Technology

Chapter 2

Faecal Sludge Quantification, Characterisation and Treatment Objectives

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Learning Objectives

- Understand the difficulties in obtaining reliable data on the quality and quantity of faecal sludge production on a citywide scale.

- Know which parameters are important for faecal sludge characterisation, how they are analysed, and which ranges determine high, medium and low strength faecal sludge.

- Be able to describe how operational factors impact the variability of faecal sludge.

- Have an understanding of faecal sludge management and treatment targets and objectives.

2.1 INTRODUCTION

The first step in designing faecal sludge (FS) treatment technologies that will meet defined treatment objectives is to quantify and characterise the FS to be treated. Ideally, this should be carried out as part of the Feasibility Study as described in Chapter 17, but is however difficult due to the lack of standardised methodologies for the quantification or characterisation of FS. This complicates the design of adequate and appropriate systems.

The quantities of FS generated and the typical FS characteristics are difficult to determine due the variety of onsite sanitation technologies in use, such as pit latrines, public ablution blocks, septic tanks, aqua privies, and dry toilets. In many cities, a mixture of these technologies often exist side-by-side, and there is generally a prevalence of different technologies in different geographical regions. For example, in Bangkok, Thailand; Dakar, Senegal; Hanoi, Vietnam, and Buenos Aires, Argentina septic tanks are the predominant form of onsite FS containment technology; whereas in Kampala, Uganda; Nairobi, Kenya; and Dar es Salaam, Tanzania, various types of pit latrines are the predominant form of FS containment technology (e.g. improved and unimproved private latrines, shared and public latrines).

The quantity and characteristics of FS also depends on the design and construction of the sanitation technology, how the technology is used, how the FS is collected, and the frequency of collection. All of these variables results in a significant difference in FS characteristics within cities, and within the same type of containment technology in different locations.

This chapter therefore aims to provide an overview of the current state of knowledge on the quantification and characterisation of FS, to identify gaps in the existing body of knowledge, and to put these into perspective with regards to FS treatment objectives.

2.2 QUANTIFICATION OF FAECAL SLUDGE

Deriving accurate estimates for the volume of FS produced is essential for the proper sizing of infrastructure required for collection and transport networks, discharge sites, treatment plants, and enduse or disposal options. Due to the variability of FS volumes generated it is important to make estimates based on the requirements specifically for each location and not to estimate values based on literature. However, no proven methods exist for quantifying the production of FS in urban areas, and the data collection required in order to accurately quantify FS volumes would be too labour intensive, especially in areas where there is no existing information. There is therefore a need to develop methodologies for providing reasonable estimates.

Two theoretical approaches that have been developed are the Sludge Production Method, and the Sludge Collection Method, depending on whether the goal is to determine total sludge production, or the expected sludge loading at a treatment plant. The Sludge Production Method for estimating FS quantities starts at the household level with an estimate of excreta production (i.e. faeces and urine), the volume of water used for cleansing and flushing and in the kitchen, and accumulation rates based on the type of onsite containment technology. The Sludge Collection Method starts with FS collection and transport companies (both legal and informal), and uses the current demand for services to make an estimate of the volume of FS. Unfortunately, many assumptions have to be made in both methods due to a lack of available information. The following sections provide an example of how these methods are used to estimate the quantity of FS.

Table 2.1   Reported faecal production rates

Location	Wet weight (g/person/day)
high income countries[1]	100-200
low income countries, rural[2]	350
low income countries ,urban[2]	250
China[3]	315
Kenya[4]	520
Thailand[5]	120-400

[1] Lentner *et al.* (1981); Feachem *et al.* (1983); Jönsson *et al.* (2005); Vinnerås *et al.* (2006)

[2] Feachem *et al.* (1983)

[3] Gao *et al.* (2002)

[4] Pieper (1987)

[5] Schouw *et al.* (2002)

2.2.1 Sludge production method

The quantity of faeces produced on a daily basis can vary significantly based on dietary habits. People with a diet consisting of unprocessed food with a high fibre content will produce a higher quantity of faeces (mass and volume) compared to people who have a proportionally higher meat based and highly processed food diet (Guyton, 1992). The frequency of faecal excretion is on average one stool per person per day, but can vary from one stool per week up to five stools per day (Lentner *et al.*, 1981; Feachem *et al.*, 1983). Reported values for faeces production are presented in Table 2.1.

The volume of urine excreted daily also varies significantly, based on factors such as liquid consumption, diet, physical activity and climate (Lentner *et al.*, 1981; Feachem *et al.*, 1983). Reported values for urine production are presented in Table 2.2.

In addition to the volume of excreta generated daily, FS accumulation depends on time and spatial habits that influence where people use the toilet, such as work schedule, eating and drinking habits, patterns of societal cohesiveness, and frequency of toilet usage. The volume of solid waste and other debris that is disposed of in the system also needs to be taken into account.

In order to obtain a good estimate of FS production, the following data is required:
- number of users;
- location;
- types and number of various onsite systems;
- FS accumulation rates; and
- population of socio-economic levels.

The collection of data can pose some challenges depending on the available information, as frequently, onsite systems are built informally, so there is no official record of how many, or what type, of systems exist on a city-level scale. An accurate estimate of this would require intensive data collection at the level of household questionnaires. In some cases detailed demographic information is available, while in others it does not exist. A further complication is the rapid population growth in urban areas of low-income countries. Estimating the volume of FS to be delivered to treatment plants also needs to take into account that vacuum trucks do not always empty the contents of the entire sanitation containment system (Koanda, 2006).

Table 2.2   Reported urine production rates

Location	Volume (g/person/day)
General value for adults[1]	1,000 - 1,300
Sweden[2]	1,500
Thailand[3]	600-1,200
Switzerland (home, weekdays)[4]	637
Switzerland (home, weekends)[4]	922
Sweden[5]	610-1,090

[1] Feachem *et al.* (1983)
[2] Vinnerås *et al.* (2006)
[3] Schouw *et al.* (2002)
[4] Rossi *et al.* (2009)
[5] Jönsson *et al.* (1999)

This method for estimating total FS production will result in an overestimation of the potential volumes to be delivered to a FSTP. Although the ultimate goal is for all FS to be delivered to a treatment plant, it is not realistic to assume that all of the FS produced will initially be collected and transported for discharge at a FSTP.

2.2.2 Sludge collection method

The quantity of FS that is currently being collected from onsite systems in an area will vary depending on the FSM infrastructure, based on factors such as acceptance and promotion of FSM, demand for emptying and collection services, and availability of legal discharge or treatment sites. The volume that is currently being collected can be estimated based on interviews, site visits, and a review of internal records of FS collection and transport companies. Estimates can be based on the number of collections made each day, the volume of FS per collection, the average emptying frequency at the household level, and the estimated proportion of the population that employ the services of collection and transport companies (Koanda, 2006). The activity of informal or illegal collection should also be taken into account, as the volumes collected can be quite significant.

Estimating generation of FS based on this method is complicated by many factors such as the presence of a legal discharge location or treatment plant (see Figure 2.1), if the discharge fees are affordable, and whether there are enforcement measures to control illegal dumping. If all of these factors are in place, then it is possible that the majority of the FS collected will be transported and delivered to a treatment site. If a legal discharge location exists, a flow meter can be installed in order to provide an indication of the volume of FS that is being discharged. However, there is currently a lack of legal discharge locations, and, collection and transport companies are hesitant to cooperate in an official study that effectively documents their illegal activities. It is difficult to quantify the volume of FS being dumped illegally directly into the environment, either by collection and transport companies, or by households that hire manual laborers to remove FS. In addition, if volumes are being estimated for a treatment plant in an area where no legitimate discharge option currently exists, once it is built, it is expected to rapidly increase the market for these services, and hence the volume that will be delivered will also increase. This could result in an underestimation of the required capacity for the FSTP.

Figure 2.1   Discharge of faecal sludge at Duombasie landfill and faecal sludge treatment site in Kumasi, Ghana (photo: Linda Strande).

The accuracy of any method to estimate the volume of FS generated will depend on the quality of the available data, and the reasonableness of assumptions that are made. Methods to estimate volumes of FS will hopefully improve rapidly as more FSTPs are built, and as Faecal Sludge Management (FSM) gains acceptance and legitimacy.

2.3   CHARACTERISATION OF FAECAL SLUDGE

Parameters that should be considered for the characterisation of FS include solids concentration, chemical oxygen demand (COD), biochemical oxygen demand (BOD), nutrients, pathogens, and metals. These parameters are the same as those considered for domestic wastewater analysis, however, it needs to be emphasised that the characteristics of domestic wastewater and FS are very different. Table 2.3 presents examples from the literature illustrating the high variability of FS characteristics and provides a comparison with sludge from a wastewater treatment plant. A more detailed comparison of wastewater sludge and FS COD fractionation is presented in Chapter 9. The organic matter, total solids, ammonium, and helminth egg concentrations in FS are typically higher by a factor of ten or a hundred compared to wastewater sludge (Montangero and Strauss, 2002).

There is currently a lack of detailed information on the characteristics of FS. However, research is actively being conducted in this field. Research results, together with empirical observations, will continue to increase the knowledge of FS characteristics, and allow more accurate predictions of FS characteristics using less labour intensive methods. Section 2.4 discusses the operational factors that affect the variability of FS. In addition to these factors, the high variability of the observed results is also due to the lack of standardised methods for the characterisation of FS.

Case Study 2.1 : Variability of feacal sludge characteristics in Ouagadougou, Burkina Faso

The variability of FS characteristics is illustrated by Bassan *et al.* (2013a). A sampling campaign was set up to sample in the dry and the rainy season in Ouagadougou, Burkina Faso (see Figure 2.4). The TS concentration in the dry season was found to be 10,658 mg/L with a standard deviation of 8,264. Due to the high variability between the samples, a significant difference in strength of FS collected in the wet or dry season could not be detected. Yet, the campaign revealed that during the rainy season a much higher number of trucks arrived at the dumping locations, up to three times as many – indicating that pit latrines and septic tanks were filling up much faster due to leakages and run-off.

Given the significant variability of FS characteristics, it is important to collect data for specific locations when designing a FS treatment system. For example, in 2010, due to a lack of locally available data the design of a FSTP in Ouagadougou, Burkina Faso was based on general characteristics from the literature. The FSTP was designed to treat 125 m³/day with a TS load of 21,000 mg/L, resulting in 96 drying beds with a surface area of 128 m². Follow-up studies on the characterisation of FS in Ouagadougou revealed that the plant was over-designed by a factor of two, and was hence actually able to treat 250 m³/day (Bassan *et al.*, 2013b). Understanding the local FS characteristics prior to design would have significantly lowered the investment costs of the FSTP. This illustrates how important it is to understand local FS characteristics prior to designing treatment facilities.

Table 2.3   Reported characteristics of faecal sludge from onsite sanitation facilities and wastewater sludge

Parameter	FS source		WWTP sludge	Reference
	Public toilet	Septic tank		
pH	1.5-12.6			USEPA (1994)
	6.55-9.34			Kengne et al. (2011)
Total Solids, TS (mg/L)	52,500	12,000-35,000	–	Koné and Strauss (2004)
	30,000	22,000	–	NWSC (2008)
		34,106		USEPA (1994)
	≥3.5%	<3%	<1%	Heinss et al. (1998)
Total Volatile Solids, TVS (as % of TS)	68	50-73	-	Koné and Strauss (2004)
	65	45	-	NWSC (2008)
COD (mg/L)	49,000	1,200-7,800	-	Koné and Strauss (2004)
	30,000	10,000	7-608	NWSC (2008)
	20,000-50,000	<10,000	500-2,500	Heinss et al. (1998)
BOD (mg/L)	7,600	840-2,600	-	Koné and Strauss (2004)
	-	-	20-229	NWSC (2008)
Total Nitrogen, TN (mg/L)	-	190-300	-	Koné and Strauss (2004)
			32-250	NWSC (2008)
Total Kjeldahl Nitrogen, TKN (mg/L)	3,400	1,000	-	Katukiza et al. (2012)
NH_4-N (mg/L)	3,300	150-1,200	-	Koné and Strauss (2004)
	2,000	400	2-168	NWSC (2008)
	2,000-5,000	<1,000	30-70	Heinss et al. (1998)
Nitrates, NO_3^- (mg N/L)	-	0.2-21	-	Koottatep et al. (2005)
Total Phosphorus, TP (mg P/L)	450	150	9-63	NWSC (2008)
Faecal coliforms (cfu/100 mL)	1×10^5	1×10^5	6.3×10^4 - 6.6×10^5	NWSC (2008)
Helminth eggs (Numbers/L)	2,500	4,000-5,700	-	Heinss et al. (1994)
	20,000-60,000	4,000	300-2,000	Heinss et al. (1998)
		600-6,000		Ingallinella et al. (2002)
		16,000		Yen-Phi et al. (2010)

2.4 OPERATIONAL FACTORS THAT IMPACT THE VARIABILITY OF FAECAL SLUDGE

The wide variability of observed FS characteristics is due not only to the range of different onsite technologies used, but also the way in which the system is used, the storage duration (filling rates and collection frequencies), inflow and infiltration, and the local climate. All of these factors should be taken into account when determining FS characteristics.

2.4.1 Toilet usage

Household habits associated with toilet usage influence the variability of FS in the onsite containment technology. The TS concentration is dependent on factors such as dry versus flush toilet, volume of flush water used, cleansing method ('washers' versus 'wipers'), and inclusion or exclusion of grey water from bathing or cooking. The fat, oil and grease concentration will increase with inclusion of kitchen wastewater without properly maintained oil and grease traps, and odors will also increase with additional organic waste streams. The filling rate will increase as more waste streams enter the toilet (e.g. solid waste from kitchen, rubbish), and with the number of people using the toilet. People also use additives to attempt to reduce filling rates such as supplemental microorganisms, salt, sugar, ash, fertiliser, and kerosene. Some additives can be quite harmful, and in general have not been found to be effective (Foxon *et al.*, 2012).

2.4.2 Storage duration

The filling rate and storage duration depends on the type of technology, quality of construction, toilet usage, and inflow and infiltration. The length of time that FS is stored in onsite containment systems before being collected and transported will greatly affect the characteristics due to the digestion of organic matter that occurs during storage. For example, in informal settlements in general, a large proportion of the population relies on public latrines that are highly frequented, and so require frequent emptying. In Kampala, 30 individuals (or 7 households) are on average sharing one single latrine (Günther *et al.*, 2011). In Kumasi, Ghana, 40% of the population relies on unsewered public toilets, which are emptied every few weeks. Hence, FS collected from public latrines tends to not be stabilised, and have high concentrations of BOD and NH_4^+-N (see Table 2.3). The emptying frequency of septic tanks varies greatly based on the volume and number of users, and can be anywhere from weeks to years. FS that has been stored in a septic tank for a period of years will have undergone more stabilisation than FS from public toilets. During the filling of onsite containment systems, the FS gets denser at the bottom due to compaction. This FS is more difficult to remove by pumping, and is therefore frequently not emptied and left at the bottom of the containment system.

2.4.3 Inflow and infiltration

The concentration and volume of FS is also greatly influenced by inflow and infiltration of leachate into the environment from the system and / or ground water into the system. The filling rate of systems will be slower if there is more leaching, resulting in a thicker FS. The permeability of containment systems is influenced by whether they are unlined, partially lined, completely lined, connected to drainfields or soakpits, and the quality of construction. If systems are permeable, the amount of inflow and infiltration will be influenced by the type of soil and the groundwater level. The exchange of ground water with FS can result in groundwater contamination which is made worse during periods of heavy and extensive rain due to an increase in flooding and the rising of the groundwater table. This is of particular concern in low-income countries where pit latrine and septic tank builders frequently come from the informal sector, and are not aware of the consequences of FS leaching into ground water, or may not have the means to determine the groundwater level.

2.4.4 Collection method

The FS collection method also influences its characteristics. FS at the bottom of containment systems that is too thick to pump will only be collected if it is manually emptied with shovels, or if water is

added to decrease the viscosity and enable pumping (see Figure 2.2.). Pit latrines which are unlined or partially lined also frequently require flushing with large amounts of water in order to pump the FS, as liquid leaching from the pit increases the thickness of the FS. FS that has been removed by pumping is generally more dilute and less viscous than FS that is manually collected.

FS emptied from septic tanks will be more dilute if more supernatant than sludge is collected, or if the pump is not strong enough to remove all of the accumulated sludge. For example, in Dakar, Senegal, 83% of collection and transport vehicles are equipped with pumps and not strong vacuums, and are therefore unable to remove solids settled at the bottom of septic tanks (Diongue, 2006; Sonko, 2008). Where soak pits are used for the infiltration of septic tank effluent, these may also require emptying of sludge due to clogging. Collection methods are covered in more detail in Chapter 4, Methods and Means for Collection and Transport.

Figure 2.2   Addition of water to aid in collection of feacal sludge from a pit latrine utilising a "Gulper" in the Kibera informal settlement, Nairobi, Kenya (photo: Linda Strande).

2.4.5 Climate
Climate has a direct influence on FS characteristics, mainly due to temperature and moisture. Tropical countries may have one season of heavy rainfall, referred to as the wet season, while others have a bi-modal rainfall and/or dry season. Temperatures may be at their lowest during the wet season and at their highest during the dry season. Frequently the highest demand on collection and transport services occurs during the rainy season, as heavy rainfalls result in overflowing and flooding of onsite systems. Rates of biological degradation are also temperature dependent, and rates increase with warmer temperatures.

2.5   TREATMENT TARGETS

The main objective of FS treatment is to ensure the protection of human and environmental health. Legislation that establishes regulations specifically for the treatment and discharge, enduse, or disposal of FS is therefore essential. Institutional frameworks are described in more detail in Chapter 12. However, in many cases legislation specific to the treatment of FS is borrowed from wastewater treatment legislation such as National Wastewater Discharge Standards or Environmental Protection Agency Guidelines, which do not take the very different nature of FS into account. Treatment targets for FS should be set based on the intended enduse or disposal goal of the sludge, and enduse or discharge of liquid effluents. A multi-barrier approach is preferred over setting prescriptive, target-based requirements, and is covered in more detail in Chapter 10, Enduse of Treatment Products.

2.6   TREATMENT OBJECTIVES

Dewatering (or "thickening") of FS is an important treatment objective, as FS contains a high proportion of liquid, and the reduction in this volume will greatly reduce the cost of transporting water weight and simplify subsequent treatment steps. Environmental and public health treatment objectives are achieved through pathogen reduction, stabilisation of organic matter and nutrients, and the safe enduse or disposal of treatment endproducts.

2.6.1 Dewatering
Common methods for dewatering of FS include gravity settling, filter drying beds, and evaporation / evapotranspiration. FS has different dewatering characteristics compared to wastewater sludge, in that it tends to foam upon agitation, and resist settling and dewatering (USEPA, 1999). The duration of onsite storage, and the age of FS also affects the ability to dewater the sludge. Empirical evidence shows that 'fresh' or 'raw' FS is more difficult to dewater than older, more stabilised FS. The dewatering, or thickening process can also include adding dry materials such as sawdust to increase the solids content, This is a common practice in processes such as composting where the sawdust also increases the carbon to nitrogen (C:N) ratio. The liquid stream that is produced during dewatering also requires further treatment, as it can be high in ammonia, salts, and pathogens. Dewatering mechanisms are presented in further detail in Chapter 3, and treatment technologies in Chapters 5-8.

2.6.2 Pathogens
FS contains large amounts of microorganisms, mainly originating from the faeces. These microorganisms can be pathogenic, and exposure to untreated FS constitutes a significant health risk to humans, either through direct contact, or through indirect exposure. FS needs to be treated to an adequate hygienic level based on the enduse or disposal option. For example, exposure pathways are very different for treated sludge discharged to the environment, used in agriculture, or combusted as a fuel. Pathogens

are covered in more detail in Section 2.10. Mechanisms for pathogen reduction and / or inactivation include starvation, predation, exclusion, desiccation, partitioning, and temperature, and are covered in more detail in Chapter 3.

2.6.3 Nutrients

FS contains significant concentrations of nutrients, which can be harnessed for beneficial resource recovery, but if not properly managed can result in environmental contamination. The nutrients in FS can supplement synthetic nitrogen based fertilisers that are heavily dependent on fossil fuels and phosphorus, which is a mined resource of which finite supplies are estimated to reach their peak availability within 100 years (the point at which demand outstrips supply) (Bentley, 2002; Steen, 1998). Environmental impacts from nutrients include eutrophication and algal blooms in surface waters (see Figure 2.3), and contamination of drinking water (e.g. nitrates leading to methemoglobinemia). Nutrients are covered in more detail below in Section 2.9.1. Further information on concerns and benefits of resource recovery of FS treatment endproducts are presented in Chapter 10.

2.6.4 Stabilisation

Untreated FS has a high oxygen demand due to the presence of readily degradable organic matter that consumes significant amounts of oxygen during aerobic respiration. If FS is discharged to the environment, it can result in depletion of oxygen in surface waters. The process of stabilisation results in a FS containing organic, carbon-based molecules that are not readily degradable, and which consists of more stable, complex molecules (e.g. cellulose and lignin). Stabilisation is achieved through the biodegradation of the more readily degradable molecules, resulting in a FS with a lower oxygen demand. Common indicators of stabilisation include measurement of Volatile Suspended Solids (VSS), BOD, and COD. In addition, stabilisation ensures that organic forms of nutrients present in treatment endproducts are stable, and can be more predictably and reliably used. Stabilisation also reduces foaming of FS, leading to better dewatering. Stabilisation is explained further in Chapter 3, Treatment Mechanisms.

Figure 2.3   Eutrophic river resulting from direct discharge of untreated faecal sludge and wastewater, Yaoundé Cameroon (photo: Linda Strande).

2.7   TREATMENT CONCERNS

The source of FS coming into a FSP should be monitored to ensure that toxic constituents are not introduced from industrial sources. Heavy metals are not removed during the treatment process, and it is therefore important to avoid contamination of the FS in the first place. Heavy metals are not usually a concern when dealing with domestic FS as these compounds typically come from industrial sources, although some contamination can occur from domestic sources, if for example batteries are disposed of into the toilet. Leachate from sludge drying beds and stabilisation ponds can be high in salinity. This is of concern if the effluent is to be used for irrigation due to impacts on plant growth, reduced soil permeability, and surface crusting. Use of a manifest system for tracking the source of FS is covered in Chapter 11, Operations and Maintenance, and the impact of metals and salinity is discussed in Chapter 10, Enduse of Treatment Products.

2.8   SAMPLING PROCEDURES AND PROGRAMMES

When characterising FS, the quality of the results are strongly influenced by the way in which samples are collected, as well as the laboratory methods and practices followed. This is exacerbated by the difficulty of trying to sample from within a closed onsite system. FS in containment structures is normally not mixed, so the sludge tends to form a scum layer on the top and is often more dense at the bottom. Where and how the sample is taken depends on the question that is being asked, and the sampling method should be reported alongside the results. For example, if the goal is to understand FS characteristics within the containment structure, versus understanding characteristics of FS that will be transported by trucks to treatment plants. For the former sampling would be done directly from the containment structure, for the later from the collection and transport truck. If the goal is to characterise FS within the containment structure, then a representative sample should be collected by taking multiple samples in the different zones (i.e. top, middle, bottom), and making a volumetrically representative composite sample.

If the goal is to characterise FS that will be delivered to a treatment plant, grab samples can be taken directly from the collection and transport truck at various intervals as the truck is discharging, and then mixed to obtain a composite sample (see Figure 2.4). The most accurate method is to take grab samples over set time periods (e.g. every 2 minutes), but samples can also be taken at the beginning, middle and end of discharge since the exact volume in the truck is not known (this is a more qualitative measurement, but has been shown to be reasonably accurate). The volume of the FS sample should be proportional to the volume of the truck from which the sample is taken as is carried out for flow proportional wastewater sampling (Vonwiller, 2007). If feasible, samples can also be taken following discharge to a storage tank fitted with a mixer in order to obtain a representative sample. Once FS is collected, settling occurs rapidly and this needs to be taken into consideration when selecting the timing and interval of sludge collection.

Other aspects that need to be taken into account include the need for sampling to take place over a short period of time, for the sample container to be closed to prevent volatilisation or contamination, and for the sample to be kept cool to prevent microbial activity. Samples should be analysed within eight hours from the time of collection, or if this is not possible, the sample should be preserved by refrigeration or freezing, or by the addition of a chemical fixative, depending on the standard method for the parameters to be measured.

Figure 2.4   Sampling campaign to quantify and characterise faecal sludge in Ouagadougou, Burkina Faso for the design of a new faecal sludge treatment plant. Currently, none exist in the city and the only option for collection and transport companies is direct discharge (photo: Hanspeter Zoellig).

Case Study 2.2: Difficulties associated with sampling for FS characterisation
(Kartik Chandran and Melanie Valencia, Columbia University, New York)

Starting in 2011, the Bill & Melinda Gates foundation funded a project to assess the possibility to produce biodiesel from FS. A partnership between KNUST in Kumasi-Ghana, Columbia University in New York and Waste Enterprisers was formed. The first step was the characterisation of f FS in Kumasi. A group of graduate students from KNUST conducted the "100 sample study" to assess solid content, ammonia, lipid content, pH and COD. The comparison was done among pit latrines, private and pubic toilets and was collected at site of discharge by the trucks. The analysis determined that toilets were the best feedstock for the purpose of maintaining a healthy fermenter system and getting a better yield of long chain fatty acids that could be precursors for biodiesel.

As the project evolved, volatile fatty acids were also considered as precursors for lipid production. This raised some concerns in terms of transporting the samples from the site to the laboratory due to the volatilisation of the material in question as well as the length of time between obtaining the sample and testing. The sample vials would then be filled up to the rim and taken to the laboratory immediately for same day VFA measurement. To obtain a homogeneous sample, especially for VFA production in the anaerobic digesters, four out of the six fermenters were mixed through pumps. Samples for gas production were collected before mixing while FS samples were collected afterwards.

Several managerial challenges were also encountered during the collection of the loads as well as during sampling. The facility is located within a pond system that serves as the wastewater treatment facility for the municipality. The first challenge was to get the trucks to discharge their FS in the experimental system rather than in the ponds. At the beginning, 5 USD (GHC10) were given to the truck drivers in compensation for their time, as it took longer to discharge the truck into the experimental system compared to the ponds. Nonetheless, during the rainy season many truck drivers refused to deliver FS because the road into the facility was damaged due to the rain. The incentive of 5 USD was no longer enough. Only a few truck drivers that became acquainted with the project continued to provide FS. Once the rainy season was over, trucks continued to not come to the facility even when the road had been fixed. Many alternatives to address this situation were considered, including making the sludge discharge opening larger for faster emptying. In the end, the fermentation team opted for doubling the pay. This attracted many more drivers and the word spread fast. More information about this and other FSM projects can be found at www.susana.org.

Case Study 2.3 : Faecal sludge sample selection and characterisation from onsite sanitation facilities in eThekwini Municipality, Durban

Characteristics of faecal sludge may vary greatly between different locations and types of facilities. In order to verify how greatly, the Pollution Research Group (PRG) at the University of KwaZulu-Natal in Durban, South Africa carried out a study of FS properties from different types of onsite sanitation facilities in the Durban Metro area, including urine diverting toilets (UDDTs), household (HH) and community ablution block (CAB) VIP latrines. The first phase involved a sampling programme (Table 2.4) to empty pits and to obtain sludge samples from selected onsite sanitation facilities followed by chemical, physical, mechanical and biological properties analyses.

A sampling method was developed for different depths at the 'front' and 'back' sections of the pit for all dry VIPs and UDDTs. The wet VIPs had a high liquid level and the sludge was concentrated as a crusty layer at the surface of the liquid. Samples were selected from the 'crust' and from the liquid beneath the sludge layer; no distinction was made between the 'front' and the 'back' of the pit. The CAB pits were full of liquid similarly to the wet VIPs. On average, eight samples were selected from each dry VIP, between four to six samples from each wet VIP, two to six samples from each UD toilet (active and inactive vault) and about 12 samples from each CAB. The samples of about one litre were stored in plastic containers at 4 °C for further analytical tests, including: Chemical Oxygen Demand (COD), ammonia, Total Kjeldahl Nitrogen (TKN), (ortho)phosphate, potassium, water content, total, volatile, fixed and suspended solids, sludge volume index (SVI), pH, thermal conductivity, specific heat, rheology (viscosity), density, particle size distribution, calorific value, heavy metals and parasites.

Some of the analytical results are summarised in Table 2.5 as an average of all samples. They indicated a relatively high moisture content of all VIP samples – about 80%. Expectedly, the UDDT samples had a lower moisture content (60%). The combination of moisture content (respectively total solids) and viscosity of the materials provides a useful starting point for assessment and design of mechanical pit emptying devices. The maximum measured sludge viscosity from a dry VIP was about 6×10^6 Pa.s, with an average value of about 3×10^5 Pa.s. However, these values are based on the untreated FS: for pit emptying purposes the content of non-faecal wastes should also be taken into account. The COD values were the lowest in the UD toilets.

Table 2.5   Average values of faecal sludge properties based on lab analyses

Type	Moisture %	SS mg/L	VSS g/g DW	Ash g/g DW	SVI ml/mg	pH -	COD mg/g DW	NH_4-N mg/g DW	TKN mg/g DS	PO_4-P mg/L	P_{tot} mg/L	Thermal conductivity W/mK	Calorific value MJ/kg	Density kg/m³
Dry VIP	83	381	0.57	0.43	0.11	7.6	680	13	40	0.73	3.86	0.54	14.06	1,356.5
Wet VIP	79	562	0.54	0.46	0.04	7.7	720	7	30	0.83	2.93	0.55	13.08	1,443.1
CAB VIP	77	139	0.49	0.51	0.51	7.4	650	3	30			0.60	14.31	1,350.1
UD	60	246	0.45	0.55	0.23	7.5	490	5	30	1.00	3.27	0.38	12.93	1,450.4

Pit sludge categorisation was carried out at WWTP site near Tongaat, north of Durban. Three sludge samples were selected from a dry VIP pit and a urine diverting (UD) toilet (from active and inactive vaults). Manual sorting by different material categories was carried out, the weight of each of them measured and then calculated as a per cent of total wet mass. An example of screening FS during a sampling event is presented in Figure 2.5.

Although different materials were identified during the manual sorting, over 85% by wet mass was determined to be organics which was FS. The second most prevalent category was 'paper', about 7-8% total wet mass, followed by textiles (1-2%). Feminine hygiene products were about 1% of the total mass. Further investigation of the particle size distribution between the different material categories is expected to provide information about the size range of those components and estimate their impact on the pit emptying devices.

2.9   PHYSICAL-CHEMICAL CONSTITUENTS

This section provides an overview of the commonly measured constituents for the characterisation of FS and the typical methods of quantification. Further information on the fundamentals of their transformations is presented in Chapter 3: Treatment Mechanisms. Methods need to be rigorously adapted for FS, but a detailed description of the analytical methods for wastewater can be found in references such as Standard Methods, e.g. APHA (2005).

2.9.1 Nutrients

Excreta contains nutrients that originate from food consumption. Of the total nitrogen, phosphorus and potassium that is consumed, 10-20% of nitrogen, 20-50% of phosphorus, and 10-20% potassium is excreted in the faeces, and 80-90% of nitrogen, 50-65% of phosphorus, and 50-80% of potassium in the urine (Berger, 1960; Lentner et al., 1981; Guyton, 1992; Schouw et al., 2002; Jönsson et al., 2005; Vinnerås et al., 2006). Ammonia (NH_3) is produced by deamination of organic nitrogen, and hydrolysis of urea ($CO(NH_2)_2$) in urine by urease. The majority of ammonia in raw FS comes from the urine

(Mitchell, 1989; Jönsson *et al.*, 2005). The nitrogen content in faeces is about 20% as ammonia, 17% as organic nitrogen in the cells of living bacteria, and the remainder as organic nitrogen (e.g. proteins, nucleic acid) (Lentner *et al.*, 1981).

Nitrogen

Nitrogen is an important parameter to consider in FS treatment, as the total nitrogen concentrations in FS is typically quite high (e.g. 10-100 times the concentration in domestic wastewater). Depending on factors such as pH, length of storage, the presence of oxygen, and the type of FS, nitrogen will be present in a combination of the following forms; ammonium (NH_4-N)/ammonia (NH_3-N), nitrate (NO_3-N)/nitrite (NO_2-N), and organic forms of nitrogen (e.g. amino acids and amines).

When quantifying ammonia concentrations in FS, a preliminary distillation step is required, followed by a titrimetric method, electrode, or a phenate method (APHA, 2005). To prevent volatilisation, samples must be refrigerated and analysed within 24 hours, or frozen or acidified to pH 2 for analysis within 28 days (APHA, 2005). Total Kjeldahl Nitrogen (TKN) is the sum of organic nitrogen and ammonia (NH_3-N)/ammonium (NH_4-N). TKN can be determined by the macro-kjeldahl method, the semi-micro-kjeldahl method, or block digestion and flow injection analysis. Nitrate and nitrite can be determined by ion chromatography, capillary ion electrophoresis, cadmium reduction, hydrazine reduction, cadmium reduction flow injection, or UV spectrophotometric method (APHA, 2005). There are also commercially available kits for these analyses, which are commonly used. Total nitrogen can be determined by oxidative digestion to nitrate followed by quantification of the nitrate, or by the sum of TKN and nitrate/nitrite results.

Figure 2.5   Municipal solid waste removed from faecal sludge with bar screens at treatment plant influent during a sampling event in Kampala, Uganda (photo: Daniel Ddiba).

Phosphorus

The concentration of phosphorus is also an important parameter to consider, as the total phosphorus concentration in FS is quite high (e.g. 2-50 times the concentration in domestic wastewater). Phosphorus in FS will be present as phosphate, the acid or base form of orthophosphoric acid (H_3PO_4 / PO_4-P), or as organically bound phosphate (e.g. nucleic acids, phospholipids and phosphorylated proteins). The fate of phosphorus in the various treatment processes will be based on factors such as sorption, precipitation, complexation, sedimentation, mineralisation, pH, plant uptake in planted drying beds, and redox potential.

Phosphate can be determined colorimetrically to determine 'reactive' phosphorus, or following hydrolysis or digestion to quantify total phosphorus, including particulate and organic fractions (APHA, 2005).

2.9.2 pH
Measurement of pH is essential for the understanding of water chemistry processes, such as acid-base chemistry, alkalinity, neutralisation, biological stabilisation, precipitation, coagulation, disinfection, and corrosion control (APHA, 2005). The pH of FS from septic tanks is normally in the range of 6.5 to 8.0 (Ingalinella *et al.*, 2002; Cofie *et al.*, 2006; Al-Sa'ed and Hithnawi, 2006), but can vary greatly from 1.5 to 12.6 (USEPA, 1994). A pH outside the range of 6 to 9 indicates an upset in the biological process that will inhibit anaerobic digestion and methane production. This could result from a change in the hydraulic loadings, the presence of toxic substances, a large increase in organic loading, or that the systems are receiving industrial or commercial wastewater. The pH can be measured with electrodes and meters and pH papers (APHA, 2005).

2.9.3 Total solids
TS concentration of FS comes from a variety of organic (volatile) and inorganic (fixed) matter, and is comprised of floating material, settleable matter, colloidal material, and matter in solution. Grit, sand and municipal waste are discussed below in Section 2.9.6. Parameters that are typically measured include total solids, fractions of volatile or fixed solids, and settleable, suspended or dissolved solids.

The total solids (TS) are quantified as the material remaining after 24 hours of drying in an oven at 103-105 °C. Volatile solids (VS) are the fraction that are ignited and burned off at a temperature of 500 °C, and this fraction is also considered to be the organic portion. The fixed solids are the amount remaining after ignition, and are generally considered to be the inorganic portion. The ratio of VS to TS is used as an indicator of the relative amount of organic matter and the biochemical stabily of FS. Total solid values are important as they are used to design and dimension FS treatment technologies such as planted and unplanted drying beds.

The suspended solids fraction of the FS are defined as the solids that are not able to pass through a filter, while the solids that do pass through are termed dissolved solids. Since these values are dependent on the pore size of the filter that is used it is important to report filter size with suspended solids data. A 0.45 μm filter is typically used for the analysis of wastewater effluents, but filters up to 2.0 μm can be used. If FS is too dense to pass through filters, then total solids concentrations are more commonly reported.

Solids that settle out of suspension after a certain period of time, for example, the solids that accumulate in the bottom of an Imhoff cone after 30 to 60 minutes, are termed settleable solids. This value is reported as the sludge volume index (SVI), and is used for designing settling tanks. More information on solids measurements can be found in Chapter 9.

2.9.4 Biochemical Oxygen Demand and Chemical Oxygen Demand

The oxygen demand of FS is an important parameter to monitor, as the discharge of FS into the environment can deplete or decrease the oxygen content of water bodies resulting in the possible death of aquatic fauna. The oxygen demand is reduced through stabilisation, and can be achieved by aerobic or anaerobic treatment. FS dewatering technologies do not necessarily decrease oxygen demand.

BOD is a measure of the oxygen used by microorganisms to degrade organic matter. The standard method for detecting BOD involves incubation at $20°C$ for 5 days, and is reported as BOD_5 in mgO_2/L. Wastewater is considered to be weak, medium, strong and very strong respectively at BOD_5 of 200, 350, 500, and >750 mg/L (Mara, 2004). As shown in Table 2.3, FS typically has a much higher BOD_5 than that of 'strong' wastewater. Non carbonaceous material can also consume oxygen, for example the oxidation of ammonia to nitrate, which can increase the reported BOD value if not taken into account. To prevent this, nitrification can be inhibited through the addition of chemicals. The particle size distribution also has an effect, as smaller and more soluble particles have faster BOD reaction rate coefficients. Other factors that can account for sample variability include sample filtration, dilutions, and sampling methodologies.

BOD only represents biodegradable organics, whereas COD represents the oxygen equivalent of the organic matter that can be oxidised chemically with dichromate, a powerful chemical oxidant. The laboratory analysis of COD is more convenient than that for BOD, taking between a few minutes to hours depending on the method.

COD concentrations will be higher than BOD for a number of reasons including:
• complex organic molecules like lignin which are resistant to biodegradation, being oxidised by COD;
• some inorganic substances also being oxidised by COD;
• inhibition of bacteria in the BOD test.

COD is determined in the laboratory with an open or closed reflux method, and commercial kits are also readily available (APHA/AWWA/WEF, 2005). The ratio of BOD to COD can also be used as an indicator of the relative biodegradability of the organic matter in different waste streams. BOD, COD, and measurements of COD fractionation are explained in detail in Chapter 9. Other metrics of organic carbon not included here are measures of total organic carbon (TOC), and specific organic compounds of concern.

2.9.5 Oil and grease

Fats, oil and grease in FS comes from a wide variety of sources including lard, meats, seeds and nuts, kerosene, and lubricating oils. Oil and grease content is important to consider because it can reduce microbial degradation due to reduced solubility, increase the scum layer in settling tanks, cause maintenance problems, and create films in surface waters if discharged. Extraction with solvents can be used to determine concentrations of oil and grease, and is reported as total oil and grease soluble in the specific solvent that is used (APHA, 2005).

2.9.6 Grit and sand

Grit and sand concentrations are important to consider in the treatment of FS, as their presence influences the required size and filling rates of tanks used for storage and treatment, and can increase the frequency of clogging in pipes and pumps. Sources of grit and sand include unlined pit latrines, cleaning and washing of utensils and vegetables, cleansing (e.g. sand tracked into house), and flooding. In areas where sand is pervasive in the FS, it is a significant treatment and design concern (e.g. Dakar,

Senegal; Case Study 2.4). In order to reduce the sand and grit content, sand traps should be installed at entry points to pipes and sinks. Concentrations of sand can be determined by first drying the sample at $105\,^{\circ}C$ in an oven, then at $550\,^{\circ}C$ to obtain the total fixed solids. The ashes are then treated with a hot mixture of nitric acid and hydrochloric acid. The amount of sand is obtained after filtration following calcination at $1,000\,^{\circ}C$.

2.9.7 Municipal solid waste

Municipal solid wastes are deposited in sanitation containment systems for a number of reasons, such as the lack of a functional system for the collection and management of municipal solid waste. In addition, menstrual hygiene products and baby diapers are commonly thrown into sanitation systems. As shown in Figure 2.6 the accumulation of these solid wastes can be significant and should be strongly discouraged through educational campaigns. Solid wastes can cause problems in the collection and transport of FS (Chapter 4), result in clogged pipes and pumps, increase required storage and treatment volumes, and affect the end quality of treatment products.

In order to prevent clogging at treatment plants, the installation of a bar screen is essential at the influent. It has been found that organic decomposable wastes are the largest constituent in the screenings from FS (Troschinetz and Mihelcic, 2009) and typically accounts for 48% of the total waste. Other constituents include pebbles, rubble, sand and fine particles (29%), iron, wood and textiles (20%), and plastics (3%) in mass (dry weight) percentage (Rouyat *et al.*, 2006). Similar results were observed in Dakar, and are presented in Case Study 2.4.

Figure 2.6   Municipal solid waste removed from faecal sludge with bar screens at treatment plant influent, Dakar, Senegal (photo: Linda Strande).

Case Study 2.4: Sand and solid waste content in faecal sludge in Dakar, Senegal; increased collection costs in Kampala, Uganda

Dakar
A study conducted in Dakar, Senegal found the average sand content in FS from septic tanks to be 935 g/m^3 (mg/L), with a range of 90 g/m^3 to 4,000 g/m^3. In poor areas of Dakar, yards are typically bare soil and access roads are unpaved. A large amount of sand is therefore tracked into latrines by bare feet or shoes. This amount increases further in the rainy season, when wet sand adheres more readily to shoes and feet. Showers are also commonly located in the latrine superstructure. In addition, the predominance of squat toilets facilitates the direct introduction of sand in the system (M'Voubou, 2004).

When passing FS through a 2 cm diameter grid, the following composition was found for the solid waste content (mass dry weight percentage after 2 days of drying in the sun): sponges, bones, wood 1% each; textiles 2.5%; plant seeds 3%; stones 11%; plastics 12%; sand 25% and decaying (organic) matter 43%.

Kampala
Next to creating problems in pit emptying and FS treatment, additional solid waste in pits leads to higher emptying fees. In Kampala, the pit emptying fees are based on the volume of removed material and the travelling distance between the emptied system and the discharge location. The presence of accumulated solid wastes in a sanitation system results in a 10-50% increment on top of the emptying cost. Table 2.6 provides the typical costs for pit emptying in a 5 km travel radius and the increased costs due to this penalty.

Table 2.6   Typical costs for pit emptying in a 5 km travel radius plus increased costs due to a rubbish penalty

Truck Capacity (m³)	Standard Costs (USD)	Penalty for rubbish (10 – 50%) (USD)	Range of total costs including rubbish fine (10 – 50%) (USD)
≤ 1.8	28	2.80 - 14	30.80 - 42
2.0 – 2.7	32	3.20 - 16	35.20 - 48
3.6 – 4.0	40	4.00 - 20	44.00 - 60
4.5 – 7.2	48	4.80 - 24	52.80 - 72
8.0 – 11	64	6.40 - 32	70.40 - 96

2.10 PATHOGENS IN FAECAL SLUDGE

Exposure to untreated FS should always be considered as a pathogenic health risk. Adequate reductions in pathogens need to be determined based on the intended enduse or disposal option for treated sludge and liquid effluents. This is described in more detail in Chapter 10, Enduse of Treatment Products. Some common pathogens of concern that may be excreted in faeces, and their importance in disease transmission, are presented in Table 2.7.

Table 2.7   Selected pathogens that may be excreted in faeces and related disease symptoms (adapted from Schönning and Stenström, 2004)

Group	Pathogen	Disease symptoms
Bacteria		
	Aeromonas spp.	Enteritis
	Campylobacter jejuni/coli	Campylobacteriosis - diarrhoea, cramping, abdominal pain, fever, nausea, arthritis, Guillain-Barré syndrome
	Escherichia coli (EIEC, EPEC, ETEC, EHEC)	Enteritis. For EHEC there are also internal haemorrhages that can be lethal
	Salmonella typhi/paratyphi	Typhoid/paratyphoid fever – headache, fever, malaise, anorexia, bradycardia, splenomegaly, cough
	Salmonella spp.	Salmonellosis – diarrhoea, fever, abdominal cramps
	Shigella spp.	Shigellosis – dysentery (bloody diarrhoea), vomiting, cramps, fever; Reiters syndrome
	Vibrio cholera	Cholera – watery diarrhoea, lethal if severe and untreated
Virus		
	Adenovirus	Various; respiratory illness, here added due to enteric types (see below)
	Enteric adenovirus types 40 and 41	Enteritis
	Enterovirus types 68-71	Meningitis; encephalitis; paralysis
	Hepatitis A	Hepatitis – fever, malaise, anorexia, nausea, abdominal discomfort, jaundice
	Hepatitis E	Hepatitis
	Poliovirus	Poliomyelitis – often asymptomatic, fever, nausea, vomiting, headache, paralysis
	Rotavirus	Enteritis
Parasitic protozoa		
	Cryptosporidium parvum	Cryptosporidiosis – watery diarrhoea, abdominal cramps and pain
	Cyclospora histolytica	Often asymptomatic; diarrhoea; abdominal pain
	Entamoeba histolytica	Amoebiasis – often asymptomatic, dysentery, abdominal discomfort, fever, chills
	Giardia intestinalis	Giardiasis – diarrhoea, abdominal cramps, malaise, weight loss
Helminths		
	Ascaris lumbricoides	Generally no or few symptoms; wheezing; coughing; fever; enteritis; pulmonary eosinophilia
	Taenia solium/saginata	Taeniasis
	Trichuris trichura	Trichuriasis - Unapparent through to vague digestive tract distress to emaciation with dry skin and diarrhoea
	Hookworm	Itch; rash; cough; anaemia; protein deficiency
	Schistosoma Spp. (blood fluke)	Schistosomiasis, bilharzias

2.10.1 The use of indicators

When measuring the treatment efficiency of FS treatment processes, it is too expensive and labour intensive to measure all types of pathogens. Instead, it is common practice to select indicators of pathogenic activity which are measured to provide an indication of the level of pathogen removal during treatment. These indicators can be either pathogenic, or non-pathogenic, but the organisms need to be carefully selected in order to provide adequate information on the inactivation of pathogens. The following requirements should be met when selecting an indicator (Mara, 2004):

- be exclusively of faecal origin;
- be in numbers greater than those of the pathogens of concern;
- have a removal that mimics, and is close to, that of pathogens of concern; and
- be simple, inexpensive, accurate, and reliable to measure.

In addition, indicator organisms should have the ability to survive longer than the pathogen of concern. Some of the typical indicator organisms for wastewater, FS and environmental contamination are the coliform bacteria, helminths and bacteteriophage (as an indicator for viruses). Other indicators of faecal contamination that have been used in pollution control and pathogen die-off studies include faecal streptococci, Klebsiella, *Clostridium perfringens, Bacteroides*, Enterococci, and *Bifidobacterium* (Feachem *et al*., 1983; WHO, 1984).

2.10.2 Coliform bacteria

Coliform bacteria are bacteria that populate the intestinal tract, and are pervasive in faeces. Their presence in the environment is therefore used as an indicator of faecal contamination. *Escherichia coli* (*E. coli*) is the target organism that has traditionally been used to identify faecal contamination in the environment (Feachem *et al*., 1983). However, there are complicating factors such as bacteria from the genus Escherichia that can grow in the environment, and the test is therefore not 100% indicative of faecal contamination. Tests have been developed to enable the quantification of total coliforms, faecal coliforms, and *E. coli*. However since these bacteria are not indicators of viral or protozoan contamination, and although they are used as indicators of faecal pollution in the environment, they do not necessarily provide a good indication of pathogen reduction in FS treatment processes.

Total and faecal coliforms are not good indicators in tropical and sub-tropical climates. The standard method for coliforms analysis relies on the production of acid and gas in medium incubated at a temperature equal to that of the human body (37 °C). The standard method of analysing thermal tolerant faecal coliforms relies on their production of acid and gas from lactose when incubated at 44 °C. However, under tropical and sub-tropical conditions, it has been found that coliforms, which are not necessarily faecal, also grow and produce acid and gas from lactose at 44 °C (Mara, 2004). Enzymatic and biochemical assays have been developed for the detection of *E. coli* (APHA, 2005), and commercial kits are also available for total and faecal coliforms and *E. coli*.

Helminths

When analysing FS, helminths are most commonly used as an indicator of the effectiveness of pathogen reduction due to their prevalence in low- and middle-income countries, and their persistence following treatment. Helminths ('parasitic worms') are eukaryotic parasites, which are prevalent in about one third of the world's population. Helminths include nematodes (round worms), cestodes (flat worms) and trematodes (flukes). These are important pathogens to monitor, as eggs from one infected person can infect hundreds of people. *Ascaris lumbricoides*, a type of round worm, is the most commonly used indicator, as the eggs are one of the pathogens most resistant to inactivation in treatment processes, and can be identified relatively easily (Feachem *et al*., 1983). The ability of *Ascaris lumbricoides* eggs to remain viable stems from a highly impermeable eggshell, which is considered to be one of the most resistant biological structures. The shell allows the passage of essential respiratory

gases while protecting the eggs from a wide array of chemicals and extreme pH conditions (Nordin *et al.*, 2009). The monitoring of the removal of Ascaris eggs therefore provides an indication that less resistant pathogens have also been inactivated (Fgure 2.7).

To use Ascaris eggs as a metric of pathogen removal, the number of eggs can be enumerated, but a more sensitive metric is to measure the viability of eggs. A viable egg is one that still has the potential to develop, versus eggs which are no longer viable and have no risk of pathogen transmission. The enumeration of viable Helminth eggs employs the coproscopic method, involving sedimentation, desorption, centrifugation and floatation. During development, this method was estimated to achieve an efficiency of 30-70% in the enumeration of viable eggs (Gaspard and Schartzbroad, 1995). However, further work has increased this to 100% based on a sensitivity of 0.4 ppm, by calculating the number of helminth eggs in the sample, and incorporating the estimated efficiency of the procedure (Malicki *et al.*, 2001). In addition, improvements in the method have significantly reduced the number of replications that are necessary based on previous methods (USEPA 1995).

The improved USEPA standard methods for the enumeration of helminths (2003) are based on 4 steps that include:
- parasite dissociation from organic matter;
- flotation with natrium nitrate solution;
- sedimentation; and
- concentration and microscopic examination using a Sedguick-Rafter counting chamber.

The South African Water Research Commission has also developed and published the 'Standard Methods for the Recovery and Enumeration of Helminth Ova in Wastewater, Sludge, Compost and Urine Diversion Waste in South Africa', which is available free of charge via the internet (Moodley *et al.*, 2008).

Figure 2.7   Analysis of viable Helminth eggs in Dakar, Senegal (photo: Linda Strande).

Viruses

Quantification of total viruses in FS can be undertaken using an electron microscope, but the easiest method of evaluation is to measure their effects on hosts (Madigan and Martinko, 2006). The bacteriophage are commonly used as viral indicators. Examples include *Salmonella typhimurium* bacteriophage 28B, enterobacteria phage MS2 and coliphage Øx174 using host strains respectively as *Salmonella typhimurium* phage type 5, *Salmonella typhimurium* WG 49 (ATCC 700730) and *E. coli* ATCC 1370. The standard double-layer agar method is used, with viruses quantified by the plaque assay with the agar overlay technique (Adams, 1959; Madigan and Martinko, 2006).

2.11 CONCLUSION

Based on the current state of knowledge, it is evident that caution must be exercised when making assumptions for quantifying and characterising FS for the design of treatment systems. Fortunately, FSM is a rapidly growing field, and there is currently a great deal of research being conducted into the characterisation of FS. In the next few years, as FSM gains in acceptance, and research results are obtained, further information will become available, allowing for the more accurate design of treatment systems.

Previous research into the characterisation of FS has focused on parameters for environmental protection and agricultural use, e.g. BOD/COD, TS, TVS, nutrients, and pathogen indicators. Current research into innovative enduses has increased this field to include parameters such as COD fractionation, lipid content for biodiesel, structural properties, and calorific value. Examples include the use of FS treatment endproducts as a potential energy source, such as the biogas produced from anaerobic digestion systems, or direct use of dried FS in industrial boilers and kilns (Murray Muspratt *et al.*, 2014). Other possibilities include treatment with black soldier flies to produce protein, and incorporation in building materials (Diener *et al.*, 2014). Other research that will assist in improving collection and transport methods, and understanding dewatering behavior, includes the analysis of rheological properties and shear strength (AIT, 2012; Radford, 2012).

2.12 BIBLIOGRAPHY

AIT (2012). Assessment of FS rheological properties. Final Research Report. Environmental Engineering Programme. School of Environment, Resources and Development, Asian Institute of Technology (AIT).

Al-Sa'ed, R. M. Y., Hithnawi, T.M. (2006). Domestic septage characteristics and co-treatment impacts of Albireh wastewater treatment plant efficiency. Dirasat Engineering Sciences 33(2), p.187-197.

APHA/AWWA/WEF (2005). Standard Methods for the examination of water and wastewater. 21st Edition. American Public Health Association, American Water Works Association, and Water and Environment Federation Publication. Washington D.C., USA. ISBN 0-87553-047-8.

Bassan, M., Tchonda, T., Yiougo, L., Zoellig, H., Mahamane, M., Mbéguéré, M., Strande, L. (2013a). Characterisation of faecal sludge during dry and rainy seasons in Ouagadougou, Burkina Faso. Refereed paper presented at the 36th WEDC International Conference, Nakuru, Kenya, 2013.

Bassan, M., Mbéguéré, M., Tchonda, T., Zabsonre, F., Strande, L. (2013b). Integrated faecal sludge management scheme for the cities of Burkina Faso. Journal of Water, Sanitation and Hygiene for Development 3(2), p.216–221.

Bentley, R.W. (2002). Global oil and gas depletion: An overview. Energy Policy 30(3), p.189-205.

Berger, E.Y. (1960). Intestinal absorption and excretion. In: Comar C. L. and Bronner F. (eds). Mineral Metabolism, p.249-286. Academic Press, New York.

Diener, S., Semiyaga, S., Niwagaba, C., Muspratt, A., Gning, J.B., Mbéguéré, M., Ennin, J.E., Zurbrugg, C., Strande, L. (2014). A value proposition: resource recovery from faecal sludge – can it be the driver for improved sanitation? Resources Conservation & Recycling (in press).

Diongue, S.T. (2006). Stratégies d'optimisation de la filière de vidange de boues de latrines à Dakar, Institut International du Génie de l'Eau et de l'Environnement (Burkina Faso)/Ecole Ploytechnique Fédérale de Lausanne (Suisse). Master: 81.

Feachem, R.G., Bradley, D.J., Garelick, H., Mara, D.D. (1983). Sanitation and Disease. Health aspects of excreta and wastewater management. World Bank studies in water supply and sanitation. John Wiley and Sons. New York.

Foxon, K., Brouckaert, C., Wood, K. (2012). How fast do pits fill up? Empirical evidence and mathematical models. FSM2, Durban, South Africa.

Gao, X.Zh., Shen, T., Zheng, Y., Sun, X., Huang, S., Ren, Q., Zhang, X., Tian, Y., Luan, G. (2002). Practical manure handbook. (In Chinese). Chinese Agricultural Publishing House. Beijing, China. In: WHO. 2006. Guidelines for the safe use of wastewater, excreta and greywater. Volume 4. Excreta and greywater use in agriculture. ISBN 92 4 154685 9.

Gaspard, P., Schwartzbrod, J. (1995). Helminth eggs in wastewater quantification technique. Water Science and Technology 31(5/6), p.443–446.

Guyton, A.C. (1992). Human physiology and mechanisms of disease. W. B. Saunders Co, Philadelphia, USA.

Heinss, U., Larmie, S. A., Strauss, M. (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. 5/98. Second Edition. Swiss Federal Institute for Environmental Science ad Technology (EAWAG) and Water Research Institute (WRI), Accra/Ghana.

Heinss, U., Larmie, S.A., Strauss, M. (1994). Sedimentation Tank Sludge Accumulation Study. EAWAG/SANDEC publications.

Ingallinella A.M., Sanguinetti G., Koottatep, T., Montangero, A., Strauss, M. (2002). The challenge of faecal sludge management in urban areas – strategies, regulations and treatment options. Water Science and Technology 46(10), p.285-294.

Jönsson, H., Baky, A., Jeppsoon, U., Hellström, D., Kärrman, E. (2005). Composition of urine, faeces, greywater and biowaste for utilization in the URWARE model. Urban water Report of the MISTRA Programme, Report 2005:6, Chalmers University of Technology, Gothenburg, Sweden. Available at: www.urbanwater.org.

Jönsson, H., Vinnerås, B., Höglund C., Stenström, T.-A. (1999). Source separation of urine. Wasser und Boden 51 (11), p.21-25.

Katukiza A.Y., Ronteltap, M., Niwagaba, C., Foppen, J.W, A., Kansiime, F., Lens, P.N.L. (2012). Sustainable sanitation technology options for urban slums. Biotechnology Advances 30(5), p.964-978.

Kengne, I.M., Kengne, S. E., Akoa, A., Bemmo, N., Dodane, P.-H., Koné, D. (2011). Vertical-flow constructed wetlands as an emerging solution for faecal sludge dewatering in developing countries. Journal of Water, Sanitation and Hygiene for Development 01(1), p.13-19.

Koanda, H. (2006). Vers un assainissement urbain durable en Afrique subsaharienne : Approche innovante de planification de la gestion des boues de vidange, École Polytechnique Fédérale de Lausanne. Thèse de doctorat: 351.

Koné, D., Strauss, M. (2004). Low-cost Options for Treating Faecal Sludges (FS) in Developing Countries – Challenges and Performance. Paper presented to the 9th International IWA Specialist group conference on wetlands systems for water pollution control; and to the 6th International IWA Specialist Group Conference on Waste Stabilisation Ponds, Avignon, France, 27th Sept. - 1st Oct. 2004.

Koottatep, T., Surinkul, N., Polprasert, C., Kamal, A.S.M., Koné, D., Montangero, A., Heinss, U., Strauss, M. (2005). Treatment of septage in constructed wetlands in tropical climate: lessons learnt from seven years of operation. Water Science & Technology 51(9), p.119-126.

Lentner, C., Lentner, C., Wink, A. (1981). Units of Measurement, Body Fluids, Composition of the Body, Nutrition. Geigy Scientific Tables. CIBA-GEIGY Ltd, Basle, Switzerland. ISBN 0-914168-50-9.

M'Voubou, K. F. (2004). Evaluation de la gestion communautaire des boues de vidange dans la Commune d'Arrondissement de Sahm-Notaire. Ville de Guédiawaye- Région de Dakar-Sénégal, Ecole Inter-états d'Ingénieurs de l'Equipement Rural / Ecole Polytechnique Fédérale de Lausanne. Mémoire de DESS: 73

Madigan, T.M., Martinko, M.J. (2006). Brock Biology of Microorganisms. 11th Edition. Pearson Prentice Hall. Pearson Education Inc., Upper Saddle River, United States of America. ISBN 0-13-196893-9.

Malicki, J., Montusiewicz, A., Bieganowski, A. (2001). Improvement of counting helminthes eggs with internal standard. Research Note. Water Research 35(9), p.2333-2335.

Mara, D. D. (2004). Domestic wastewater treatment in developing countries. Earthscan UK and US. ISBN 1-84407-019-0.

Moodley, P., Archer, C., Hawksworth, D. (2008). Standard Methods for the recovery and enumeration of helminth ova in wastewater, sludge, compost and urine diversion waste in South Africa. A report of Water Research Commission, SA.

Murray Muspratt, A., Nakato, T., Niwagabe, C., Dione, H., Stupin, L., Regulinski, I., Mbéguéré, M., Strande, L. (2014). Fuel potential of feacal sludge: calorific value results from Uganda, Ghana, and Senegal. Journal of Water, Sanitation and Hygiene in Developing Countries (in press).

Niwagaba, C. (2009). Treatment technologies for human faeces and urine. PhD Thesis, Doctoral Thesis No. 2009: 70. Swedish University of Agricultural Sciences, Uppsala, Sweden. ISBN 978-91-576-7417-3.

NWSC (National Water and Sewerage Corporation) (2008). Kampala Sanitation Program (KSP) - Feasibility study for sanitation master in Kampala, Uganda.

Radford J.T., Fenner, R.A. (2013). Characterisation and fluidisation of synthetic pit latrine sludge. Journal of Water, Sanitation and Hygiene for Development 3(3), p.375–382.

Rossi, L., Lienert, J., Larsen, T.A. (2009). Real-life efficiency of urine source separation. Journal of Environmental Management 90, p.1909-1917.

Rouyat, J., Broutin, C., Rachmuhl, V., Gueye, A., Torrasani, V., Ka, I. (2006). La gestion des ordures ménagères dans les villes secondaires du Sénégal. Vers des politiques municipales incluant les quartiers périphériques, Éditions du Gret.

Schönning, C., Stenström, T.-A. (2004). Guidelines for the safe Use of Urine and Faeces in Ecological Sanitation. Report 2004-1. Ecosanres, SEI. Sweden.

Schouw, N.L., Danteravanich, S., Mosbaek, H., Tjell, J.C. (2002). Composition of human excreta – a case study from Southern Thailand. Science of the Total Environment Journal 286(1-3), p.155-166.

Sonko, E.M. (2008). Traitement des boues de vidange de systèmes autonomes d'assainissement à Dakar (Sénégal): évaluation de l'efficacité de la séparation solide/liquide de lits de séchage non plantés soumis à différentes charges de boues de vidange et à divers apports. Mémoire de DEA : Institut des Sciences de l'Environnement, UCAD. 73 p.

Steen, I. (1998). Phosphorus recovery in the 21st Century: Management of a non-renewable resource. Phosphorus and Potassium Journal 217, p.25-31.

Troschinetz, A. M., Mihelcic, J. R. (2009). Sustainable recycling of municipal solid waste in developing countries. Waste Management 29, p.915-923.

United States Environmental Protection Agency (USEPA). (1994). Guide to Septage Treatment and Disposal. Document EP/625/R-94/002. Washington D.C. 20460.

United States Environmental Protection Agency (USEPA) (1999). Decentralized Systems Technology Fact Sheet, Septage Treatment/Disposal. Document EPA 932-F-99-068. Office of Water, Washington D.C.

Vinnerås, B., Palmquist, H., Balmér, P., Weglin, J., Jensen, A., Andersson, Å., Jönsson, H. (2006). The characteristics of household wastewater and biodegradable waste - a proposal for new Swedish norms. Urban Water 3, p.3-11.

WHO (1984). Guidelines for drinking water quality, volume 2: Health criteria and other supporting information. WHO publication. ISBN 92 41541695.

Yen-Phi, V.T., Rechenburg, A., Vinnerås, B., Clemens, J., Kistemann, T. (2010). Pathogens in septage in Vietnam. Science of the Total Environment 408 (9), p.2050-2053.

Additional Reading Material

Ayres, R.M., Stott, R., Lee, D.L., Mara, D.D., Silva, S.A. (1989). Comparison of techniques for the enumeration of human parasitic helminth eggs in treated wastewater. Environmental Technology 12, p.617–623.

Badji K. (2008). Traitement des boues de vidange: Eléments affectant la performance des lits de séchage non-plantés en taille réelle et les mécanismes de séchage, Ecole Supérieure Polytechnique de Dakar, Mémoire de fin d'étude, 167 p.

Bradley, R.M. (1981). Disposal of septic-tank contents in Cyprus, Water Pollution Control 80, p.131–137.

Butler, D., Payne, J. (1995). Septic Tanks: Problems and Practice. Building and the Environment 30(3), p.419-425.

Chan, L., Li, Y. (2008). Protocol evaluation of the total suspended solids and suspended sediment concentration methods: Solid recovery efficiency and application for stormwater analysis. Water Environment Research 80(9), p.796-805.

Chen, M. (1988). Pollution of groundwater by nutrients and fecal coliforms from lakeshore septic tank systems, Water, Air and Soil Pollution 37, p.407–417.

Collin J.J., Salem, G. (1989). Pollution des eaux souterraines par les nitrates dans les banlieues non assainies des pays en développement, le cas de Pikine (Sénégal). Symposium Internationale sur des solutions intégrées pour des problèmes de pollution de l'eau, Lisbonne.

Franceys R., Pickford J., Reed, R. (1995). Guide de l'assainissement individuel. OMS. Genève.

Radford J.T., Fenner, R.A. (2013). Characterisation and fluidisation of synthetic pit latrine sludge Journal of Water, Sanitation and Hygiene for Development (IWA), Available on-line 15 February 2013 doi:10.2166/washdev.2013.023.

Strauss, M., Heinss, U., Montangero, A. (2000). On-Site Sanitation: When the Pits are Full – Planning for Resource Protection in Faecal Sludge Management. In: Proceedings, Int. Conference, Bad Elster,20–24 Nov. 1998. Schriftenreihe des Vereins fuer Wasser-, Boden und Lufthygiene,2000;105:353-60: Water, Sanitation and Health – Resolving Conflicts between Drinking Water Demands and Pressures from Society's Wastes (I. Chorus, U. Ringelband, G. Schlag, and O. Schmoll, eds.). IWA Publishing House and WHO Water Series.

Strauss, M., Larmie, S. A. (1997). Treatment of sludges from on-site sanitation - low-cost options. Water Science and Technology 35(6) p.129-136.

Strauss, M., Larmie, S. A., Heinss, U. (1998). Solids separations and ponds systems for the treatment of faecal sludges in the tropics: lessons learnt and recommendations for preliminary design. 05/98, SANDEC.

WHO (2006). Guidelines for the safe use of wastewater, excreta and greywater. Volume 4. Excreta and greywater use in agriculture. ISBN 92 4 154685 9.

End of Chapter Study Questions

- List four parameters which are important for FS characterisation, explain how they are analysed and which ranges determine high, medium and low strength FS.

- Describe how each of the following operational factors impact the variability of FS: toilet usage, storage duration, inflow and infiltration and climate.

- Describe two theoretical methods that can be used in the quantification of FS, and the difficulties in obtaining the relevant data.

- Describe FS treatment objectives, why they are important, and how their effectiveness can be monitored.