FINAL REPORT

Assessment of Faecal Sludge Rheological Properties

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SUMMARY

Field survey and analysis for faecal sludge (FS) properties were conducted during August to December, 2011. Nonthaburi, Lampang, Ratchaburi and Nakorn Ratchaseema provinces were selected as studied areas since they represent densely urban area, general urban area, rural area, and new town, respectively. This study focused on onsite sanitation systems treating black water which collected from 4 types of sanitation system such as septic tank system, one cesspool system, two cesspools in series system and commercial treatment system. This study presents sanitation information, rheological, physical, chemical properties, desludging equipments, routing and GIS map, and management practices of each area.

FS management system in Nonthaburi municipality is quite well organized by the office of public health and environmental department which can coverage FS for whole area (Nonthaburi municipality). There are about 35 households were selected as sampling points. For Nakorn Lampang municipality, although the truck under this study is the only private sector that is officially authorized to work in the area, illegal FS emptying trucks can be found. There are 12 households were selected as sampling points. While in Suan Pheung, Ratchaburi, this area surrounded by mountains and rivers, households settled in a slope and valley of the landscaping. Most of households do not have any problems with filled septic tanks since the liquid part of FS is easily absorbed into soil layers. Therefore, there is no FS emptying truck service in this area, about 10 households were selected as sampling points. New town in Nakhon Ratchasima province represents an area using new type of septic tank, commercial system, treating black water before discharging effluent into drainage system. There are 6 households were selected as sampling points.

Based on sanitation interviews, majority of households lacks of information concerning sanitation system expenses. Since the houses are rented or septic tanks were constructed at the same time of building house. Average number of toilet is 1-2 rooms per household. Mostly use flushing system in Nonthaburi and Nakhon Ratchasima, both flushing and pouring system in Lampang and pouring system in Suan Pheung Ratchaburi.

Based on field observation of onsite treatment system configuration demonstrated that total volume of onsite systems in Thailand such as septic tank, one cesspool, two cesspools in series and commercial septic tank were range of 0.4 – 6.3 m^3/ household which the average of 1.48, 1.42, 1.35 and 1.42 m^3, respectively. The variation of total volume probably was due to type of onsite treatment system and location of the community. Considering sludge accumulation rate illustrated that one cesspool present the highest of average accumulation rate which about 300 L/cap/year while the other system shown about 135 – 180 L/cap/year.

Samples were collected from two parts, wet fluidized sludge and wet bottom sludge. Dried sample was developed from wet bottom sample. Results indicate that the maximum density of wet bottom sludge were not significantly different among different studied areas which ranged between 1.0923-1.1585 g/cm^3. The average viscosity from septic tank system, one cesspool system, two cesspools in series system and commercial system were presented about 25.3, 52.4, 77.7 and 77.6 cP, respectively. For physical and chemical properties, they are

illustrated that concentrations of bottom sludge were higher than fluidized sludge about 1.5 – 5 times for almost parameters. Therefore TS concentrations of fluidized sludge were ranged from 830 – 288,840 mg/L whereas concentrations from bottom sludge were ranged from 2,160 – 188,480 mg/L. COD concentrations of fluidized sludge were ranged from 3,290 – 33,090 mg/L whereas concentrations from bottom sludge were ranged from 5,710 – 125,660 mg/L. On the other hand the conductivity and water content from fluidized sludge and bottom sludge were not significantly different which presented about 1.9 and 2.0 ms/cm for conductivity and 33% and 32% for water content, respectively. The %TC and %TN in dried sludge, were between 14.36 – 47.65 and 1.03 – 6.94, respectively. Dried sample of 6.42 mg was tested at temperatures between 25 to 100 ^{o}C, the specific heat values were between 1.67 to 5.45 J/g ^{o}C. The composition of dried FS found are depended on each source which can be sorted out into sludge, plastic, sand, debris especially seed of paprika, and human hair.

Considering emptying process, the vacuum truck service usually has variety of capacity sizes depended on workload such as 2 m^3, 4 m^3 and 6 m^3. With about 2 – 3 employees per service truck, serves 8 – 10 households per day. Small truck is usually assigned for small road or areas which closer to the dumping site. While the big truck is used for the long route. Sometimes, the big truck is used as mother trucks situated at each suitable areas in order to transfer FS from small trucks to the dumping site.

Overall contributions have been made in understanding and quantifying solids accumulation rates and sludge characterization in onsite treatment system. As well as, the information gained from the analysis of the data collected provides a meaningful insight into the factors influencing sludge characteristic within individual residential tanks, and points to future research directions for understanding the factors influencing FS management.

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LIST OF ACRONYMS AND ABBREVIATIONS

Acronyms

AIT	Asian Institute of Technology
EEM	Environmental Engineering and Management
GTE	Geotechnical Engineering
LGA	Local Government Authorities
MTEC	National Metal and Materials Technology Center

Abbreviations

COD	Chemical Oxygen Demand
DS	Dried Solid
FS	Faecal Sludge
GIS	Geographic Information System
GPS	Global positioning System
H_3BO_3	Boric Acid
HCL	Hydrochloric Acid
ml	Milliliter
NaOH	Sodium Hydroxide
ORP	Oxidation-Reduction Potential
OSS	Onsite Sanitation System
RPM	Round Per Minute
TC	Total Carbon
TN	Total Nitrogen
TS	Total Solid
US	United Stated
VIP	Ventilated Improved Pit
VS	Volatile Solids

I. Introduction

1.1 Background

The majority of developing countries are situated in the tropical climate with warm weather that has effects on characteristics and distribution patterns of fecal sludge (FS) from residences. Septic tank and other onsite systems are the units used to receive blackwater or/and greywater. In which, primary treatment or separation of solid and liquid fractions of human excreta are occurring.

Supernatant or liquid part from septic tank or onsite system are seeped into soil or discharged into sewer system. Remaining of solid part in septic tanks or other onsite systems is called faecal sludge (FS) or septage. In most cases, faecal sludge is usually disposed off to vacant lands or directly into waterways without any treatments resulting in increasing of pollution to canals, rivers, lakes or ground water as well as spreading of excreta-related pathogens.

The 1992 Public Health Act of Thailand delegates responsibility for septage management to local government authorities (LGAs). LGAs had adopted local regulations requiring FS to properly collected and treated before disposal. As the regulations do not require regular maintenance, households usually desludge their onsite systems when they have a problem.

Thailand uses four types of onsite sanitation system (OSS): (1) one cesspool; (2) two-cesspool in series; (3) septic tank and (4) commercial septic tank. In actuality, neither system can be called a proper septic tank since they both have open bottoms, which can lead to groundwater contamination in urban areas where onsite sanitation prevalence are densely clustered. In Bangkok metropolitan, soakage pits often do not work properly because the soil consists of low-permeability clay and the groundwater table is high. This raises the potential for groundwater contamination and septic tank overflows. In most cases, however, black water enters the septic tank and liquid effluent flows into drains or canals; whereas grey water enters the drains or canals directly.

Apart from the high concentrations of pollutions in the FS (conventional chemical and physical characteristics), which is a prerequisite for consideration of the proper management practices, the rheological properties of FS should be determined to ensure the effectiveness of technical equipments/facilities in emptying, transporting and treatment. Presently, there has been limited information on the rheological properties of FS that could also be highly fluctuated subjecting to the onsite system conditions. This study has generated the first hand data on FS rheological properties in relation to its management practices, emptying techniques and technologies.

1.2 Objectives

The overall objective of this research was to generate a firsthand data set on fecal sludge mechanical properties in order to provide information for professional design latrines emptying technologies.

Specific objectives including:

- To generate first hand data on faecal sludge characteristics from onsite sanitation technologies (such as latrines, VIP, septic tanks, etc.)
- To establish a correlation between FS management practices and sludge quality/ quantity

- To develop mapping of latrines distribution and accessibility by emptying truck in representative urban settings by GIS.
- To describe the technical equipment used for mechanical emptying and transportation

1.3 Approaches and Activities

In order to achieve the objectives of the study, approaches were designed according to each field area to get information and sampling points. Research team had accompanied with municipalities officers, private service providers and emptying trunk to requested houses for sludge emptying. General information concerning sanitation system, characteristics at households and FS emptying practices, questionnaires and field observations were taken into account. Properties of collected FS were studied by in laboratory.

Routings of FS collection trucks were observed and mapped by using GIS and timing techniques. Emptying process and equipments of FS collection truck were studied by observations and interviews.

II. Framework and Methodology

This part describes the analytical framework and methodology used in the data collection and analysis. The overall conceptual research framework is shown in Figure 1.

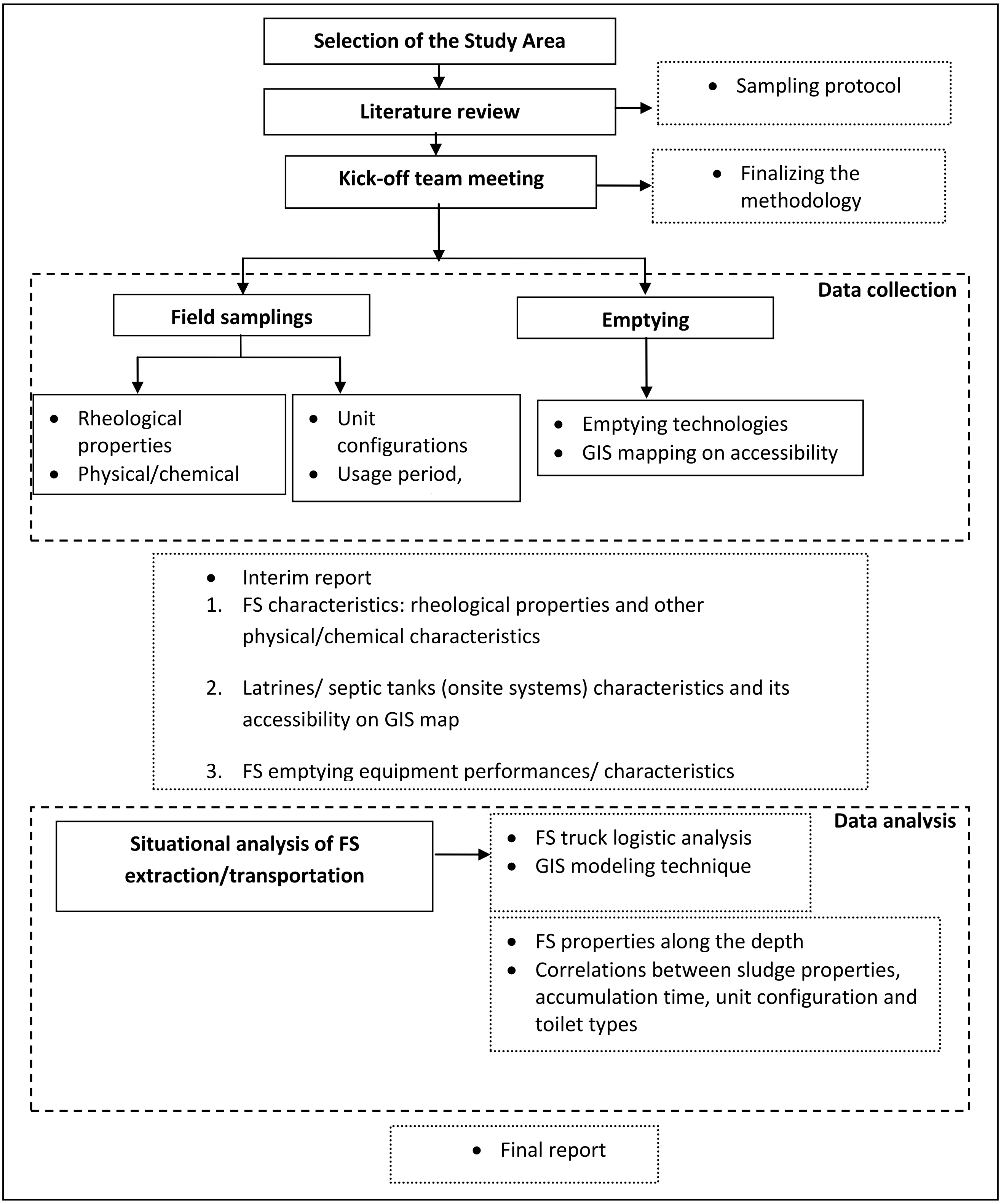


Figure 1: Conceptual Research Framework

2.1 Study Areas

This study focused on 4 areas, Nonthaburi, Nakorn Lampang, Suan Pheung and Nakhon Ratchasiema municipalities, representing densely urban, general urban, rural areas and new town area, respectively. Nonthaburi municipality was selected as the study area since it is a dense urban city (third-largest city in Thailand). Nonthaburi municipality located in the central part of Thailand, north of Bangkok (Figure 2a), has a population of 260,555 with 117,294 households (April, 2011) in a total area of 38.90 m^2. Density of the area is about 6,698 populations per square kilometers. Nonthaburi Municipality has established the best example of FS treatment in the country. Treatment system uses anaerobic digestion tanks, sludge drying beds, and oxidation pond to transform FS into fertilizer. Each year, the municipality has the desludging or sludge emptying around 3,300 onsite tanks from the request of households and collecting almost 9,000 m^3 of FS. Five people operate the plant, which uses very low energy consumption. Each month, the facility produces five tons of fertilizer or soil conditioner, collects around 560 US dollars from households' fee and obtains around 210 US dollars from fertilizer sales.

Figure 2a: Nonthaburi Municipality Boundary

Nakorn Lampang municipality representing general urban type of study area is the capital of Lampang province which is located 640 kilometers north of Bangkok. With the area of 22.17 km^2 (Figure 2b), it inhabits around 65,000 residents currently. Density in the area is around $2931.8/km^2$. The faecal sludge management is operated by a private sector, under the control of Nakorn Lampang municipality. The private sector is responsible for FS emptying service, carrying and transferring to the dumping site.

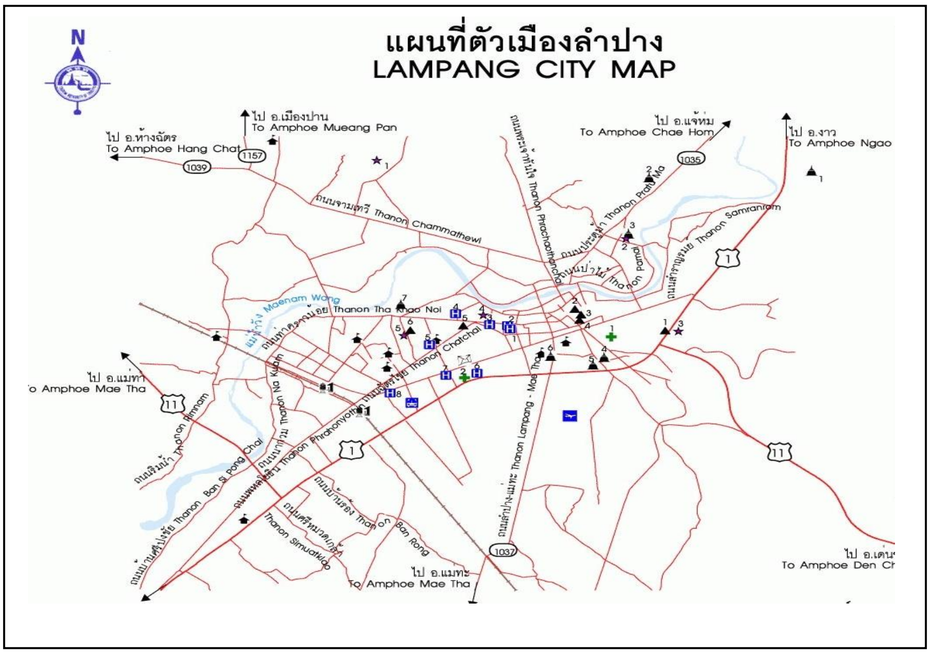


Figure 2b: Map of Nakorn Lampang Municipality

Rural area type in the study was Tumbon Suan Pheung municipality, situated in Ratchaburi province in western region of Thailand. Figure 2c shows Suan Pheung municipality's boundary. There are about 10,416 residents from 3,579 households. Tumbon Suan Pheung is located in foot-hill areas surrounded by mountains and rivers. Therefore, there is no FS emptying service in the area. Most of septic tanks were simply designed and used cement rings.

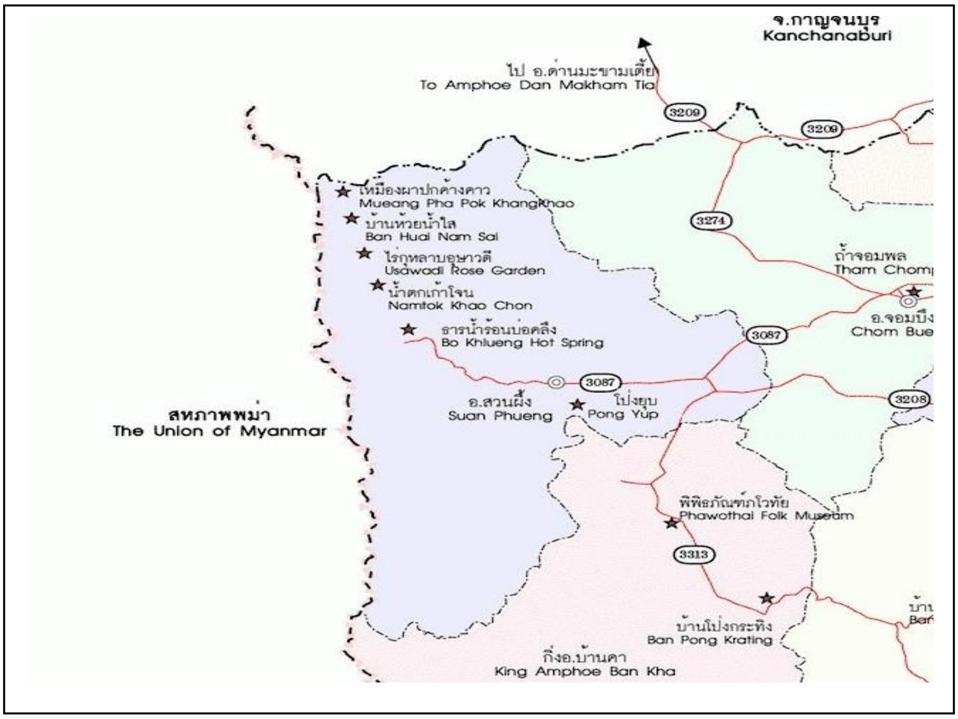


Figure 2c: Suan Pheung Boundary

2.2 Sampling and Data Collection Method

In Nonthaburi and Nakorn Lampang municipalities, 35 (AIT 1-35) and 12 (AIT 36-47) samples were collected respectively. Sampling households were households which requested municipality to desludge the system that is fully deposit and/or needs maintenance period. Therefore, all data were collected by the interviews from the following of the municipality's emptying truck to service households. Moreover, Suan Pheung Ratchaburi was randomly sampled for 10 (AIT 48-57) households, relevant to the requirements. For Nakhon Ratchasima, 6 (AIT 58-63) more samples were collected in order to fulfill the laboratory results of commercial type of OSS. It is important to emphasize that all 63 samples were studied and analyzed for their Physical and Chemical characteristics. However, only samples of AIT 1-47 were studied for management practices and emptying techniques.

2.2.1 Field Survey and Questionnaires

In field survey, questionnaires and semi-structure interviews were used to get the feedback from local people and FS service providers. Field observations for the local conditions were also conducted to conceptualize the ongoing FS management problems. The inhabitants were interviewed about dimensions of the onsite system association with specific background information such as soil condition, number of users, period of accumulation, etc (Appendix A). The total interviewed households for the whole study were approximately about 135 households, based on about 47 households of sampling points and about 90 households neighboring.

2.2.2 Faecal Sludge Sampling Process

FS samples were collected from fluidized and bottom parts of septic tanks, to study typicality of physical/chemical characteristics such as moisture content, total solids, sand content, non faeces-related matters, and etc. Bottom part was also tested for rheological properties in order to represent the most difficult part of FS emptying. Some significant differences between municipal types, densely urban, general urban, rural areas and new town as well as types of onsite sanitation systems such as one cesspool, two-cesspool in series, septic tank and commercial septic tank, were analyzed and compared. Analytical parameters of FS properties are summarized in Table 1.

Table 1: Laboratory Analysis for FS Properties

Parameters	Number of Samples
Compaction	5
Particle Size Distribution	59
Shear Stress	40
Shear Rate	40
Viscosity	40
Density	40
COD	98
ORP	98
Conductivity	98
% TC	40
% TN	40
VS	98
Fixed	98
TS	98
Ash	98
Particle Size Composition	57
Thermal Conductivity	4
Specific Heat	4

Procedures of FS Sampling in Nonthaburi and Nakorn Lampang Municipalities

After septic tank was opened, level of sludge was then measured. Amount of liquid sample from the surface part was collected by grab sampling (Figure 3a). The bottom part was collected using vacuum truck by manually controlled and adjusted according to the level of FS in septic tank. Therefore, procedures of bottom part collection are: 1) turn on the vacuum pump for some time in order to suck FS, 2) closed the valve to trap FS inside the hose 3) after that, turn off the vacuum pump and release out sludge sample that stuck in the pipe into a provided bucket. Surface part and bottom part were mixed together for fluidized sample according to proportion of supernatant and sludge parts.

(a) Opened septic tank cover

(b) Sampling of liquid part

(c) Turn on vacuum pump

(d) FS Suction Process

(e) Turn off Controlling Valves

(f) Release FS from the hose

(g) Finish Sampling Process from Each Household

(h) Washing

Figure 3a: FS Sampling Process in Nonthaburi and Nakorn Lampang Municipalities

Procedures of FS sampling in Suan Pheung Ratchaburi

Suan Pheung Ratchaburi has different landscape characteristics from Nonthaburi and Muang Lampang municipalities, since it is located on the foot-hill areas. Villages are located in rural area, surrounded by mountains and rivers. Most of the collected FS samples were quite thick. Moreover, residents in the areas were hill-tribe people working as farmers and having a poor living standard. There is no FS emptying truck giving services in the areas because people cannot afford the FS emptying service charge.

Since most of OSS in these areas were one-cesspool type made by concrete rings. The covers were on the ground's surface which it was accessible to FS without using FS emptying truck. Figure 3b shows pictures and descriptions of FS sampling process in Suan Pheung Ratchaburi.

(a) Identify pit location

(b) Clean up cover's surface if necessary.

(c) Open pit's cover in order to take out samples.

(d) A bucket is used with liquid part of FS

(e) A shovel is used with thick FS in order to take out the sample.

(f) Sample is contained in a bucket wrapped with plastic bags.

Figure 3b: Pictures and Descriptions of FS Sampling Process in Suan Pheung Ratchaburi

2.2.3 Unit Dimensions and Emptying Practices

At the same time of FS sampling process, unit dimension of onsite sanitation system was determined by interviewed specific background information together with calculation from total volume and depth of FS. In addition, two neighboring houses of each sample site were conducted the interviews with regarding to problems of FS emptying practices, services, accessibility of faecal sludge tanker, fee and quality of service and etc.

2.2.4 Emptying Equipments

Existing FS hauling system including emptying equipments, the preparation time, average emptying time and type of storage as well as the capacity of the truck was investigated for the whole emptying process. The averaged operational travel speed on various transportation facilities and logistic information of hauling system were also explored by GIS map and timing technique.

2.3 Samples Preparation

Samples are categorized into 5 groups as shown on Fig. 4. Some parameters used dried FS for analysis such as groups 1, 3 and 5. While, some parameters used wet FS for analysis such as groups 2 and 4. Details of parameters in each group are explained below.

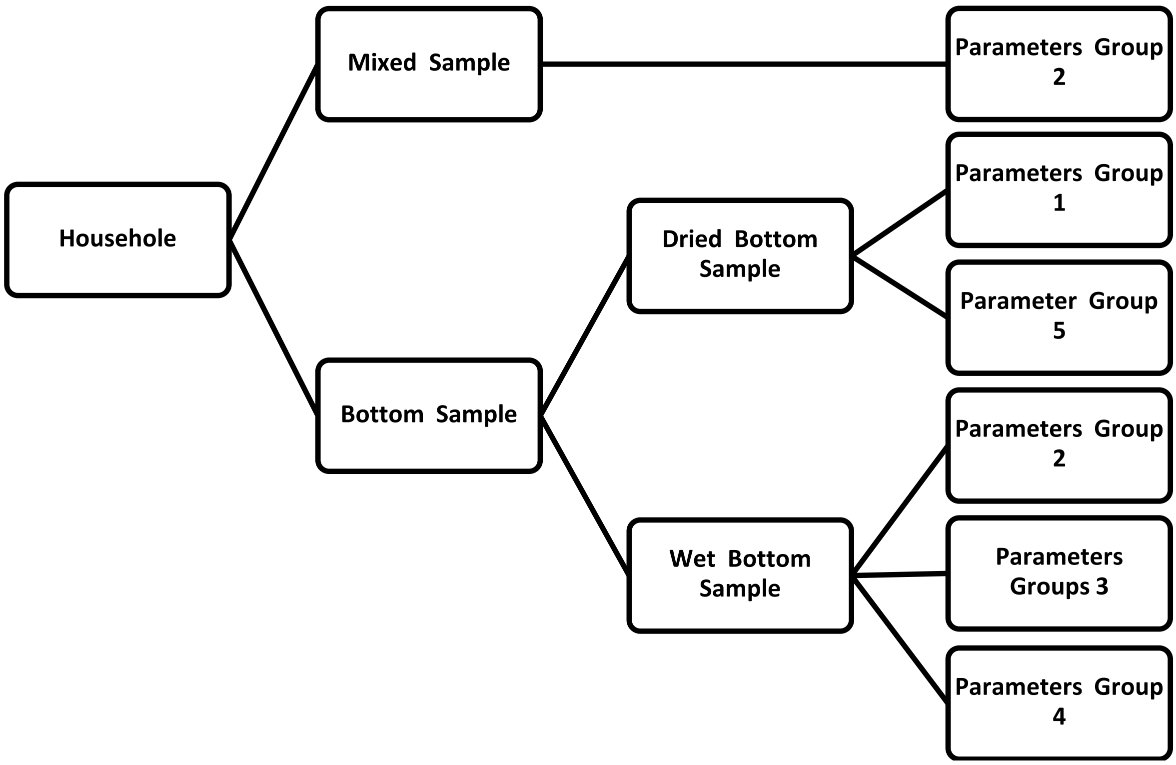


Figure 4: Sample Preparation Flow Diagram

Remarks :

Parameters Group 1 : TC, TN, Total weight; hair, debris, sand, plastic, etc.

Parameters Group 2 : COD, ORP, Conductivity, Volatile, Fixed, Dry weight(% TS)

Parameter Group 3 : Shear stress, Shear rate, Apparent viscosity, Density

Parameter Group 4 : Specific heat

Parameters Group 5 : Particle distribution, Compaction

Parameters groups 3 and 4 were analyzed by Powder Characterization Laboratory and Thermal analysis laboratory, Materials Characterization Research Unit, MTEC, Thailand. Whereas, parameters groups 1, 2 and 5 were analyzed at EEM and GTE laboratory.

<u>Steps of sludge preparation</u>

Collected FS was usually in half liquid and solid form. In order to conduct sludge property analysis, dewatering process is taken into account. The preparation processes are as follow:

- Collected FS samples were dried out at ambient laboratory until becoming solid forms.

- Dried sludge samples were further put into the oven at the temperature lower than 60 ^{0}C for 2-3 days and then ready to use for analysis as dried solid (DS).

Pictures and Step Descriptions for sludge preparation are shown in Figure 5.

(a): Collected sludge sample from households

(b): Buckets of sludge samples for drying process

(c): Sludge drying process on canvas

(d): Sludge samples after 2 days.

(e): Dried sludge sample

(f): Plastic cover from rain

Figure 5: Pictures and Step Descriptions for Sludge Preparation

2.4 Rheology

Rheological properties in relation to FS management practices, emptying techniques and technologies are given characteristics for the choosing of desludging techniques. Analytical parameters of FS rheological properties in the study included shear stress, shear rate, density, particle size distribution and compaction. Details of analytical method are expressed as follows:

1. Parameter1: Viscometer DV II + (Brookfield)

Test Method : Cylinder Rotational Viscosity (Viscometer DV II+)
Conditions : Temperature: Lab Temperature (19-20 ◦C)
Spindle No. : SC-21 (small volume)
Speed : Vary rpm (20-200 rpm)
Measurement: record the viscosity values every 30 seconds.
Number of measurement: 1
Sample preparation: 1. 8 ml of original sample put into container.
2. Sample was analyzed with Viscometer DV II + (Brookfield) at lab temperature at 19-20 ◦C.

2. Parameter 2: Ultrapycnometer 1000 (Quantachrome)

Test Method : Gas displacement technique
Conditions : Gas: Helium gas (99.999%)
Cell: Large cell
Number of experiments: 5
Temperature: 22.6 ◦C
Sample preparation : Put 76.7887 grams of sample in large cell was analyzed by Ultrapycnometer 1000

3. Parameter 3: Thermal Analysis

Instrument : Mettler Toledo DSC822^{e}
Test Method : Differential Scanning Calorimetry (DSC)
Condition : Held at 10 ^{o}C for 2 minutes, heat from 10 ^{o}C to 105 ^{o}C with a scanning rate of 10 ^{o}C/min and held at 105 ^{o}C for 2 minutes, under nitrogen atmosphere.
Measurement Detail : Evaluation of Cp based on the known specific heat of sapphire. (For calculation of the Cp according DIN 51007)
Sample Preparation : Fill the sample into aluminum crucible, then heated the samples using condition specified above.

4. Parameter 4: Thermal Conductivity

Thermal Conductivity is a property of materials that expresses the heat flux f (W/m^2) that will flow through the material if a certain temperature gradient DT (K/m) exists over the materials. The thermal conductivity is a property that described the semi static situation: the temperature gradient is assumed to be constant. As soon as the temperature starts changing, other parameters enter the equation.

The thermal conductivity is usually expressed in W/m.K. The usual formula is:

$$\text{Flux} = \text{thermal conductivity} * \text{temperature difference}$$

Procedures

1. Fill the stainless steel container (with **k** = 16 W/m^{-o}C) with prepared sample and close the lid.

2. Put the container filled with sample into the Thermal Conductivity Analyzer (Brand: P.A. HILTON, Model: B480).

3. Input all required data such as bulk density, temperature difference between hot plate and cold plate (ΔT) and hot plate temperature ($T_{\text{hot plate}}$). Then start analyzing.

4. After starting the analysis, it usually takes around 2-3 hours until the system becomes steady state, after that the analyzer automatically reports the **k** value in printing.

5. The thermal conductivity can be calculated from reported **k** value.

2.5 Physical and Chemical Properties

Bottom sludge and fluidized sludge were analyzed for physical properties such as volatile, fixed, ash, total solids and composition. Chemical properties for instance, COD, TC, TN, ORP and Conductivity were conducted from the same samples of physical properties.

2.5.1 Carbon Content

Carbon content of the ingredient was measured by estimation of % C based on the volatile solids content. Volatile Solids (VS) are the components (large carbon, oxygen and nitrogen) which burn off an already dry sample in laboratory furnaces at 500-600 ◦C, leaving only the ash (largely calcium, magnesium, phosphorus, potassium and other mineral elements that do not oxidize). For most biological materials, the carbon content is between 45 to 60 percent of the volatile solids fraction. The formula for estimation of carbon content is as follows:

$$\% \text{ Carbon} = (\% \text{ VS}) / 1.8, \quad \text{where } \% \text{ VS} = 100 - \% \text{ Ash}$$

Ash Content

Equipments:

1. A Muffle furnace (thermostatically controlled at 550 ◦C).
2. A desiccators with fresh silica gel desiccant
3. Silica crucibles

Procedure:

1. Place the required number of crucibles into a muffle furnace for 15 minutes, remove dishes, cool in desiccators to room temperature and weigh dry crucibles to the second decimal place.
2. Transfer about 5 g of the prepared sample to the crucible

3. For dry sample, dry for 12 hours in an oven (100 ◦C) or overnight. Remove the dish from oven, cool in desiccators and weigh the crucible and contents as rapidly as possible.
4. Place the crucibles inside the muffle furnace as near to the center as possible and ash overnight at 550 ◦C.
5. Remove the crucibles from the muffle furnace and place in a desiccators and allow to cool down at room temperature.
6. Re-weight each crucible + ash and calculate the percentage of ash as follows:

Calculation:

Weight of clean, dry crucible	=	W_0
Dry sample	=	W_1
Weight of clean, dry crucible + ash	=	W_2
Ash content of the sample (%)	=	$\frac{W_2 - W_0}{W_1}$ X100

2.5.2 Total Nitrogen Analysis (Kjeldahl method)

Equipments:

1. Digester
2. Digestion tubes
3. Kjeltec distilling unit
4. Biuret stand, Biuret
5. Analytical balance
6. Pipettes (25 mL, 10 mL)
7. Erlenmeyer flasks (250 mL)
8. Aluminum foil

Chemicals:

1. Kjeltabs: Add two Kjeltabs S/3.5 (3.5 g K_2SO_4 + 3.5 g Se) or M/3.5 (3.5 K_2SO_4 and 0.175 HgO) or laboratory prepared catalyst (7 g K_2SO_4 + 0.8 g $CuSO_4.5H_2O$)
2. Alkali: Use technical grade NaOH (35-40%, w/w). Dissolve 400 g NaOH in 1 L deionized water.
3. Mixed Indicator: Mix 0.1 g methyl red and 0.1 g bromcresol green in 100 mL ethanol.
4. Boric acid (4%): Prepare a saturated boric acid solution with hot deionized water (dissolve 400 g Boric acid in 9 L water).
5. Standard acid solution: (HCl) Prepare 0.2 M HCl solution.
6. Na_2CO_3 stand solution: Weight approximately 10 g of anhydrous sodium bicarbonate. Dry for 1 hr. at 265 ◦C or for 2 hrs. at 200 ◦C. After cooling in a dedicator, transfer Na_2CO_3 to a beaker with a tight lid. Store it in the desiccators.

<u>Acid Digestion of Samples method</u>

1. Switch on the fume cupboard and the digester. Heat the digester to 420 ◦C.
2. Mark the digestion tubes with consecutive numbers. Digestion tubes must be always dried and cleaned before use.
3. Weight small piece of smooth aluminum foil on the analytical balance to 5 decimal places (d.p) and record the reading.
4. Add sample to foil and re-weight to 5 d.p.
5. Carefully transfer sample to the digestion tube and re-weight empty foil to 5 d.p.

6. Add two Kjeltabs (0.35g Se) and 7 ml of concentrated H_2SO_4 and gently shake to "wet" the samples with the acid.
7. Add 3 drops of anti-forming agent.
8. Load the rack with exhaust into a preheated digestion block (420 ^{O}C)
9. After about 5 minutes turn down the water aspirator until the acid fumes are just contained within the exhaust head.
10. Digest until samples are clear. This will normally be after 30-60 minutes depending on the sample type.
11. Remove the rack of tubes with exhaust still in place and put into the stand to cool for 10-20 minutes.

<u>Distillation of the digested samples</u>

1. Check the water level in the distilled/deionized water tank and also check NaOH and Boric acid in reagent tanks (Note: water NaOH and H_3BO_3 level should be above the sensor).
2. Turn on water supply to the distillation unit.
3. Switch the Kjeldahl analysis unit and wait until the display show "Select Operation".
4. Select the program that indicates "add 70 ml of water". Place the empty conical flask on the tray.
5. Press "ENTER" and then place the empty tube in the distillation unit. Close the safety door. The unit will automatically run and warm-up the distillation unit.
6. Remove both the digestion tube and conical flask.
7. Replace the conical flask with a flask containing 5 drop of mixed indicator.
8. Select the program P1 (which indicate to add 20 ml of saturated boric acid, 30 ml of NaOH and 20 ml of water).
9. Press "ENTER".
10. Place the tube containing digested feed sample and close the safety door. The receiver solution in the distilled flask will now turn green indicating the presence of an alkali-Ammonia.
11. After all the samples are analyzed, repeat 4-5 to clean up the system.
12. Close down the distillation unit and wipe/clean the tray and digestion chamber.

<u>Titration</u>:

Titrate blank and distilled sample against 0.2 M HCl and record value. End point of titration color changes from blue to grey and stop at first hint of orange.

<u>Calculation</u>:

$$\text{N content (\%)} = \frac{\text{(Titration - Blank) x Normality of the acid x 14.007x 100}}{\text{mg of sample}}$$

Protein (%) = N content (%) x Conversion factor (6.25)

2.5.3 Dry Sieving

Sieving method is a method to classify the size distribution of FS. FS samples that are used in this method must be completely dried in order to make sure that particles are separated out from one another. And having the sample completely dried, can guarantee the actual weight of soil.

Equipments for soil sieving

1) Sample Splitter
2) Mixing Pan (Size: 45x45 cm or 60x60 cm)
3) Sieve
4) Sieve Shaker
5) Analytical Balance
6) Soil Scoop

2.5.4 Analytical Methods

Analytical methods for COD, ORP, Conductivity and Total Solid parameters are described as follows:

- COD, 100 times dilution technique and close reflux method are used
- OPR and Conductivity, ORP and conductivity probe are used
- Total Solid (TS) and related portions are conducted on water bath, oven and weighting techniques following to Standard method

2.6 Routing and GIS Map

On sampling days, one of the research team members was responsible for recording the GPS readings when following the FS emptying truck. The GPS reading was recorded at every turn that the truck made. Every day, the starting point of the route was Nonthaburi municipality office since the truck driver had to come and pick up the assigned works from the officer before starting the work every day. The GPS reading consists of 2 numbers that are relevant to X and Y directions. By doing this, the GPS regarding routes of truck and unit dimensions (distance estimation), the GIS map can be produced. It is important to note that, the municipality officer is responsible for assigning the truck that was followed each day which depends on various factors such as, route with less traffic congestion and service households are located close by to one another. So that it is impossible to exactly estimate number of samples that can be collected each day. Each sampling location of the onsite system was mapped by GIS technique with illustration of roads, paths, truck points and etc. The study process was also conducted the same way for Nakorn Lampang municipality.

2.7 Desludge Equipments

In this study, the attention has also been drawn upon desludging technique by Nonthaburi municipality's FS emptying team. Besides, recording the GPS reading as mentioned in 2.4, the same person was also responsible for recording time consumed by commuting of the FS emptying truck. In addition, the traffic description was also recorded. Pictures of the truck at each studied household were taken as well as sketching of access points. Moreover, general information of FS emptying technique and equipments had been observed. The required information is as follows:

- Travel time from origin to household
- Travel time of opening the tank
- Average Emptying time
- Packing time (After finish)
- Pit location
- Access point of truck (Description and Picture)
- Preparation time
- Parking description of the truck for each service household
- Step of Preparation
- Position of end-pipe
- Volume of sucked fecal sludge
- Sucking speed

III. Results and Discussion

3.1 Sanitation System of Studied Areas

Field survey, interviews, samplings, and data collection were conducted for 11 days in Nonthaburi municipality for 35 samples, 2 days in Nakorn Lampang municipality for 12 samples. Total number of questionnaires of studied households was 47 and total number of questionnaires for neighboring households was 92. For neighboring households, 70 questionnaires were collected from Nonthaburi municipality and the other 22 questionnaires were collected from Nakorn Lampang municipality. Results of the questionnaire survey are shown in Appendix A whereas results are discussed in the next sessions.

a) Nonthaburi:

FS management system in Nonthaburi municipality is quite well organized by the office of public health and environment since it pledged to be the municipality that is environmental friendly. In order to receive the service from municipality, the official requesting form must be submitted.

Process on requesting for FS emptying service:

1. Forms can be taken at the municipality office or downloaded via http://www.nakornnont.com/service/list.php
2. Fill out the requesting form including sketch of the route to household.
3. Form can be submitted in person or by fax.
4. It usually takes about 1-2 days for the truck to be able to serve households after submitting the requesting form.
5. Service charge rate can be as follows:

    (a): The first cubic meter costs 250 baht.

    (b): The excess part, if less than ½ m^3 costs 150 baht.

    (c): The excess part, if more than ½ m^3 costs 250 baht.

In Nonthaburi municipality, a dumping site has been constructed under the King's project of bio-fertilizer. Once the FS emptying truck is full, FS will be transferred from the truck to provided tank relevant to the date of collection in order to easily estimate retention time of fertilization. Pictures of dumping site are shown in Figure 6.

(a): The King's project of bio-fertilizer

(b): There are total 31 FS tanks with specific date for each one.

(c): The sign "Put FS here" is shown on the tank of the current date.

(d): FS transferring process at the dumping site.

(e): The sign "Put FS here" is shown on the tank relevant to the date of collection

(f): FS in the tanks is then transferred to the opened spaces in order to dry out the sludge.

Figure 6: Pictures of Dumping Site in Nonthaburi Municipality

Nonthaburi municipality has been having a problem with illegal FS truck. Illegal FS truck usually runs around town to the residential areas and serves in front of the household's door. So that it is convenient for resident that they can have the service right away. The truck basically looks like the truck from municipality and the employees seem to be reliable so that it is quite difficult to notice that they are not really from the municipality.

At household, during the FS emptying process, the employees usually claim that there is a blockage in septic tank and ask the house owner to open the septic tank in order to check if there is something wrong and change some of the toilet equipments even it is not necessary. By doing what have mentioned, the service charge can be almost ten times higher than regular service charge from the municipality. The office of environment at Nonthaburi municipality has been trying to inform people in the area to notice that the FS emptying truck must be in white/green color with municipality's logo. And also request to see the submitted requesting form. Nonthaburi municipality, tried to get rid of the illegal FS emptying truck in the area and recently, none of them has been found.

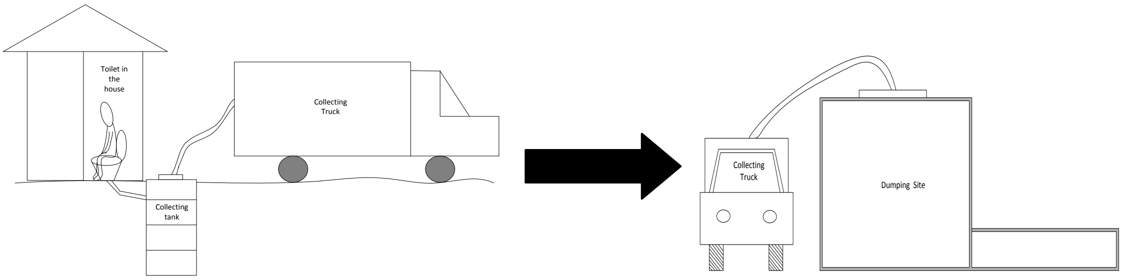


Figure 7: Sanitation System in Nonthaburi and Nakorn Lampang Municipalities

b) Nakorn Lampang:

In Nakorn Lampang municipality, the FS emptying service is responsible to a private sector under control of the municipality. The truck gives service from Monday to Sunday, starting from 8.30 am to 5 pm or until the work is finished for the day. Household owners request for the truck service directly, however it can be one day in advance or within the day of service. Usually, before the truck starts the service, all of the addresses of requested households will be analyzed so that the truck driver can design the most effective routing however, there can be some calls requesting for FS emptying service during the day. The FS emptying service charge costs 300 baht per cubic meter. For Nakorn Lampang municipality, although the truck under this study is the only private sector that is officially authorized to work in the area, illegal FS emptying trucks can be found, Figure 7 illustrates Sanitation System in Nonthaburi and Nakorn Lampang municipalities. It sometimes happens that one household call for service from two sectors that results in a small competition so that the legal truck must reach the house before the other one.

c) Suan Pheung Ratchaburi:

Suan Pheung Ratchaburi is surrounded by mountains and rivers. High land is the overall landscape of the area. And more importantly, hill tribe people are the major residents in the area. The rural area made households wide spread in different places. With mentioned characteristics of the area, most of households do not have any problems with filled septic tanks since the liquid part of FS is easily absorbed into soil layers. Or once the septic tank is filled, permanently closing it and having a new one are usually common solutions in the area. So that, there is no FS emptying truck service from municipality in this area. See Figure 8 for sanitation system in Suan Pheung Ratchaburi.

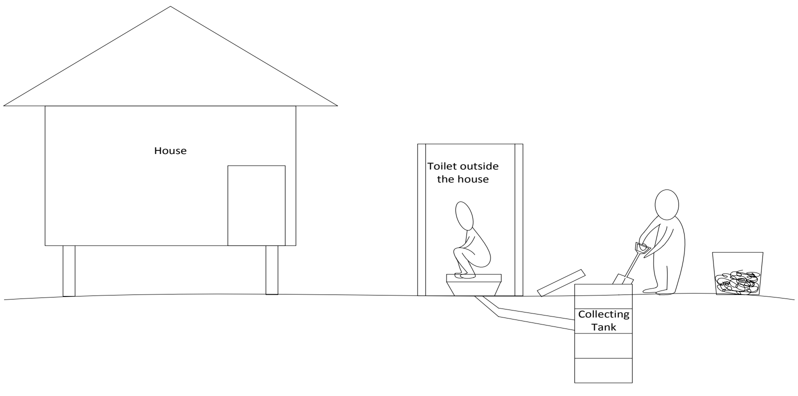


Figure 8: Sanitation System in Suan Pheung, Ratchaburi

3.1.1 Studied Household

Results from questionnaire surveys reveal that majority of households lack information concerning sanitation system expenses. Since most houses are rented or OSS were constructed at the same time as the house so that the current residents do not have information in hands. Studied households were all family residences, that resulted in the average number of toilet is about 1-2 rooms per household with mostly flushing system in Nonthaburi and Nakorn Lampang municipalities. Sanitation system of households in studied areas in Ratchaburi province was only found to be pouring system since it is affordable for residents. Three out of four of studied households constructed cesspool type of sanitation system. Moreover, all of households in Nonthaburi municipality were served by the municipality in terms of FS emptying service and information distribution while a private company is in charge of FS emptying service in Nakorn Lampamg municipality. For Suan Pheung, Ratchaburi, there is no FS emptying service since it is located in rural high areas. The septic tanks are usually closed and well covered once they are completely filled. Detailed information about questionnaires results can be found in Appendix A.

The characteristics of the results of questionnaires are as follows:

- The number of members is varied from 1-9 people per household but majority of household consist of 2-3 people. Moreover, all studied households have not more than 3 toilets in each one.

- Household interviewees usually lack of information concerning sanitation system expenses. Since the houses are rented or OSS were constructed at the same time as the house. Only a few households were able to estimate the cost of sanitation construction which was around 3,000 – 20,000 baht in the past 10 to12 years.

- Out of 47 studied households, 12 households installed both the pouring type of toilet, and the flushing type. 11 households installed only flushing type of toilets. It is noticeable that, households with flushing type of toilets have been newly constructed in the past 10 years.

- Number of septic tank varies from 1-2 in household that usually varies due to number of toilets. 31 households had only one septic tank when 21 households have one septic tank to store FS from more than one toilet in the house.

- For types of septic tank, 24 households constructed cesspool type of OSS with the year of construction of the house more than 30 years. Number of households that constructed two-cesspools in series and commercial tank are 10 and 3 respectively.

- Nonthaburi municipality usually experiences flooding, 5 out of 18 studied households have never experienced flooding when the rest of 13 have. The collected samples were usually come in the liquid form with the contamination of excess ground water.

- Since Nakorn Lampang municipality is located in a high mountain areas in the northern of Thailand so that the city has never experienced flooding. The collected samples were found to be a bit thicker than samples from Nonthaburi municipality.

- Household owners always request for FS emptying service from municipality when the toilets are blocked. However, the reasons of blockage of toilets can be because of debris or the toilet is full. FS emptying staff usually checks and gives some suggestions to household owners when debris is found to be cause of blocked toilets.

- Households in both Nonthaburi requested FS emptying services from municipality office and households in Nakorn Lampang municipality requested FS emptying service from a private company under the control of municipality. As a result, the service charge for FS emptying service varied from 250 – 500 baht depended on amount of FS which is found to be reasonable under the control of governmental offices. However, some of sampled households have unintentionally experienced illegal FS emptying service before and they had to pay for about 2,000-3,000 baht per time.

a) Nonthaburi

Based on questionnaires and interviews, it can be seen that the accumulation period of FS in households for one year distributed to 28 % so that it represents that majority of household in Nonthaburi request for FS emptying service once a year, see Figure 9 for pie charts. In general, volume of FS is about 0.6 to 1.0 m^3 which is the biggest share of 51%. From pie chart for volume of FS, 29% belongs to amount of FS that is less than 0.5 m^3. Number of toilet users in each household varies from 1 to 7 people depends on size of the family. 4 to 6 and 1-3 people represent that main characteristic in this aspect with quite similar percentage of 46% and 48% respectively.

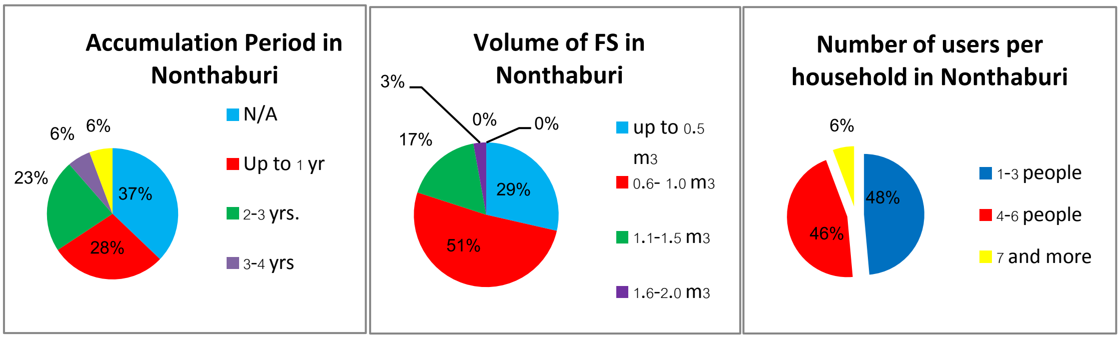


Figure 9: Accumulation Period, Volume and Number of Users in Nonthaburi Municipality

From the graph in Figure 10, it is obvious that accumulation period in Nonthaburi has wider variety than Nakorn Lampang, this could be because of the more convenient in requesting for FS emptying service that households can directly contact to the truck driver. When in Nonthaburi municipality, households need to officially submit the requesting forms so that was not temptying for households to request for the service. However, the accumulation period of one year gives the highest percentage in both Nonthaburi and Nakorn Lampang municipalities which means majority of households in densely urban and general urban request for the FS emptying service once a year.

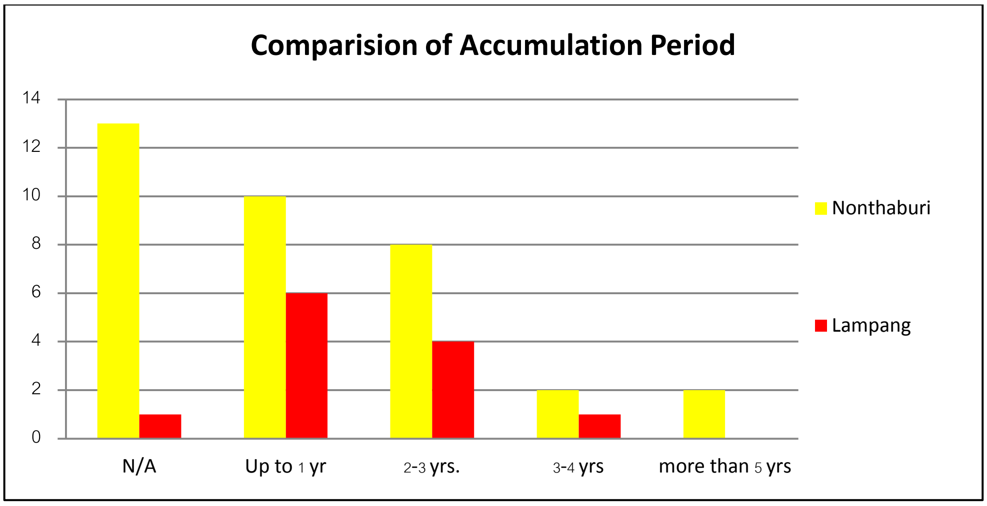


Figure 10: Comparison of Accumulation Period of FS in Nonthaburi and Nakorn Lampang Municipalities

b) Nakorn Lampang

From pie charts in Figure 11, accumulation period of one year has the biggest share for 50% so that it can be assumed that households in Nakorn Lampang usually request for FS emptying service once a year, where the second largest belongs to 2-3 years of accumulation period accounted for 34%. It is found that volume of FS in each household in Nakorn Lampang varies from 0.5 m^3 to 2.5 m^3 when 0.6-1.0 m^3, 1.1-1.5 m^3 and 1.6-2.0 m^3 have the same share of 25 %. When it comes to number of toilet users in each household, 1-3 people and 4-6 people distributed to about 50%.

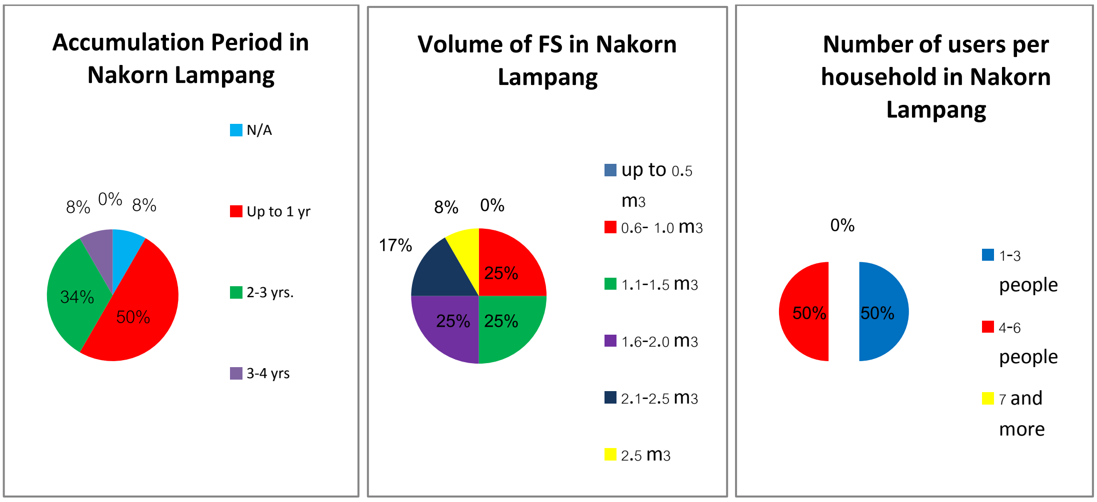


Figure11: Accumulation Period, Volume and Number of Users in Nakorn Lampang municipality

Figure 12 Shows that number of toilet users in households in Nonthaburi varies from 1 to more than 7 people when the largest number of toilet users in Nakorn Lampang is 6 people. It could be possible that because Nonthaburi is a big metropolitan city so that the lands and houses are in high prices, as a result, all family members prefer to live together in one house.

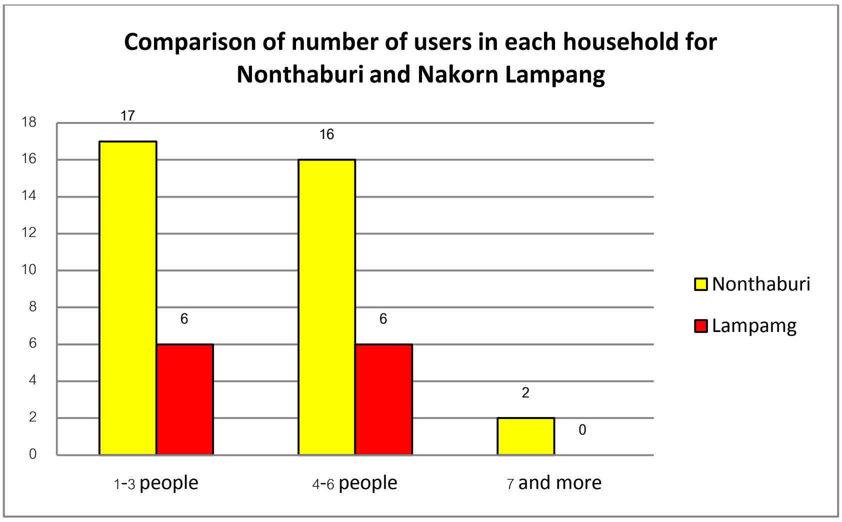


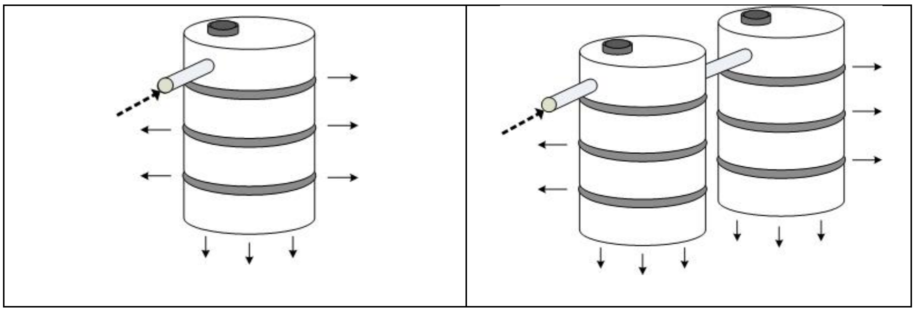
Figure 12: Comparison of Number of Users in Each Household in Nonthaburi and Nakorn Lampang Municipalities

c) Suan Pheung Ratchaburi

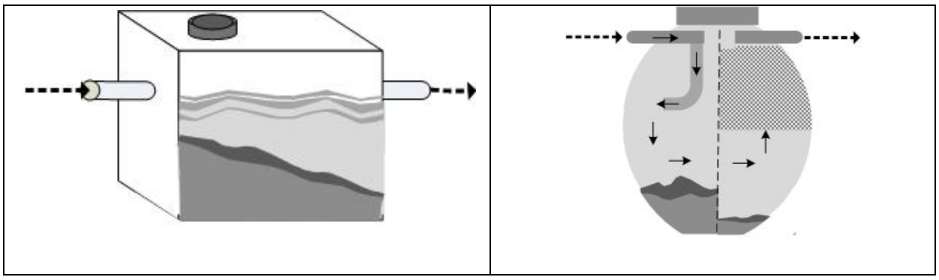
Samples collected from this study area focused only on analysis of Physical and Chemical properties. Most of households in the area constructed simple toilets made from woods or bamboo trees. Pouring toilet is the only type of toilet that was found in the area since the studied areas are located in rural area without water supply service. Moreover, the septic tanks were found to be cement wheels penetrated under the soil surface. Since households were randomly selected so that it did not always mean that selected households had problem with filled septic tanks.

3.1.2 Onsite Sanitation System of Studied Areas

From interviews and observations of requested household for FS emptying, mostly households in rural area use one cesspool system type of OSS. In contrary, newly developed area as housing estate or new house uses commercial septic tank. The typical OSS is mostly used by house in town or urban area which had the drainage system next to the houses. Due to the availability and competitive price of commercial system in market now, new houses are popular to use this type. However, it is found that in case there is no drainage system, one cesspool and two-cesspool system were still in uses. Types of OSS are shown in Figure 13. From the history, cesspool system made by brick wall and later adapted to the concrete rings type. Therefore, when it is properly sealed and added the outlet pipe for supernatant, this configuration is called septic tank. In Thailand, concrete ring are popular and available as people use for water well. In the same time, new modern of septic tank as commercial type is more popular use as it claims closing system, longer need for sludge emptying, environmental protection, light weight by Poly Ethylene (PE) made. Even it is more costly comparing to the traditional septic tank system however it is convenient to installation. Presently, it can be produced in country making lower cost than the previous time. The available products are seen in the market with the competition from many brands.



a) **One cesspool** b) **Two-cesspool in series**



(c) Septic tank **d) Commercial septic tank**

Figure 13: Onsite sanitation system in Thailand

3.1.3 Sample Identification

Samples were collected at studied household. In these fifteen days, four types of onsite sanitation systems are found as septic tank, one cesspool, two-cesspool in series and commercial tank. Effluent from OSS is connected to municipal drain system while effluent of cesspool is seeped into surrounding soil. There are some households that have no samples because the WC was clogging not the full of sludge. Details of samples are shown in Table 2.

Table 2: Sample Identification

Date of collection	Studied Household no.	Sample label	Type of sanitation	Remark
24 Aug 2011	1	AIT-1	Septic tank	Nonthaburi
	2	AIT-2	One cesspool	Nonthaburi
	3	-	One cesspool	No sample/ Nonthaburi
26 Aug 2011	1	AIT-3	One cesspool	Nonthaburi
	2	-	Septic tank	No sample/ Nonthaburi
	3	AIT-4	One cesspool	Nonthaburi
29 Aug 2011	1	-	-	No sample/ Nonthaburi
	2	-	-	No sample/ Nonthaburi
	3	AIT-5	One cesspool	Nonthaburi
	4	AIT-6	Septic Tank	Nonthaburi
30 Aug 2011	1	AIT-7	One cesspool	Nonthaburi

Date of collection	Studied Household no.	Sample label	Type of sanitation	Remark
	2	AIT-8	Two cesspools in series	Nonthaburi
	3	AIT-9	Two cesspools in series	Nonthaburi
	4	AIT-10	Commercial	Nonthaburi
	5	AIT-11	Two cesspools in series	Nonthaburi
	6	AIT-12	Two cesspools in series	Nonthaburi
1 Sep 2011	1	AIT-13	One cesspool	Nonthaburi
	2	AIT-14	One cesspool	Nonthaburi
	3	AIT-15	One cesspool	Nonthaburi
2 Sep 2011	1	AIT-16	Two cesspools in series	Nonthaburi
	2	AIT-17	Septic tank	Nonthaburi
	3	AIT-18	Commercial	Nonthaburi
19-9-2011	1	AIT-19	Commercial	Nonthaburi
	2	AIT-20	Septic Tank	Nonthaburi
	3	AIT-21	Septic Tank	Nonthaburi
20-9-2011	1	AIT-22	Two Cesspools in Series	Nonthaburi
	2	AIT-23	One Cesspool	Nonthaburi
21-9-2011	1	AIT-24	Commercial	Nonthaburi
	2	AIT-25	One Cesspool	Nonthaburi
	3	AIT-26	Two Cesspools in Series	Nonthaburi
	4	AIT-27	Septic Tank	
22-9-2011	1	AIT-28	Septic Tank	Nonthaburi
	2	AIT-29	One Cesspool	Nonthaburi
	3	AIT-30	One Cesspool	Nonthaburi
	4	AIT-31	One Cesspool	Nonthaburi
23-9-2011	1	AIT-32	Two Cesspools in Series	Nonthaburi
	2	AIT-33	Septic Tank	Nonthaburi
	3	AIT-34	Two Cesspools in Series	Nonthaburi
	4	AIT-35	Septic Tank	Nonthaburi
17-10-2011	1	AIT-36	One Cesspool	Lampang
	2	AIT-37	One Cesspool	Lampang
	3	AIT-38	Septic Tank	Lampang
	4	AIT-39	One Cesspool	Lampang
	5	AIT-40	Two Cesspools in Series	Lampang
	6	AIT-41	One Cesspool	Lampang
18-10-2011	1	AIT-42	Two Cesspools in Series	Lampang
	2	AIT-43	Two Cesspools in Series	Lampang

Date of collection	Studied Household no.	Sample label	Type of sanitation	Remark
	3	AIT-44	One Cesspool	Lampang
	4	AIT-45	One Cesspool	Lampang
	5	AIT-46	One Cesspool	Lampang
	6	AIT-47	One Cesspool	Lampang
31-10-2011	1	AIT-48	One Cesspool	Ratchaburi
	2	AIT-49	One Cesspool	Ratchaburi
	3	AIT-50	One Cesspool	Ratchaburi
	4	AIT-51	One Cesspool	Ratchaburi
	5	AIT-52	One Cesspool	Ratchaburi
1-11-2011	1	AIT-53	One Cesspool	Ratchaburi
	2	AIT-54	One Cesspool	Ratchaburi
	3	AIT-55	One Cesspool	Ratchaburi
	4	AIT-56	One Cesspool	Ratchaburi
	5	AIT-57	One Cesspool	Ratchaburi
23-12-2011	1	AIT-58	Commercial	Nakorn Ratchaseema
	2	AIT-59	Commercial	Nakorn Ratchaseema
	3	AIT-60	Commercial	Nakorn Ratchaseema
	4	AIT-61	Commercial	Nakorn Ratchaseema
	5	AIT-62	Commercial	Nakorn Ratchaseema
	6	AIT-63	Commercial	Nakorn Ratchaseema

In order to clarify the identification of samples according to its type of onsite sanitation system, samples were grouped for further analysis.

For all 63 collected samples, 35 samples were collected from Nonthaburi municipality, 12 samples were collected from Nakorn Lampang municipality and 10 samples were collected from two villages in Suan Pheung, Ratchaburi province as well as 6 more sampled from Nakhon Ratchasima. Table 3 shows that more than half of sampled households or about 35 sampled households constructed one cesspool type of sanitation system which is considered the largest portion compared to other types. In contrast, only 11 households constructed two cesspools in series type of sanitation system when septic tanks were found in 5 studied households for the whole survey.

More importantly, Nonthaburi municipality and Nakorn Lampang municipality are considered larger cities with more population and better economic flows compared to studied areas in Ratchaburi province so that the wide variety of sanitation systems in households could be observed. In contrast, two studied villages in Suan Pheung, Ratchaburi province are located in rural area with less population and worse living standards compared to those municipalities which results in only one cesspool type of sanitation system was found because of its low cost of instruction.

3.1.4 Sludge Accumulation

Sludge accumulation rates in cesspool and septic tanks are dependent on a variety of factors, the most important of which are the number of users, the degree to which the pit or tank is emptied, and the degree to which the pit is used for disposal of other household waste.

Figure 14 shows settled sludge depth, supernatant depth and free space of difference onsite treatment system; the observation demonstrated that commercial septic tank system achieved the highest settled sludge depth which about 50% of the tank-depth whereas septic tank, one cesspool and two cesspools in series could achieve about 36%, 32% and 31%, respectively. Therefore the average emptying period of commercial septic tank could reach longer period than the other system which was every 1.8 years while septic tank, one cesspool and two cesspools in series were about 1.63, 1.73 and 1.44 years, respectively. The results revealed that commercial septic tank system could achieve higher sludge settled level which longer maintenance period.

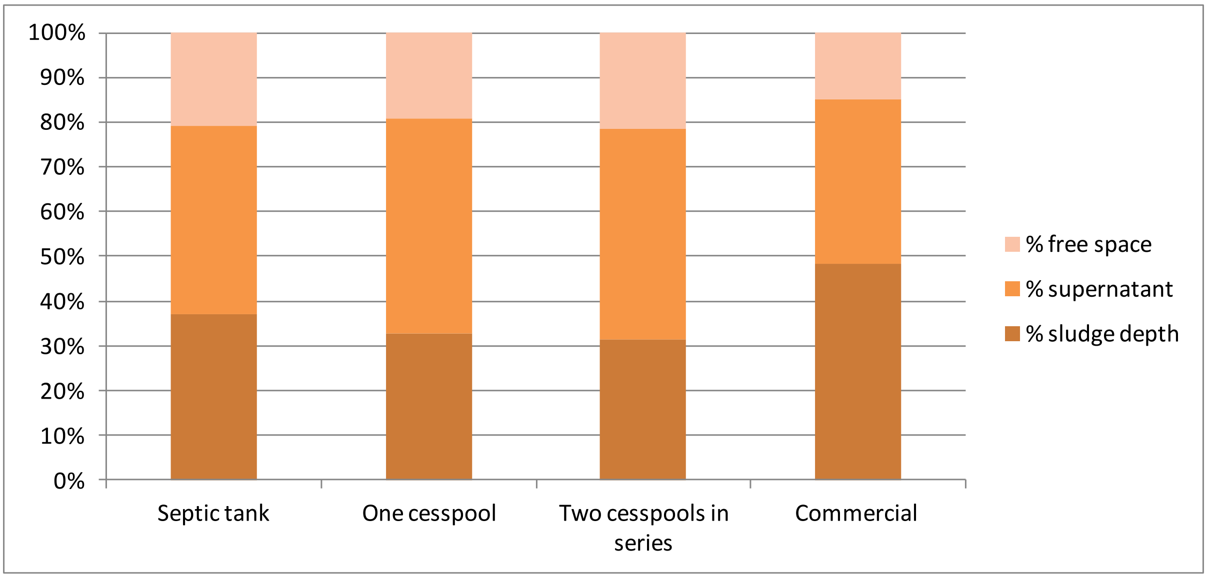


Figure 14: Proportion of sludge depth in onsite treatment system

Table 3 below shows range of sludge accumulation rate from difference onsite treatment systems. Therefore total volume of onsite systems in Thailand such as septic tank, one cesspool, two cesspools in series and commercial septic tank were range of 0.4 – 6.3 m^3/ unit which the average were 1.48, 1.42, 1.35 and 1.42 m^3, respectively. The variation of total volume probably was due to type of onsite treatment system and location of the community.

Considering sludge accumulation rate of onsite treatment system, demonstrated that one cesspool present the highest of average accumulation rate which about 300 L/cap/year while the other system shown about 135 – 180 L/cap/year. Although sludge accumulation rates in this study presented higher than data from literature which Still D.A. (2002) reported about 10 – 100 L/cap/year and Gray N.F. (1995) proposed of 90 L/cap/year. On the other hand sludge accumulation rate in term of the deposit per surface area in this study presented that slightly difference amount variant types of onsite treatment systems which one cesspool shown the highest about 80 cm/m^2/year while septic tank, two cesspools in series and commercial septic tank were about 70, 60 and 50 cm/m^2/year, respectively. The variation in sludge accumulation could possibly be related to differences in influent characteristics, environmental conditions (e.g., temperature), emptying period and/or water usage.

Table 3: Sludge Accumulation Rate from Difference onsite Treatment System

Sample	Volume tank (m^3)	Emptying Period (Years)	Sludge accumulation rate	
			L/cap/year	$cm/m^2/year$
Septic tank				
AIT-1	1.18	1	113.64	55.00
AIT-6	0.98	1	75.00	40.00
AIT-17	0.78	1	90.74	90.00
AIT-20	6.26	1	284.38	2.64
AIT-21	0.81	1	20.47	33.93
AIT-27	0.24	1	52.94	191.25
AIT-28	0.80	2	18.37	39.38
AIT-33	1.38	7	35.71	4.57
AIT-35	1.20	1	300.00	60.00
AIT-38	1.15	0.25	346.15	156.00
Average	**1.48**	**1.63**	**133.74**	**67.28**
One cesspool				
AIT-2	1.25	5	25.00	4.80
AIT-3	1.30	6	8.33	5.00
AIT-5	0.55	0.33	482.09	462.00
AIT-4	0.67	1	37.04	36.00
AIT-7	0.83	1	250.00	36.00
AIT-13	0.60	3	25.00	20.00
AIT-14	0.40	2	18.00	56.25
AIT-15	1.29	0.33	231.43	70.00
AIT-23	1.30	1	60.00	30.00
AIT-25	1.76	0.50	175.56	22.78
AIT-29	0.24	1	33.33	270.00
AIT-30	0.86	2	23.33	19.29
AIT-31	0.82	2	21.05	15.83
AIT-36	1.69	2	37.50	21.33
AIT-37	2.75	1	416.67	20.00
AIT-39	2.22	0.08	1,600.00	162.00
AIT-41	2.75	5	68.75	3.64
AIT-44	4.29	2	107.14	2.92
AIT-45	1.35	0.25	625.00	115.20
AIT-46	1.11	0.25	1,333.33	216.00
AIT-47	1.83	0.50	666.67	72.00
Average	**1.42**	**1.73**	**297.39**	**79.10**
Two cesspool				
AIT-8	0.39	1	136.11	90.00
AIT-9	0.38	1	21.88	93.33
AIT-11	0.51	0.25	109.09	330.00
AIT-12	2.19	0.75	67.50	11.85

Sample	Volume tank (m^3)	Emptying Period (Years)	Sludge accumulation rate	
			L/cap/year	L/cap/year
AIT-16	0.56	5	13.89	18.00
AIT-22	1.85	0.33	969.23	56.88
AIT-26	0.75	1	75.00	40.00
AIT-32	1.14	1	47.62	26.25
AIT-34	1.20	3	83.33	16.67
AIT-40	1.67	1	375.00	27.00
AIT-42	2.75	2	69.44	15.00
Average	**1.35**	**1.44**	**178.92**	**61.29**
Commercial				
AIT-10	0.98	3	43.59	30.59
AIT-18	1.56	1	156.00	72.12
AIT-19	0.87	1	134.62	121.33
AIT-24	1.77	1	82.73	29.62
AIT-58	1.50	2	125.00	25.00
AIT-59	1.50	2	200.00	40.00
AIT-60	1.50	2	300.00	60.00
AIT-61	1.50	2	250.00	50.00
AIT-62	1.50	2	300.00	60.00
AIT-63	1.50	2	200.00	40.00
Average	**1.42**	**1.80**	**179.19**	**52.87**

Furthermore in this study was investigating sludge accumulation rate of one cesspool system in both units (L/cap/year and cm/m^2/year) according to emptying period. As shows in Figure 15 demonstrated during emptying period of 0.08 (1 month) to 1 year, sludge accumulation rate was suddenly decreased according to emptying period whereas between 1 to 6 years sludge accumulation period was slightly decreased. The higher value of sludge accumulation rate during 0.08 (1 month) to 1 year might be because of sludge input is not balancing yet with sludge degradation and output. In addition the reason of the slightly sludge accumulation rate decreasing during 1 – 6 years emptying period might possible due to the equivalence between inlet, degradation rate, outlet and holding capacity of each onsite system.

Therefore the key conclusion to be drawn from these studies is that there is no standard method to measuring sludge accumulation and no set of standard parameters to measuring system health or its ability to effectively degrade the accumulated sludge.

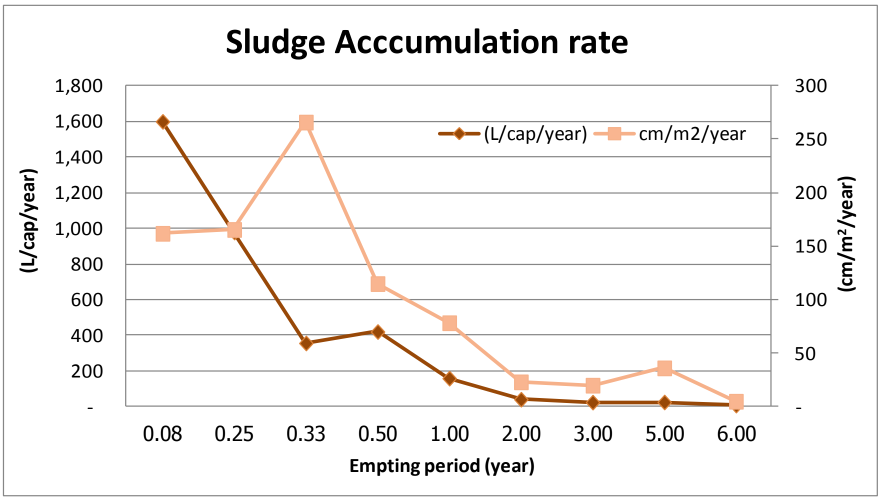


Figure 15: Sludge accumulation rate according to emptying period

3.2 Rheological Prosperities

3.2.1 Compaction and Size Distribution

For compaction and size distribution tests were conducted at GTE laboratory, school of Engineering, Asian Institute of Technology (AIT). Samples were collected from Nonthaburi, Nakorn Lampang, Ratchaburi and Nakhon Ratchasima which represent samples from dense urban area, general urban area and rural area, respectively. Results of compaction are expressed in Table 4.

Characteristics of dried FS in terms of maximum dry density and water content at the maximum density were ranged between 0.1957 – 0.2530 g/cm^3 and 18.69 – 35.20 %, respectively. Therefore Nonthaburi 1 and Nonthaburi 2 represent sludge from single household and mixed sludge from Nonthaburi samples, respectively. The results demonstrated that the maximum dry density from different household in Nonthaburi samples were not significantly different. Moreover the maximum dry density from Nakorn Lampang and Ratchaburi samples were present slightly higher than Nonthaburi which about 0.2518 and 0.2530 g/cm^3, respectively. In addition samples taken from Nakhon Ratchasima gave the maximum dried density of 0.2544 g/cm^3 with the relevant water content was about 54.15 %.

They are quite different when comparing with clay in which the maximum dry density and water content at maximum density were between 1.4-1.7 g/cm^3 and 20-30%, respectively. In addition, landfill final cover soils are highly compacted in order to prevent precipitation infiltration. Weeks et al. (1992) reported that bulk density (ρb) has a range from 1.57 to 1.74 (g/cm^3) for differently-textured landfill cover soils. Moreover Wickramarachchi et al. (2010) showed that the in situ bulk density reached 1.90 (g/cm^3). This result can indicate that the dried FS has the less capacity for compaction material.

Table 4: Results of Compaction Analysis

Sample	Average wet density (g/cm^3)	Average dry density (g/cm^3)	Average water content (%)	Maximum dry density (g/cm^3)	Water content at maximum dry density (%)
Nonthaburi 1	0.6285	0.1908	36.62	0.1957	35.20
Nonthaburi 2 (Mixed)	2.7606	0.2496	24.86	0.1957	29.73
Lampang	2.6090	0.2483	18.69	0.2518	54.3156
Ratchaburi	3.0605	0.2521	20.29	0.2530	71.53
Nakhon Ratchasima	3.4164	0.2549	48.64	0.2544	54.15

Remark: Detail of results is shown in appendix B.

Size distribution of FS (Table 5) was tested by sieve analysis from ¾” opening container to Pan Container (less than 0.07 mm). By weighting, particle size from septic tank, one cesspool, two cesspools in series and commercial systems about 60%, 55%, 55% and 50% presented bigger than 1.19 mm, respectively. Therefore mostly portions were between 1.19 – 2.36 mm which was considered to be 20 – 35 %.

Sample AIT-7 with one cesspool type had the smallest particle sizes distribution which the size varies from < 0.07 – 0.59 mm. The biggest distribution of particle size belongs to sample AIT-18 with commercial type.

Table 5: Results of Percent Size Distribution

Sample	¾” (19.05 mm)	½” (12.7 mm)	3/8” (9.53 mm)	#4 (4.76 mm)	#8 (2.36 mm)	#16 (1.19 mm)	#30 (0.59 mm)	#50 (0.30 mm)	#100 (0.15 mm)	#20 (0.07 mm)	Pan (<0.07 mm)
Septic tank											
AIT-1	0.00	1.21	3.87	19.41	15.32	13.13	12.81	16.96	11.94	3.48	1.87
AIT-6	0.00	0.00	0.00	21.22	46.05	17.60	9.05	3.29	1.64	0.82	0.33
AIT-38	0.00	0.00	0.00	0.14	3.93	33.15	10.75	26.75	9.14	10.11	6.04
One cesspool											
AIT-2	0.00	0.00	0.00	0.00	0.45	22.65	34.98	22.87	9.87	6.50	2.69
AIT-3	0.00	0.00	2.64	10.22	16.95	17.54	14.99	17.60	15.27	3.53	1.26
AIT-4	0.00	0.00	0.00	10.75	22.92	21.55	16.83	13.08	7.53	4.48	2.88
AIT-5	0.00	0.00	14.30	11.80	27.30	19.90	13.00	1.10	6.20	4.30	2.10
AIT-7	0.00	0.00	0.00	21.22	46.05	17.60	9.05	3.29	1.64	0.82	0.33
AIT-13	0.00	0.00	0.00	0.00	0.00	0.00	27.57	41.62	18.92	8.11	3.78
AIT-14	0.00	0.00	0.00	0.00	4.63	56.86	35.37	1.65	0.50	0.66	0.33
AIT-36	0.00	0.00	0.00	0.00	0.00	28.13	49.48	13.54	4.17	3.13	1.56
AIT-37	0.00	0.00	0.18	3.04	15.89	42.28	7.74	16.41	6.60	5.61	2.25
AIT-39	0.00	0.00	0.00	2.17	24.26	45.23	6.32	10.08	5.28	4.52	2.14
AIT-41	0.00	0.00	0.00	5.29	26.92	36.11	6.38	12.94	4.45	5.00	2.91
AIT-49	0.00	0.00	0.47	5.51	19.86	39.42	6.87	15.58	5.02	4.75	2.52
AIT-50	0.00	0.00	0.00	5.98	22.38	40.24	7.80	12.06	4.17	3.18	4.20
AIT-51	0.00	0.00	0.16	3.12	15.36	39.21	7.95	17.85	8.90	4.49	2.87

Sample	¾” (19.05 mm)	½” (12.7 mm)	3/8” (9.53 mm)	#4 (4.76 mm)	#8 (2.36 mm)	#16 (1.19 mm)	#30 (0.59 mm)	#50 (0.30 mm)	#100 (0.15 mm)	#20 (0.07 mm)	Pan (<0.07 mm)
Two cesspools in series											
AIT-8	0.00	0.00	1.41	15.69	6.91	16.36	13.68	26.00	15.59	2.85	1.31
AIT-9	0.00	0.00	0.00	0.00	0.00	42.11	31.17	12.04	8.40	4.55	1.72
AIT-16	0.00	0.00	0.00	5.04	22.36	33.33	18.73	10.98	5.24	3.12	1.21
AIT-40	0.00	0.00	0.09	4.68	15.85	41.45	8.44	17.26	5.73	4.91	1.59
AIT-41	0.00	0.00	0.47	5.51	19.86	39.42	6.87	15.58	5.02	4.75	2.52
AIT-42	0.00	0.00	0.08	1.77	17.61	29.46	8.46	20.60	8.13	8.05	5.81
AIT-43	0.00	0.00	0.00	2.78	14.90	42.31	6.70	17.42	6.28	5.60	4.00
Commercial septic tank											
AIT-10	0.00	0.00	0.00	12.48	46.88	24.62	7.08	4.38	2.19	1.69	0.67
AIT-18	0.00	2.56	4.36	10.54	1.36	36.24	20.58	11.32	6.00	4.06	2.98
AIT-58	0.00	0.00	0.00	2.49	12.44	33.39	8.76	19.86	8.91	8.50	5.65
AIT-59	0.00	0.00	2.64	1.52	9.91	28.74	9.81	25.56	9.12	9.04	3.65
AIT-60	0.00	0.00	2.64	2.93	14.85	30.34	6.48	17.09	10.90	8.93	5.85
AIT-61	0.00	0.00	0.00	0.94	8.27	15.47	8.86	16.92	18.18	21.36	10.00
AIT-62	0.00	0.00	0.00	1.89	7.30	20.55	9.50	23.08	15.70	12.91	9.06
AIT-63	0.00	0.00	0.00	2.19	14.96	33.06	7.77	20.49	9.45	8.08	4.01

Remark: Detail of results is shown in appendix B.

3.2.2 Viscosity and Density

Sample was sent to Powder Characterization Laboratory under Materials Characterization Research Unit, MTEC. In this report 40 samples were analyzed and results of analysis are as follows:

Ideally, viscosity values are acceptable when the % torque value is near 100%. It was found that at the %DS of less than 5%, the % torque is very low and less than 10% torque (the limitation). Another difficulty in measuring viscosity is due to the heterogeneous between solid mixtures and water. The measuring is captured during solid still not yet settled down after centrifuging. In order to gave reasonable results, concentration of sludge were then made to thickener by approximately of 30% DS. Based on this condition, % torque of samples were mostly more than 10% at selected speed of 200 rpm, and shear rate of 186 1/sec.

AIT-50, AIT-37, AIT-40, AIT-48 and AIT-49 were the highest than the rest of samples, which are 36.5, 35.74, 35.70, 35.65 and 35.2 respectively. AIT-7 with one cesspool type gave about 80.84 cP for viscosity value and 150.30 D/cm^2 for shear stress which is considered the highest among rest of samples. Shear rate for all samples is 186.00 l/sec.

Comparing with the other study, viscosity values of this study was higher than Hung, C. and Li, K. C.(2003) study which reported water sludge viscosity about 1.63 – 2.81 cp. Therefore ZPlus Company (2008) reported that oil viscosity is about 110 cp which slightly higher than sludge in this study. For further pump selection, viscosity of diaphragm pump, rotary pump, screw pump and mono pump are raged between 2,500 – 20,000 cp, 1 – 100,000 cp, 1,000 – 4,000 cp and up to 1,000,000 cp, respectively.

Table 6: Results of Viscosity

Sample	Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm^2)	Shear Rate (1/sec)
Septic tank					
AIT-1	200	10.1	25.3	47.00	186.00
AIT-6	200	2.50	5.54	7.90	186.00
AIT-17	200	10.2	24.56	45.60	186.00
AIT-20	200	11.0	28.50	47.25	186.00
AIT-21	200	30.50	75.4	136.80	186.00
AIT-35	200	12.75	30.25	45.00	186.00
AIT-38	200	8.0	12.8	20.0	186.00
One cesspool					
AIT-2	200	31.14	79.36	147.6	186.00
AIT-3	200	1.60	4.00	7.44	186.00
AIT-4	200	29.34	73.36	136.42	186.00
AIT-5	200	4.04	10.10	18.78	186.00
AIT-7	200	32.23	80.84	150.30	186.00
AIT-13	200	28.0	65.60	120.5	186.00
AIT-14	200	5.0	10.26	15.7	186.00
AIT-15	200	8.0	25.0	45.50	186.00
AIT-23	200	15.5	40.2	50.25	186.00
AIT-25	200	30.1	78.80	141.0	186.00
AIT-31	200	2.3	5.0	8.9	186.00
AIT-36	200	30.25	75.0	142.0	186.00
AIT-37	200	35.75	80.80	150.50	186.00
AIT-39	200	32.40	81.25	148.54	186.00
AIT-41	200	28.9	78.25	136.50	186.00
AIT-48	200	35.65	89.0	156.0	186.00
AIT-49	200	35.2	88.5	155.0	186.00
AIT-50	200	36.5	89.2	160.5	186.00
Two cesspools in series					
AIT-8	200	33.62	84.08	156.32	186.00
AIT-9	200	27.46	68.66	127.70	186.00
AIT-11	200	32.14	80.38	149.44	186.00
AIT-12	200	20.1	56.4	95.2	186.00
AIT-16	200	25.35	70.1	125.3	186.00
AIT-22	200	29.5	89.5	136.8	186.00
AIT-26	200	31.2	80.5	145.5	186.00
AIT-32	200	33.8	85.6	150.1	186.00
AIT-34	200	32.5	88.6	156.8	186.00
AIT-40	200	35.7	88.90	156.5	186.00
Commercial septic tank					
AIT-10	200	31.02	77.56	144.24	186.00
AIT-19	200	34.8	89.5	150.2	186.0
AIT-58	200	25.9	80.0	136.7	186.0
AIT-59	200	28.5	82.6	135.9	186.0
AIT-60	200	30.30	85.0	138.4	186.0
AIT-61	200	28.65	82.8	140.0	186.0
AIT-62	200	29.5	78.65	136.8	186.0
AIT-63	200	27.5	80.0	135.5	186.0

From Table 7, the density for samples from one-cesspool type of OSS was found to be between 1.09 – 1.15 g/cm^3. Sample AIT-11 with two cesspools in series type gave the highest value of density for 1.16 g/cm^3.

Table 7: Results of Density

Sample	Volume (cm^3)	Apparent Density (g/cm^3)
Septic tank		
AIT-1	67.86	1.13
AIT-6	50.20	1.11
AIT-17	45.45	1.11
AIT-20	48.9	1.09
AIT-21	47.2	1.12
AIT-35	50.5	1.11
AIT-38	49.1	1.09
One cesspool		
AIT-2	42.60	1.12
AIT-3	29.81	1.14
AIT-4	41.25	1.11
AIT-5	43.24	1.15
AIT-6	49.41	1.11
AIT-7	46.59	1.09
AIT-13	45.35	1.12
AIT-14	50.65	1.11
AIT-15	50.25	1.13
AIT-23	50.38	1.12
AIT-25	45.80	1.11
AIT-31	44.5	1.15
AIT-36	47.65	1.11
AIT-37	39.5	1.12
AIT-39	39.4	1.12
AIT-41	45.2	1.11
AIT-48	45.78	1.14
AIT-49	47.6	1.12
AIT-50	44.2	1.11
Two cesspools in series		
AIT-8	47.09	1.12
AIT-9	44.80	1.10
AIT-11	14.07	1.16
AIT-12	20.45	1.13
AIT-16	30.65	1.12
AIT-22	40.24	1.12
AIT-26	40.58	1.11
AIT-32	45.65	1.14
AIT-34	38.50	1.15
AIT-40	28.60	1.11
Commercial septic tank		
AIT-10	47.91	1.11
AIT-19	30.59	1.11
AIT-58	45.50	1.09

Sample	Volume (cm^3)	Apparent Density (g/cm^3)
AIT-59	40.40	1.08
AIT-60	45.0	1.11
AIT-61	36.80	1.10
AIT-62	60.28	1.09
AIT-63	50.30	1.11

3.3 Physical and Chemical Properties

Analyses of Chemical properties were conducted in EEM laboratory, AIT. Results from fluidized sludge and bottom sludge of different on-site sanitation systems are shown in Table 8 and 9.

Physical and Chemical properties of fluidized and bottom sludge

In this study focused on the on-site sanitation systems treating black water which collected from 4 types of on-site sanitation system such as septic tank, one cesspool, two cesspools in series and commercial treatment systems.

Table 8: Chemical Properties of Fluidized Sludge from Different Onsite Sanitation System

Type of onsite	Samples	Parameter													
		COD (mg/l)		Total Solid (mg/l)		Conductivity (mS/cm)		% Water Content		%DS		Volatile Solid (mg/l)		Fixed Solid (mg/l)	
		Fluidized sludge	Bottom Sludge	Fluidized sludge	Bottom Sludge	Fluidized sludge	Bottom Sludge	Fluidized sludge	Bottom Sludge	Fluidized sludge	Bottom Sludge	Fluidized sludge	Bottom Sludge	Fluidized sludge	Bottom Sludge
Septic tank	AIT-1	24816.00	33088.00	3668.00	37616.00	1.23	2.40	99.63	96.22	0.37	3.78	2364.00	28682.00	1304.00	8934.00
	AIT-6	3288.00	16272.00	3288.00	8244.00	0.02	0.13	99.33	98.33	0.67	1.67	2172.00	5854.00	1116.00	2390.00
	AIT-17	16272.00	32088.00	14820.00	27576.00	1.43	1.23	98.49	97.24	1.51	2.76	12340.00	23072.00	2480.00	4504.00
	AIT-20	24816.00	33088.00	10153.33	55833.33	3.47	0.39	98.77	93.23	1.23	6.77	7316.67	33333.33	2836.67	22500.00
	AIT-21	33088.00	41360.00	80010.00	123105.00	0.32	0.09	92.04	89.85	7.96	10.15	62140.00	90975.00	17870.00	32130.00
	AIT-27	30976.00	30976.00	20868.00	40396.00	1.46	1.82	97.93	95.87	2.07	4.13	12244.00	24372.00	8624.00	16024.00
	AIT-28	-	-	828.00	2160.00	1.69	3.31	99.92	99.78	0.08	0.22	548.00	1340.00	280.00	820.00
	AIT-33	30202.00	61178.00	26556.00	72732.00	3.94	2.53	97.30	92.77	2.70	7.23	11524.00	30636.00	15032.00	42096.00
	AIT-35	14714.00	30202.00	8864.00	18824.00	2.25	1.86	99.10	98.09	0.90	1.91	7684.00	16464.00	1180.00	2360.00
	AIT-38	5712.00	11424.00	5200.00	11632.00	0.21	0.63	99.67	98.74	0.33	1.26	4400.00	5600.00	800.00	6032.00
	Average	**20431.56**	**32186.22**	**17425.53**	**39811.83**	**1.60**	**1.44**	**98.22**	**96.01**	**1.78**	**3.99**	**12273.27**	**26032.83**	**5152.27**	**13779.00**
	Std	**10987.71**	**14212.90**	**23473.59**	**36639.14**	**1.32**	**1.12**	**2.32**	**3.15**	**2.32**	**3.15**	**18051.12**	**25465.66**	**6441.76**	**14209.78**
One cesspool	AIT-2	16544.00	24816.00	4576.00	16582.00	2.50	0.08	99.54	98.33	0.46	1.67	3522.00	11534.00	1054.00	5048.00
	AIT-3	8272.00	16544.00	8666.00	40624.00	1.50	2.19	99.12	95.89	0.88	4.11	6506.00	29730.00	2160.00	10894.00
	AIT-4	8272.00	16544.00	9796.00	17314.00	0.14	5.20	99.01	98.98	0.99	1.75	6684.00	12426.00	3112.00	4888.00
	AIT-5	16272.00	40680.00	16472.00	46404.00	0.14	0.17	96.70	90.62	3.30	9.38	7800.00	19006.00	8672.00	27398.00
	AIT-7	13760.00	31488.00	13760.00	26996.00	4.15	4.56	98.61	97.30	1.39	2.70	7404.00	22252.00	6356.00	4744.00
	AIT-13	8136.00	16372.00	15112.00	34484.00	0.17	0.84	98.47	96.49	1.53	3.51	12752.00	28796.00	2360.00	5688.00
	AIT-14	16372.00	32544.00	4168.00	4504.00	1.05	0.84	99.58	99.54	0.42	0.46	3520.00	3508.00	648.00	996.00
	AIT-15	8136.00	16372.00	1384.00	4600.00	3.06	3.80	99.86	99.83	0.14	0.17	1068.00	1808.00	316.00	148.00
	AIT-23	8136.00	16272.00	11000.00	29430.00	1.60	1.10	-	-	-	-	-	-	-	-
	AIT-25	23232.00	38720.00	25016.00	50492.00	2.86	3.96	97.47	93.97	2.53	6.03	18388.00	32288.00	6628.00	18204.00
	AIT-29	4000.00	8000.00	4708.00	18784.00	1.49	1.97	99.52	98.09	0.48	1.91	3392.00	14664.00	1316.00	4120.00
	AIT-30	8000.00	16000.00	12028.00	33792.00	3.48	3.65	98.78	96.60	1.22	3.40	9956.00	28144.00	2072.00	5648.00

One cesspool (cont'd)	AIT-31	8000.00	16000.00	5776.00	6952.00	2.02	2.03	99.41	99.29	0.59	0.71	2588.00	2652.00	3188.00	4300.00
	AIT-36	-	17136.00	-	40368.00	-	6.72	-	95.76	-	4.24	-	23600.00	-	16768.00
	AIT-37	28560.00	39984.00	8000.00	75868.00	1.53	6.27	99.18	92.21	0.82	7.79	7600.00	40400.00	400.00	35470.00
	AIT-39	22848.00	34272.00	12000.00	71200.00	2.11	1.46	98.78	92.45	1.22	7.55	10000.00	42000.00	2000.00	29200.00
	AIT-41	5712.00	17136.00	8400.00	39348.00	0.60	1.20	99.15	96.05	0.85	3.95	6800.00	28000.00	1600.00	11350.00
	AIT-44	-	9160.00	-	9676.00	-	2.02	-	98.96	-	1.04	-	5276.00	-	4400.00
	AIT-45	-	18320.00	-	56044.00	-	1.15	-	94.01	-	5.99	-	45108.00	-	10936.00
	AIT-46	-	16488.00	-	27284.00	-	5.04	-	97.02	-	2.98	-	22336.00	-	4948.00
	AIT-47	-	18320.00	-	47972.00	-	4.43	-	94.24	-	5.76	-	34620.00	-	12452.00
	AIT-48	-	45696.00	-	156800.00	-	0.09	-	82.26	-	17.74	-	51600.00	-	105200
	AIT-49	-	11424.00	-	96944.00	-	1.74	-	96.57	-	3.43	-	43600.00	-	53340.00
	AIT-50	-	51408.00	-	188480.00	-	0.50	-	72.96	-	27.04	-	78800.00	-	109680.00
	AIT-51	-	8568.00	-	104800.00	-	0.27	-	99.37	-	0.63	-	67600.00	-	37200.00
	AIT-52	-	5712.00	-	14480.00	-	0.66	-	99.52	-	0.48	-	43600.00	-	53344.00
	AIT-53	-	45696.00	-	136896.00	-	0.50	-	89.53	-	10.47	-	90000.00	-	46896.00
	AIT-54	-	51408.00	-	101600.00	-	6.76	-	91.64	-	8.36	-	64400.00	-	37200.00
	AIT-55	-	69544.00	-	96944.00	-	6.46	-	90.13	-	9.87	-	43600.00	-	53344.00
	AIT-56	-	125664.00	-	188480.00	-	0.27	-	85.22	-	14.78	-	78800.00	-	109680.00
	AIT-57	-	34272.00	-	104800.00	-	0.06	-	88.23	-	11.77	-	67600.00	-	37200.00
	Average	**12765.75**	**29372.90**	**10053.88**	**60933.61**	**1.78**	**2.45**	**98.88**	**94.04**	**1.12**	**5.99**	**7198.67**	**35924.93**	**2792.13**	**28689.47**
	std	**7201.50**	**23725.75**	**5822.94**	**52329.28**	**1.22**	**2.24**	**0.84**	**5.98**	**0.84**	**5.96**	**4418.66**	**24125.71**	**2493.58**	**31912.34**
Two cesspool in series	AIT-8	4723.00	62975.00	1512.00	12276.00	0.99	1.28	39.45	29.14	60.55	70.86	908.00	6200.00	604.00	6076.00
	AIT-9	15744.00	23616.00	2484.00	9056.00	3.35	6.56	29.34	39.85	70.66	60.15	1784.00	6880.00	696.00	2176.00
	AIT-11	31488.00	62976.00	19000.00	42396.00	4.44	2.06	39.25	23.83	60.75	76.17	9484.00	28592.00	9516.00	13804.00
	AIT-12	7872.00	15744.00	5512.00	8424.00	1.85	1.78	35.76	29.27	64.24	70.73	3352.00	5828.00	2160.00	2596.00
	AIT-16	8136.00	16272.00	6560.00	15256.00	3.04	3.06	35.71	39.46	64.29	60.54	5212.00	12972.00	1348.00	2284.00
	AIT-22	8136.00	16136.00	10623.33	31106.67	2.10	2.00	25.87	23.52	74.13	71.37	6636.67	19466.67	3986.67	9528.00
	AIT-26	30976.00	38720.00	8180.00	33940.00	2.00	2.17	30.09	26.06	69.91	63.72	5032.00	17232.00	3148.00	15752.00
	AIT-32	30202.00	53434.00	22416.00	40808.00	2.01	0.30	28.45	36.28	71.55	76.48	17868.00	31280.00	4548.00	16708.00
	AIT-34	22458.00	45690.00	25964.00	44320.00	2.84	3.57	25.50	28.63	74.50	73.94	10588.00	28568.00	15376.00	11640.00
	AIT-40	11424.00	28560.00	7600.00	52060.00	1.85	5.04	26.94	25.02	73.06	74.98	11200.00	388000.00	3600.00	13260.00
	AIT-42	-	54960.00	-	30196.00	-	1.77	-	96.96	-	3.04	-	20128.00	-	10068.00
	AIT-43	-	65956.00	-	94032.00	-	1.76	-	90.73	-	9.27	-	57172.00	-	36860.00
	Average	**17115.90**	**40419.92**	**10985.13**	**34489.22**	**2.45**	**2.61**	**98.87**	**96.36**	**1.13**	**3.64**	**7206.47**	**22759.89**	**4498.27**	**11729.33**
	std	**10713.62**	**19738.76**	**8500.16**	**23880.24**	**0.98**	**1.72**	**0.86**	**2.42**	**0.86**	**2.42**	**5155.37**	**15192.82**	**4611.72**	**9451.50**

Commercial septic tank	AIT-10	23616.00	31488.00	23868.00	32432.00	1.33	1.44	97.62	96.75	2.38	3.26	11900.00	20892.00	11968.00	11540.00
	AIT-19	8272.00	49632.00	8666.67	58043.00	2.98	0.21	98.94	93.06	1.06	6.94	5373.33	34110.00	3293.33	23933.33
	AIT-58	7328.00	31144.00	263268.00	275136.00	1.81	1.93	74.38	72.34	25.62	27.66	7660.00	24364.00	270928.00	250772.00
	AIT-59	12824.00	29312.00	234248.00	245716.00	1.23	1.48	73.56	72.61	26.44	27.39	9480.00	16884.00	224768.00	228832.00
	AIT-60	51296.00	62288.00	288836.00	308048.00	1.49	1.45	71.02	69.21	28.98	30.79	36412.00	42912.00	252424.00	265136.00
	AIT-61	3664.00	16488.00	234484.00	279556.00	1.40	1.71	76.64	71.79	23.36	28.21	4724.00	18848.00	229760.00	260708.00
	AIT-62	5496.00	23816.00	240148.00	259384.00	1.74	2.65	74.99	72.39	25.01	27.61	6028.00	14312.00	234120.00	245072.00
	AIT-63	7328.00	67784.00	226276.00	279204.00	1.13	1.46	77.10	69.10	22.90	30.90	3072.00	29640.00	223204.00	249564.00
	Average	**14978.00**	**38994.00**	**189974.33**	**217189.88**	**1.64**	**1.54**	**80.53**	**77.16**	**19.47**	**22.85**	**10581.17**	**25245.25**	**181308.17**	**191944.67**
	Std	**15938.19**	**18644.18**	**109143.32**	**107839.51**	**0.59**	**0.68**	**11.12**	**11.09**	**11.12**	**11.08**	**10805.18**	**9710.89**	**108387.69**	**108115.58**

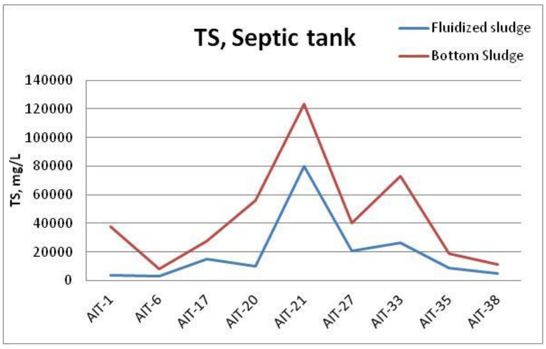
Table 9: Total Nitrogen and Total Carbon from Different Onsite Sanitation System

Type of onsite	Samples	% TN	%TC
Septic tank			
	AIT-1	1.17	30.60
	AIT-6	4.12	39.46
	AIT-17	3.09	35.32
	AIT-27	2.65	27.14
	AIT-35	2.59	29.93
	Average	**2.72**	**32.49**
Two cesspools in series			
	AIT-8	4.44	44.87
	AIT-9	6.94	46.19
	AIT-11	4.07	43.46
	AIT-12	4.64	47.32
	AIT-16	3.06	36.21
	AIT-26	3.63	34.29
	AIT-34	3.07	21.54
	AIT-42	3.8	32.1
	AIT-43	2.62	32.17
	Average	**4.03**	**37.57**
Commercial septic tank			
	AIT-10	3.54	39.42
	AIT-18	2.53	39.16
	AIT-58	3.32	41.02
	AIT-59	1.99	24.84
	AIT-60	2.34	31.91
	AIT-61	1.66	24.01
	AIT-62	1.03	14.36
	AIT-63	2.10	31.93
	Average	**2.31**	**30.83**

Type of onsite	Samples	% TN	%TC
One cesspool			
	AIT-2	2.18	39.19
	AIT-3	3.54	42.03
	AIT-4	3.54	42.43
	AIT-5	3.24	20.34
	AIT-6	5.22	47.65
	AIT-7	3.46	46.42
	AIT-13	3.46	46.42
	AIT-14	1.51	15.72
	AIT-15	2.18	39.19
	AIT-25	3.54	31.52
	AIT-29	3.35	32.04
	AIT-30	4.12	32.68
	AIT-44	4.30	37.25
	AIT-45	3.64	36.57
	AIT-46	4.31	45.43
	AIT-47	3.32	41.02
	AIT-49	3.05	31.24
	AIT-50	2.19	21.24
	AIT-51	2.07	17.73
	AIT-52	3.14	37.53
	AIT-53	4.12	37.18
	AIT-54	4.69	44.89
	AIT-55	2.93	27.24
	AIT-56	2.54	25.62
	AIT-57	3.52	36.28
	Average	**3.45**	**34.84**

Septic tank system, the results in this study were collected from 10 households. As shown in Figure 14, the results demonstrated that TS concentrations of fluidized sludge were ranged from 3,288 – 80,000 mg/L with the average concentration of 19,270 mg/L. The variation of TS probably due to OSS of some sampling household was not filled (AIT-1). There was a block within the tank that resulted in difficulty for toilet flushing thus leaded to lower concentration of fluidized sludge whereas the maximum TS concentration was presented from sampling household which did not empty their system for more than 10 years (AIT-21). The TS concentrations from bottom sludge were ranged from 8,240 – 123,100 mg/L with the average concentration of 44,000 mg/L. Therefore TS concentration from bottom sludge was more concentrated than from fluidized sludge about 2 folds. Similar to TS concentration, volatile and fixed solid of bottom sludge was higher than fluidized sludge which about 28,780 and 13,580 mg/L for volatile solid and about 15,220 and 5,700 mg/L for fixed solid, respectively.

Considering COD concentration, the results revealed that the bottom part of sludge presented higher COD concentration than the fluidized sludge about 1.5 folds (32,190 and 20,430 mg/L, respectively). On the other hand, the conductivity and water content from fluidized sludge and bottom sludge were not significantly different which presented about 1.6 and 1.2 ms/cm for conductivity and 34% and 32% for water content, respectively.



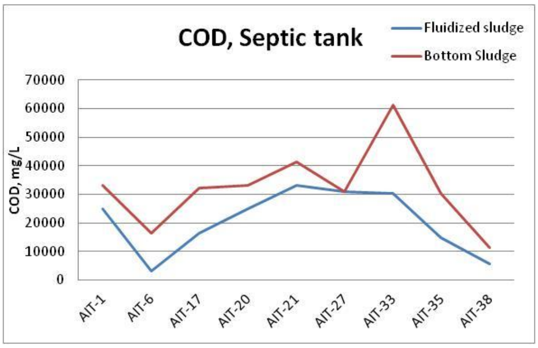


Figure 16: TS and COD Concentration of Septic Tank System from Different Sampling Household

One cesspool system, the results in this study were collected from 30 households as shown in Figure 16. Samples from AIT-2 to AIT-39 were collected from urban area of Nonthaburi and Lampang province which observed that sludge was clarify separated as fluidized and bottom part thus sample could be collected from both layers. The samples from AIT-49 to AIT-57 were collected from rural area of Ratchaburi province, which mostly use less water from pouring their toilets thus the observed samples were homogenize as bottom sludge.

As shown in Figure 17A, the results demonstrated that TS concentrations of fluidized sludge were ranged from 1,380 – 25,020 mg/L with the average concentration of 10,440 mg/L. The TS concentrations from bottom sludge were ranged from 4,500 – 188,480 mg/L with the average concentration of 62,730 mg/L. The lowest TS concentration (AIT-15, 1,380 and 4,500 mg/L) was observed from the household which the owner working outside during day-time and not often use toilet at their household. Similar to septic tank system, TS concentration from bottom sludge was more concentrated than from fluidized sludge about 6 times. In the same way as TS, volatile and fixed solid of bottom sludge was about 5 – 10 folds higher than fluidized sludge which about 37,070 and 7,530 mg/L for volatile solid and about 29,530 and 2,760 mg/L for fixed solid, respectively.

Considering COD concentration (Figure 17B), the results revealed that the average concentration from bottom part of sludge presented higher COD concentration than the fluidized sludge about 2.3 folds (29,820 and 12,770 mg/L, respectively). On the other hand the conductivity and water content from fluidized sludge and bottom sludge were not significantly different which presented about 1.8 and 2.5 ms/cm for conductivity and 99% and 94% for water content, respectively.

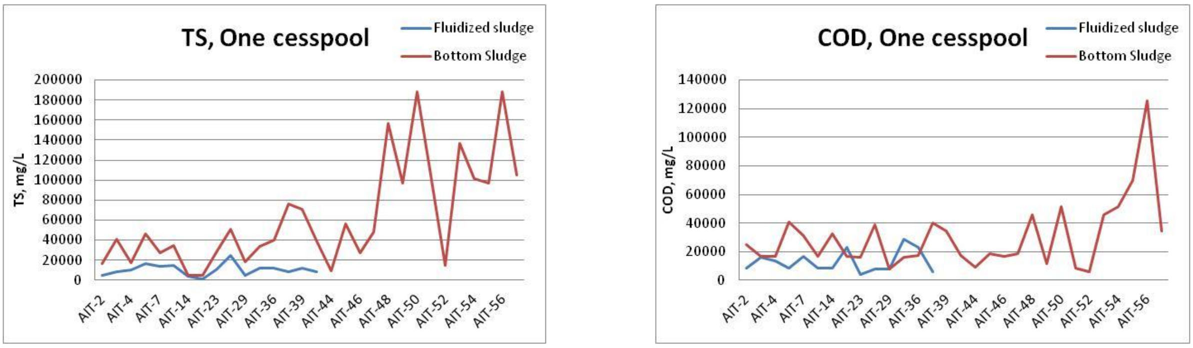


Figure 17: TS and COD Concentration of One Cesspool System from Difference Sampling Household

Two cesspools in series system, the results in this study were collected from 12 households. As shown in Figure 18, the results demonstrated that TS concentrations of fluidized sludge were ranged from 1,510 – 25,970 mg/L with the average concentration of 10,990 mg/L. The TS concentrations from bottom sludge were ranged from 8,420 – 94,030 mg/L with the average concentration of 34,490 mg/L. The lowest TS concentration (AIT-8, 1,510 mg/L) was observed from the household which has only one person live in the house and not frequency use the toilet. TS concentration from bottom sludge was more concentrated than from fluidized sludge about 3 times. In the same way as TS, volatile and fixed solid of bottom sludge was about 2 – 3 folds higher than fluidized sludge which about 22,760 and 7,210 mg/L for volatile solid and about 11,730 and 4,500 mg/L for fixed solid, respectively.

Considering COD concentration (Figure 18B), the results revealed that at the average concentration from bottom part of sludge was presented higher COD concentration than the fluidized sludge about 2.3 folds (40,420 and 17,120 mg/L, respectively). On the other hand the conductivity and water content from fluidized sludge and bottom sludge were not significantly different which presented about 2.5 and 2.6 ms/cm for conductivity and 99% and 96% for water content, respectively.

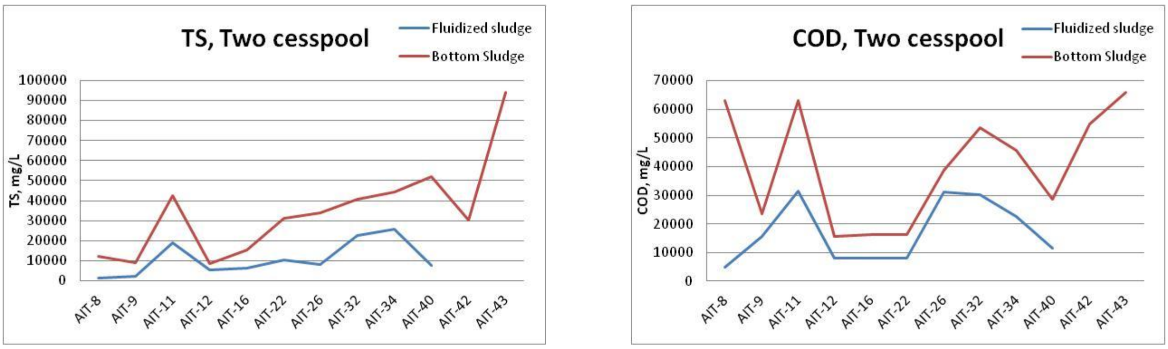
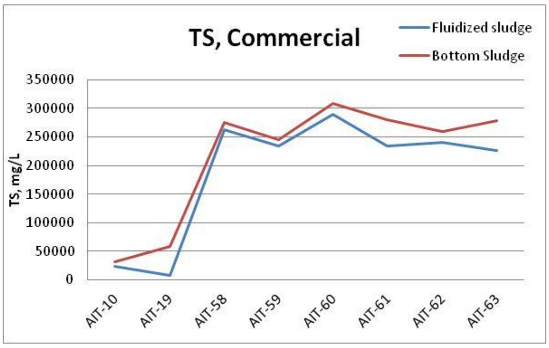


Figure 18: TS and COD Concentration of Two Cesspool System from Difference Sampling Household

Commercial system, the results in this study were collected from 8 households. As shown in Figure 19, TS concentration of bottom sludge was higher than fluidized sludge for about 4.5 time which were about 217,190 and 189,970 mg/L, respectively. Similar to TS concentration, volatile and fixed solid of bottom sludge was higher than fluidized sludge about 2 – 3 time which about 25,250 and 10,580 mg/L for volatile solid and about 191,940 and 181,310 mg/L for fixed solid, respectively.

For COD concentration, the bottom sludge was higher than fluidized sludge about 2.5 times which about 39,000 and 14,980 mg/L, respectively. On the other hand the conductivity and water content from fluidized sludge and bottom sludge were not significantly different which presented about 1.6 and 1.5 ms/cm for conductivity and 80% and 77% for water content, respectively.



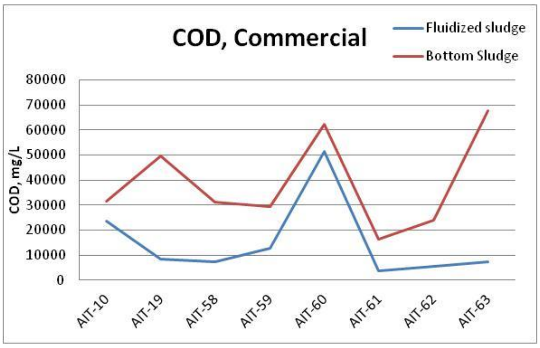


Figure 19: TS and COD Concentration of Two Cesspool System from Different Sampling Households

Physical composition of different onsite treatment system

Table 10 demonstrated physical compositions of different onsite treatment system. Therefore all samples were collected from bottom sludge of 4 types of on-site sanitation system such as Septic tank, One cesspool, Two cesspools in series and Commercial treatment system. The composition of dried faecal sludge found are depended on each source which can be sorted out into hair, debris (especially seed of paprika), sand, plastic and sludge.

Septic tank system, the data were collected from 9 sampling households. The results demonstrated that about 40 – 95 % was presented in terms of sludge, following by debris for about 4 – 26 %, sand was presented about 0.5 – 50 % and slightly contained of plastic and hair which the average value of 82%, 10%, 9%, 0.1 and 0.04%, respectively. However the different composition was presented at AIT-6 and AIT-17 which mostly presented in term of sand and sludge.

One cesspool system, the data were collected from 31 sampling households. The results demonstrated that about 78% was presented as pure sludge, debris 7.26%, sand 7.23%, hair 6.28% and plastic 2.47%.

Two cesspool system, the data were collected from 13 sampling households. The compositions were presented in form of sludge, debris, sand, hair and plastic about 81%, 12%, 6%, 1.6% and 0.15%, respectively.

Commercial system, the data were collected from 10 sampling households. The compositions of dried FS were presented in term of sludge 89% and debris 11%.

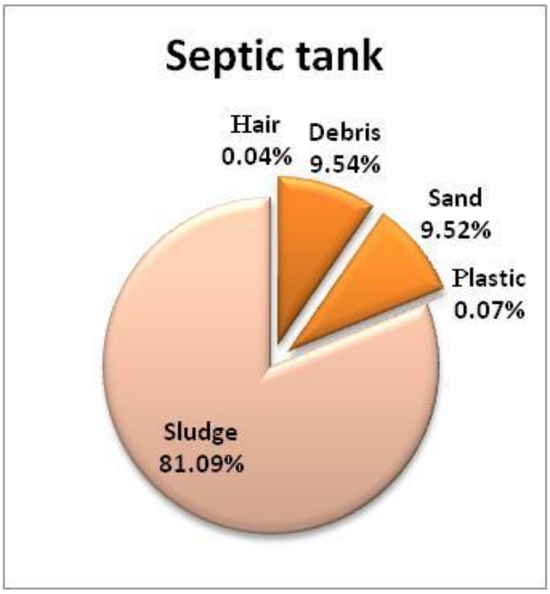
Table 10: Composition of Each Onsite Treatment System

Type of onsite treatment system	Samples	% Composition				
		Hair	Debris	Sand	Plastic	Sludge
Septic tank	AIT-1	0.07	3.88	0.47	0.49	95.09
	AIT-6	0.00	8.17	42.95	0.00	48.88
	AIT-17	0.00	26.20	30.95	0.00	42.85
	AIT-20	0.00	4.00	0.00	0.00	96.00
	AIT-21	0.00	9.00	0.00	0.00	91.00
	AIT-27	0.00	10.00	0.00	0.00	90.00
	AIT-33	0.00	5.00	9.00	0.00	86.00
	AIT-35	0.00	7.00	0.00	0.00	93.00
	AIT-38	0.26	12.60	0.00	0.13	87.01
	Average	**0.04**	**9.54**	**9.26**	**0.07**	**81.09**
One cesspool	AIT-2	0.00	22.26	1.98	1.57	74.19
	AIT-3	0.00	14.36	50.85	0.00	34.79
	AIT-4	0.00	7.14	0.00	60.97	31.89
	AIT-5	0.00	1.06	1.16	0.00	97.78
	AIT-7	0.00	3.60	19.22	0.00	77.16
	AIT-13	0.00	26.20	30.95	0.00	42.85
	AIT-14	0.44	22.14	32.95	0.00	44.47
	AIT-23	0.00	6.00	1.00	0.00	93.00
	AIT-36	0.00	11.00	0.00	0.00	89.00
	AIT-37	0.00	5.70	0.00	0.00	94.30
	AIT-39	0.25	0.75	0.00	0.00	99.00
	AIT-41	0.00	22.00	0.00	0.00	78.00
	AIR-44	0.00	9.08	0.00	0.00	90.92
	AIT-45	0.00	12.30	0.00	0.00	87.72
	AIT-46	0.00	17.32	0.00	0.00	82.68
	AIT-47	0.00	7.81	6.97	0.00	85.22
	AIT-48	3.51	0.00	0.00	0.00	96.49
	AIT-49	33.75	0.00	0.00	0.00	66.25
	AIT-50	10.23	0.00	0.00	0.00	89.77
	AIT-51	13.00	0.00	33.00	0.00	54.00
	AIT-52	27.00	0.00	0.00	0.00	73.00
	AIT-53	18.00	0.00	9.00	1.64	71.36
	AIT-54	18.00	0.00	0.00	0.00	82.00
	AIT-55	9.00	0.00	0.48	0.00	90.52
	AIT-56	13.00	0.00	0.44	0.00	86.56
	AIT-57	17.00	0.00	0.00	0.00	83.00
	Average	**6.28**	**7.26**	**7.23**	**2.47**	**76.77**
Two cesspools in	AIT-8	0.75	15.04	0.28	0.00	83.93

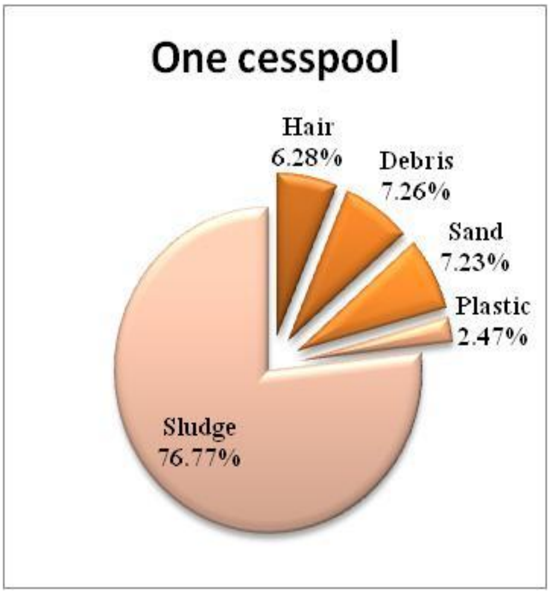
series	AIT-9	8.59	0.21	0.28	0.00	90.92
	AIT-11	0.13	27.78	42.95	0.00	29.14
	AIT-16	0.00	14.37	2.38	1.64	81.61
	AIT-22	0.00	8.00	0.00	0.00	92.00
	AIT-32	0.00	9.00	0.00	0.00	91.00
	AIT-34	0.00	3.00	2.00	0.00	95.00
	AIT-40	8.59	22.00	0.00	0.00	69.41
	AIT-41	0.00	22.00	0.00	0.00	78.00
	AIT-42	0.00	3.78	11.40	0.00	84.82
	AIT-43	0.00	3.12	2.30	0.00	94.58
	Average	**1.64**	**11.66**	**5.60**	**0.15**	**80.95**
Commercial septic tank	AIT-10	0.00	5.83	0.00	0.00	94.17
	AIT-19	0.00	7.00	0.00	0.00	93.00
	AIT-58	0.00	2.83	0.00	0.00	97.17
	AIT-59	0.20	17.62	0.00	0.00	82.18
	AIT-60	0.00	8.83	0.00	0.00	91.17
	AIT-61	0.74	18.29	0.00	0.00	80.97
	AIT-62	0.00	7.78	0.00	0.00	92.22
	AIT-63	0.00	16.86	0.00	0.00	83.14
	Average	**0.12**	**10.63**	**0.00**	**0.00**	**89.25**

As shown in Figure 20, sludge from commercial septic tank presented the lowest contaminated particle, by only about 11% debris were observed, which the highest percentage of sludge contented (89%). Therefore two cesspools in series system and septic tank were contained pure sludge about 81%. In addition, one cesspool system contented pure sludge slightly lower than the other system which about 76%. The variation of the sludge composition from onsite system, probably due to the difference of the configuration which mostly commercial onsite systems have small screening connected at the first part of the system for debris and garbage separation.

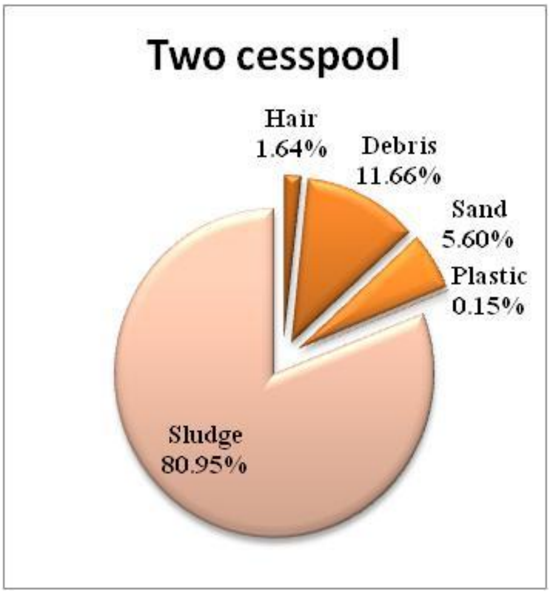
Considering one cesspool and two cesspools in series, the result demonstrates that one cesspool system contained about 23% of contaminated particle which comprise of 7.5% debris, 7.5% sand, 6.3% hair and 2.5% plastic whereas two cesspools in series presented pure sludge about 81% by the rest are presented as 12% debris, 6% sand, 1.6% hair and 0.2% plastic. The higher sludge composition from two cesspool system probably because of solid part of FS was settled in the first cesspool and supernatant flows to the second cesspool.



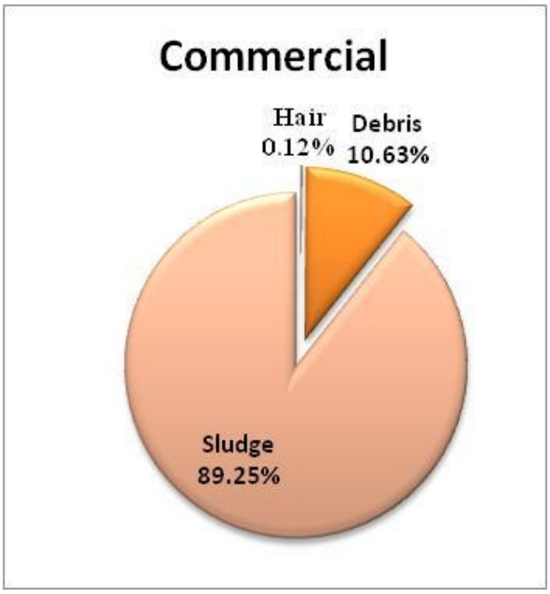
(a) Septic Tank system



(b) One cesspool system



(c) Two cesspools in Series system



(d) Commercial system

Figure 20: Sludge Composition of Difference Onsite Treatment System

3.4 Thermal Properties

Thermal properties analysis is also conducted at MTEC. Results of specific heat and thermal conductivity are shown in Table 11 and 12, respectively.

Dried sample of 6.42 mg from Nonthaburi1 with septic tank type of OSS was tested between 25 to 100 ^{o}C. The specific heat values were presented between 1.67-5.45 to 6.44 J/g ^{o}C. Two cesspools in series type of OSS was also tested with the temperature of 25-100 ^{o}C and the specific heat was shown to range from 1.87 to 6.44 J/g ^{o}C. Furthermore, one cesspool type of OSS was tested with the same condition gave the specific heat was about 1.39-3.37 J/g ^{o}C. The result from this study was higher than specific heat capacity of dry soil is about 0.84 J/g ^{o}C whereas Specific heat capacity of sludge is about 0.9 J/g ^{o}C which reported in the literature.

Considering specific heat from different onsite system demonstrated that two cesspools in series presented the highest of specific heat value while commercial septic tank system achieved the lowest value.

Table 11: Specific Heat

Sample	Type of onsite system	Mass (mg)	Temperature (^{o}C)	Specific heat (J/g- ^{o}C)
Nonthaburi 1	Septic tank	6.42	25 – 100	1.67 – 5.45
Mixed sample from Nonthaburi	Two cesspools in series	5.98	25 – 100	1.87 – 6.44
Mixed sample from Lampang	Septic tank	6.12	25 – 100	1.57 – 4.47
Mixed sample from Ratchaburi	One cesspool	6.28	25 – 100	1.39 – 3.37
Nakhon Ratchasima	Commercial septic tank	6.35	25 – 100	1.33 – 3.50

Thermal conductivity of dried sludge from septic tank and two cesspools in series showed the same results of about 0.04 W/m-ºC which presented lower than soil with organic matter (0.15 – 2 W/m-ºC) and the other study. Thermal Conductivity of mixed sample from Nonthaburi (67% DS) with septic tank type of OSS showed the highest value of 0.14 W/m-ºC. Therefore Wang, K.S. *et al* reported in 2005 that the thermal conductivity of the sewage sludge ash (SSA) low to be 0.0763–0.2474 W/m-ºC. In addition, the thermal conductivity of this study illustrated that numerous lower than coconut palm shall, husk and bagasse which about 0.22–0.32, 0.20–0.26 and 0.18–0.24 W/m-ºC, respectively (Siriterasat P., et al, 2007).

Table 12 Thermal Conductivity of Septic Tank

Sample	Type of onsite system	Thermal conductivity (W/m-ºC)
Mixed sample from Nonthaburi (Dried solid)	Septic tank	0.04
Mixed sample from Nonthaburi (67% DS)	Septic tank	0.14
Mixed sample from Lampang (Dried sample)	Two cesspools in series	0.04
Mixed sample from Ratchaburi (dried sample)	One cesspool	0.05
Mixed sample from Nakhon Ratchamima (Dried sample)	Commercial septic tank	0.03

3.5 GIS map

3.5.1 General Background of Routing

Nonthaburi municipality has an outstanding system of FS management in this study. The entire process of requesting for FS emptying service is administered by the officials. Households need to officially submit the requesting form attached with a house's map at the municipality office in order to receive the service. The environmental office at the municipality is responsible for assigning the work for each FS truck. The workload for each truck depends on the amount of FS at service points, for instance, if service points for the day consists of apartments or factories, the big truck with capacity of 6 cubic meters will be assigned. While the smaller truck with capacity of 4 cubic meters usually serves household type of residence. Routes and traffic conditions are also necessary for assigning the workload for FS trucks. Since Nonthaburi municipality is a densely urban type of area, traffic condition is not so convenient. The sampling process usually started at 8:30 am which is considered a rush hour that many people were on their way to work. As a result, the big truck is assigned to the route that relates to main roads when smaller truck is assigned to the route with the access to narrow alley. The road condition in Nonthaburi municipality was not a major obstacle to the sampling process in the study since the roads are well made from concrete. Moreover, the well experienced driver of FS truck could make it easy in finding households for service. However there could be some confusion with the maps and addresses in the requesting forms at times.

As mentioned in the earlier part, Nakorn Lampang municipality assigned the FS service to the private sector. Households informally request for the FS service directly to the truck driver by making a phone call one day prior to the service day. Although the route of FS truck is designed according to the closer location of requested households for the FS service, an immediate change of service route can be observed according to the appropriation. Since Nakorn Lampang is considered to be a general urban area, the non-metropolitan city makes the traffic condition quite convenient. In contrast, narrow and tight characteristics of Nakorn Lampang's roads could lead to obstacles for the sampling process at times. There are mixed types of road conditions in Nakorn Lampang municipality, concrete roads can be mostly found right in the city center when farm tracks and dirt roads can also be found in the area. Due to the experienced FS truck's driver, the travel time to each service household was not too much and finding for households was not that difficult. However, as in Nonthaburi municipality, there could be some confusion with the addresses of the requesting households at times.

Since there is no FS emptying service neither from Suan Pheung municipality and a private sector, discussions in terms of request from households and route design are not relevant.

Suan Pheung Ratchaburi is a representative of a rural area in this study. With the landscape of mountainous and high areas, the roads to studied areas are sharp with curves. However there is no traffic in the area. The villages in studied area are under the administration of Suan Pheung municipality so that the road conditions are quite smooth and secure even though they are dirt roads. The villages are well designed as households for hill tribe people, usually houses are made from woods and dried-grass.

3.5.2 Routing of FS Collection and Transportation

From the observation of FS truck routing, details on routing for each day can be found in Appendix C. Summary of distance for FS truck's service for each sampling day is shown in Table 13.

Table 13: Summary of Distance for FS Truck's Service for Each Sampling Day

Sampling Day	No. of Household	Total Distance (km)
1	2	12.29
2	2	19.59
3	2	21.13
4	6	23.02
5	3	12.10
6	3	22.42
7	3	11.6
8	2	17.6
9	4	53.82
10	4	5.59
11	4	17.8
12	6	125.63
13	6	29.1

FS emptying service in Nonthaburi municipality, overall for each day of the service, each truck (big and small ones) serves for about 6-7 households that include all kinds of residence such as, households, apartments, factories and companies for instance. Since this study focused on household type of residence, number of collected samples was not always relevant to number of serving household. Basically, the big truck with capacity of 6 cubic meters is able to serve for about 6 households with the estimation of 1 cubic meter per household. As Nonthaburi is considered to be a metropolitan city, there are usually apartments or companies request for the service. As a result, the truck is sometimes full and needs to be unloaded at the dumping site according to the truck driver's consideration.

In general, summary of routes are depended on household areas, traffic condition and capacity of the truck. Houses with the same or close areas will be grouped and assigned by one truck. Then the next criteria will be capacity of the truck, a big truck is usually assigned to route that contains apartments or companies when the smaller one serves households.

In Nakorn Lampang, the FS emptying service is able to serve up to ten households per day because of its smaller area than Nonthaburi and convenient traffic however narrow roads and too much amount of vehicles on the roads can be the obstacles at times. With the capacity of 4 cubic meters for FS truck resulted in high frequency of transferring of FS at the dumping site. The dumping site at Nakorn Lampang is located quite out of town. Having to transfer FS many times a day can cause an inconvenient and consume fuel so that having a transfer truck in between of the serving route should help enhance the capacity of FS truck. But the bigger truck with more capacity might not help because is it not appropriate with the road characteristics.

3.6 FS Emptying Process

In this study, the FS emptying process has been observed by the methods of following the FS truck, GPS reading and process timing. The results have been discussed in the following sections.

3.6.1 Collected Data from Field Observations

Results of field observations for FS truck have been reported from Nonthaburi and Nakorn Lampang municipalities. Timing and GPS reading were conducted in order to analyze working time and route to households.

For Nonthaburi municipality, in general, time consumed for traveling to each sampled household is not more than 20 minutes which is considered to be quite effective since the suitable routes have been designed and assigned to relevant trucks in advance. Although, the traveled time seems to be quite effective in order to be able to serve all requested households in one day, less traffic could help reduce the travelled times. For Nakorn Lampang municipality, most of travelled time to household took less than 10 minutes since the city is smaller and less metropolitan compared to Nonthaburi municipality. And also the truck driver is a local person so that taking short cut routes was helpful to reach the targeted household with less time.

There is no significant difference for Pre-preparation process and opening tank process in FS emptying in both Nonthaburi and Nakorn Lampang municipalities. As a result, time consumed for this process is quite relevant between two areas with not more than 2 minutes. However, few households are found to require more time than usual because of some difficulties. Generally, difficulties in this process can be categorized as follows:

- Cement blocked on the top of manhole.
- The manhole has never been opened before so that the cover gets rusty.
- For manholes located inside of the house, it has sometime found that furniture and other belongings block the way so that it is not quite convenient for workers.

Average emptying time for both studied areas in Nonthaburi and Nakorn Lampang municipalities are quite similar because those two trucks have the same capacity. As a result, the differences in time consumed in this process depended on amount of FS in septic tanks. Normally, it takes less than 10 minutes for the emptying process.

The total length of suction pipe for FS truck from both Nonthaburi and Nakorn Lampang municipalities is about 40 meters. From the observation in Nonthaburi, the insufficient length of suction pipe had never been found. In contrast, there were a few cases that required a very long suction pipe. The solution that has been observed was having a spare suction pipe connected to the main one in order to be able to reach the targeted manholes.
The average length of suction pipe varied from 10 to 30 meters depends on distance from septic tank to truck's access point.

Data information from field survey and observations concerning FS emptying process at each studied household can be found in Table 14.

Table 14: Data Information on Operation of the Truck at Each Household

Data Information (AIT-)	Time from origin to household (mins)	Pre-Preparation time (mins)	Opening tank time (seconds)	Post-Preparation time (mins)	Average Emptying time (mins)	Pit Location (Position in the house)	Volume of sucked fecal sludge (m^3)	Hose Length (m)
1	14.30	2.20	30	1.58	5.25	Backside	1	25
2	6.18	2	15	1.03	10.36	Backside	1	20
3	9.02	3.50	10	1	11.13	Front	0.8	35
4	9.32	3.07	20	1.49	12.50	Backside	0.5	40
5	12.5	1.05	10	1.20	6.13	Outside	0.5	42
6	15.0	2.50	3.50	2.08	8.33	Backside	0.75	15
7	12.43	1.49	23	45 sec	8.46	Backside	0.75	20.5
8	20.41	34 sec	33	30 sec	3.11	Inside	0.35	32.5
9	0 (In front of AIT-8)	1.15	36	2.56	4.16	Back side	0.3	14
10	19.45	1.25	5.30	3.32	9.53	In the kitchen	0.85	20
11	17	1.48	35	2.08	3	Inside	0.4	15.5
12	4.53	1.09	2.01 mins	3.58	7.18	Backside	1.35	17
13	14.46	1.53	33	3	3.29	Outside	0.5	
14	16.36	1.09	0.45	1.53	7.02	In the kitchen	0.3	15
15	5.61	1.20	25	3.04	3.24	In the kitchen	0.9	12
16	11.09	56 sec	16	3.17	2.52	Backside	0.5	23
17	21.05	1.44	1.47	1.54	5.16	Beside	0.7	22.5
18	10.52	1.08	10	1.56	3.10	Outside	1.3	18
19	6.32	1.04	5	1.34	8.33	Front	0.75	16.5
20	13.23	1.46	1.09	2.12	9.35	Backside	1.55	28.5
21	16.15	2.33	10	1.48	22.50	Backside	0.7	19
22	12.67	0.52	0.14	2.47	6.55	Inside	1.2	30.5
23	16.05	0.51	2.22 mins	1.45	6.36	Inside	1.1	12.0
24	13.43	1.17	28	1.16	6.04	Backside	1.3	18.5
25	1.58	2.32	47	0.44	3.86	Inside	1.5	12
26	7.20	1.16	28	1.34	3.29	Backside	0.6	32.5
27	15	1.28	10	1.13	6.34	Backside	0.2	17.5
28	19.36	30 sec	28	1.05	3.32	Backside	0.6	29
29	3.50	48 sec	2.61 mins	53 sec	4.28	Beside	0.2	17.5
30	3.15	1.45	4	2	7.40	Beside	0.7	25
31	4.44	1.18	8	1.36	5.53	Backside	0.6	14.5
32	13.40	0.42	1.48	9.01	8.22	Backside	1	35
33	27.51	2.30	1.30	2.04	8.58	Backside	1	16.5
34	8.02	3.35	23	1.58	6.55	Front	1	23
35	11.20	2.41	50	1.02	3.07	Backside	1	20.5
36	16.32	25 sec	20	10 sec	5.58	Front	1.5	17
37	16.29	1.22	20	3.18	4.47	Backside	1.75	20
38	7.22	39 sec	20	56 sec	7.23	Front	0.75	15

39	7.51	20 sec	10	1.05	4.07	Beside	2	6.5
40	5.55	1.01	36	1.37	2.09	Backside	1	17.5
41	11.42	18 sec	1.57	1.32	6.30	Front	2.2	15
42	5.13	20 sec	1 min	1.54	11.54	Outside	2.5	25
43	3.44	20 sec	58	1.30	4.33	Backside	2	40
44	2.10	10 sec	17	1.42	9.03	Front	3	27.5
45	2.32	49 sec	10	1.51	5.25	Backside	1.25	17.5
46	8.07	3.35	38	3.56	8.43	Inside	1	20
47	7.23	39 sec	32	1.18	8.09	Inside	1.5	22.5

From the observation of the truck for FS emptying service, the truck usually commuted within the distance between 10 to 20 km in the municipality that took around 5-20 minutes, depends on the traffic and clarification of house's addresses. The preparation for the FS emptying process that is mainly for moving the hose to manhole, took about 1-4 minutes depends on difficulty of access points. The time spent on the tank opening process was usually less than 1 minute since the equipments are quite effective and useful. However, timing for the FS emptying process quite varied depends on situation at each household, for example, some households had too many debris that need to be taken out during suction process. In post-preparation time, time spent in the process was quite little due to the well-design of the equipments and experienced employees.

3.6.2 Access Points of Truck at Each Household

In order to study the whole process of FS emptying at households, pictures and sketches for the access of truck are helpful in this matter. The desludging process in Nonthaburi municipality and Nakorn Lampang municipality at each studied household is shown in Appendix D.

Figure 21 shows example of sketches and pictures for households in Nonthaburi municipality. The access point of FS truck and the location of septic tank are identified in the sketch as well as sanitary type. Pictures of access point of the truck, process of opening manhole, FS emptying process and post-preparation process as well as FS level are also displayed. Most of households in Nonthaburi municipality constructed toilets inside the houses. Toilets are located in variety of places in the house, for instance, the front, the back but mostly in the kitchen. As a result, manholes are also inside the houses as well, usually 2-3 meters away from the toilets. However, manholes located inside of the toilet can also be found. For Nonthaburi municipality, majority of the houses were constructed in the past few decades with town-house style. The pattern of houses is quite similar. The suction pipe laying method usually takes at least two people. For households with manholes located outside of the house, the suction pipe laying method can be done quite easily compared to inside location. Since the materials for suction pipe are made from PVC and metal string, they make the pipe heavy and not really flexible. When taking samples at households with manhole located inside of the house, the difficulty can be observed. Households with complicated house-plan can lead to high difficulty in terms of laying the suction pipe and somehow require more people to work on it. Suction pipes that are made of softer materials should lead to more flexibility so that the laying process can be more convenient and effective.

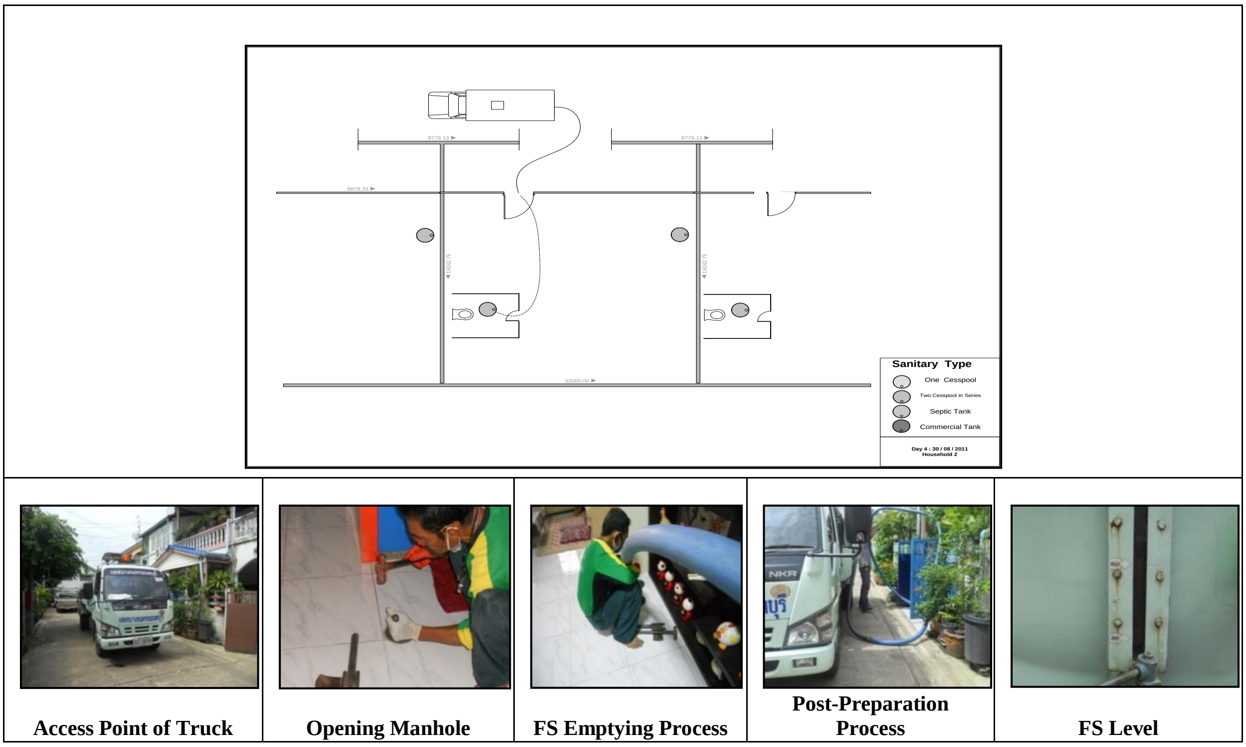


Figure 21: Example of Sketches for Access Points of Truck at Households in Nonthaburi Municipality

Figure22 shows example of sketches for access points of the truck at households in Nakorn Lampang municipality. It is quite similar to Nonthaburi municipality, variety of toilet location has been found in studied households. Locations of toilet were found to be in the front, in the back and even inside of the kitchen. The FS truck usually parks in front of the house where it is the most convenient position. In some cases, the truck parked on the side or in the back of the house. There could be obstacles in parking of the truck so that the truck driver identifies the access point accordingly.

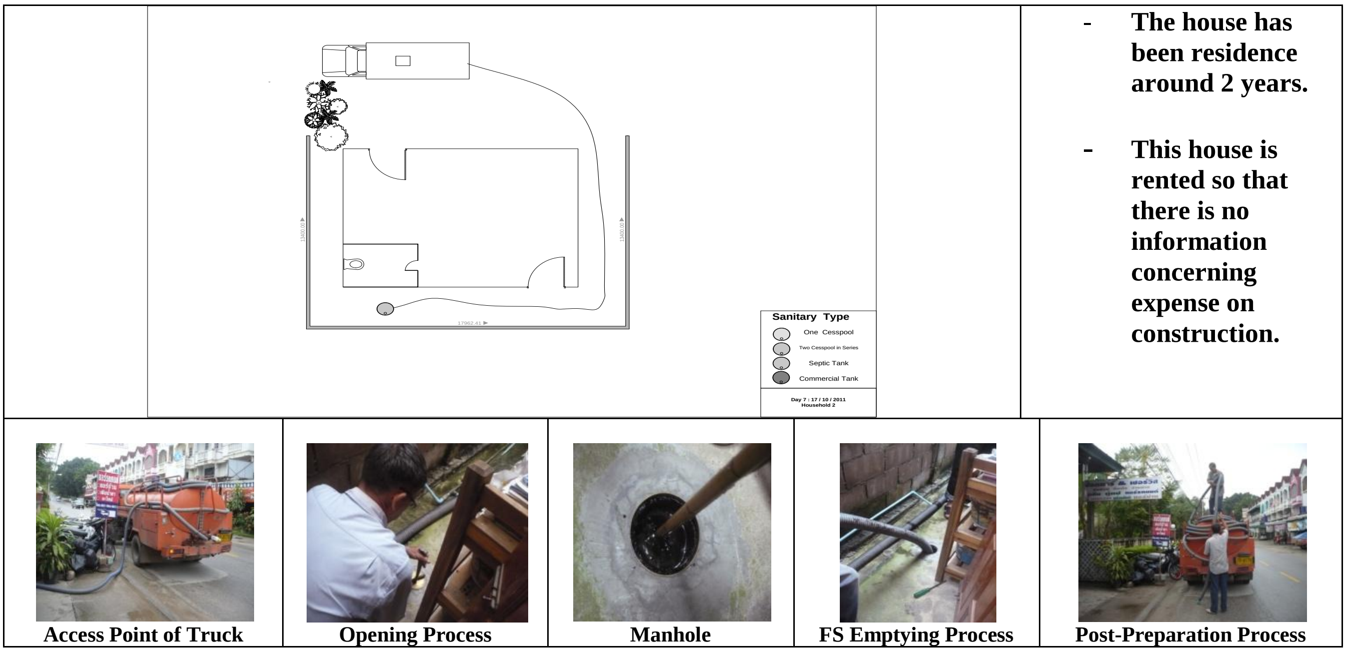


Figure 22: Example of Sketches for Access Points of Truck at Households in Nakorn Lampang Municipality

As mentioned in the earlier sections, there is no FS emptying service in Suan Pheung Ratchaburi. Since the majority of inhabitant is hill tribe people, the houses and toilets were simply constructed by woods and dried-grass, see Appendix D for pictures of toilets in studied areas. Toilets have been found to be outside of the house for all of households in studied areas. They are usually made of bamboo trees or cloths. Toilets with opened-roof were also found in some households. It is noticeable that all of septic tanks are all located right behind the toilets for every household in studied areas. According to the interviews, it is found that toilets were not constructed in several households therefore when in need of the use for toilet, household members usually use neighborhood's or go into the woods. Figure23 and 24 present characteristics of 2 villages in Moo 5 & 6 that were used as studied areas. There are about 20 households and 18 households in Moo 5 and Moo 6 villages. In which, households with red dot are sampled households in the study.

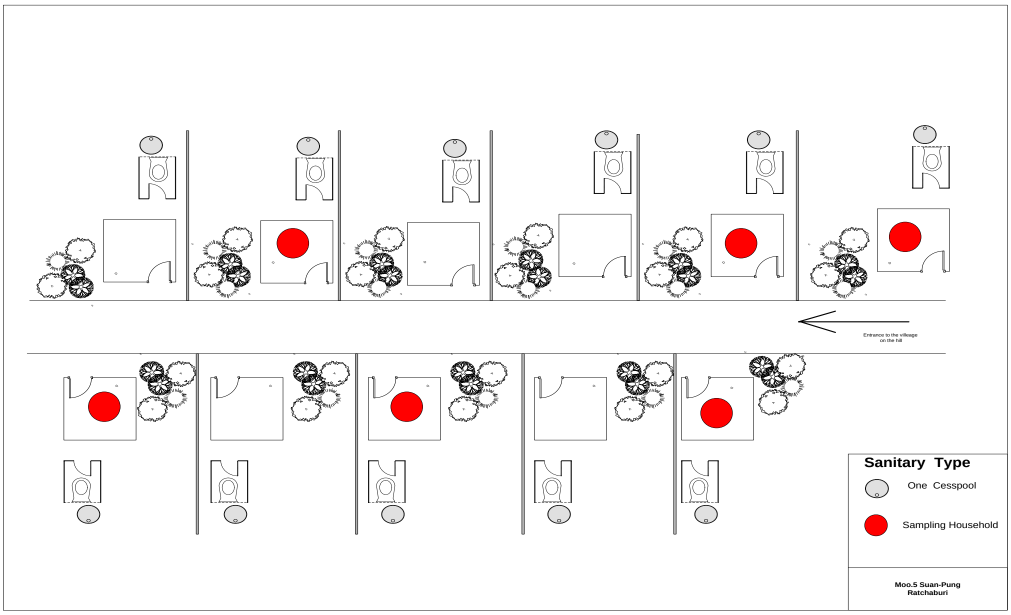


Figure 23: Village Characteristic of Moo 5

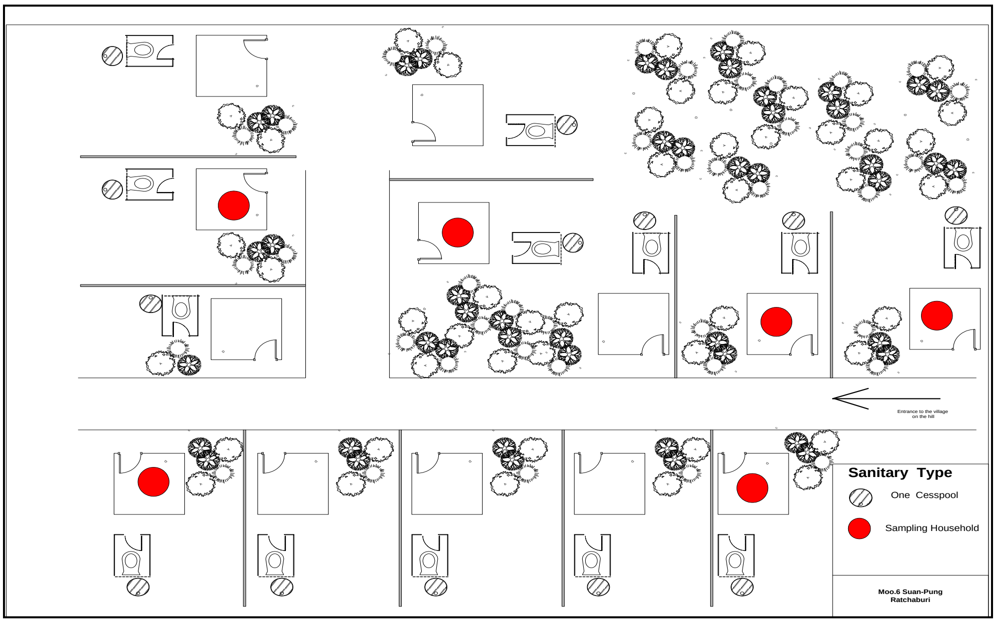


Figure 24: Village Characteristics of Moo 6

3.6.3 FS Truck Characteristics and Emptying Process

Nonthaburi municipality uses two trucks serving for FS emptying service. The service trucks come in different sizes depends on workload for the day. The capacity of the bigger truck is 6 m^3 when the smaller one can contain about 4 m^3 of FS. Both of the trucks are in charge of service every day, although they are running in different route of service. An officer in Department of Sanitation and Environment is responsible for assigning the works to those two trucks according to routings to households and traffic characteristics. Households that need to remove FS, the house owners have to contact the office in person and fill out the form in order to request for the FS emptying service. Each day, one truck can serve about 5-6 households.

There are usually two employees accompanying the truck, one is a driver who is also in charge of controlling the valves and arranging the hose. Another person, whom can be called an assistant, is responsible for opening the manhole in household using specific equipments as well as manually controlling level of hose-ended during operation. Table 12 below illustrates truck characteristics and equipments as well as descriptions.

For Nakorn Lampang municipality, a private stakeholder is in charge of FS emptying service however it is under the control of municipality officers. House owners can directly contact the person in charge to request for the FS emptying service. There are 2 trucks in service currently with the capacity for the bigger truck is 4 m^3 and 2 m^3 for the smaller one. Usually, there are 2 employees and an owner accompanying the truck. With total of 3 employees which are considered more potential than Nonthaburi municipality, Nakorn Lampang municipality serves 8-10 households per day.

Procedures of FS emptying service are similar to Nonthaburi since the truck and all equipments are the same type. One person of the employees control pressure valves which have to always standby at the end of the truck. While other two people help with opening manholes and control level of manhole-end when sucking FS from septic tanks.

Generally, in Thailand’s market, there are mainly 5 types of FS truck according to its capacity. Trucks with capacity of 3, 4, 5, 6 and 7 cubic meters are suitable with different workloads. With 6 wheels, a driver’s cockpit and a container in the back make the appearances are quite similar among those types of FS truck. There were two types of trucks under the study, type 1 with capacity of 4 cubic meters that is used in both Nonthaburi and Nakorn Lampang municipalities. And type 2, with capacity of 6 cubic meters that is used only in Nonthaburi municipality. For FS truck with capacity of 4 cubic meters, the maximum load is 8.4 tons (including weights of truck and equipments) when the truck with capacity of 6 m^3 has the maximum load of 12 tons (including weights of truck and equipments).

In comparison, the truck with capacity of 4 cubic meters installed the engine with 120-135 horsepower when the 6 cubic meter truck has a higher power with 175-210 horsepower engine. The engine of the truck is the major source to generate power for the suction process. The container is designed in the oval shape that can lie down in the back of the truck and made of steel with 2-4.5 mm thick. At the top of the container, attached the hole with diameter of 50 cm as an access for the work to clean inside of the container.
For both types of FS truck under the study have quite similar details of capacity. The suction equipment can generate the vacuum state for up to 720 mmHg and the pressure for more than 2 kg/cm^2. The suction capacity can be up to 3,000-4,300 cm^2/round.

Sampling areas in Ratchaburi province have different characteristics than Nonthaburi municipality and Muang Lampang Municipality since it is located on the foot-hill areas. Villages are in rural area, surrounded by mountains and rivers. Most of the collected FS samples were quite thick. Moreover, residents in the areas were hill-tribe people and worked as farmers which resulted in pour living standards. Because of the long commute and people in the village cannot afford the FS emptying service charge, there is in the areas.

Differently to Nonthaburi municipality and Muang Lampang municipality, Suan Pheung Ratchburi has no FS emptying truck giving services. Septic tanks used to contain FS in the villages were one-cesspool type made by concrete rings. Since the areas are located in high land which the ground water is quite low, making the FS is thicker. Households do not often have problems concerning their septic tanks. When the tank is filled, it will be permanently closed and covered by soil. A new septic tank will be constructed as a replacement.

<u>FS Emptying Process</u>

The FS emptying process is likely to be the same at every household except for when there is difficulty which depends on the situation at each household. Table 25 describes truck characteristics, equipments, and procedures

The FS emptying process can be described as follows:

- Once the truck arrives at service household, the manhole of septic tank will be identified and opened by specific equipments.
- The hose from the truck is arranged and delivered into household to the identified manhole.
- When everything is ready, the controlling valves are turned on.
- The hose-ended must always be controlled according to level of FS in septic tank.
- After the septic tank is emptied, controlling valves must be turned off.
- Cleaning of equipments after emptying process is necessary.
- The hose is delivered back to the truck.

(a): The FS sludge collection tank is in the back of the truck. The hose installed with the truck is about 50 m. long.

(b): In the back of the truck, installed equipments for emptying activities such as hose joint connections, scale for FS measurement, pressure scale and pump controllers.

(c): In the back of the truck, there are two controlling valves for inlet and outlet of FS. From the picture, both of the valves are closed.

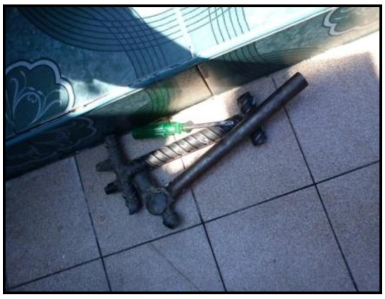
(d): During the operation, the inlet valve must be opened and at the same time the outlet valve has to be closed.

(e): Another valve in the back of the truck that controls the vacuum system.

(f): Pressure scale that shows real time pressure during operation of FS emptying system. Usually, there is no adjustment of pressure during operation except for when there is difficulty that requires high pressure of vacuum system.

(g): End of hose that is used to suck out FS in sanitation system. Usually, the hose-ended is manually controlled according to level of FS.

(h): Water is prepared for cleaning of equipments after emptying process is finished.



(i): Specific equipments for opening manhole.

(j): Usually, the driver of the truck is responsible for arranging the hose to be delivered to service house.

(k): Another person is responsible for controlling level of hose-ended and makes sure that all of FS is sucked out from septic tank.

(l): There must always be one person control all related valves.

(m): Sludge level in the tank is shown on scale.

Figure 25: Truck Characteristics, Equipments, and Procedures

In Nonthaburi municipality, there are two FS trucks serving households in municipality. The big truck with capacity of 6 cubic meters is relevant to serve major residences such as, apartments, companies and factories. Once the route related to main roads cannot be avoided, this big truck will be assigned. It usually happens that the big truck is assigned to the area with long commute to the dumping site because of its large capacity that requires less frequency of transferring for FS.

Small truck with capacity of 4 cubic meters serving Nonthabutri municipality, is usually relevant to route consists of narrow tracks. As a result, its smaller size makes it more convenient to go through roads with obstacles. Although, smaller truck is more suitable for routes other than main roads compared to bigger truck, its capacity is significantly less. With less amount of FS that can be contained by small truck, it requires more frequency of transferring at the dumping site. As a result, the small truck is usually assigned to the areas closer to the dumping site.

From the observation, with a lot of workload for the day, the big truck sometimes needed to transfer FS at the dumping site for a few times. That caused an inconvenient for transportation from sampling household to dumping site and from dumping site back to the next household. Having mother trucks situated at each suitable areas in order to transfer FS without coming to the dumping site, should be able to help enhance the effectiveness of the working truck. However, there are many factors need to be concerned in operating the mother trucks. For instance, the location of the mother truck should not be in or close to residential areas in order to avoid unpleasant smell at the same time it has to be located in the area that can help reduce travel time compared to traveling to the dumping site. Frequency of emptying the mother truck needs to be well designed relevant to cost- effective.

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