ACCUMULATION RATES OF THICKENED-BOTTOM SLUDGE AND ITS CHARACTERISTICS FROM WATER-BASED ONSITE SANITATION SYSTEMS IN THAILAND

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ABSTRACT

In emptying faecal sludge from any onsite sanitation systems (OSS), it has been widely recognized that the most difficult part to withdraw the sludge is at the bottom most of the tank. This paper describes accumulation rates of the thickened-bottom sludge and its characteristics which were analyzed from the samples taken from the conventional water-based OSS in Thailand: (1) manmade-cement septic tank; (2) a single cesspool; (3) double cesspools in series; and (4) commercial plastic treatment package. The results obtained from field investigations in 3 provinces demonstrate that the total solid (TS) concentrations of the mixture of supernatant and thickened-bottom sludge are in the range of 10,000 - 17,500 mg/L, while the TS of the thickened-bottom sludge could be at the concentrations of 40,000 - 220,000 mg/L. The highest TS concentrations were obtained from the samples of thickened-bottom sludge in commercial plastic units and contained relatively high fixed solids, possibly due to the relatively large amount of disposal of tissue papers. Likewise, VS contents in the thickened-bottom sludge of commercial plastic units were only 11% of TS whereas those in other OSS systems were in the range of 60 - 70% of TS. The survey results also indicate the highest depth of thickened-bottom sludge were observed in the commercial plastic units at about 50% of tank depth while the others have about 30-35% of tank depth. Considering sludge emptying frequency, the commercial plastic system requires every 2.5 years while an average frequency of once in 1.5 years is for the others. The accumulation rate of the thickened-bottom sludge does not depend on types of OSSs, but rather dependent of land use and soil texture. For example, the accumulation rate of single cesspool system in an urban area with loamy soil (Lampang province) presented the highest average value of 1,610 L/cap/year while those in urban area with clay soil (Nonthaburi province) was only 270 L/cap/year. The difference in accumulation rate of the thickened-bottom sludge is probably due to the higher infiltration rate of loam soil than that of clay soil, enabling liquid infiltration into surrounding soil. The lowest rate was found in OSS located in rural area with sandy soil (Ratchaburi province) at the rate of 40 L /cap /year. Regarding compositions of the faecal sludge, it is apparent that commercial plastic treatment package had the lowest contaminants of about 10%, most of which is debris. Sludge in single cesspools, double cesspools in series and manmade-cement septic tanks contained higher contaminants of about 25%, 20% and 20%, respectively, including hairs, textiles and debris. The results of these findings could reaffirm the challenges in emptying sludge from OSS which require specific techniques for the thickened-bottom sludge with such unique rheological properties.

Keywords: COMMERCIAL SEPTIC TANK, FAECAL SLUDGE, ONSITE SANITATION SYSTEM, THICKENED-BOTTOM SLUDGE

INTRODUCTION

Septic tank and other onsite sanitation systems (OSS) are the units used to receive blackwater or/and greywater. Supernatant or liquid part is seeped into soil or discharged into sewer systems. Remaining of solid part in OSS is called faecal sludge (FS) or septage. In most cases in developing countries, faecal sludge is usually disposed of on unused lands or directly discharged into waterways without any pre-treatments resulting in severely polluting canals, rivers, lakes or groundwater as well as spreading of excreta-related pathogens. By regulation, each house in Thailand must have the OSS in place with or without sewer line and FS need to be properly managed. Presently, FS management practices are done by municipality or private entrepreneurs if there is no governmental service. However, people do not really aware of the treatment or disposal places of FS especially those of illegal FS trucks. Thailand basically uses four types of OSS: (1) manmade-cement septic tank; (2) a single cesspool; (3) double cesspools in series; and (4) commercial plastic treatment package. FS is regularly pumped from OSS only when the users face operational problems such as bad smell, flushing problems, etc. In general, household uses soakage pit for disposal of the OSS effluent but several do not function properly because of low-permeable soil and high groundwater level. This could raise a potential of groundwater contamination and OSS overflow problems.

The objective of this paper is to describe characteristics of FS from each type of OSS along with establishment of correlation between FS management practices and sludge quality and quantity. The obtained information could be further use for developing a promising technology for FS management such as emptying technique, sludge hauling and transportation truck and the alternative reuse practices.

MATERIALS AND METHODS

Study Areas

Four main types of OSS: manmade-cement septic tank, a single cesspool, double cesspools in series, and commercial plastic treatment package were investigated in densely-populated urban centre, less-populated urban community, rural district and newly-developed housing estate in Thailand. The four representative areas are namely Nonthaburi, Lampang, Rachaburi and Nakorn Ratchasrima provinces.

Nonthaburi and Lampang municipalities are both characterized as densely-populated urban centre and less-populated urban community in Central and Northern provinces of Thailand, respectively. Characteristics of households depend on old- or newly-developed areas which its sanitation systems could be either with or without sewers. Suan Pheung community in Rachaburi province, representing a rural district in Central part of Thailand, has a unique characteristic because of its location on foot hills, and residing by hill-tribe people whose toilets are basically made of perennial woods or bamboo. In a newly-developed city of Nakorn Ratchasrima province, we collected samples at a village which has been developed for about 3 years which should represent a modern type of onsite wastewater management with sewer system.

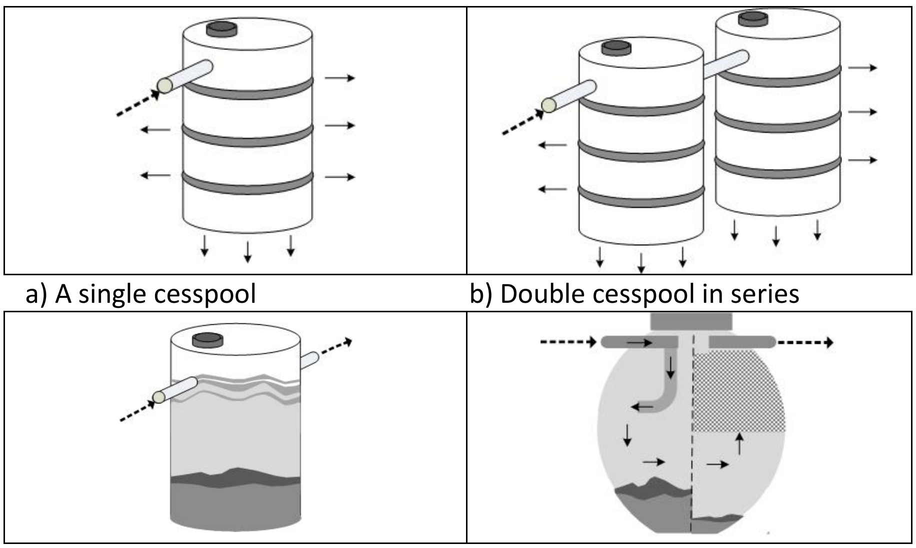
Sampling and Data Collection

A sampling program starts by a call from household that require sludge emptying service from either municipality or private company. Prior to collecting FS samples from each OSS unit, the depths of supernatant and thickened-bottom sludge layers were determined by using white-cloth wrapped stick. Supernatant samples were then collected by manually removal of scum whereas the thickened-bottom sludge parts were collected by a vacuum pump of an FS truck. After that, both supernatant and thickened-bottom sludge samples were mixed at the ratio of supernatant and sludge layer depths which could represent FS concentration of each individual OSS unit. In addition, in-depth interviews and field observations were undertaken during the emptying service in order to understand user practices on their OSS units.

RESULTS AND DISCUSSIONS

Onsite Sanitation Systems

Based on interviews and observations, most of the households in rural area use a single cesspool system made of concrete ring at a diameter of 1 m (**Table 1**), whereas newly-developed areas such as housing estate or newly-built house (less than 3 years) use commercial plastic treatment package. A typical manmade-cement septic tank is mostly used in city or urban areas where drainage system avails. Possibly due to its competitive price, less-frequent sludge emptying, and relatively light weight, the commercial package is becoming more popular to use for newly-built houses. In case there is no drainage system, a single cesspool and double cesspool in series system are still in use. Schematic drawings of typical OSS units are shown in **Figure 1**. Few decades ago, the cesspool systems were used to be fabricated by bricks but recently use concrete ring which is cheaper and faster to install. When a concrete-ring cesspool is properly sealed and installed with T-pipe outlet for supernatant draining, this configuration is called as a septic tank.



a) A single cesspool b) Double cesspool in series

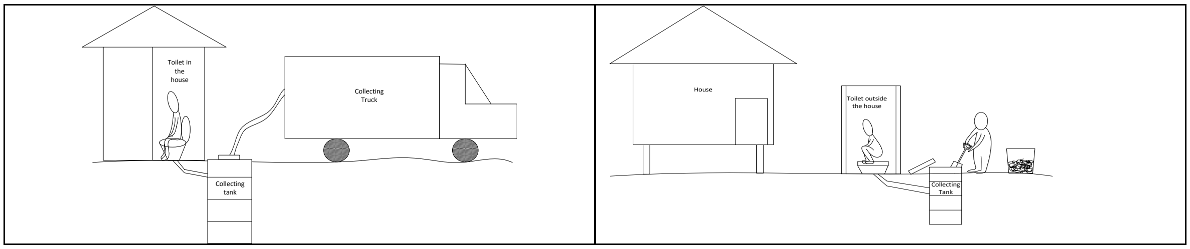
c) Manmade-cement septic tank d) Commercial plastic treatment package

Figure 1 Onsite sanitation system in Thailand

Table 1 Dimensions of each onsite treatment system

Type	Surface area (m^2)	Depth of onsite sanitation system (m)
Manmade-cement septic tank	0.5 – 1.5	1.00 – 1.40
A single cesspool	0.3 – 1.8	1.00 – 1.80
Double cesspool in series	0.3 – 1.8	1.00 – 1.65
Commercial plastic treatment package	1.00	1.50

Figure 2 illustrates FS emptying practices in urban and rural areas in Thailand which only emptying truck service is possible in an urban community. FS management in urban areas including Nonthaburi, Lampang and Nakorn Ratchasrima provinces are under control of municipalities, some of which have to outsource its services to private sectors. In a rural area like Suan Pheung municipality of Ratchaburi province, the FS emptying is manually operated by villagers.



a) FS emptying by vacuum truck in urban area b) Manual FS emptying in rural area

Figure 2 FS emptying practices in Thailand

<u>Faecal sludge accumulations</u>

Effects of OSS types and locations

There are several factors that household needs to empty the OSS such as failure of flushing toilet, full of OSS, high water table. Accumulation of sludge is the main factor that influences OSS operation. Some households may require FS emptying service for their OSS unit after more than 10 years of uses if soil permeability is relatively high. In cases with high groundwater table, it generally requires more frequent FS emptying services. **Table 2** shows average emptying period and amount of FS accumulation from various OSSs and locations.

According to field survey and user interviews, there are about 3 to 5 members in each household in the study areas with which its OSS system requires the emptying period between 1.5 – 5.5 years. Households with single cesspool unit in rural area of Ratchaburi province exceptionally requires the emptying period of about 5.5 years, probably due to its location on foothill with sandy soil which the liquid could easily permeate out of the system. In other urban areas the average emptying period of commercial treatment package requires about every 2.5 years which is longer than those of other systems i.e. septic tank, a single cesspool and double cesspools in series require approximately 1.63, 1.73 and 1.44 years, respectively. It was also observed that the holding capacity of OSS systems range from 0.4 to 6.3 m^3/unit which could generate FS at the rates of 0.88 - 1.41 m^3/time depending on types of OSS and household locations.

Figure 3 shows the depth of thickened-bottom sludge, supernatant layer and free space in the different OSS types. The field observations demonstrated that commercial treatment package could maintain the highest thickened-bottom sludge depth of about 50% of the tank-depth, whereas in the septic tank, single cesspool and double cesspools in series the sludge were about 36%, 32% and 31%, respectively. In some cases where groundwater table is relatively low, the level of accumulated sludge in a single cesspool can increase greater than 69%. Previous studies on sludge accumulation in septic tanks with various designs and volumes indicated that the sludge pump-out heights largely depend on the effective volume of the septic tank. A range of the pump-out levels, expressed in percentage, have been reported: 33% (Kinsley et al., 2005), 48% (Gray, 1995), and 50% (Philip et al., 1993). The selection of the level at which to remove the solids from the tank can be a critical parameter as it can have a large impact on the pump out period, which in turn affects the cost of operation. It is important to note that although a maximum level of solids in the tank can be set, onsite investigation or monitoring, in conjunction with established procedures and equipment that can adequately determine the solids level, is required to determine when this level is reached.

Table 2 FS production rate and sludge accumulation depth from various OSS

Type of onsite sanitation system	Location	Land use	Soil percolation type	Number of user (cap/unit)	Emptying period (years)	Volume of FS (m^3)	Volume of thickened-bottom sludge (m^3)	FS production rate (L/cap/ year)*	Rate of sludge accumulation depth (cm/m^2/ year)**
Manmade-cement septic tank	Nonthaburi	Densely urban area	Clay soil	4.3±2.7	1.8±1.7	1.2±1.1	0.4±0.2	340±245	57±42
A single cesspool	Nonthaburi	Densely urban area	Clay soil	3.8±1.5	2.0±1.7	0.8±0.3	0.2±0.1	270±196	49±22
	Lampang	General urban area	Loamy soil	3.6±1.3	0.7±0.3	1.3±0.2	0.6±0.3	1,610±500	42±29
	Ratchaburi	Rural area	Sandy soil	5.2±2.1	5.5±4.3	1.0±0.5	0.4±0.1	40±25	28±12
Double cesspool in series	Nonthaburi	Densely urban area	Clay soil	3.5±1.6	1.5±1.0	0.8±0.4	0.3±0.1	220±141	67±48
	Lampang	General urban area	Loamy soil	3.5±1.7	2.3±1.8	1.9±0.7	0.9±0.3	355±209	26±0.2
Commercial plastic treatment package	Nonthaburi	Densely urban area	No soil percolation, effluent dispose to drainage	4.1±1.0	1.5±1.2	1.0±0.3	0.5±0.1	230±80	75±45
	Nakorn Ratchasrima	Newly developed area	No soil percolation, effluent dispose to drainage	2.7±0.5	2.5±0.0	1.5±0.0	0.46±0.1	300±20	92±25

Remark: * refer to the total content of faecal sludge in each OSS unit (sludge + supernatant)

** refer to the height of thickened-bottom sludge layer indicating by TS at the concentration greater than 35,000 mg/L

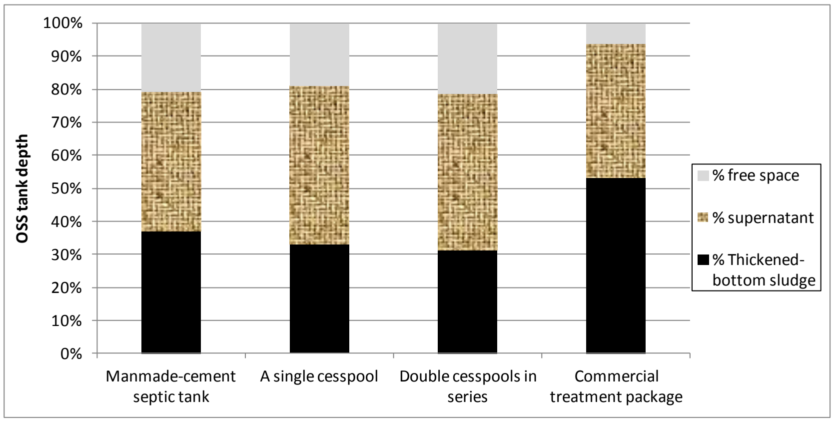


Figure 3 Percentage of sludge level in OSS tank before emptying

Types of OSS seemed not to significantly affect FS generation rate but likely depending on soil type, location and groundwater table, as illustrated in **Table 2.** This study refers the rate of sludge accumulation height to indicate the increased level of thickened-bottom sludge in OSS units. FS production rate of the single cesspools from urban area with loamy soil (Lampang province) presented the highest average value of 1,610 L/cap/year, while those in urban area with clay soil (Nonthaburi province) was only 270 L/cap/year. The lowest rate was found in single cesspool located in rural area with sandy soil (Ratchaburi province) at the rate of 40 L/cap/year, which are comparable to those observed in a septic tank by Still (2002) and Gray (1995) at the rates of 10 – 100 L/cap/year of 90 L/cap/year, respectively.

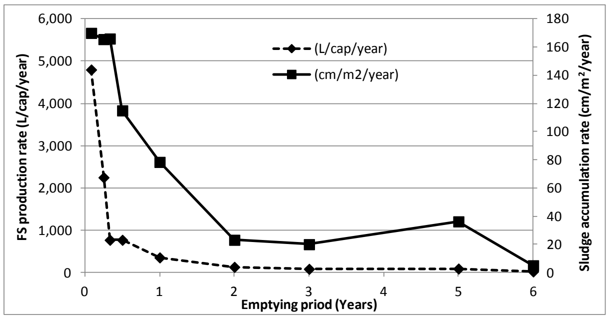
FS production rate could depend on the emptying period due to stabilization or biodegradation processes of organic contents in the sludge. Philip et al. (1993) reported that over a 3-year period sludge starts to stabilize and then begin to decrease. It could be indicated by the solids accumulation rate was 82 L/cap/year within 3 years, while after 3.5 years it was 60 L/cap/year (Philip et al., 1993). Apart from the effect by emptying period, this study suggests other factors such as soil conditions and OSS types would affect the FS production rate especially for those units discharging their effluent by soil percolation. For instance, a household installed with single cesspool in sandy soil area can retain FS for almost 10 years before emptying but the FS production rate is about 60 L/cap/year. The solid content in FS from a cesspool with relatively long emptying period is exceptionally high which is discussed in the following sections.

The rate of sludge accumulation depth (SAD) expresses the increase of dense sludge in the bottom most of OSS unit which is typically difficult to remove. The results indicate that the double cesspools in series could collect the sludge at the highest rate of 67 cm/m^2/year while a single cesspool, septic tank, and commercial septic tank were about 49, 57 and 60 cm/m^2/year, respectively. It could be noticed that the relatively high FS production rate does not affect the increase in SAD, but possibly depending on other factors such as emptying period, amount of flushing water or type of toilets.

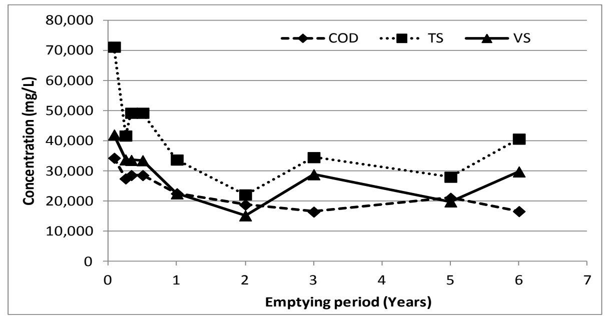
Effects of emptying period

Figure 4a shows the correlation of FS production rate and sludge accumulation depth from a single cesspool with the emptying period. The field observations demonstrated that the longer the emptying period required by OSS unit, the lower the sludge accumulation rate could be obtained. The higher value of sludge accumulation rate for those units with emptying unit of less than 1 year could be because of the relatively high FS production rate. Relatively lower sludge accumulation rate were observed at the emptying period of 2 - 6 years, possibly due to anaerobic biodegradation of organic contents.

Relationships between COD, TS and VS concentrations of the thickened-bottom sludge samples and sludge emptying period are shown in **Figure 4b**. It could demonstrate that COD concentrations sharply decreased at the emptying period of no longer than 2 years whereas the lower decreases in TS and VS concentrations could be observed. This incidence could indicate biodegradation in single cesspool units. In case of emptying period is longer than 2 years, the less biodegradation rate would occur even with continuous feeding of feces or urine from the toilets. These results could suggest that an appropriate emptying period is more than every 2c years in order to ensure efficient biodegradation in a cesspool which is lower than USEPA recommendation of every 3-5 years (USEPA, 2002; Seabloom et al., 2004). This suggested emptying period would be appropriate for topical region. In order to obtain additional insight in the changes in sludge accumulation rate, it would be necessary to revisit the tanks after several more years had elapsed.



(a) FS production rate and sludge accumulation rate



(b) COD, TS and VS as a function of emptying period

Figure 4 Effects of emptying period on a single cesspool system

Faecal Sludge Properties

To investigate FS properties in this study, sludge samples were collected from 2 sources i.e. bottom layer in an OSS tank and fluidized sludge from an emptying truck. Zoltan et al. (2008) defined that settle sludge is a sludge layer in the bottom of a septic tank includes various solids which are not dissolved in the septic effluent and dense enough to fall to the bottom of the tank. Results in **Table 3** shows that average TS concentrations of thickened-bottom sludge were 39,800, 60,930, 34,500, 217,200 mg/L for septic tank, a single cesspool, double cesspool in series and commercial systems, respectively. The highest TS concentrations in thickened-bottom sludge of commercial system were greatly contributed by the fixed solids which could likely result from the uses of toilet papers. VS contents in the thickened-bottom sludge samples from every OSS types were in the same range at 60 to70% of TS. Characteristics of the fluidized sludge samples indicate the lower concentrations than those from thickened-bottom sludge due to a mixing with its supernatant (**Table 4**). The analytical results were in the same ranges of FS samples from Bangkok studied by Koottatep et al (2005) which reported the average TS, TVS, and COD concentrations of 2,200 to 67,000 mg/L, 900 to 52,500 mg/L and 1,200 to 76,000 mg/L, respectively. It is however apparent that, if the management of fluidized and thickened-bottom sludge could be separated instead of mixed to be FS, the dewatering or treatment processes would be more efficient and easy to handle.

Regarding chemical characteristics, COD concentrations of the thickened-bottom sludge samples were 30,100, 29,400, 40,400, 39,000 mg/L for septic tank, a single cesspool, double cesspool in series and commercial systems, respectively. An exceptionally high COD concentration of 44,939 mg/L was obtained from 10 samples collected from cesspools located in sandy soil. In dried thickened-bottom sludge samples, the ranges of N and C contents were 2. 3 - 4.0 % and 30.8 - 37.6%, respectively, which are similar to the previous studies (Schouw et al., 2002: Koottatep et al., 2005).

For rheological properties especially for those thickened-bottom sludge samples, the analyses include viscosity, shear stress and density. A difficulty in measuring viscosity is due to heterogeneous mixtures in sludge samples such as sand, hair, debris, etc. Viscosity and shear stress values of the thickened-bottom sludge samples indicate that to remove sludge from double cesspool and commercial plastic treatment package is more difficult than those in a single cesspool or manmade cement septic tank. Especially for those areas having no efficient vacuum pumps, it will create great difficulty to remove the thickened-bottom sludge, except diluting by tap water.

Viscosity and shear stress values of the thickened-bottom sludge samples from septic tank and a single cesspool showed the relatively low value of 30.8, 58.6 cP, and 64.3, 105.1 D/cm^2, respectively. Meanwhile, double cesspool and commercial systems showed the similar values of 79.56 and 82.01 cP for viscosity and 144.24 and 139.72 D/cm^2 for shear stress, respectively. Presently, sludge emptying by vacuum truck could force to over shear rate at more than 1000 cP which could mostly overcome the emptying difficulty. Viscosity and shear rate of the thickened-bottom sludge in this study were higher than those investigated in wastewater sludge before dewatering by Hung and Li, (2003) which reported at a range of 1.63 to 2.81 cP with an average TS concentration of 30,000 mg/L. Unlike viscosity and shear stress, the density and conductivity values of sludge samples range between 1.10 – 1.13 g/cm^3, 1.22 – 2.61 mS/cm, which do not express any significant difference from various OSS types.

Table 3 Solid characteristics of FS from different OSS types

Type		Sample size (N)	Total Solid (mg/L)	Volatile Solid (mg/L)	Fixed Solid (mg/L)	Dried Solid (%)**
Thickened-bottom sludge	**Manmade-cement septic tank**	10	39,812 ± 36,639	26,033 ± 25,466	13,779 ± 14,210	3.99 ± 3.15
	A single cesspool in clay and loamy soil areas	21	60,934 ± 52,330	35,925 ± 24,126	28,690 ± 31,914	2.45 ± 2.2
	A single cesspool in sandy soil areas	12	119,022 ± 51,645	64,220 ± 17,280	53,788 ± 29,150	9.65 ± 8.2
	Double cesspool in series	12	34,489 ± 23,880	22,760 ± 15,193	11,729 ± 9,452	3.64 ± 2.42
	Commercial plastic treatment package	10	217,189 ± 107,840	25,245 ± 9,711	191,945 ± 108,116	22.85 ± 11.08
Fluidized sludge*	**Manmade-cement septic tank**	10	17,425 ± 23,474	12,273 ± 18,051	5,152 ± 6,441	1.78 ± 2.32
	A single cesspool in clay and loamy soil areas	21	10,054 ± 5,822	7,199 ± 4,419	2,292 ± 2,494	1.12 ± 0.84
	Double cesspool in series	12	10,958 ± 8,500	7,206 ± 5,153	4,498 ± 4,12	1.13 ± 0.86
	Commercial plastic treatment package	10	189,974 ± 109,143	10,581 ± 10,805	181,308 ± 108,387	19.47 ± 11.12

Remark: * There is no data of fluidized sludge samples from a single cesspool in sandy soil areas
** Dried solid refers to samples after drying at 105°C

Table 4 Physical and chemical characteristics of thickened-bottom sludge from different OSS types

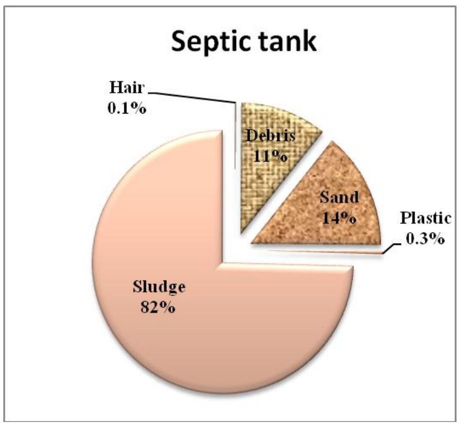
Type	Sample size (N)	COD (mg/L)	Conductivity (mS/cm)	N* (%)	C* (%)
Manmade-cement septic tank	10	32,186 ± 14,212	1.44 ± 1.12	2.72 ± 1.06	32.49 ± 4.37
A single cesspool in clay and loamy soil areas	21	21,960 ± 10,012	1.22 ± 2.02	3.63 ± 0.97	37.15 ± 9.46
A single cesspool in sandy soil area	12	44,939 ± 35,442	1.73 ± 2.62	3.14 ± 1.03	30.99 ± 10.41
Double cesspool in series	12	40,420 ± 19,739	2.61 ± 1.72	4.03 ± 1.28	37.57 ± 8.56
Commercial plastic treatment package	10	38,994 ± 18,644	1.54 ± 0.86	2.31 ± 0.83	30.83 ± 9.28

Remark: * %N and %C in dried sludge

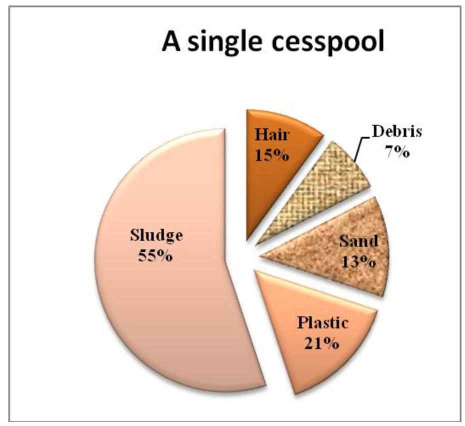
Table 5 Rheological properties of thickened-bottom sludge from different OSS types

Type	Sample size (N)	Viscosity (cP)	Shear stress (D/cm^2)	Density (g/cm3)
Manmade-cement septic tank	10	30.8	64.3	1.11
A single cesspool in clay and loamy soil areas	21	58.6	105.1	1.12
Double cesspool in series	12	79.6	144.2	1.13
Commercial plastic treatment package	10	82.0	139.7	1.10

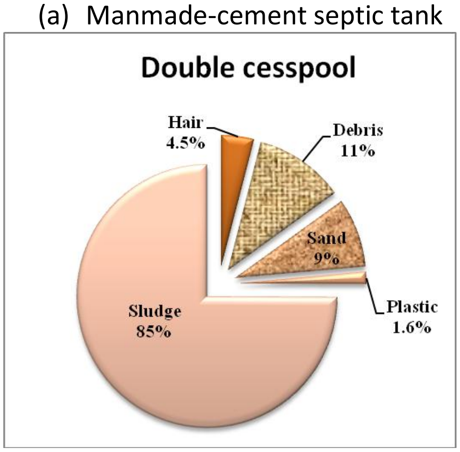
Another factor that may cause difficulty in sludge emptying is the other solid contaminants such as sand, hair, debris, etc. Likely due to a pre-fabricated material and a screen unit of the commercial package system, its sludge samples contain the lowest contaminants with only 6% of debris as shown in **Figure 5**. A single cesspool, double cesspools in series and manmade septic tank systems have the accumulated sludge at the higher solid contaminants such as 15% of hair in a single cesspool system and 14% of sand in a manmade septic tank. The rate of contaminants could result from behavior of toilet users who may drop additional materials (e.g. sanitary napkins, etc.) after defecation or discharging other wastewaters from washing or bathing activities. Unsealed bottom of a single or double cesspool would be a cause of sand and debris contamination during sludge emptying at high speed.



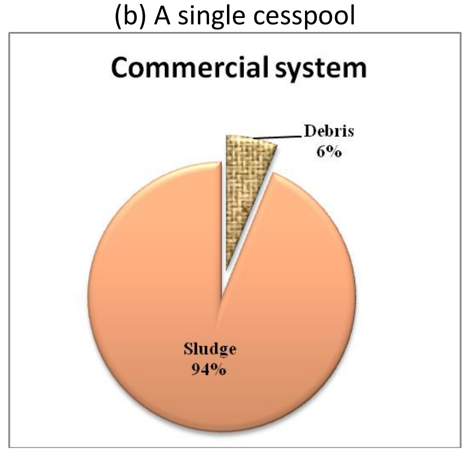
(a) Manmade-cement septic tank



(b) A single cesspool



(c) Double cesspool in series



(d) Commercial plastic treatment package

Figure 5 Sludge composition of different Onsite Sanitation System (OSS)

CONCLUSIONS

Onsite sanitation systems are basically installed for receiving backwater of every household in Thailand consisting of 1) Manmade-cement septic tank 2) A single cesspool 3) Double cesspool in series and 4) Commercial plastic treatment package. A single cesspool is widely used in rural or peri-urban areas while a commercial treatment package is selected in newly-developed urban areas but, for more than 10-years-old houses, manmade septic tanks and double cesspools in series were installed. Considering sludge-emptying frequency, the commercial plastic package system requires every 2.5 years while an average frequency of once in 1.5 years is for the others. FS production and sludge accumulation rates of the thickened-bottom sludge does not depend on types of OSSs, but rather dependent of land use and soil texture. For example, the accumulation rate of single cesspool system in an urban area with loamy soil (Lampang province) presented the highest average value of 1,610 L/cap/year while those in urban area with clay soil (Nonthaburi province) was only 270 L/cap/year. The difference in accumulation rate of the thickened-bottom sludge is probably due to the higher infiltration rate of loam soil than that of clay soil, enabling liquid infiltration into surrounding soil. The lowest rate was found in OSS located in rural area with sandy soil (Ratchaburi province) at the rate of 40 L /cap /year. Based on the field investigations, TS concentrations in FS were averaged at 39,800, 60,930, 34,500, 217,200 mg/L from septic tank, a single cesspool, double cesspool in series and commercial septic tank, respectively, were approximately of 30,100, 29,400, 40,400, 39,000 mg/L for COD. With the trend of change for the modernized and urbanized, commercial septic tanks will be more popular uses which requires proper management practices i.e. sludge emptying, handling, hauling and transportation and treatment. Some rheological properties of the thickened-bottom sludge in this study should be helpful in the design of emptying facilities especially for those areas having no vacuum trucks.

ACKNOWLEDGEMENTS

Field investigations of this research was mainly supported by the Bill & Melinda Gates Foundation with a partial funding from the Swiss National Centre of Competence in Research (NCCR) North-South program.

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