urban Areas, Case Study Reports, April 2016

USEPA (1999). Decentralized Systems Technology Fact Sheet Septage Treatment/Disposal, EPA 932-F-99-068, September 1999

WRC (2012). Tackling the Challenges of Full Pit Latrines Volume 1: Understanding sludge accumulation in VIPs and strategies for emptying full pits, Report to the Water Research Commission by David Still and Kitty Foxon, July 2012.

WRC (2015). The Status of Faecal Sludge Management in Eight Southern and East African Countries, Sanitation Research Fund for Africa (SRFA) Project of the Water Research Commission and the Bill and Melinda Gates Foundation, May 2015

WSP (2012) Living without Sanitary Sewers in Latin America The Business of Collecting Fecal Sludge in Four Latin American Cities, Water and Sanitation Program, March 2012

WSP (2013). A Review of Fecal Sludge Management in 12 Cities, Water and Sanitation Program, March 2013

Annex 1: Detailed guidance from relevant literature on design of FS co-treatment systems

Design considerations for co-treatment (SANDEC, 1998)

The problems described in this paper which may arise when treating faecal sludge in pond systems are also relevant for the combined treatment of FS and sewage in waste stabilisation ponds (WSP). Three critical variables should be considered when planning to co-treat wastewater and faecal sludge, viz. organic loading rate, solids load and ammonium/ammonia nitrogen concentration.

• Organic loading rate: Anaerobic and facultative ponds are sensitive to excessive organic (BOD) loading. In anaerobic ponds, the most serious symptomatic problem resulting from overloading is odour nuisance. In facultative ponds, it will impair the development of aerobic conditions and algal growth. The permissible additional faecal sludge load is dependent on the initial organic load exerted by the wastewater and on the loading rates for which the ponds were originally designed.

• Solids load: Ponds may fill up at undesirably fast rates due to high solids contents in FS. Options for pretreatment of FS are described in Chpt. 4. Separation of the FS solids prior to treating the liquid in wastewater stabilization ponds contributes to optimum WSP performance and to minimising shortcircuiting and sludge removal operations.

• Ammonia nitrogen: The maximum NH_3 concentration tolerated by the algae in the facultative pond is an additional factor influencing the permissible FS load in a WSP system. Under the conditions prevailing in facultative ponds in tropical climates ($T \geq 25$-$28\ °C$; pH 7.5 - 8), ammonia (NH_3) amounts to 2-6 % of the ammonium (NH_4) concentration. If the permissible NH_3-N concentration in facultative ponds is set at 20 mg/l, and assuming that 5 % of NH_4 are NH_3, the maximum NH_4-N concentration of the combined waste in the influent to the facultative pond amounts to 400 mg/l. The bulk of the septage, usually stored for a period of up to several years, does not exhibit very high NH_4-N concentrations.

Fresh FS such as public toilet sludge, however, may contain NH_4-N concentrations of up to 5,000 mg/l.

SANDEC (1999)

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.

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

3. Fresh, undigested excreta and FS contain high NH4 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.

Discusses design parameters when co-treating at WSP for:

1. Organic loading rates:
2. Ammonia concentration and toxicity levels (Faecal sludges which have been stored over an extended period, e.g. septage, usually exhibit NH4-N concentrations of 400 mg/l. Fresh FS from unsewered low or zero flush toilets may contain NH4-N concentrations of 5,000 mg/l which would lead to an algae growth inhibition if excessive quantities were mixed. The guidance includes design example to estimate permissible FS loading based on NH3 concentration.
3. 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. The guidance includes design parameters for Sedimentation/thickening tanks and sludge drying beds for solids pre-treatment.

Includes design examples to estimate permissible loading in ASP at various processes – upstream of aeration process and design of critical units, and addition to the sewage sludge stream.

Strande et al (2014)

Co-treatment in WSPs:

1. Waste stabilisation ponds can be used for the co-treatment of wastewater with the effluent following solid-liquid separation of FS in settling-thickening tanks
2. Problems have been reported by researchers when dosing FS after screening directly into the anaerobic pond.
3. Typically, due to the high ammonia concentration and high organic loads and solid content, treating solely FS in WSPs is not recommended, nor is the addition of large quantities

Recommendation:

WSPs can be used for the co-treatment of FS and can treat liquid byproducts of other FS treatment technologies, including:

- Leachate from unplanted and planted drying beds. Leachate is low in organic matter compared to domestic wastewater and direct discharge into the facultative pond might be possible as the solid fraction is relatively low. However, the ammonia concentration can still present a problem, and algae and methanogenic inhibition by free ammonia can also occur.
- Effluent from settling-thickening tanks. This was implemented in Argentina as co-treatment with the influent of anaerobic ponds, where tests were conducted for the treatment of the effluent from settling ponds. This solution has also been adopted in Dakar, Senegal, where preliminary solid/liquid separation is done by settling tanks, the effluent is co-treated with wastewater in a WSP, and the thickened sludge is dewatered with unplanted drying beds.

Advantages and constraints of co-treating in WSPs:

- WSPs are simple to build and have relatively low O&M requirements.
- Technology is appropriate for tropical climates given land is available
- FS addition without solids separation could result in high rate of solids accumulation and potential inhibition due to high salt and ammonia concentrations. The removal of sludge that accumulates in the anaerobic ponds may require heavy mechanical equipment.

Co-treatment at STPs:

The authors do not recommend co-treatment of FS with wastewater as a common practice in low-income countries. A co-management option could include co-management of FS with the sludge produced during wastewater treatment.

Challenges with co-treatment:

1. WWTPs are typically not designed for FS loadings, and process disruptions and failures are frequently possible.
2. Common problems with co-treatment of FS in WWTPs range from the deterioration of the treated effluent quality to overloading tanks and inadequate aeration.

Considerations for co-treatment:

1. Transport of FS to STP: Uncontrolled dumping of FS into sewers needs to be carefully regulated and prevented. The considerably higher solids content of FS may lead to severe operational problems such as solids deposition and clogging of sewer pipes. Hence, the first step in designing a co-treatment system includes determining how the FS will be transported to the treatment facility and discharged into the influent stream.
2. Detailed guidance on limiting FS to ensure a) treated water quality; b) adequate aeration capacity and c) adequate sludge management. The researchers observe that accumulation of

TSS is the limiting parameter for the co-treatment of FS. If the increase exceeds the maximum plant capacity, the plant can experience serious operational problems ranging from overloading of aeration and secondary settling tanks (with associated solid-liquid separation problems) to a considerable decrease in the oxygen transfer efficiency (which can lead to insufficient aeration and therefore to oxygen limiting conditions). Modeling results indicated that low FS influent volumes (as low as 0.5% for medium- and high-strength FS and of 2.5% for low-strength) could also overload the plant and exceed the maximum recommended design concentrations for aeration tanks. In addition, the increase in TSS and mixed liquor suspended solids (MLSS) concentrations will also result in increased volumes of waste sludge. There must be sufficient capacity in the sludge handling and disposal/enduse facilities of the plant to deal and cope with the higher sludge volumes generated.

3. FS disposal can also impact oxygen transfer efficiency and therefore aeration requirements of the plant as well as performance of the secondary settling tanks.
4. Dynamic loading of FS at STPs: FS flow rates can be much more dynamic than wastewater because they are not just dependent on diurnal patterns, they are also dependent on factors such as the working schedule of service providers, the customer demand for collection services, and the season. This can result in peak loads during the busiest times that can overload the treatment plant. Results of modelling concluded that, under dynamic conditions, the maximum volumes that can be co-treated in an activated sludge plant without causing any process disruption or (effluent) deterioration sometimes need to be up to 10 times lower than those allowable under steady-state conditions the modeling also tested the impact of dynamic loading during off-peak hours, (discharge during the night) and the potential contribution of primary sedimentation tanks, with little impact on plant performance under dynamic conditions. This illustrates the importance of equalisation tanks to ensure a more even loading, and the need to distribute influent FS evenly through the entire day to approach steady-state conditions.

Co-treatment at STPs with Nitrogen removal

The organic content to nitrogen ratios in typical FS samples presented by the researchers indicate that organic concentrations in FS are not sufficient for nitrogen removal by denitrification. The researchers recommend that FS should only be considered for co-treatment in processes that include nitrogen removal if the influent wastewater has a high COD:TKN or BOD5:TKN ratio (i.e. 12-16 and 6-8, respectively). In contrast, the COD:TP and BOD_5:TP ratios in FS are relatively high, which suggests that there could be sufficient organic matter for biological phosphorus removal

Impact on cost of new STPs

The researchers indicated that while for new STPs can be designed to receive an treat FS, however, the design will probably lead to larger tank volumes, larger settling tanks, and higher installed capacity for aeration and sludge handling, treatment and disposal. For instance, compared to municipal wastewater treatment alone, for 1% FS co-treatment (regardless of the strength), the tank volumes will need to be 300% larger, the aeration capacity at least 200% higher, the secondary settling tanks 5 times larger and the sludge facilities 4 times larger. This will have a considerable impact on plant capital and O&M costs.

Impact of FS treatment in anaerobic treatment systems

Co-treatment of FS and wastewater in anaerobic processes is an alternative for sludge stabilisation, volume reduction and increased dewaterability. Possibilities include upflow anaerobic sludge blanket reactors (UASB), anaerobic digesters and anaerobic ponds. Anaerobic treatment can offset treatment costs through the production of biogas, which can be used for heating or for the generation of electricity. Pathogen reduction can also be achieved with thermophilic digestion.

The researchers suggest that FS from septic tanks (digested FS) may not be appropriate for anaerobic co-treatment, depending on the level of stabilization it has undergone. In this case, the low concentrations of biodegradable organics in digested FS will lead to low biogas production but high solids accumulation resulting in significant operational costs with limited benefits.

The researchers observe that anaerobic treatment processes are disrupted by overloading of COD, ammonia inhibition, pH variations, and sulfide inhibition. Therefore, these factors need to be carefully monitored, and controlled, to ensure proper operation of co-treatment of FS in anaerobic treatment systems.

1. In UASB reactors, to prevent overloading, the maximum COD or VSS design loading rates must not be exceeded, and reactors must have consistent and uniform feeding
2. For anaerobic co-treatment in digesters, it is recommended that the feeding, including FS, is always lower than one twentieth of the digester volume. This approach would mean a maximum 5% FS loading, regardless of its strength, to prevent overloading or significant reduction in the SRT.
3. Ammonia Inhibition: The anaerobic co-treatment of FS can be inhibited by the high concentrations of ammonia present in FS. The researchers suggest that their volumes need to be limited to no more than 2, 5 and 8% for high-, medium- and low-strength FS, respectively (based on the total nitrogen concentrations expected in co-treatment of wastewater and fresh FS).
4. pH variations: In anaerobic systems, the pH needs to be carefully monitored and kept between 7.0 and 7.5. Monitoring, and if possible adjusting, the alkalinity levels and buffer capacity of the system can help to reduce pH fluctuations and maintain an adequate pH range. Other practices, such as gradual feeding and the controlled addition of external compounds (including charcoal ashes to enhance pathogen removal and nutrient recovery), also need to be carefully performed.