National Centre
of Competence
in Research
North-South

NCCR north south

UPGRADING CONVENTIONAL SEPTIC TANKS BY INTEGRATING IN-TANK BAFFLES

Thesis submitted in partial fulfillment of the requirements for the degree of Master of Engineering

Joint Areas
of Case Studies:

East Africa
Horn of Africa
West Africa
South-East Asia
South Asia
Central Asia
Central America
and Caribbean
South America
Switzerland

Sri-Anant Wanasen

2003

office

Author:

Sri-Anant Wanasen

Examination Committee:

Dr. Thammarat Koottatep (Chairman)
Prof. Chongrak Polprasert
Dr. Hiroyasu Satoh

Supervising Institute:

Asian Institute of Technology (AIT)
School of Environment, Resources and Development (SERD)

Scholarship Donor:

Royal Thai Government Fellowship

Supporting Programs and Institutes:

National Competence Centre in Research North-South, Switzerland

Swiss Federal Institute for Environmental Science and Technology, Switzerland

Contents

Figures

Tables

1 Introduction

1.1 Background

Of all the wastewater in the world, most of it is released to the environment without treatment (Lens et al., 2001). According to WHO (1996), as a consequence to this lack of sanitation, 3.3 million people die annually from diarrhoea diseases, out of 3.5 billion infected. In Africa alone, 80 million people are at risk from cholera, and the 16 million cases of typhoid infections each year are a result of lack of adequate sanitation and clean drinking water. Although there are fewer problems in United States of America and European countries, regular epidemic breakthroughs (such as Cryptosporidium, Giadia, Legionella and cholera) indicate that developed countries also face problems of improper sanitation.

One of the main reasons for this situation is the high costs of wastewater treatment methods and the excluded locations in the rural areas. The high-tech centralized wastewater treatment system could be very expensive (both in investment and operation). High investment is required to install the sewerage systems required, and the maintenance of these systems is also expensive.

Decentralized Wastewater Systems (DEWATS) may be defined as the collection, treatment, and disposal/reuse of wastewater from individual homes, clusters of homes, isolated communities, industries, or institutional facilities, as well as from portions of existing community at or near the point of waste generation (Tchobanoglous, 1995). A wide variety of onsite system designs exist from which to select the most appropriate for a given site. A criterion for selection of one design over another is protection of the public health while preventing environmental degradation or contamination with reduced cost of treatment by retaining water and solids near their point of origin through reuse.

Conventional septic tanks have been used as onsite sanitation system in residential areas in developing countries, including Thailand. Septic tanks are enclosed receptacles designed to collect used water from households and other public uses, such as, wastewater collected from toilets, laundry-use, and cooking. Most septic tanks are made out of watertight concrete or fibreglass. The septic tank systems are designed to separate settable solids, oils and greases from the wastewater before discharging it to leaching fields or pits (Metcalf and Eddy, 2003). Chemical oxygen demand (COD), biochemical oxygen demand (BOD), total Kjeldahl nitrogen (TKN), total suspended solids (TSS) and helminth eggs are partially removed through this process. The septic tank hardly produces a wastewater which reaches effluent standards. However, this treatment system is still widely used, because it is cost effective, energy-free, and requires low maintenance.

To improve the effluent of septic tanks, there are some upgrading techniques, such as, coupling the removing process with anaerobic filters or installing in-tank baffles. By integrating in-tank baffles, the solid retention time is increased, leading to a considerable improvement of the removal efficiencies (Langenhoff et al., 1999). The anaerobic process has been studied for treatment of the low-strength wastewater over the past decades.

In this study, the ultimate goal was to examine and monitor the treatment performance of upgraded conventional septic tanks by coupling in-tank baffles. The effects due to different numbers of baffles, hydraulic retention times (HRT) and the presence of anaerobic filter media on the treatment efficiency were investigated.

1.2 Objectives

The objective of this research study was to compare the treatment performance of the conventional septic tank system with upgraded septic tank systems, and to try to define the optimal operation conditions. The study focused on the following specific objectives:

- To investigate the feasibility of using baffled-septic tanks to treat toilet wastewater, and compare them to a conventional septic tank.

- To investigate and monitor the effects of hydraulic retention times (HRT), number of baffles, and anaerobic filter media on the treatment performances of the upgraded septic tanks compared to a conventional one. The removal efficiencies, in terms of COD, BOD, TS, TSS, TKN, TP, and faecal coliforms were determined.

1.3 Scope of study

The experiments were conducted by using laboratory-septic tank units located at the ambient laboratory and environmental research station of the Asian Institute of Technology (AIT). To achieve the above mentioned objectives, the scope of study was as follow:
Laboratory - scale experiments were conducted to investigate and monitor the operating conditions of septic tank units by varying HRT (1-2 days), numbers of baffles (2-3 baffles) and the presence of anaerobic filter media. The units were fed intermittently at the same flow rate throughout the day.
All septic tank units were fed with a mixture of Bangkok septage and AIT wastewater at the HRT of 24-48 hours. Each unit's removal efficiencies were investigated and analyzed with regard to the mass balance.

2 Literature review

2.1 Decentralized Wastewater Treatment System (DEWATS)

2.1.1 Centralized VS. Decentralized Wastewater treatment systems

In urban areas, wastewater is usually carried over via sanitary sewers to large-scale centralized treatment plants, which can satisfy all the requirements for safe and nuisance-free wastewater disposal. Unfortunately, complete sewerage is not possible or desirable for small communities through out the world. Due to their geographical locations and size, small communities located in the rural areas are faced with a variety of problems that make the construction and operation of community-wide managed wastewater facilities impossible. These problems are related to the stringent discharge requirements, high per capita cost, limited finances, and limited operation and maintenance budget. In Figure 2.1 shows that sewers are present only in a small part of urban areas in developing countries. The number of people without sewers is increasing because the population growth exceeds the provision of new sewer connections (Polprasert et al., 1982).

Figure 2.1 Urban sanitation in developing countries (Polprasert et al., 1982)

The small communities are also asked to provide the same degree of treatment that discharges effluent up to the same standards as the large communities. It is believed that the decentralized wastewater management concept will get more and more importance in the future. A number of new technologies have been introduced for small treatment systems that have made it possible to produce an effluent of the same quality, or even better, as compared to large treatment plants.

The concept of centralized wastewater treatment system is to have one system that treats wastewater for a whole area or city. Figure 2.2 illustrates the concept of centralized wastewater system. The concept of Decentralized Wastewater Treatment System (DEWATS) is to have a wastewater treatment systems as close as possible to the wastewater source (Figure 2.3).

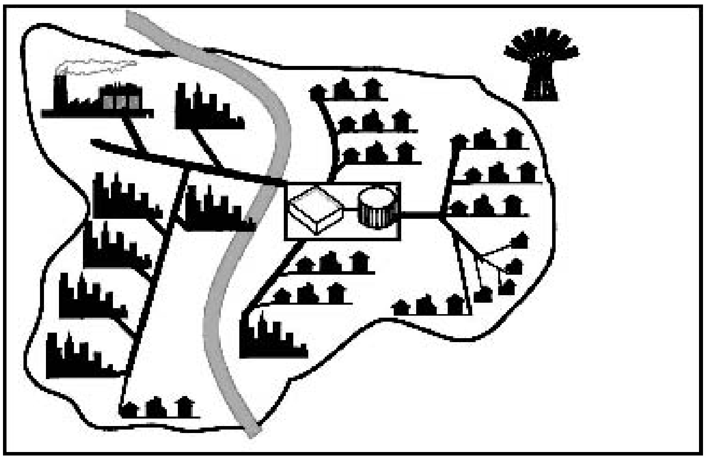


Figure 2.2: A centralized wastewater treatment system

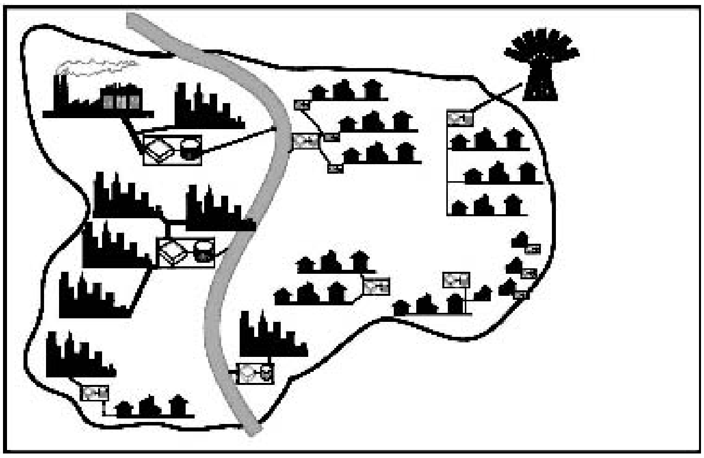


Figure 2.3: A DEWARS system

2.1.2 Existing situation of DEWATS and their treatment options

A number of old and new technologies have been introduced for decentralized wastewater treatment systems that have made it possible to produce an effluent of the same quality as compared to large treatment plants. Decentralized systems require limited funds for operation and maintenance. The development of these technologies has focused on technologies which require low operation and maintenance, and as little energy as possible (Crites and Tchonologous, 1998). There are many DEWATS options, such as conventional septic tanks and effluent screens, septic tanks with recirculating-trickling filters, combination of septic tanks with sand filters or soil absorption systems, grease interceptor tanks, Imhoff tank, disposal fields, disposal beds and pits, intermittent sand filters, recirculating granular-medium filters, shallow-trench and-filled pressure-dose disposal fields, mound systems, complete recycle units, grey water systems, and many others. The principal wastewater management options available for unsewered areas are shown in Table 2.1.

Table 2.1: Wastewater management options for unsewered (Metcalf and Eddy, 1991)

SOURCE OF WASTE-WATER	WASTEWATER TREATMENT AND/OR CONTAINMENT	WASTEWATER DISPOSAL
Residential areas: Combined wastewater Black water Grey water **Public facilities** **Commercial establishments** **Industries**	**Primary treatment:** Septic tank Imhoff tank **Secondary treatment:** Aerobic/anaerobic units Aerobic units are 1) Intermittent sand filter 2) Recirculating granular medium filter 3) Constructed wetlands **Onsite containment:** Holding tank Privy	**Subsurface disposal:** Disposal fields Seepage beds Disposal trenches Mound systems Evapotranspiration/percolation **Others:** beds/ponds Drip application Wetland (marsh) Discharge to water bodies

One of the most known and most used onsite system options is the septic tank system. The main advantage of the septic tank system is its flexibility and adaptability to a wide variety of individual household waste disposal requirements. Like other DEWATS, septic tanks have no moving parts and therefore, need little mechanical maintenance. However, there are some limitations. Since DEWATS systems require very little maintenance, as a result, many system failures occurred. The principal mode of failure has been a premature clogging of the infiltrative capacity of the disposal field, due to mismanagement and operation of the primary treatment unit – the septic tanks.

2.2 Conventional Septic Tanks

2.2.1 Introduction

Conventional septic tanks are used to receive wastewater discharged from individual residences, and other non-sewer facilities, for examples; toilet water, water used from cooking or bathing. While relatively simple in construction and operation, the septic tank provides a number of important functions through a complex interaction of physical and biological processes. The essential functions of the septic tank are as follow:

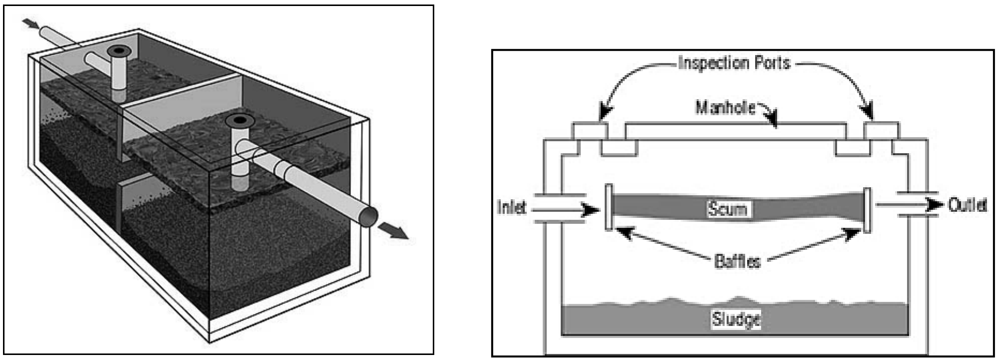
- To separate solids from the wastewater flow.
- To cause reduction and decomposition of accumulated solids.
- To provide storage for the separated solids (sludge and scum).
- To pass the clarified wastewater (effluent) out to a leaching field or pit.

Septic tanks (Figure 2.4a and 2.4b) provide a relatively quiescent body of water where the wastewater is retained long enough to let the solids, oils and greases separate by both settling and flotation. This process is often called a *primary treatment* and results in three products: scum, accumulated sludge (or *septage*), and effluent. These tanks serve as combined settling and skimming tanks, unheated unmixed anaerobic digesters, and as sludge storage tanks (Crites and Tchobanoglous, 1998). In some countries, the septic tank is followed by a soil absorption system, or another post-treatment unit. The organic material retained in the bottom of the tank undergoes facultative and anaerobic decomposition and is converted to more stable compounds and gases such as carbon dioxide (CO_2), methane (CH_4), and hydrogen sulphide (H_2S). The sludge that accumulates in the septic tank is composed primarily of ligneous material contained in toilet paper. While these materials will be eventually decomposed biologically, the rate is extremely slow, which accounts for the accumulation (USEPA, 1980).

In order to improve the treatment performance, an in-tank baffle is sometimes used to divide the tank, and access ports are provided to permit inspection and cleaning (Figure 2.5). Two compartments have been used to limit the discharge of solids in the effluent from the septic tank. Based on measurements made in both single and double compartments, the benefit of a two-compartment tank appears to depend more on the design of the tank. Currently, most houses in several cities of developing countries are equipped with septic tank or other on-site systems.

(a) (b)

Figure 2.4: Typical Conventional Septic Tanks: (a) Concrete type with reinforcing steel (under construction) and (b) fibreglass type (http://www.wieserconcrete.com)



(a) (b)

Figure 2.5: Schematic Typical Septic Tanks: (a) two-compartment tank and (b) a single compartment tank (http://www.septic-info.com)

The use of septic tanks can be traced back to the year 1860 in France (Crites and Tchobanoglous, 1998). Septic tanks are made out of concrete, steel, redwood or polyethylene, but the use of steel and redwood tanks is no longer accepted by most regulatory agencies. Polyethylene tanks are inferior to concrete and fibreglass tanks because they will deform after some years in operation. Today, most of the conventional septic tanks are made out of concrete or fibreglass. Fiberglas septic tanks are rather expensive. They are usually used in areas where concrete septic tanks cannot be installed. Regardless of the material of construction, a septic tank must be watertight and must be able to withhold the wastewater loads if it is to function properly; especially where subsequent treatment units such as intermittent or recirculating packed bed filters or pressure sewers are to be used.

2.2.2 Wastewater from a household

In order to properly treat wastewater, it is essential to understand the nature of the wastewater. There are 4 broad types of wastewater from the household, which can be characterized as follow (Winnerberger, 1969; Li et al., 2001):

1)	Greywater	washing water from kitchen, bathrooms, laundry, etc. without faeces and urine
2)	Blackwater	water from flush toilets (faeces and urine with flush water)
3)	Yellowwater	urine from separation toilets and urinals (with or without water for flushing)
4)	Brown water	black water without urine or yellow water

The strength of wastewater depends mainly on the degree of water dilution, which can be categorized as strong, medium, or weak, as shown in Table 2.2. These wastewater characteristics can vary widely with local conditions, hour of the day, day of the week, season, and type of sewers (either separate or combined sewers where storm water is included) (Polprasert, 1996). Table 2.2 shows typical characteristics of domestic wastewater, generally containing sufficient amount of nutrients (based on BOD_5/N/P ratio) suitable for biological waste treatment and recycling where microbial activities are used. Table 2.3 shows the wastewater characteristics from different household sources.

Table 2.2: Typical characteristics of domestic wastewater (Polprasert, 1996)

Parameters	Concentration (mg/l)		
	Strong	Medium	Weak
BOD_5	400	220	110
COD	1,000	500	250
Org-N	35	15	8
NH_3-N	50	25	12
Total N	85	40	20
Total P	15	8	4
Total Solids	1,200	720	350
Suspended solids	350	220	100

Table 2.3: Typical characteristics of domestic wastewater fractions (US EPA, 1980)

Parameters	Concentration (mg/l)	
	Black water	Grey water
BOD_5	280	260
SS	450	160
Nitrogen	140	17
Phosphorus	13	26

2.2.3 Design criteria for conventional septic tanks

As shown earlier in
Figure 2.5, some septic tanks are divided into two compartments by an in-tank baffle, and access ports are provided to permit inspection and cleaning. Two compartments are used to limit the discharge of solids in the effluent from septic tanks. Based on previous studies on both single and two-compartment tanks, the benefits of two-compartment tank appears to depend more on the design of the tank than on the use of two compartments (Metcalf and Eddy, 2003). A more effective way to eliminate the discharge of untreated solids involves the use of an effluent filter in conjunction with a single-compartment tank, as mentioned earlier. To provide highly efficient treatment capable of yielding effluent that is relatively free of oils and greases, solids and other constituents that can clog and foul collection and disposal equipment, tanks should be properly sized and constructed. To ensure sufficient capacity, Bounds (1997) suggested the operating requirements as follow:

1. HRT should range between 24-48 hours for normal use.

2. An operating zone should be sufficient to accommodate peak inflows without causing nuisance or excessive hydraulic gradients.

3. HRT should be sufficient for allowing oils and greases, and other settable materials to settle. HRT is based on average daily flows.

4. The space for storing sludge and scum must be big enough (Bounds, 1997).

5. Septic tank volume must be sized based on amount of wastewater to be handled (Centre et al., 1985)

There were reports that a single compartment tank usually provides acceptable performance, but a two-compartment tank is reported to perform better. One of the reasons for this is the trapping action of the second compartment. Hourly and daily flows from home can vary greatly. During high flow periods, compartment tanks can reduce the effect of peak loads.

Many rectangular septic tanks are known which are equipped with an interior baffle to divide the tank and access ports to permit inspection and cleaning. The larger chamber formed by the interior baffle typically contains about two third of the tank volume. This larger compartment should be situated immediately after the inlet. If the liquid capacity of the first compartment is less than that of the second compartment, it would result in a large flow, disrupting the sludge contained in the first compartment and causing wash-out into the second compartment. Furthermore, there were previous reports which suggested the benefit of dividing a septic tank into a multi-compartment tank to provide better BOD/COD removal efficiencies (Polprasert et al., 1982).
However, not all engineers agree about the two-compartment idea. From other reports, some had suggested that the divider in the tank actually limits the available surface area for scum and sludge accumulation, therefore reduce its removal efficiencies; and it could be more rational to place a baffle longitudinally to improve the removal of scum and sludge (Crites and Tchobanoglous, 1998).

2.2.4 Septic Tank Volume

It is important that septic tanks are sized based on the amount of wastewater to be handled. A factor of safety should be provided to allow variations in wastewater loading and future changes in the character of household wastewater. Oversized tanks will not be cost-effective and undersized ones will yield effluent discharges which may not reach the effluent's standards. Therefore, the first step of selecting the appropriate tank volume is to determine the average daily flows; however measurements will not be possible for buildings that are under construction. The design volume for household septic tanks can be based on the number of bedrooms and average number of persons per bedroom (Canter et al., 1985). Each septic tank's design could vary in different countries, and the way water is used to flush the toilet. For example, in Thailand, the minimum required household septic tank liquid volume is 1.5 m^3, and is calculated based on number of residents in the building; while in the USA and Europe; the volume requirement is calculated according to the number of bedrooms in the house, for example, the minimal septic tank volume is 750 gallons or 2.84 m^3 per one bedroom in USA (as shown in Table 2.10 and 2.11). It would not be very practical to use numbers of bedrooms to calculate septic tanks' sizes in developing countries because there could be more residents living in the same bedrooms comparing to those living in developed countries.

Table 2.4: Septic tank requirements in Thailand (PCD, 2003)

Number of residents	Amount of wastewater (m^3/d)		Septic Tank dimension recommended (m)			
	Old style toilet	Western-style toilet	Volume (m^3)	Depth (depth)	Width (m)	length (m)
5	0.1	0.3	1.5	1.00	0.90	1.70
5-10	0.2	0.6	2.0	1.00	1.00	2.00
10-15	0.3	0.9	2.5	1.25	1.00	2.00
15-20	0.4	1.2	3.0	1.25	1.10	2.20
20-25	0.5	1.5	3.5	1.25	1.20	2.40
25-30	0.6	1.8	4.0	1.40	1.20	2.40
30-35	0.7	2.1	4.5	1.50	1.20	2.50
35-40	0.8	2.4	5.0	1.60	1.20	2.60
40-45	0.9	2.7	5.5	1.60	1.30	2.60
45-50	1.0	3.0	6.3	1.60	1.40	2.80

Table 2.5: Single household unit septic tank liquid volume requirements (US EPA, 2003)

	FEDERAL HOUSING AUTHORITY	U.S. PUBLIC HEALTH SERVICE	UNIFORM PLUMBING CODE
Minimum (m^3)	2.84	2.84	2.84
1-2 bedrooms (m^3)	2.84	2.84	2.84
3 bedrooms (m^3)	3.41	3.41	3.79
4 bedrooms (m^3)	3.79	3.79	4.54
5 bedrooms (m^3)	4.73	4.73	5.68
Additional bedrooms (each, m^3)	0.95	0.95	0.57

There are various formulas, codes and standards which relate to the capacity of the septic tanks to the number of bedrooms per home, the number of users and the average daily flow of sewage.
Canter (1985) had suggested that a proper septic tank volume could be calculated using a simple formula that relates to the expected daily wastewater flow rate; or

$$V = 1{,}125 + 0.75Q \qquad \text{Equation 2.1}$$

Where: V = net volume of the tank (gallons, 1 gallon equals to 3.785l)
Q = daily wastewater flow (gallons/day)

Another general formula suggested in a paper review by Polprasert (1982), expressed in litres, calculated septic tank size as follow:

$$V = A + P(rq+ns) \qquad \text{Equation 2.2}$$

Where: V = net volume of the tank (litres)
A = constant, based on a code of practice
P = number of residents or users contributing to the tank
r = retention time (days)
q = wastewater flow (litres/person/day)
n = number of years between desludging
s = rate of sludge accumulation (litres/person/year)

There are other considerations when designing a septic tank, such as shape and dimension of the tank. As a rule of thumb, Crites and Tchobanoglous (1998) also suggested that the volumetric capacity of large septic tanks should be equal to about 5 times the average flow, and must be bigger than the minimal tank size requirement.

2.2.5 Shape of the tank

The shape of septic tanks also plays an important role on their treatment efficiencies. It influences the velocity of wastewater flowing through the tank, the way of sludge accumulation, and the separation of the solid-liquid-scum layers. A rectangular septic tank has been reported to be better than a square septic tank, while long narrow tanks are most satisfactory (Polprasert et al. 1982). A very deep tank would reduce the surface area, and reduce the sedimentation efficiency. Septic tanks with greater surface area and shallow depth are preferred, because it increases liquid surface area and increases surge storage capacity. Higher surface areas also allow a longer time for separation of the sludge and scum that could be mixed by turbulence resulting from the influent surge. Figure 2.8 shows typical shapes of septic tanks.

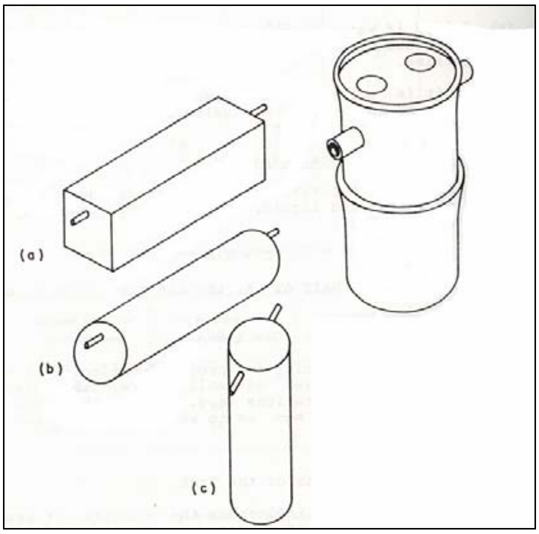


Figure 2.6: Typical shapes of septic tanks

2.2.6 Conventional septic tank biology

Septic tanks are passive low-rate anaerobic digesters, with their own ecosystem, in which facultative and anaerobic bacteria perform complex biochemical processes. The tank operates as a plug-flow type of reactor. There is no mixing or heating, particles ascend or descend and stratification develops. Effluent quality suffers when this stratification does not develop. The environment within the tanks' clear zone is generally anoxic, while sludge and scum layers may be completely free of oxygen (anaerobic). The inflow wastewater directed into the clear zone by the inlet fixture normally contains high levels of dissolved oxygen, and bacteria will rapidly deplete it (Bounds et al., 1997). Facultative bacteria solubilize complex organic material to volatile organic acids, while strict anaerobes ferment the volatile organic acids to gases (methane, carbon dioxide, hydrogen sulphide, etc.) Although hydrogen sulphide is produced in septic tanks, odours are not usually a problem because the hydrogen sulphide combines with the metals in the accumulated solids to form insoluble metallic sulphides. When long-term storage is allowed, the effectiveness of digestion within the layers of stored volatile solids can be as great as 80 percent (Metcalf and Eddy, 2003).

As mentioned earlier, the sludge that accumulates in the septic tank is composed primarily of ligneous material. While these materials will be eventually decomposed biologically, the rate is extremely slow (Crites and Tchobanoglous, 1998), which accounts for the accumulation. Even though the volume of the solid material being deposited is being reduced continually by anaerobic decomposition, there is always a net accumulation of sludge in the tank. Material from the bottom of the tank that is buoyed up by the adhesion of decomposition gases will often stick to the bottom of the scum layer, increasing its thickness. Long-term accumulation of scum and sludge can reduce the effective settling capacity of the tank. This is why it is important to have sludge removed from septic tanks periodically (Crites and Tchobanoglous, 1998).

2.2.7 Operational problems of the conventional septic tanks

Septic tanks are operated by feeding wastewater through the inlet pipe (the influent line). Settable solids in the wastewater will settle and form a sludge layer at the bottom of the tank, and consist of both organic and inorganic materials. After operating for a certain period of time, the semi-liquid materials or the septic tank sludge (septage) should be removed. Oil and grease and other light materials will float to the surface, where a scum layer is formed as floating materials. The settled and skimmed wastewater will flow between the scum layer and septage to the effluent line (Metcalf and Eddy, 2003).

Several problems have been found from the use of septic tanks. One of the most serious problems is effluent coming out from the tanks, with high solids, oil and grease contents. The carryover of solids, oils and greases in the septic tank effluent has led to a premature reduction in the hydraulic acceptance rate of leach fields or receiving water bodies. A later development in attempting to improve the effluent quality was to install an effluent filter, or anaerobic media into a septic tank (Figure 2.6). An effluent filter can range from 4 to 18 inches in diameter (Figure 2.7) and is installed at the end of the tank (Metcalf and Eddy, 2003).

Other operational problems are over-loading and waste overflow from the tank, lack of physical space, lack of facilities for off-site treatment, high water table, poor soil absorption capability, and lack of users' understanding (Crites and Tchobanoglous, 1998). Many households in developing countries, such as

Thailand, do not have enough land available for leach fields or pits, and do not have any treatment unit connected to the septic tanks. Many times the effluent is discharged into nearby natural water bodies, such as, rivers or canals, and open storm ditches, contaminating water sources. Therefore it is essential to find a way to upgrade septic tanks that would perform well enough to meet the effluent standards.

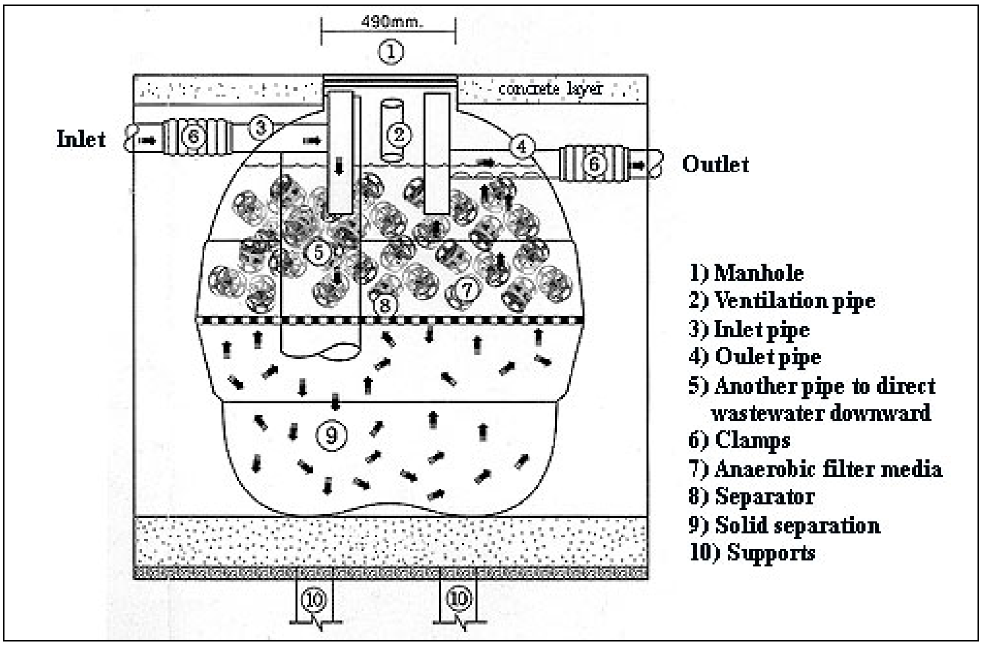


Figure 2.8: A modern septic tank that is used to treat household wastewater (http://www.ptthai.com)

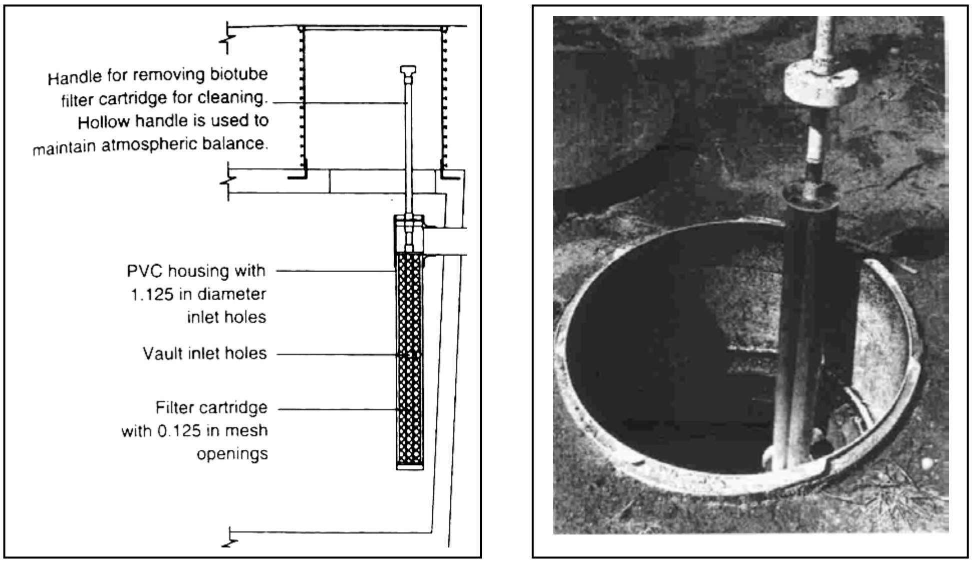


Figure 2.7: Effluent filter of the septic tank (http://www.cet.nau.edu)

2.2.8 Septage

Septage is generally defined as the liquid and solid material pumped from a septic tank or cesspool during cleaning. Septage is normally characterized by large quantities of grit and grease, a highly offensive odour, great capacity to foam upon agitation, poor settling and dewatering characteristics, a high solids and organic content. Its high waste strength is due to the accumulation of sludge and scum in the septic tank (Crites and Tchobanoglous, 1998).
Septage characteristics vary widely from one location to another. This variation is due to several factors, including: the number of people utilizing the septic tank and their cooking and water use habits; tank size and design; climatic conditions; pumping frequency; and the use of tributary appliances such as garbage grinders, water softeners, and washing machines. Knowledge of septage characteristics and variability is very important in determining the proper handling and disposal methods (Crites and Tchobanoglous, 1998).

Septage characteristics and generation rates were found to be widely varying in different literatures. Table 2.6 is a report of septage characteristics done by US EPA in 1984. This table summarizes septage characteristics in the U.S.A. and Europe/Canada. Characteristics of some septage in Asia are shown in Table 2.7 (Polprasert, 1996).

Table 2.6: Physical and chemical characteristics of septage, as found in the literature, with suggested design values [a,b] (US EPA, 1984)

Parameter	USA	Europe/Canada	EPA mean	Suggested design values
TS (mg/l)	34,106	33,800	38,800	40,000
TVS (mg/l)	23,100	31,600	25,260	25,000
TSS (mg/l)	12,862	45,000	13,000	15,000
VSS (mg/l)	9,027	29,900	8,720	10,000
BOD5 (mg/l)	6,480	8,343	5,000	7,000
COD (mg/l)	31,900	28,975	42,850	15,000
TKN (mg/l)	588	1,067	677	700
NH3-H (mg/l)	97	-	157	150
Total P (mg/l)	210	155	253	250
Alkal. (mg/l)	970	-	-	1,000
Grease (mg/l)	5,600	-	9,090	8,000
pH	-	-	6.9	6.0

[a] *Values expressed inmg/l, except for pH*

[b] *The data presented in this table were compiled from many sources. The inconsistency of individual data sets results in some skewing of the data and discrepancies when individual parameters are compared. This is taken into account in offering suggested design values.*

Table 2.7: Characteristics of septage in Asia (Polprasert, 1996)

Parameter	Japan	Bangkok, Thailand
TS (mg/l)	25,000–32,000	5,000–25,400
TVS (mg/l)	–	3,300–19,300
TSS (mg/l)	18,000–24,000	3,700–24,100
VSS (mg/l)	50–70% of TSS	3,000–18,000
BOD5 (mg/l)	4,000–12,000	800–4,000
COD (mg/l)	8,000–15,000	5,000–32,000
TKN (mg/l)	3,500–7,500	–
NH3-H (mg/l)	–	250–340
Total P (mg/l)	800–1,200	–
Total coliforms, (no/100mL)	800–1,200	–
F. coliforms,(no/100mL)	–	10^6–10^8
pH	7–9	7–8
Grit (%)	0.2–0.5	–

2.3 The anaerobic baffled reactor (ABR)

2.3.1 Introduction

One way to modify septic tanks is to install baffles, imitating an Anaerobic Baffled Reactor (ABR). Typically, an ABR consists of chambers in series. In each chamber, it has a vertical baffle to force wastewater to flow under and over it (as shown in Fig 2.9). The bacteria within the reactor tend to rise and settle with gas production, but move horizontally at a relatively slow rate. The wastewater can, therefore, come into contact with a large active biological mass as it passes through the ABR, and the effluent’s solid contents will be reduced through the process. The last chamber could have a filter in its upper part in order to retain flow-over solid particles. An ABR is easy to construct and inexpensive because there is no moving part or mechanical mixing device (Polprasert et al., 1992). The process of ABR was first used and described by Bachman (1983 and 1985) with strong synthetic wastewater (COD = 8,000mg/l), and was described as a series of UASB reactors (Sasse, 1998).

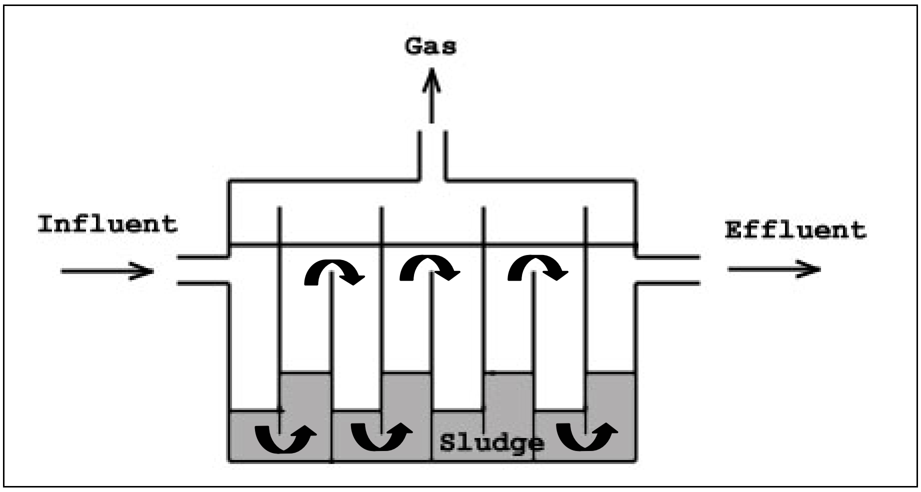


Figure 2.9: A four-chamber anaerobic baffled septic tank

Sasse (1998) described that an anaerobic baffled reactor operates with a combination of several anaerobic process principles - the three basic steps involved are: (a) hydrolysis, (b) fermentation, and (c) methanogenesis. The ABR is a fluidized bed reactor similarly to the upflow anaerobic sludge bed (UASB) process. Equal inflow distribution, and the wide spread contact between new and old substrate are important process features.

It is known that a three-chamber reactor, together with physical modifications, provided a longer solid retention time and superior performance than the reactor with only two compartments. Further analysis showed that despite losing more solids, the three-compartment reactor was more efficient at converting the trapped solids to methane (Barber and Stuckey, 1999). Therefore, it is recommended in many literature sources that the anaerobic baffled reactor should be equipped with at least 3 chambers. There is no absolute answer on which reactor is the absolute best. There are many factors to be considered, for examples, cost, land availability, wastewater characteristics, etc. Some reactors might work well in one particular situation, while the others do not.

2.3.2 Types of ABR

There are three common types of the ABR:

- ABR without anaerobic filter media
- ABR with media which is known as anaerobic filter (AN/F)
- ABR with media at the upper or lower part of each chamber, or only at the final chamber which is known as hybridized anaerobic baffled reactor (HABR) (Kemmadarong, 1992).

Boopathy et al. (1988) found out that the ABR shows advantages of stability with a large void volume, as well as reducing the risk of clogging and sludge bed expansion with the resulting microbial loss. COD removal of up to 90% were observed, and methane production rates exceeded 4 volumes per day per unit volume of reactor.

2.3.3 Treatment of wastewater by ABR systems

Typical domestic wastewater is usually diluted. This leads to a low mass transfer driving force between biomass and substrate, and subsequently biomass activities will be greatly reduced according to Monod Kinetics. As a result, treatment of low strength wastewaters has been found to encourage the dominance of scavenging bacteria such as *Methanosaeta* in the ABR (Polprasert et al., 1992).

It appears that biomass retention is enhanced significantly to lower gas production rates. This suggests that low hydraulic retention times (2-6 hours) can be applied for low strength wastewater treatment. The decreasing of overall gas production while HRT is increased could be a result of biomass starvation in later compartments (chambers) at longer detention times (Orozco, 1988). Barber and Stuckey (1999) recommended that baffled reactors should be started-up with higher biomass concentrations in order to obtain a sufficiently high sludge blanket and better gas mixing in a short time. Fig 2.10 shows the reactors' COD removal efficiencies against different organic loading rates (OLR).

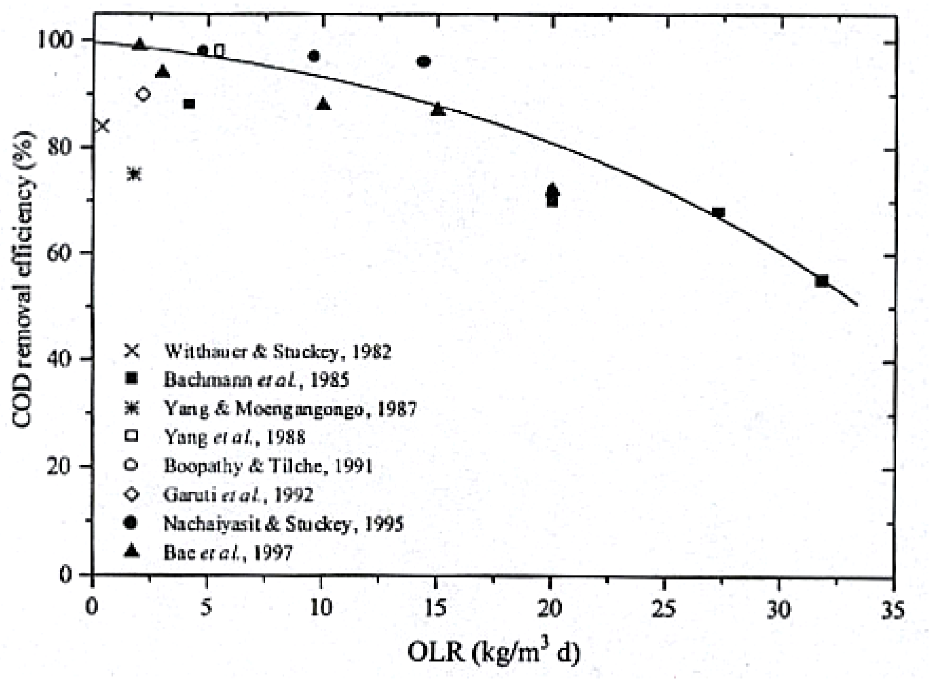


Figure 2.10: COD removal efficiencies versus different organic loading rates (OLR) observed in previous studies (Barber and Stuckey, 1999)

ABR systems have shown to effectively treat low-strength synthetic wastewater, such as greywater (Manariotis et al., 2002), wastewater from slaughter house (Polprasert et al., 1992), and domestic or municipal wastewater (Tosonis et al., 1994; Orozco et al., 1997). COD removal of ABR units can vary between 60-90%. There were different numbers of baffles used in these studies, ranging from two to eleven chambers. Many times, the chambers were filled with packing filter materials, yielding a modified ABR system.

2.3.4 Advantages and limitations of using an aerobic baffled reactor

Barber and Stuckey (1999) summarized the main advantages over other wastewater treatment systems as follow:

Construction:
- Simple design
- No moving parts
- No mechanical mixing
- Inexpensive to construct
- High void volume
- Reduced clogging risk
- Reduced sludge bed expansion
- Low capital and operating costs

Biomass:
- Adapted to biomass with unusual settling properties
- Low sludge generation
- High solids retention times
- Retention of biomass without fixed media or additional solid-settling chamber

Operation:
- Low HRTs possible
- Intermittent operation possible
- Extremely stable to hydraulic and organic shock loads
- Protection from toxic materials in influent
- Long operation times without sludge wasting

The anaerobic baffled septic tank is simple to build and simple to operate. Hydraulic and organic shock loads have little effect on the treatment efficiency (Sasse, 1998). The reactor also has good solids retention, low bed bypass; requires low maintenance and operational attentions. The ABR process avoids the limitations of systems such as the anaerobic filter and UASB (especially, the risk of clogging and sludge bed expansion is minimized) and maintains a high void volume (without the need for filter media) (Manariotis et al., 2002).

Despite these many potential advantages, the aerobic baffle reactor must be shallow in order to maintain acceptable liquid and gas upflow velocities. It seems difficult to maintain an even distribution of the influent (Tilche and Vieira, 1991). Moreover, there are not many studies on replacing septic tanks with ABR systems to treat domestic wastewater. More research needs to be done before it can be decided whether or not the ABR technology is a real option for the treatment of domestic wastewater in developing countries.

3 Methodology

3.1 Wastewater Source

The objective of this research study was to investigate the appropriateness of the upgraded septic tanks or ABR to treat toilet wastewater, or black water from households.

For the purpose of the study Bangkok septage was mixed with AIT wastewater to the desired range of influent concentrations (approximately at 1:10 ratio), to represent black water. This mixture of wastewater was used for all experimental treatment units. The septage was brought from Bangkok area, and stored at the Environmental Engineering Research Station collection tank, AIT. Characteristics of Bangkok septage and AIT wastewater are presented in Table 3.1.

Table 3.1: Characteristics of Bangkok septage and AIT wastewater

Parameters	Septage*	Bangkok Septage**	AIT wastewater
		Range	Range
COD (mg/l)	5,000	13,900-24,900	90-120
COD:BOD ratio	8:1 - 5:1	3:1-5:1	1:1.5-1:3
COD filtered (mg/l)	n/a	340-940	35-60
NH4-N (mg/l)	157	250-1080	15-40
TS (mg/l)	38,800	15,500-21,600	20-100
SS (mg/l)	13,000	4,800-10,300	10-80
TKN (mg/l)	677	610-1740	610-1070
pH	6.9	7.4-8.3	7.0-8.2

**Source: Crites and Tchobanoglous, 1998.*
***Both Bangkok septage and AIT wastewater's characteristics were based on 40 samples.*

3.2 Experimental setup

The laboratory-scale experiments were carried out at the Environmental Engineering Laboratory, at Asian Institute of Technology (AIT), Pathumthani Province, Thailand. The laboratory-scale units shown in Figure 3.1 - 3.4, were made out of clear acrylic plastic with a total volume of 64 litres. in each tank. Each laboratory-scale treatment unit has a dimension of 64 cm long, 40 cm tall and 25 cm deep. The down-flow chambers are 3.0 cm above the reactor's bottom to route the flow to the centre of the up-flow chamber to achieve better contact and greater mixing of feed and solids. The liquid surface height is 4 cm above the overflow baffle. The total liquid volume of each septic tank unit is approximately 40 litres. The liquid volume of each down-flow chamber is 1.95 litres (Figure 3.1-3.4). The influent was fed to each reactor by a peristaltic pump. The experimental setup is shown in Figure 3.2. There are four sets of experimental reactor setups: a three-baffled septic tank is shown in Figure 3.1.

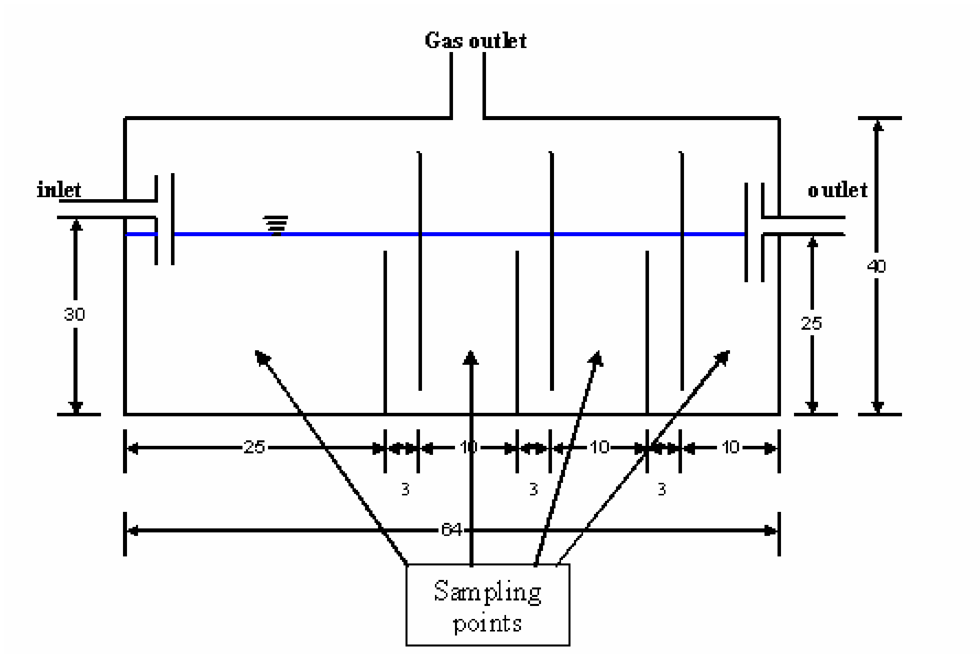
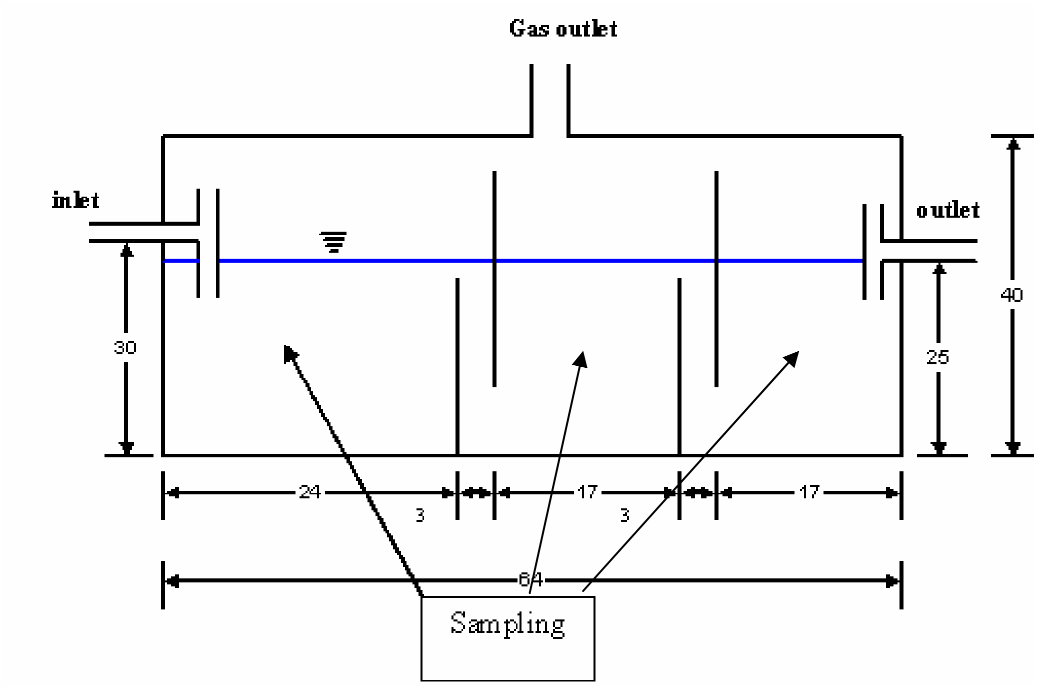


Figure 3.1: Setup of a three-baffled septic tank

A two-baffled septic tank is shown in Figure 3.2. It has two sets of in-tank baffles and 40 litres of liquid volume.



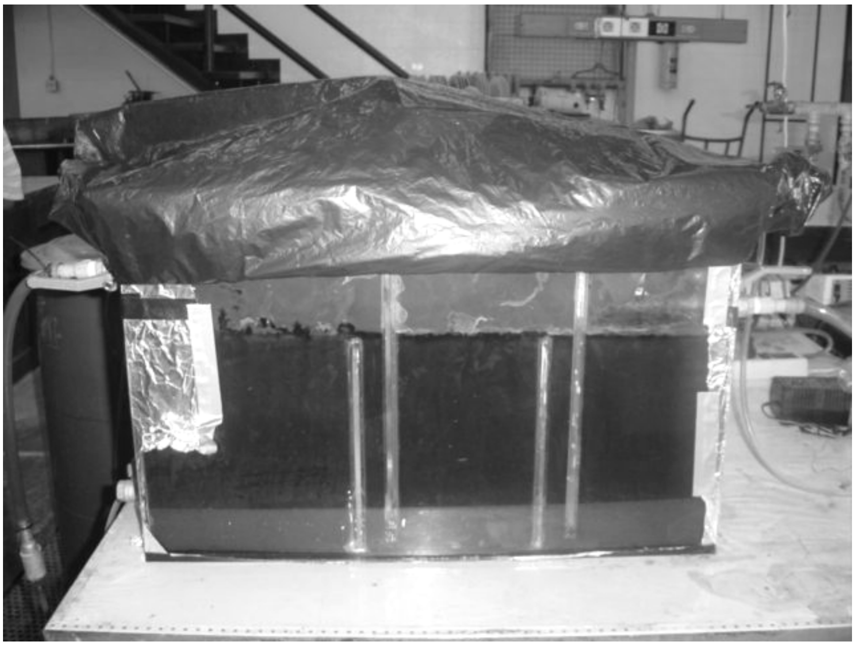


Figure 3.2: Setup of a two-baffled septic tank

A two-baffled septic tank with anaerobic filter media is shown in Figure 3.3. This unit also has two sets of in-tank baffles with commercial anaerobic filter media. The media used is a commercial media with surface area per volume of 240 m^2/m^3. 100 pieces of media were installed in the last chamber of the two-baffled septic tank.

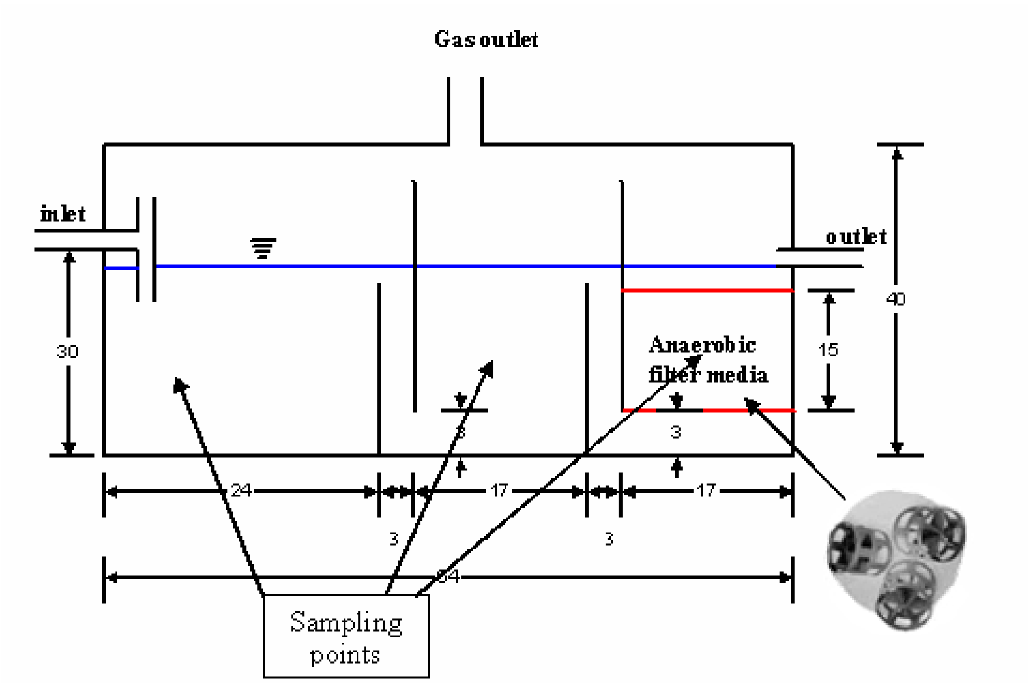


Figure 3.3 Setup of a two baffled septic tank with anaerobic filter media

Figure 3.4 shows the set up of conventional septic tank. The first compartment is approximately 2/3 of the tank volume.

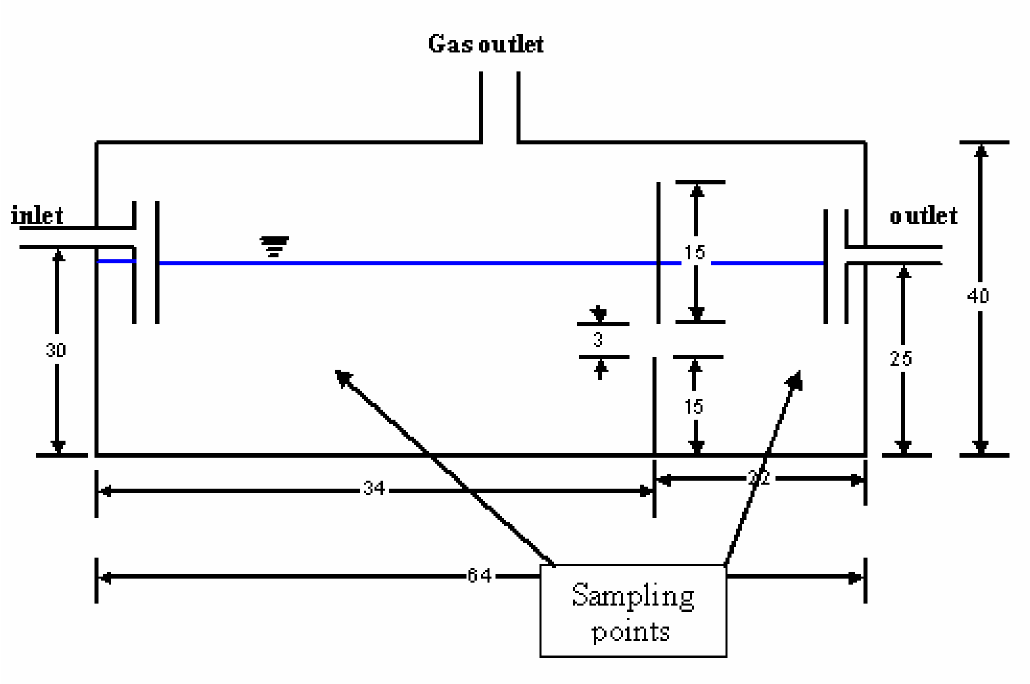


Figure 3.4 Schematic drawing of a conventional septic tank and its setup in the laboratory

The performance of each reactor was evaluated by the determination of the influent and effluent concentration and characteristics in terms of pH, COD, BOD_5, TS, TSS, TKN, solid accumulation, amount of gas collected, gas composition, and faecal coliforms. All reactors were covered with aluminium foil to prevent light penetration.

3.3 Experimental Conditions

The experimental setup of the four septic treatment units (Figures 3.5 and 3.6) was used for the intermittent experiment. To observe and determine the optimal removal efficiencies condition, influent and effluent samples were collected periodically according to the different hydraulic retention times (HRT) through out the experiment. The treatment units were subjected to changes of organic loading rate (OLR) and number of baffles installed in the tanks. HRT of 48 hours was chosen as the first operation condition. Barber et al. (1998) suggested that anaerobic treatment should be operated with lower OLR and high HRT during the acclimatisation phase. Once the steady state has been reached, the conditions can be varied. Table 3.2 shows the different operating conditions of this experiment.

Table 3.2: Operation conditions of experimental setup

Operating Conditions	Range
- Flow, L/d	- 80 L/d (constant)
- HRTs, days - HRT = 48 hours - Intermittent feed for 15 min of every hour. - HRT = 24 hours - Intermittent feed for 30 min of every hour.	- 24 and 48 hours
- OLRs , kgCOD/m^3/day	- Depending on the COD concentration of the influent.

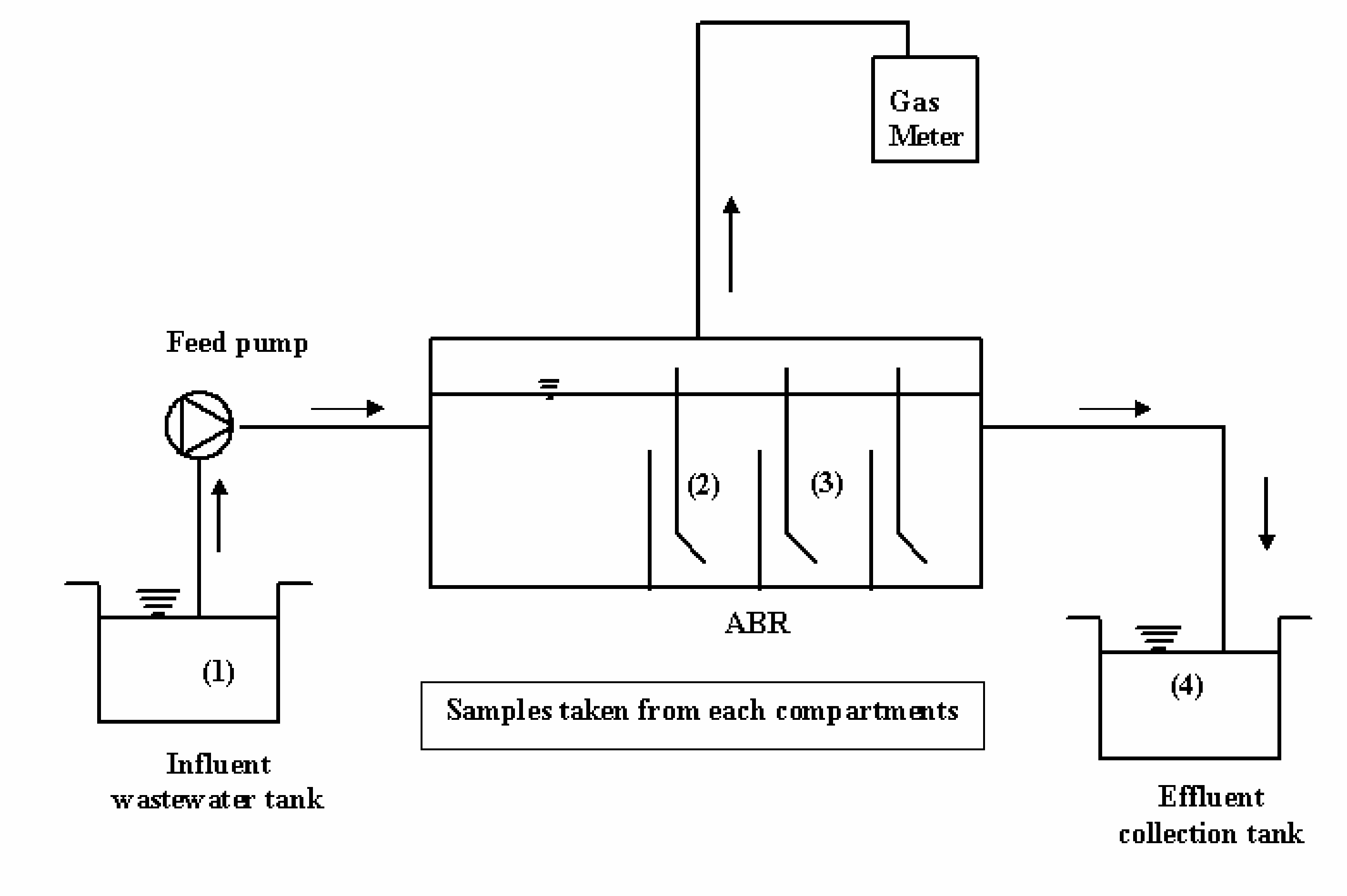


Figure 3.5: Schematic drawing of the experimental setup. Note: 1, 2, 3 and 4 are sampling points.

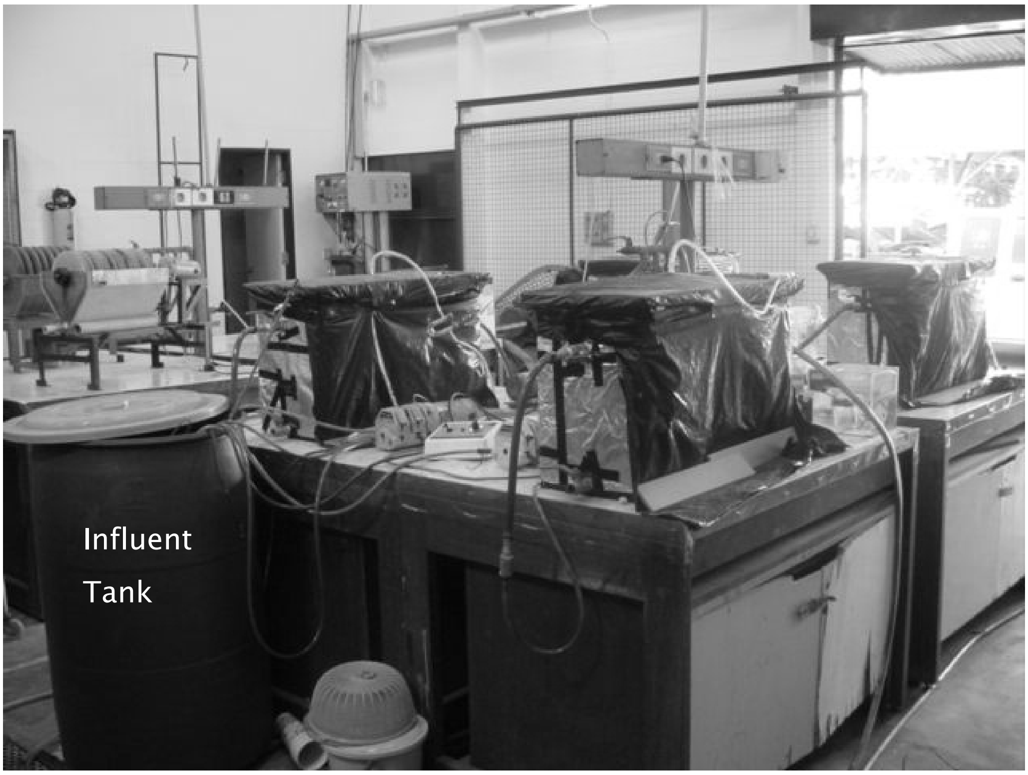


Figure 3.6: Septic tank units setup in the SERD laboratories

3.4 Solid mass balance

The mechanisms of TS removal in the treatment units were evaluated by studying the mass balance of amount of TS in the effluent, amount of sludge formed inside the treatment tank and amount of TS in the influent. A mass balance of TS removal is given in Equation 3.2

$$TSinf = TSeff + TSaccumulated + TSin\text{-}tank + TSunaccounted \qquad \textit{Equation 3.1}$$

Where:

TS_{inf} = TS in the influent, g
TS_{eff} = TS in the effluent, g
$TS_{accumuated}$ = TS accounted sludge settling in the tanks, g
$TS_{in\text{-}tank}$ = TS in the liquid part inside the tank, g
$TS_{unaccounted}$ = TS that is unaccounted for, g

$TS_{accumuated}$ was calculated from measuring the height of sludge accumulated in each compartment inside the tank, and total volume of sludge accumulated in the tank was identified. The amount of sludge inside the tank was calculated by multiplying total sludge volume with the sludge's density. The total solid accumulated in the tank was finally calculated by multiplying percentage of total solids with the amount of sludge calculated earlier.

The $TS_{in-tank}$ was calculated by measuring the TS concentration from the samples taken from sampling ports at different compartments, as shown in Figure 3.5. After TS concentrations inside the tank were identified, the amount of TS in the liquid part was calculated by multiplying TS concentration with the liquid volume of that compartment. TS concentrations of the first compartment were assumed to be equal to the TS concentration of the influent, and TS concentrations of the last compartment were assumed to equal to the TS concentration of the effluent.

3.5 Sedimentation Test

Particles in the relatively dilute solutions will not act as discrete particles but will coalesce during sedimentation. As coalescence or flocculation occurs, the mass of the particle increases, and it settles faster. The extent to which flocculation occurs is dependent on the opportunity for contact, which varies with the over flow rate, the depth of the basin, the velocity gradients in the system, the concentration of particles, and the range of particle sizes (Crites and Tchobanoglous, 1998).

In order to determine the settling characteristics of a suspension of particles, a settling column was used. The column was 10cm. in diameter, and had a height of 2m. Sampling ports were inserted at a 1ft (0.3m) interval. Figure 3.7 shows the settling column used in this experiment. The wastewater was introduced into the column in such a way that a uniform distribution of particle sizes occurs from top to bottom. At various time intervals, samples were taken from the sampling ports and analyzed for the suspended solids (SS). The removal percentage was computed for each sample analyzed and plotted as a number against time and depth (Figure 3.8), as elevations was plotted on a survey grid. Curves of equal removal percentage were drawn.
In this study, a column with a diameter of 10 cm. and height of 2 m was used. The used influent had an average TSS concentration of 1,760mg/l. At the beginning, suspended solid particles were uniformed through out the column. At the end point, most solids settled at the bottom of the column, and water became clearer.

Samples were taken from sampling ports every two minutes and analyzed. The removal percentage was computed for each analyzed sample and plotted as a number against time and depth. Between the plotted points, curves of equal removal percentage were drawn, as shown in Figure 3.8.

Figure 3.7: A settling column

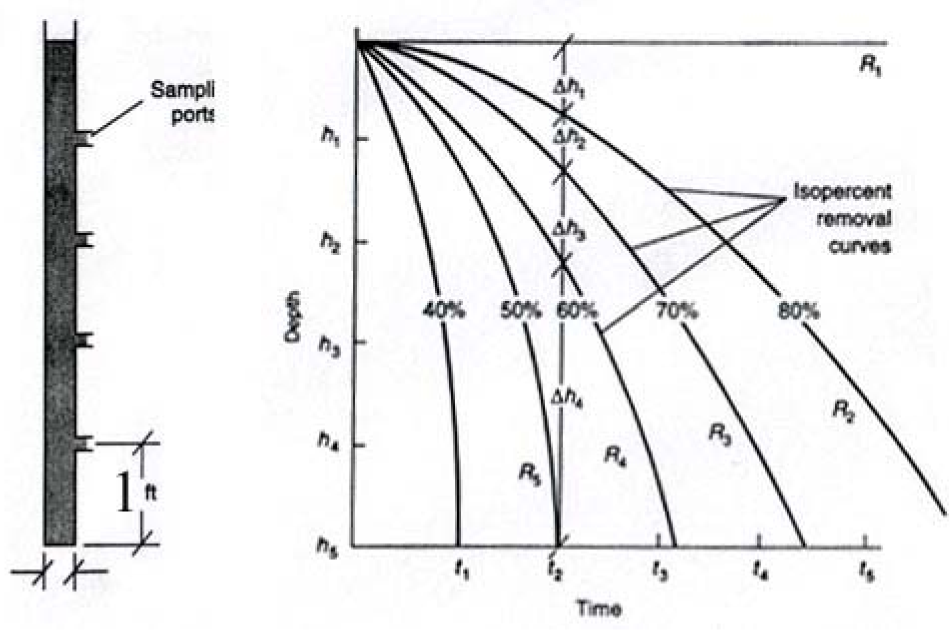


Figure 3.8: Schematic diagram for the analysis of flocculant settling (Crites and Tchobanoglous, 1998)

3.6 Sampling points of the treatment units

In order to investigate each chamber's performance, three samples of wastewater were taken and analyzed for each unit's removal efficiencies every 24-48 hours. The sampling points are shown in Figure 3.1-3.4. Parametric analysis included measuring COD, BOD, TSS, VSS, TKN, pH, amount of gas collected, amount of solids accumulated, and faecal coliforms.

3.6.1 Analytical methods

Effluent samples taken from the treatment units were compared to a treatment unit that represents a conventional septic tank. Chemical and physical parameters of the influent and effluent samples were analyzed according to the methods described in "Standard Methods" (APHA, AWWA, WEF, 1998) as shown in table 3.3.

Table 3.3: Parameters and analytical methods following Standard Methods for the examination of water and wastewater (APHA, AWWA and WPCF, 1998)

Parameters	Methods of analysis
pH	pH meter
COD (mg/l)	Closed dichromate reflux
BOD_5 (mg/l)	Azide Modification
TSS (mg/l)	Evaporation
VSS (mg/l)	Evaporation/Burning
TKN (mg/l)	Macro Kjeldahl
Alkalinity (mg/l)	Titration
Faecal coliforms (MPN/100mL)	Multiple-tube fermentation
Gas volume (L)	Gas meter
Gas composition	Gas chromatography
Amount of sludge (g.)	Scale

3.6.2 Gas composition

The composition of the biogas was analyzed by a gas chromatography which was equipped with a thermal conductivity detector and a steel column packed with Propak Q (80/100 mesh). Helium was used as the carrier gas at 30 ml/min and the oven temperature was kept at 50 °C. The gas samples, taken from all treatment units with gastight syringes were analyzed in terms of CH_4, CO_2, and N_2+ O_2, etc. CH_4 percentage in the biogas was determined using a gas chromatograph instrument (Shimadzu CD-15 A) fitted with a thermal conductivity detector.

4 Results and Discussion

4.1 Overall characteristics of the influent

A mixture of Bangkok septage and AIT wastewater were mixed at 1:10 ratio, and fed to each treatment unit. The influent characteristics are shown in Table 4.1.

Table 4.1: Characteristics of influent used during the research study

PARAMETERS	RANGE	AVERAGE	STANDARD DEVIATION
COD,mg/l	640-3,000	1,968	615
$COD_{filtered}$,mg/l	42-205	112	50
BOD,mg/l	200-1,200	625	194
TS,mg/l	826-1,924	1,284	343
TSS,mg/l	340-1,860	1,351	360
[a]Alkalinity,mg/l	240-450	280	37
pH	7.4 - 8.5	8.2	1.3
[a]TKN,mg/l	42-89	56	22
[a]TP,mg/l	27-70	50	15
[a]Faecal coliforms, MPN/100mL	$2.4x10^5$ - $7x10^5$	5×10^5	

Note: Values are based on 60 samples.
[a] Values are based on 20 samples.

4.2 Treatment performance

4.2.1 The three-baffled septic tank

At a HRT of 48 hours, the effluent COD concentration of the three-baffled septic tank unit ranged from 105 to 426mg/l, with an average concentration of 292mg/l. At this operating condition, the average COD removal was 84% (see Appendix 1.1). At a HRT of 24 hours, the effluent COD concentration ranged from 157 to 305mg/l, and the average COD concentration in the effluent was 234mg/l. At this operating condition, the average COD removal was 89%. Even at higher COD loading rates, effluent COD concentrations did not vary much.

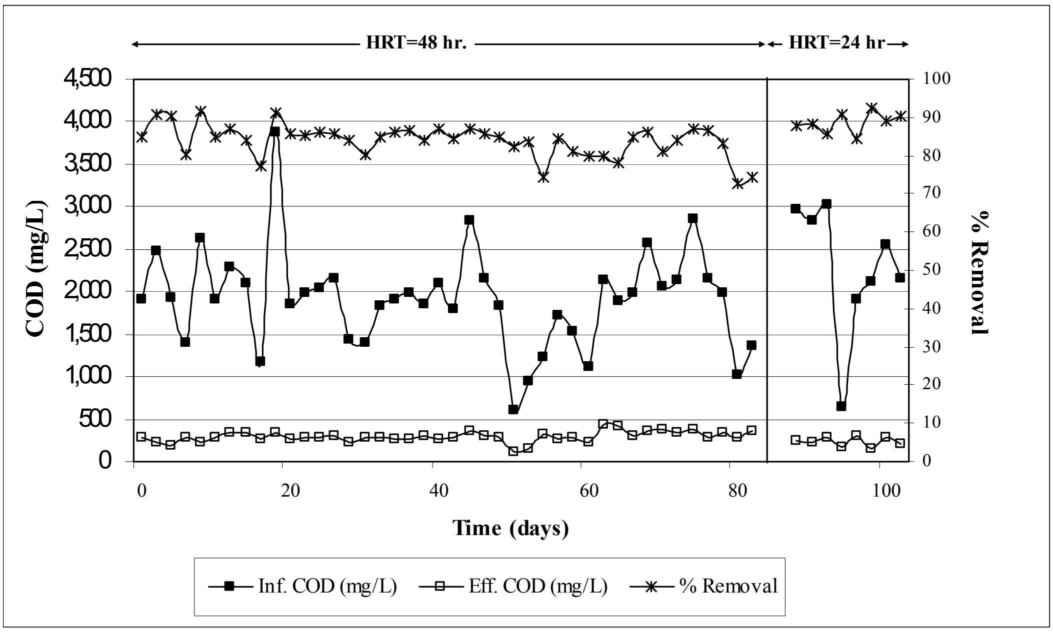


Figure 4.1: COD removal in the three-baffled septic tank

Figure 4.1 shows the COD removal efficiency of the three-baffled septic tank when operating at different HRTs. It suggests that at different HRTs, the three-baffled septic tank performance did not change much. Other parameters show similar trends as the one indicated in Figure 4.1.

Considering TS removal, at a HRT of 48 hours, the effluent TS concentration of the three-baffled septic tank unit ranged from 226 to 876mg/l, with an average concentration of 443mg/l. At this operating condition, the average TS removal efficiency was 65%. At a HRT of 24 hours, the effluent TS concentration ranged from 455 to 913mg/l, with an average TS concentration of 731mg/l. The average TS removal was 54%. With higher loads of TS, the removal efficiency fell by 11% (see Table 4.2 and Appendix 1).

Considering BOD removal, at a HRT of 48 hours, the effluent BOD concentration of the three-baffled septic tank unit ranged from 29 to 125mg/l, with an average concentration of 80mg/l. At this operating condition, the average BOD removal was 86%. At a HRT of 24 hours, the effluent BOD concentration ranged from 54 to 265mg/l, with an average concentration of 188mg/l. At this operating condition, the average BOD removal was 75%. With higher loads of BOD, the removal efficiency dropped by 11%.

Considering TSS removal, at a HRT of 48 hours, the effluent TSS concentration of the three-baffled septic tank unit ranged from 62 to 302mg/l, with an average TSS concentration of 131mg/l. At this operating condition, the average TSS removal was 73%. At a HRT of 24 hours, the effluent TSS concentration ranged from 109 to 407mg/l, with an average TSS concentration of 244mg/l. At this operating condition, the average TSS removal was 80%. With higher loads of TSS, the removal efficiency did not go down, but went up by 7%, suggesting the feasibility of using a three-baffle septic tank with higher hydraulic loading rates.

Considering TKN removal, at a HRT of 48 hours, the effluent TKN concentration of the three-baffled septic tank ranged from 27 to 30mg/l with an average of 28mg/l. At this operating condition, the average TKN removal was 45%. At a HRT of 24 hours, the effluent TKN concentration ranged from 39 to 41mg/l, with an average TKN concentration of 40mg/l. At this operating condition, the average TKN removal was 40%. With higher loads of TKN, the removal efficiency fell by 5%.

Considering TP removal, at a HRT of 48 hours, the effluent TP concentration of the three-baffled septic tank ranged from 22 to 24mg/l with an average of 23mg/l. At this operating condition, the average TP removal was 62%. At a HRT of 24 hours, the effluent TP concentration ranged from 40 to 44mg/l, with an average concentration of 42mg/l. At this operating condition, the average TP removal was 30%. The decrease of the HRT from 48 to 24 hours resulted in a bisection of the TP removal efficiency.

During this experiment, pH and Alkalinity were measured daily. The range of the effluent pH was from 7.1 to 7.9, with an average pH equals to 7.4. Compared to the average influent pH which was 7.9, the pH dropped by an average of 0.5. The range of effluent alkalinity was from 240 to 420mg/l as $CaCO_3$, with the average effluent alkalinity equals to 282mg/l as $CaCO_3$. The average influent alkalinity was 283mg/l as $CaCO_3$. There was no significant change in alkalinity during the process.

Values of pH presented here are close to neutral pH, which is optimal for the anaerobic process. Alkalinity is the ability to neutralize acid. Alkalinity values that are usually found in most anaerobic processes range between 1,000-5,000mg/l as $CaCO_3$ (Metcalf and Eddy, 2003). Although alkalinity measured from influent and effluent samples were lower than the values observed b y Metcalf and Eddy (2003), the pH values of the effluent observed indicate that the condition inside the reactor was, indeed, suitable for anaerobic processes.

The characteristics of effluent collected from a three-baffled septic tank are present in Table 4.2 as follow.

Table 4.2: Effluent characteristics of the three-baffled septic tank

PARAMETERS	RANGE	AVERAGE
COD,mg/l	105-426	283
$COD_{filtered}$,mg/l	53-102	65
BOD,mg/l	29-265	97
TS,mg/l	266-876	631
TSS,mg/l	62 - 407	149
[a]Alkalinity,mg/l as $CaCO_3$	240-420	282
pH	7.1 - 7.9	7.4
[a]TKN,mg/l	27-47	34
[a]TP,mg/l	9-44	22
[a]Faecal coliforms, MPN/100mL	8.0×10^4 - 5×10^5	3.0×10^5

Note: Values are based on 60 samples.

[a] Values are based on 20 samples.

4.2.2 The two-baffled septic tank

At a HRT of 48 hours, the effluent COD concentration of the two-baffled septic tank unit ranged from 90 to 418mg/l, with an average COD concentration of 260mg/l. At this operating condition, the average COD removal was 85%. At a HRT of 24 hours, the effluent COD concentration ranged from 206 to 976mg/l, with an average COD concentration of 735mg/l. At this operating condition, the average COD removal was 72% (see Table 4.3). The removal efficiency decreased as the HRT decreased by an average of 13%. Figure 4.2 shows the COD removal by the two-baffled septic tank. TS, BOD, TSS removal had similar trends as the one presented in Figure 4.2.

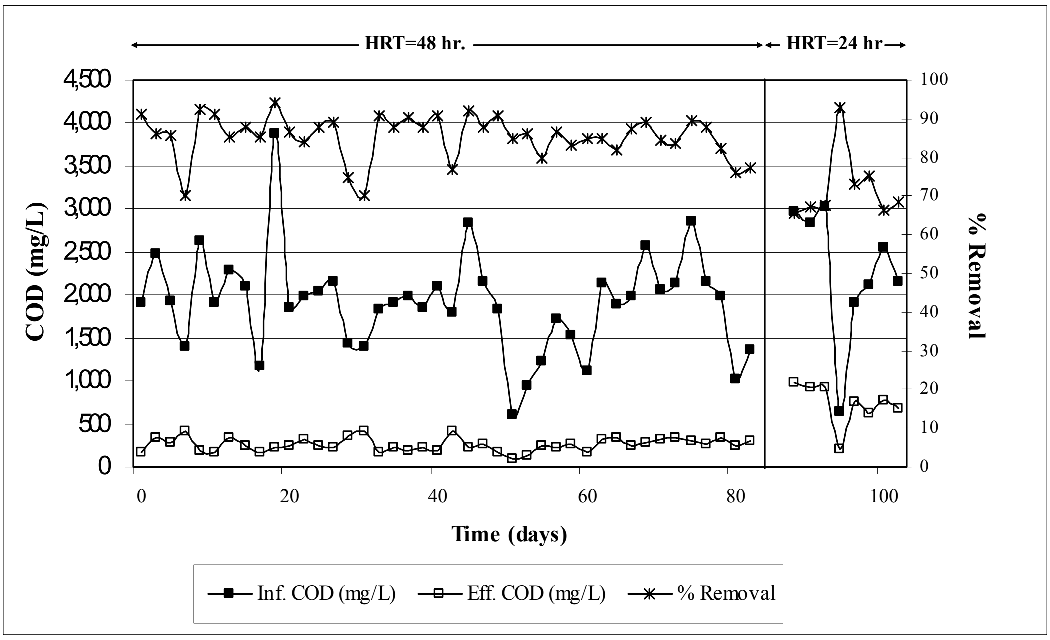


Figure 4.2: COD removal in the two-baffled septic tank

Considering TS removal, at a HRT of 48 hours, the effluent TS concentration of the three-baffled septic tank unit ranged from 169 to 730mg/l, with an average TS concentration of 416mg/l. At this operating condition, the average TS removal was 67%. At a HRT of 24 hours, the effluent TS concentration ranged from 530 to 1,170mg/l, with an average TS concentration of 855mg/l. At this operating condition, the average TS removal was 47%. By doubling the loads of TS, the removal efficiency dropped by 20% (see Table 4.3).

Considering BOD removal, at a HRT of 48 hours, the effluent BOD concentration of the two-baffled septic tank unit ranged from 35 to 130mg/l, with an average BOD concentration of 76mg/l. At this operating condition, the average BOD removal was 86%. At a HRT of 24 hours, the effluent BOD concentration ranged from 60 to 276mg/l, with an average concentration of 213mg/l. At this operating condition, the average BOD removal was 71%. By doubling the BOD loading rates, the removal efficiency dropped by 15%.

Considering TSS removal, at a HRT of 48 hours, the effluent TSS concentration of the two-baffled septic tank unit ranged from 25 to 185mg/l, with an average TSS concentration of 70mg/l. At this operating condition, the average TSS removal was 86%. At a HRT of 24 hours, the effluent TSS concentration ranged from 215 to 872mg/l, with an average concentration of 579mg/l. At this operating condition, the average TSS removal was 55%. The removal efficiency went up by 31% by doubling the loading rates of TSS.

Considering TKN removal, at aHRT of 48 hours, the effluent TKN concentration of the three-baffled septic tank ranged from 26 to 30mg/l with an average of

28mg/l. At this operating condition, the average TKN removal was 44%. At a HRT of 24 hours, the effluent TKN concentration ranged from 65 to 69mg/l, with an average TKN concentration of 68mg/l. At this operating condition, the average TKN removal was 14%. By doubling the loads of TKN, the removal efficiency dropped by 30%.

Considering TP removal, at a HRT of 48 hours, the effluent TP concentration of the two-baffled septic tank ranged from 17 to 22mg/l with an average of 24mg/l. At this operating condition, the average TP removal was 47%. At a HRT of 24 hours, the effluent TP concentration ranged from 29 to 31mg/l, with an average TP concentration of 30mg/l. At this operating condition, the average TP removal was 50% (see Table 4.3). The impact of the HRT on the TP removal efficiency seem no to be important in the range of 24-48 hours.

The range of effluent pH was from 6.9 to 7.7, with an average pH of 7.3. The range of effluent alkalinity was from 245 to 440mg/l as $CaCO_3$, with an average effluent alkalinity equals to 286mg/l as $CaCO_3$. The pH of the effluent collected from two-baffled septic tank did not drop below neutral, and was suitable for an anaerobic activity. The removal efficiencies of the different parameters were not significantly different between the two- and the three-baffled septic tanks.

Table 4.3: Effluent characteristics of the two-baffled septic tank

PARAMETERS	RANGE	AVERAGE
COD,mg/l	90-976	336
$COD_{filtered}$,mg/l	19-69	38
BOD,mg/l	35-276	98
TS,mg/l	169-1,170	486
TSS,mg/l	25-872	151
[a]Alkalinity,mg/l as $CaCO_3$	245-440	286
pH	7.1 - 7.9	7.4
[a]TKN,mg/l	39-69	49
[a]TP,mg/l	7-31	17
[a]Faecal coliforms, MPN/100mL	5.0×10^4 - 3×10^5	2.2×10^5

Note: Values are based on 60 samples.

[a] Values are based on 20 samples.

4.2.3 The two-baffled septic tank with anaerobic filter media

At a HRT of 48 hours, the effluent COD concentration of the two-baffled septic tank with anaerobic filter unit ranged from 105 to 347mg/l, with an average concentration of 235mg/l. At this operating condition, the average COD removal was 87%. At a HRT of 24 hours, the effluent COD concentration ranged from 198 to 701mg/l, with an average COD concentration of 520mg/l. At this operating condition, the average COD removal was 80%. With higher COD loading rates, removal efficiency dropped by 7% (see Table 4.4).

Considering TS removal, at a HRT of 48 hours, the effluent TS concentration ranged from 168 to 783mg/l, with an average concentration of 404mg/l. At this operating condition, the average TS removal was 68%. At a HRT of 24 hours, the effluent TS concentration ranged from 557 to 1,013mg/l, with TS concentration of 811mg/l. At this operating condition, the average TS removal was 49%. With higher loads of TS, the removal efficiency fell by 19%.

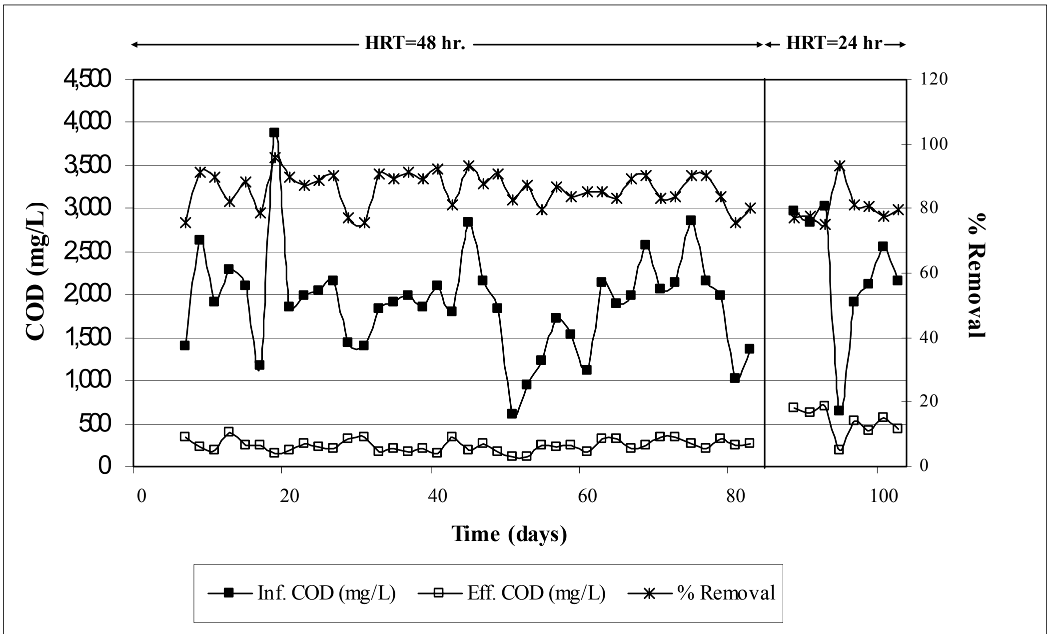


Figure 4.3: COD removal in the two-baffled septic tank with anaerobic filter media

For BOD removal, at a HRT of 48 hours, the effluent BOD concentration ranged from 32 to 119mg/l, with an average concentration of 79mg/l. At this operating condition, the average BOD removal was 86%. At a HRT of 24 hours, the effluent BOD concentration ranged from 60 to 266mg/l, with an average concentration of 202mg/l. At this operating condition, the average BOD removal was 72%. With higher BOD loads, the removal efficiency fell by 14%.

Considering TSS removal, at a HRT of 48 hours, the effluent TSS concentration ranged from 3 to 155mg/l, with an average concentration of 131mg/l. At this operating condition, the average TSS removal was 67%. At a HRT of 24 hours, the effluent TSS concentration ranged from 220 to 765mg/l, with an average concentration of 475mg/l. At this operating condition, the average TSS removal was 61%.

Considering TKN removal, at a HRT of 48 hours, the effluent TKN concentration of the two-baffled septic tank with anaerobic filter media ranged from 26 to 30mg/l with an average of 28mg/l. At this operating condition, the average TKN removal was 44%. At a HRT of 24 hours, the effluent TKN concentration ranged from 61 to 66mg/l, with an average TKN concentration of 68mg/l. At this operating condition, the average TKN removal was 19%. With higher loads of TKN, the removal efficiency fell by 25%.

Considering TP removal, at a HRT of 48 hours, the effluent TP concentration ranged from 17 to 22mg/l with an average of 24mg/l. At this operating condition, the average TP removal was 60%. At a HRT of 24 hours, the effluent TP concentration ranged from 34 to 38mg/l, with an average concentration of 30mg/l. At this operating condition, the average TP removal was 47%.

During this experiment, pH and alkalinity were measured daily. The range of effluent pH was from 7 to 7.7, with an average pH of 7.3. The average of influent pH was 7.9.

The range of effluent alkalinity was from 240 to 380mg/l as $CaCO_3$, with an average effluent alkalinity of 280mg/l as $CaCO_3$. There was no significant change in alkalinity during the process.

Table 4.4: Effluent characteristics of the two-baffled septic tank with anaerobic filter media

PARAMETERS	RANGE	AVERAGE
COD,mg/l	105-368	296
$COD_{filtered}$,mg/l	53-102	65
BOD,mg/l	29-265	160
TS,mg/l	266-876	631
TSS,mg/l	62 - 407	260
[a]Alkalinity,mg/l as $CaCO_3$	269-292	282
pH	7.1 - 7.9	7.3
[a]TKN,mg/l	35-66	45
[a]TP,mg/l	5-38	18
[a]Faecal coliforms, MPN/100mL	1.3×10^5 - 5×10^5	3.7×10^5

Note: [a] Values are based on 20 samples, others on 60 samples

4.2.4 The conventional septic tank

At a HRT of 48 hours, the effluent COD concentration of the conventional septic tank ranged from 165 to 890mg/l, with an average COD concentration of 500mg/l. At this operating condition, the average COD removal was 73%. At a HRT of 24 hours, the effluent COD concentration ranged from 226 to 1,487mg/l, with an average concentration of 945mg/l. At this operating condition, the average COD removal was 64% (see Table 4.5).

Considering TS removal, at a HRT of 48 hours, the effluent TS concentration of the conventional septic tank ranged from 236 to 950mg/l, with an average concentration of 524mg/l. At this operating condition, the average TS removal was 59%. At a HRT of 24 hours, the effluent TS concentration ranged from 533 to 1,383mg/l, with an average TS concentration of 994mg/l. At this operating condition, the average TS removal was 35%. With higher loads of TS, the removal efficiency dropped by considerable 24%.

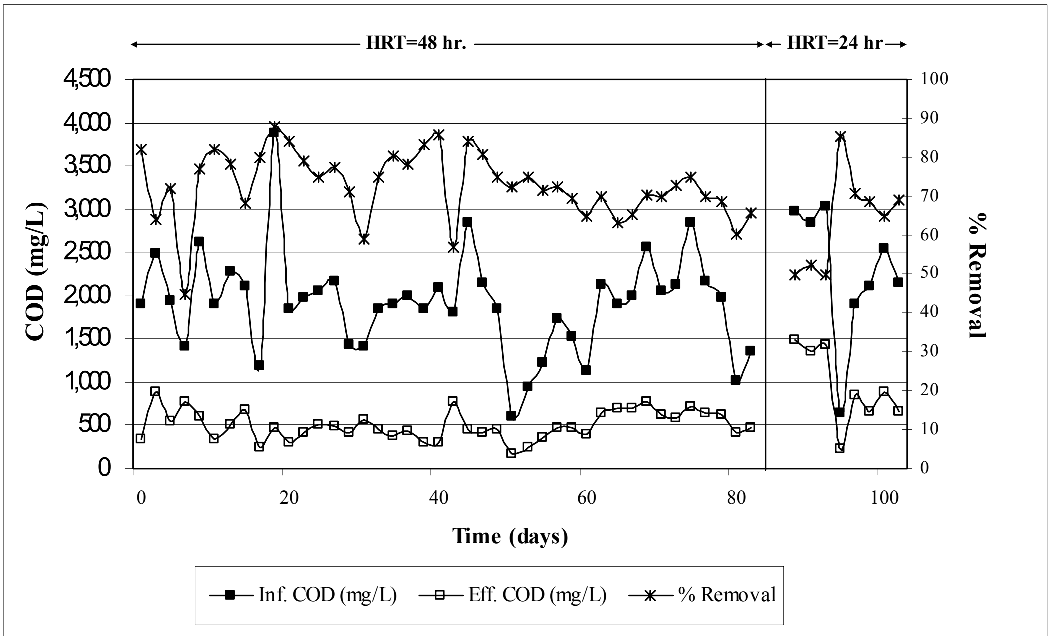


Figure 4.4: COD removal in the conventional septic tank

Considering BOD removal, at a HRT of 48 hours, the effluent BOD concentration of the conventional septic tank ranged from 50 to 218mg/l, with an average concentration of 144mg/l. At this operating condition, the average BOD removal was 75%. At a HRT of 24 hours, the effluent BOD concentration ranged from 67 to 440mg/l, with an average BOD concentration of 276mg/l. At this operating condition, the average BOD removal was 64%. With higher BOD loads, the removal efficiency dropped by 11%.

Considering TSS removal, at a HRT of 48 hours, the effluent TSS concentration of the conventional septic tank ranged from 62 to 253mg/l, with an average TSS concentration of 131mg/l. At this operating condition, the average TSS removal was 76%. At a HRT of 24 hours, the effluent TSS concentration ranged from 270 to 1,100mg/l, with an average TSS concentration of 667mg/l. At this operating condition, the average TSS removal was 47%. With higher loads of TSS, the removal efficiency dropped by 29%.

Considering TKN removal, at a HRT of 48 hours, the effluent TKN concentration of the conventional septic tank ranged from 30 to 33mg/l with an average of 28mg/l. At this operating condition, the average TKN removal was 44%. And at a HRT of 24 hours, the effluent TKN concentration ranged from 57 to 60mg/l, with an average TKN concentration of 59mg/l. At this operating condition, the average TKN removal was 24%. With higher loads of TKN, the removal efficiency fell by 20%.

Considering TP removal, at a HRT of 48 hours, the effluent TP concentration of the conventional septic tank ranged from 17 to 22mg/l with an average of 24mg/l. At this operating condition, the average TP removal was 47%. At a HRT of 24 hours, the effluent TP concentration ranged from 29 to 31mg/l, with an average concentration of 30mg/l. At this operating condition, the average TP removal was 60%.

The range of effluent pH was from 7.0 to 7.7, with the average pH of 7.4. The range of effluent alkalinity was from 240 to 365mg/l as $CaCO_3$, with an average effluent alkalinity equals to 275mg/l as $CaCO_3$.

Table 4.5: Effluent characteristics of the conventional septic tank

PARAMETERS	RANGE	AVERAGE
COD,mg/l	165-1,487	296
$COD_{filtered}$,mg/l	12-78	29
BOD,mg/l	50-440	165
TS,mg/l	236-1,383	599
TSS,mg/l	62 - 1,100	290
[a]Alkalinity,mg/l as $CaCO_3$	240-365	275
pH	7-7.7	7.3
[a]TKN,mg/l	34-60	43
[a]TP,mg/l	7-31	17
[a]Faecal coliforms, MPN/100mL	5×10^4 - 5.8×10^5	4.3×10^5

Note: Values are based on 60 samples. [a] Values are based on 20 samples.

4.2.5 Comparison of the Treatment Performance

As earlier mentioned, the purpose of this experiment was to investigate the applicability of the anaerobic baffled reactor for the treatment of domestic wastewater, and to monitor the performance when operated with different HRTs and OLRs. The effluent COD concentrations and the average removal efficiencies of each unit are presented in Table 4.6 and 4.7.

Table 4.6: COD removal performance of the experimental units at a HRT = 48 hours

TREATMENT UNIT	EFFLUENT COD (MG/L)		COD REMOVAL,%	
	Range	Average	Range	Average
3 baffled septic tank	105 - 368	292	72 - 91%	83%
2 baffled septic tank	90 - 418	260	70 - 93%	85%
2 baffled ST with filter media	105 -347	218	76 - 96%	80%
Conventional septic tank	165 - 763	500	57 - 88%	73%

Table 4.7: COD removal performance of the experimental units at a HRT = 24 hours

TREATMENT UNIT	EFFLUENT COD (MG/L)		COD REMOVAL,%	
	Range	Average	Range	Average
3 baffled septic tank	156 - 304	234	82 - 94%	89%
2 baffled septic tank	206 - 976	731	66 to 93%	72%
2 baffled ST with filter media	198 - 701	520	75 - 93%	80%
Conventional septic tank	226 - 1,487	945	50 - 85%	64%

As shown in Table 4.6, with approximately 80% confidence, the septic tanks with integrated in-tank baffles had better removal efficiencies compared to the conventional septic tank. However, it is difficult to determine which treatment unit with in-tank baffles had the best performance when operating at a HRT of 48 hours (Table 4.6).

When operated at a HRT of 24 hours, the three-baffled septic tank's COD removal efficiency had the highest removal percentage, while other baffled septic tanks' removal efficiencies were lower (Table 4.7). The septic tank unit had the lowest COD removal efficiencies under both HRT conditions. Figure 4.5 shows the COD removal of the four treatment units. The average OLR for HRT = 48 hours was 0.95 g/L*d, and the average OLR for HRT = 24 hours was 2.3 g/L*d.

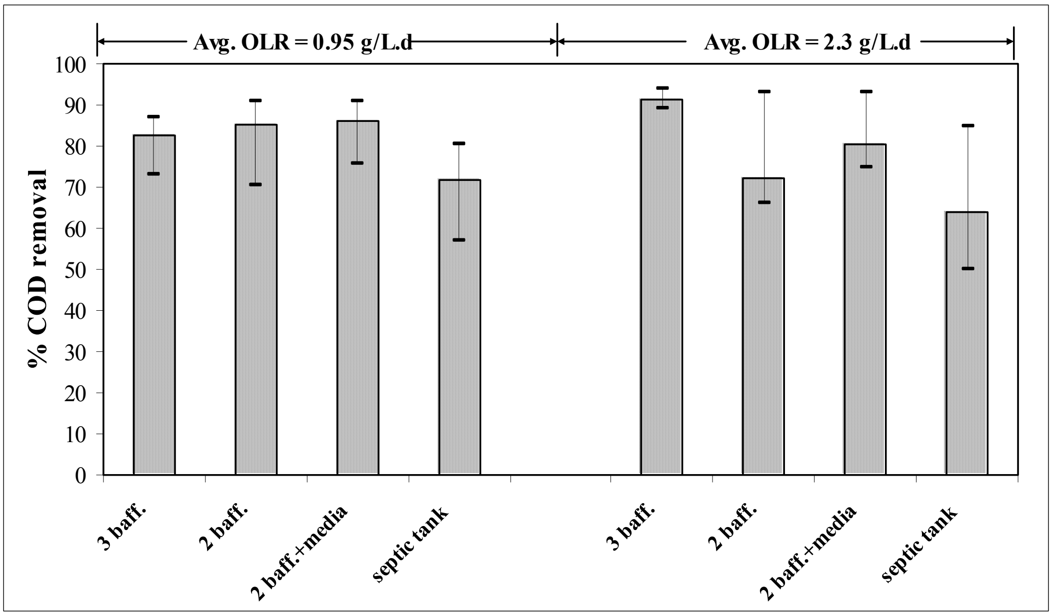


*Figure 4.5: Comparison of COD removal rates for different organic loading rates (g/L*d)*

From Figure 4.5, one can see that the increase of the OLR from 0.95g/l*d to 2.3g/l*d resulted in a decrease of the COD removal efficiency by 10%. The upper and lower marks indicate the variability of the data collected. The conventional septic tank strongly reacted to the increase of the OLR, where an average reduction of the COD removal efficiency of 10% was observed. Other parameters' removal had the same trends as the one shown in Figure 4.5.
Figures 4.6 and 4.7 show BOD and TS removal.

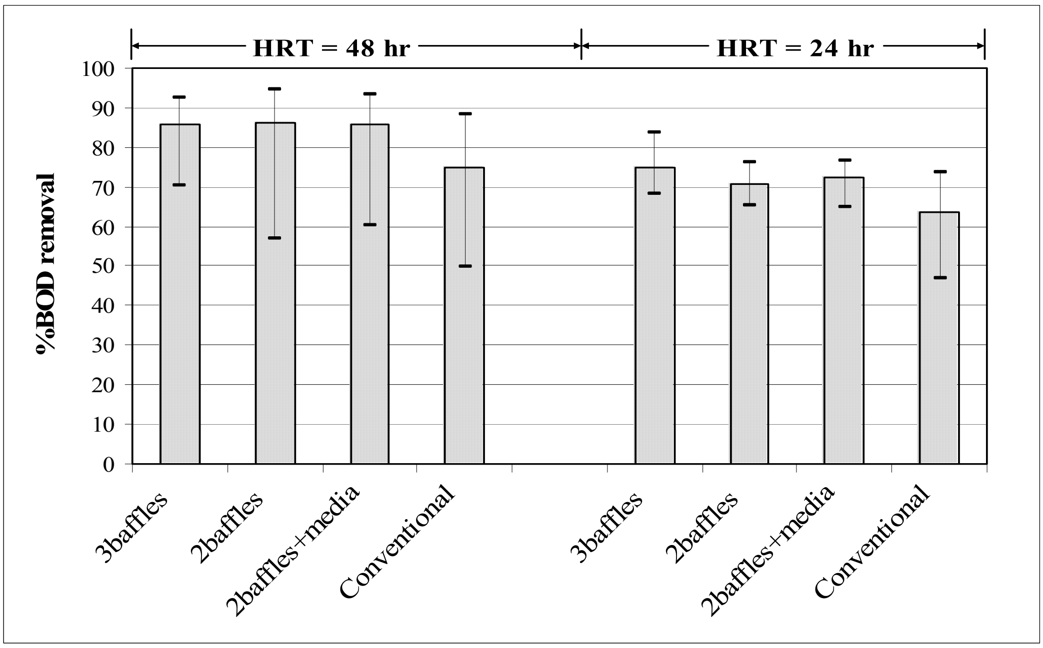


*Figure 4.6: Comparison of BOD removal rates for different organic loading rates (g/L*d)*

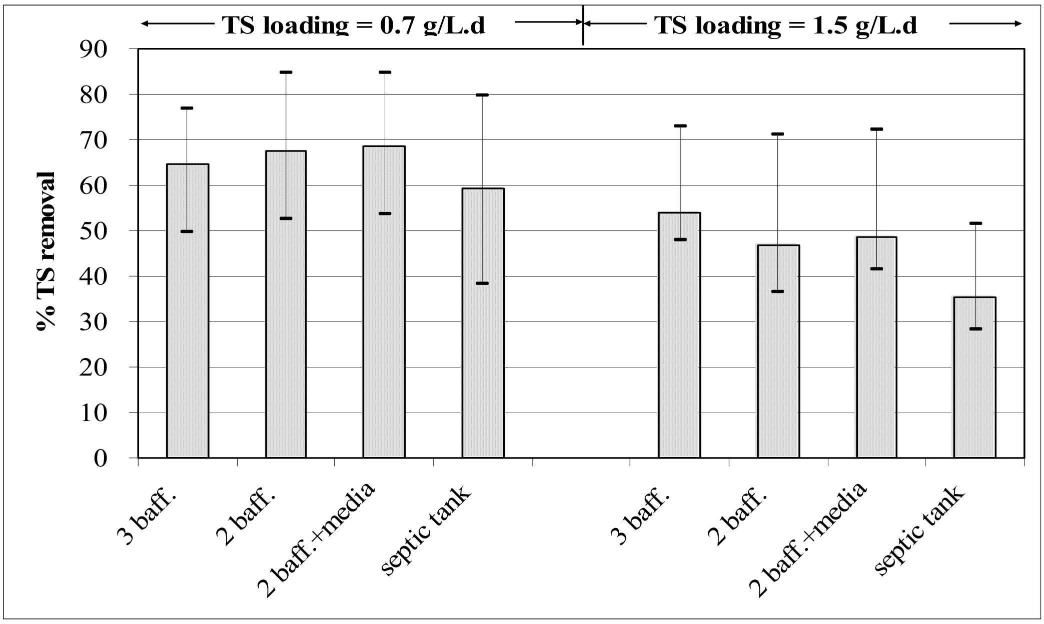


Figure 4.7: Comparison of TS removal rates for different solids loading rates

4.3 Gas Composition

By using Gas chromatography, some percentage of methane was found to be released from all treatment units. Figure 4.8 shows the percentage of methane collected from each unit after all reactors had been in operation for 60 days. The figure suggests that the three-baffled septic tank had the highest methane gas production.

In all ABR units some methane gas could be detected, but it was not possible to quantify the volume produced. This lack of gas production could be an indication that the treatment units did not reach their steady state yet, but there was some anaerobic activities going on inside the reactor tanks. Another possibility why there was only little methane gas detected was the way samples were collected. When samples were collected from the outlet of the tank, it is possible that any methane gas that was produced could escape there.

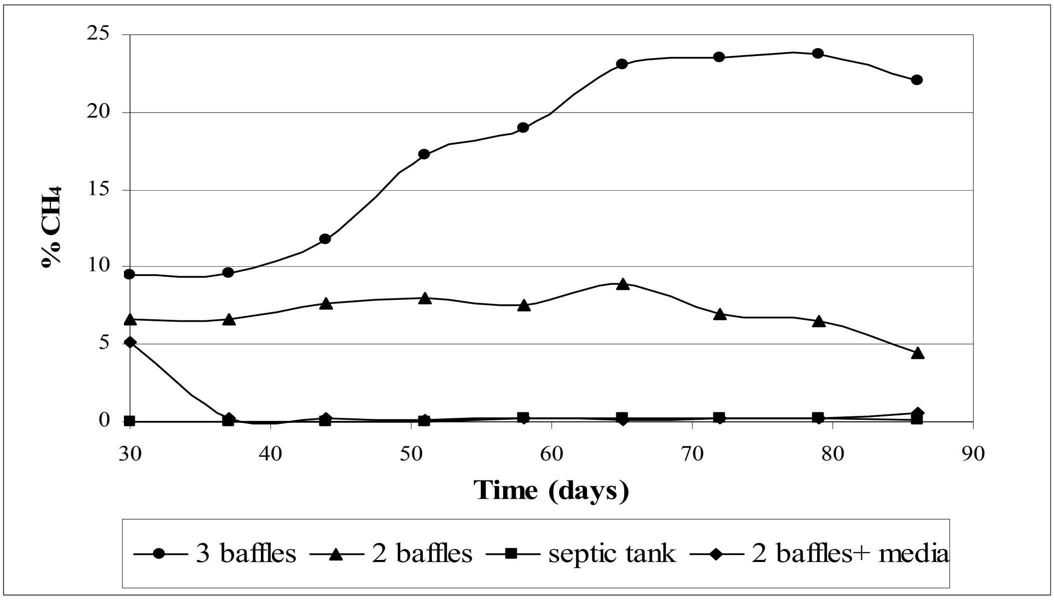


Figure 4.8: Percentage of methane observed in the gas composition

4.4 TS accumulation and mass balance

One of the mechanisms septic tanks use to remove solids is to make solids settle as sludge at the bottom of the tanks (Crites and Tchobanoglous, 1998). The amount of solids accumulated in each tank is shown in Figure 4.9. It was found that the sludge accumulated in the reactors had an average solid content of 29%, and a density of 0.86g/ml. The solid accumulation over time is presented in Figure 4.9.

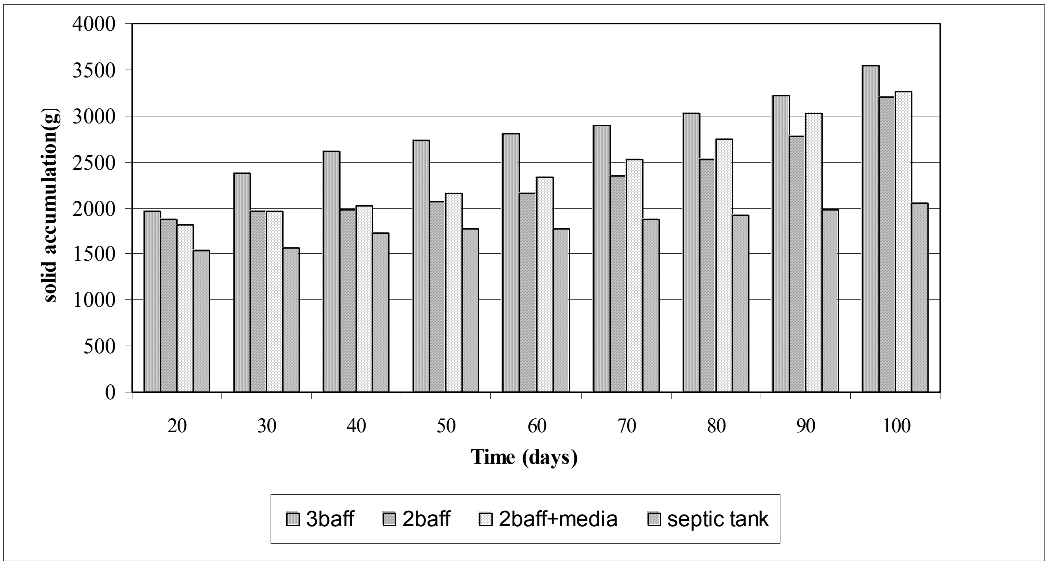


Figure 4.9: Accumulation rate of solids over time

Figure 4.9 shows the solid mass balance. When operating with a HRT of 48 hours, the three-baffled septic tank was found to have an average accumulated TS load of 0.3 g/L*d, effluent TS of 0.22 g/L*d, in-tank TS of 0.13 g/L*d, and unaccounted for TS of 0.01 g/L*d; the two-baffled septic tank had an average accumulated TS of 0.33 g/L*d, effluent TS of 0.2 g/L*d, in-tank TS of 0.12 g/L*d, and unaccounted for TS of 0.01 g/L*d; the two-baffled septic tank with anaerobic filter media had an average accumulated TS load of 0.36 g/L*d, effluent TS of 0.2 g/L*d, in-tank TS of 0.11 g/L*d, and no unaccounted for TS; and the conventional septic tank had an average of accumulated TS of 0.21 g/L*d, effluent TS of 0.28 g/L*d, in-tank TS of 0.19 g/L*d, and in-tank TS of unaccounted for TS of 0.001 g/L*d.

When operating with HRT of 24 hours, the three-baffled septic tank was found to have an average accumulated TS load of 0.73 g/L*d, effluent TS of 0.62 g/L*d, in-tank TS of 0.09 g/L*d, unaccounted for TS of 0.01 g/L*d; the two-baffled septic tank had an average accumulated TS of 0.58 g/L*d, effluent TS of 0.72 g/L*d, in-tank TS of 0.1 g/L*d, and unaccounted for TS of 0.04 g/L*d; the two-baffled septic tank with anaerobic filter media had an average accumulated TS load of 0.61 g/L*d, effluent TS of 0.7g/L*d, in-tank TS of 0.1 g/L*d, and unaccounted for TS of 0.04 g/L*d; and the conventional septic tank had an average of accumulated TS of 0.18 g/L*d, effluent TS of 0.45 g/L*d, in-tank TS of 0.32 g/L*d, and unaccounted for TS of 0.006 g/L*d.

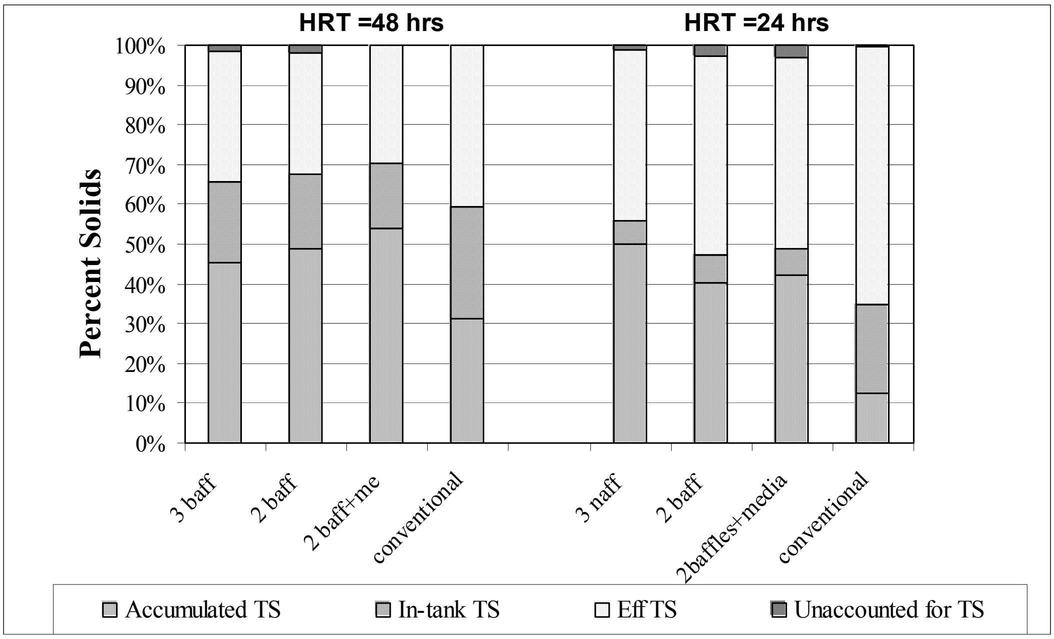


Figure 4.10: Mass balance for Total Solids (TS)

Figure 4.10 shows that the amount of solids, or sludge, accumulated in the treatment units with baffles were clearly higher than the amount accumulated in the septic tank. Solids accumulated inside the tank acted as filter; therefore more solids were retained inside the tank. This is the reason why the tanks with baffles had better solids removal efficiencies.

Figure 4.10 also shows that the wash-out effect of solids was much higher with shorter HRTs. The conventional septic tank released the most solids in the effluent. The three-baffled septic tank showed to have highest solids retention.

The unaccounted for TS could represent the solid degradation and solid loss during sample collection. As shown in Figure 4.9, the unaccounted for solid in all reactor were smaller than 2.8%. This indicates that there was only little solids degradation inside the tank, and therefore, anaerobic activities were low. This could be one explanation why no methane gas was detected with the gas collector.

4.5 Faecal coliforms

The average numbers of faecal coliforms found in effluent and influent samples are presented in Table 4.8. Based on experimental results showed in Table 4.8, it can be concluded that the removal of faecal coliforms in these experimental units could not meet water standard. The pollution control department, Thailand (2003), has a standard of faecal coliforms in surface water ranging between 1,000-4,000 MPN/100mL. This effluent is therefore not safe to be directly discharged to natural water sources. Disinfection is recommended for the septic tank effluent.

Table 4.8: Number of faecal coliforms observed in the influent and effluent samples

Time (days)	Faecal coliforms (MPN/100ml)				
	Influent	3 baffles	2 baffles	2 baffles with media	Septic tank
15	5.0×10^5	3.0×10^5	2.2×10^5	5.0×10^5	5.0×10^5
30	5.0×10^5	3.0×10^5	2.7×10^5	2.2×10^5	5.0×10^5
45	3.0×10^5	3.0×10^5	2.4×10^5	5.0×10^5	5.0×10^5
60	7.0×10^5	5.0×10^5	3.0×10^5	5.0×10^5	5.0×10^5
75	2.4×10^5	8.0×10^4	5.0×10^4	1.3×10^5	5.0×10^4

4.6 Critical time for wastewater sedimentation

Samples were taken from different ports along the column and analyzed for TSS concentration as shown in Table 4.9, and then plotted according to depth and time intervals, according to the procedure described in chapter 3.5.

Table 4.9: Solids removal at different times and depths

Time	Percentage of total suspended solids removed at indicated depth					
[Min]	30 cm	60 cm	90 cm	120 cm	180 cm	240 cm
2	75	71	67	59	49	
4	81	88	73	62	57	
6			86	70	65	59
8				88	71	68
10					87	76
12						84

**Based on 20 samples*

According to Figure 4.11, it is possible to predict the TSS removal according to the depth of the reactor and a critical settling time. For example, if the settling time is 5.3 min, the predicted percent removal is 60%. If the flow is increased, the removal will be lower and the removal efficiency will be reduced. Figure 4.11 help to design settling velocity or overflow rate, and the detention times for the treatment tank.

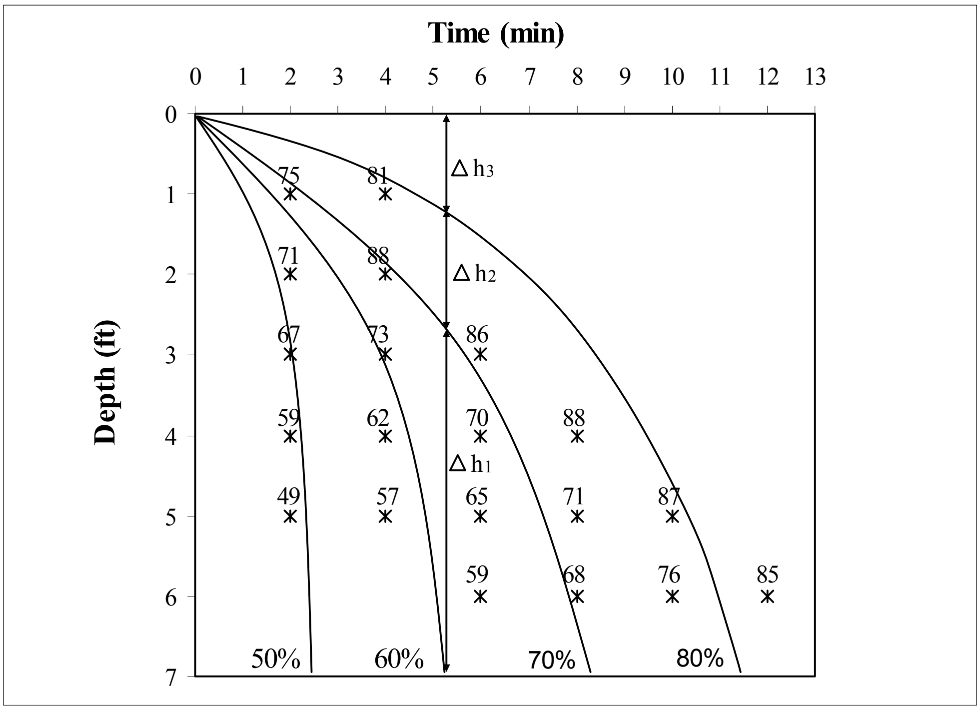


Figure 4.11: Definition sketch of settling curves for the particles in the effluent

However, the critical settling time predicted from this data could not be used with these experimental units. The column used was 2 m. high, but the experimental units were 25 cm in depth. Satisfactory correlation of the sedimentation in the column and in the tank could be established when designing the tank with the same height.

5 Conclusions and Recommendations

5.1 Conclusions

1. In this study, the experimental units were operated at a HRT of 24 and 48 hours. The COD removal efficiency of every treatment unit fluctuated depending on the different COD concentrations of the influent, and the HRT. The OLR was maintained at 0.95g/l*d and 2.31g/l*d, for the HRT of 48 and 24 hours, respectively. These loading rates were lower than the recommended range of 1.0-8.0 g/L*d by Metcalf and Eddy (2003).

2. When operated with a HRT of 48 hours, the baffled septic tanks had approximately the same removal efficiencies (in terms of COD, BOD, TS, TSS, TKN and TP) at a statistical confidence of approximately 75-80%. However, when operated with a HRT of 24 hours, the overall performance of the baffled septic tanks dropped around 10%, and 15-25% for the conventional septic tank, at a statistical confidence of approximately 68-76%. With a statistical confidence of approximately 90%, the three-baffled septic tank removal efficiencies were 10-15% higher than the one observe in the conventional septic tank.

3. From TS mass balance, it was clearly shown that the baffled septic tanks can retain much more solids than the conventional septic tank. With a HRT of 48 hours, the baffled septic tanks can retain around 45-55% of solids, and the conventional septic tank can retain around 30%. With a HRT of 24 hours, and higher TS loading rates, the three baffled septic tank was able to retain around 65% of the solids, both of the two-baffled septic tanks retained about 40% of the solids, and the septic tank retained only about 15% of the solids.

4. There was some methane gas detected from a gas chromatography, but there was not enough gas to quantify how much methane gas was actually produced. This lack of gas production could be an indication that all the treatment units did not reach their steady state yet, and there was low anaerobic activities going on inside the tanks. The TS mass balance showed that there was very little solid degradation (according to the 0-2.5% unaccounted for TS). It suggests that anaerobic activities did not establish in the tank.

5. By determining the settling characteristic of the wastewater in the tank, it could help designing the treatment unit and identifying the optimal detention time for the highest removal efficiencies of solids. The sedi-

mentation test done in this experiment used a column with 2 m. height, but the laboratory-scale septic tanks were 40 cm in height. The column should be equal in height to the depth of the proposed tank (Metcalf and Eddy, 2003). Therefore, the settling time found in this experiment should be used for a septic tank with 2 m. in depth.

6. Another possibility why no gas was detected was due to the gas leakage at the effluent pipe. It is recommended that a U-tube should be connected to the effluent outlet to prevent gas leakage when collecting samples.

7. The effluent collected from the septic tanks (all units) contains faecal coliforms concentrations higher than 10^5 MPN/100mL. Therefore, a post-treatment is recommended for the septic tank effluent.

5.2 Recommendations

1. The performance of pilot-scale baffled septic tanks should be further investigated.

2. More experiments should be set up with various OLRs, and HRTs. Treatment units' performance should be examined when operating under very high influent loads (shock loads), imitating real life situations.

3. Instead of using a mixture of Bangkok septage and AIT wastewater as influent, black water collected from households could be used to investigate the performance of the baffled septic tanks.

4. Trace of toxic substances should be measured as well. Various chemicals from household cleaning released in wastewater should be examined, because they could interrupt the growth of micro-organisms.

5. Microbial community of methanogens, acidogens, and sulphate-reducing bacteria could be observed and quantified using fluorescent in situ hybridization (FISH) method.

6. Further study of pathogenic bacteria removal by this treatment method is also recommended.

Bibliography

- Bachman, A., Beard, V.L., and Mccarthy P.L. (1985). Performance characteristics of the anaerobic baffled reactor. Wat. Res. 19 (1): 99-106.

- Barber, W.P. and Stuckey, D.C. (1999). The use of the anaerobic baffled reactor (ABR) for wastewater treatment: A review. Wat. Res. 33 (7): 1,559-1,578.

- Barber, W.P. and Stuckey, D.C. (2000). Nitrogen removal in a modified anaerobic baffled reactor (ABR): 2, Nitrification. Wat. Res. 34 (9): 2,423-2,432.

- Boopathy, R., and Tilche, A. (1991). Anaerobic-digestion of high-strength molasses waste-water using a hybrid an-aerobic baffled reactor. Wat. Res. 25 (7): 785-790.

- Boopathy, R., and Tilche, A. (1992). Pelletization of biomass in a hybrid anaerobic baffled reactor (HABR) treating acidified waste-water. Bioresource Technology. 40 (2):101-107.

- Bounds, T.R., Bedinger, M.S., Johnson, A.I., Felming, J.S. (1997) Design and Performance of Septic Tanks. American Society for Testing Materials, Philadelphia.(http://www.csuchico.edu/cwtrc/PDFFILES/sytemdesign/Boundsseptictank.pdf)

- Brandes, M. (1977). Accumulation rate and characteristics of septic tank sludge and septage. Research report W63. Ministry of the Environment, Ontario.

- Cohen, A., Breure, A.M., Van Andel, J.G., and Vandeursen, A. (1982). Influence of phase separation on the anaerobic digestion of glucose, II. Stability and kinetic responses to shock loadings. Wat. Res. 16: 449-455.

- Crites, R. and Tchobanoglous, C. (1998). Small and Decentralized Wastewater_Management Systems, Mcgraw-Hill, Inc., New York.

- Grobicki, A.M.W. and Stuckey, D.C. (1992). Hydrodynamic characteristics of the anaerobic baffled reactor. Wat. Res. 26: 371-378.

- Grobicki, A.M.W. and Stuckey, D.C. (1989). The role of formate in the anaerobic baffled reactor. Wat. Res. 23 (12):1599-1602.

- Grobicki, A.M.W. and Stuckey, D.C. (1991). Performance of the anaerobic baffled reactor under steady state and shock loading conditions. Biotechnol. Bioeng. 37: 344-355.

- Koottatep, T., Polprasert, C., Oanh, N.T.K., Surinkul, N., Montangero, A. and Strauss, M. (2002). Constructed wetlands for septage treatment towards effective faecal sludge_management. International conference on wetland systems for water pollution control. Tanzania.

- Langenhoff, Alette A.M., Intrachandra, N., Stuckey, C. (2000) Treatment of dilute soluble and colloidal wastewater using an anaerobic baffled reactor: Influent of hydraulic retention time. Wat. Res. 34 (4): 1307-1317.

- Langenhoff, Alette A.M., Stuckey, C. (2000) Treatment of dilute soluble and colloidal wastewater using an anaerobic baffled reactor: Effect of low tremperature. Wat. Res. 34 (15): 3867-3875.

- Larry W., Knox, R.C. (1985). Septic tank system effects on Ground water quality. Lewis publishers, Inc. Michigan.

- Lens, P., Zeeman, G., Lettinga, G. (2001) Decentralized sanitation and Reuse: Concepts, systems and implementation. WIA publishing, UK.

- Metcalf and Eddy (2003). Wastewater Engineering: Treatment, Disposal and Reuse, 4th edition, Mcgraw-Hill, Inc., New York.

- Nachaiyasit, S., Stuckey, D.C. (1997). The effect of schock loads on the performance on an anaerobic baffled reactor (ABR). 2. Step and transient hydraulic shocks at constant feed strength. Water Resource 31(11): 2,747-2,754.

- Masters, G. M.. (1997) Introduction to Environmental Engineering and Science. 2nd Edition. Prentice-Hall, Inc.

- Mcconnachie, G. L., Liu, J. (2000). Design of baffled hydraulic channels for turbulence-induced flocculation. Water Resource. 34(6): 1,886-1,896.

- Montangero, A., Strauss, M. (2003) When Septic Tanks are Full - Challenges in Faecal Sludge Management and Treatment. Swiss Federatl Institute of Environmental and Science & Technology (EAWAG). Department of

Water and Sanitation in Developing Countries(SANDEC), Switzerland. (http://www.sandec.ch/files/AIDIS_Mendoza_eng.pdf)

- Orozco, A. (1998). Pilot and full-scale anaerobic treatment of low-strength wastewater at sub-optimal temperature (15 C) with a hybrid plug flow reactor. Proceedings of the 8th International Conference on Anaerobic Digestion. 2: 183-191.

- Polprasert, C. (1996). Organic Waste Recycling, 2nd edition John Wiley and Sons, London.

- Sasse, L. (1998). Decentralized Wastewater Treatment in Developing Countries (DEWATS), BORDA publication.

- Sawyer, C.N., Mccarty, P.L., Parkin, G.F. (1994) Chemistry for Environmental Engineering. 4th Edition. International Edition. Mcgraw-Hill, Inc.

- Segel, I.H. (1976) Biochemical Calculations. 2nd Edition. John Wiley & Sons, Inc.

- Tchobanoglous, G., Schoroeder, E.D. (1987) Water Quality. Addison-Wesley Publishing Company, Inc.

- Tilche, A. and Vieira S.M.M. (1991). Discussion on reactor design of anaerobic filters and sludge bed reactors. Wat. Sci. Technol. 24(8): 193-206.

- US. EPA. (1980). Design manual: Onsite wastewater treatment and disposal systems. Office of water program Operations, Washington DC.

- Weiland, P. and Rozzi, A. (1991). The start-up, operation and monitoring of high-rate anaerobic treatment systems: discussions report. Wat. Res. 24(8): 257-277.

- Winnerberger, J.H.T. (1974). Manual of grey water treatment practice. Ann Arbor Science Publishers, Inc. Michigan, U.S.A.

- Yang, P.Y. and Moengangongo, T.H. (1987) Operational stability of a horizontally baffled anaerobic reactor for diluted Seine wastewater in the tropics. ASAE. 30(4): 1105-1110.

- Zarnett, G.D. (1974). Centrifugation of Raw Sewage. Research Report No. W50. Ministry of the Environment, Ontario.

- Zarnett, G.D. (1977). Accumulation rate and Characteristics of Septic tank Sludge and Septage". Research Report W63. Ministry of the Environment, Ontario.

- Zevala, Lopez M.A., Funamizu, N., Takakuwa, T (2002). Onsite wastewater differential treatment system modelling approach. Water Science and Technology. 46 (6-7): 317-324.

Appendix

Appendix 1: Daily measures of various parameters in the three-baffled septic tank

Date	Day	pH	Temp (ºC)	OLR (g/d)	COD (mg/L)			BOD (mg/L)			TS (mg/L)			TSS (mg/L)			Alkalinity (mg/L)	
					Inf.	Eff.	Rem%	Inf.	Eff.	Rem%	Inf.	Eff.	Rem%	Inf.	Eff.	Rem%	Inf.	Eff.
25-Mar-03	1	7.48	36	38.1	1,905	290	85%	600	87	86%	1,290	557	57%	350	137	61%	270	285
27-Mar-03	3	7.53	36	49.5	2,477	232	91%	715	70	90%	1,217	393	68%	326	122	63%	270	285
29-Mar-03	5	7.54	37	38.7	1,935	186	90%	621	58	91%	1,218	387	68%	379	90	76%	250	250
31-Mar-03	7	7.45	35	28.1	1,405	279	80%	300	89	70%	1,217	393	68%	580	209	64%	270	285
2-Apr-03	9	7.45	36	52.5	2,625	225	91%	800	60	93%	2,434	876	64%	333	125	62%	450	270
4-Apr-03	11	7.41	35	38.1	1,905	290	85%	500	87	83%	1,533	536	65%	523	110	79%	405	350
6-Apr-03	13	7.39	35	45.7	2,287	343	87%	650	95	85%	1,144	377	67%	451	95	79%	270	285
8-Apr-03	15	7.33	36	42.1	2,105	337	84%	420	87	79%	1,257	497	60%	782	120	85%	250	265
10-Apr-03	17	7.32	37	23.6	1,180	268	77%	370	76	79%	1,160	268	77%	325	185	43%	265	270
12-Apr-03	19	7.26	35	77.4	3,871	341	91%	1,200	90	93%	1,027	460	55%	446	118	74%	300	250
14-Apr-03	21	7.23	36	36.9	1,846	266	86%	500	72	86%	1,130	520	54%	723	115	84%	270	285
16-Apr-03	23	7.15	36	39.7	1,984	289	85%	654	72	89%	1,488	493	67%	1,204	302	75%	245	240
18-Apr-03	25	7.12	37	41.0	2,049	286	86%	678	69	90%	1,373	490	64%	895	198	78%	255	250
20-Apr-03	27	7.09	35	43.2	2,158	307	86%	750	69	91%	1,446	443	69%	1,102	127	88%	265	270
22-Apr-03	29	7.18	37	28.7	1,433	229	84%	400	67	83%	1,133	429	62%	235	101	57%	280	290
24-Apr-03	31	7.10	36	28.1	1,405	279	80%	400	81	80%	1,124	279	75%	351	168	52%	270	285
26-Apr-03	33	7.44	36	36.9	1,843	276	85%	620	84	86%	1,106	276	75%	356	101	72%	275	265
28-Apr-03	35	7.36	37	38.0	1,902	267	86%	620	76	88%	1,294	414	68%	377	89	76%	255	265
30-Apr-03	37	7.56	36	39.7	1,986	263	87%	650	70	89%	1,331	431	68%	489	95	81%	275	280
2-May-03	39	7.70	35	37.0	1,849	296	84%	615	79	87%	1,294	394	70%	660	145	78%	285	275
4-May-03	41	7.53	34	41.9	2,096	270	87%	670	80	88%	1,362	475	65%	510	112	78%	250	260
6-May-03	43	7.59	35	36.1	1,805	279	85%	585	85	85%	1,217	393	68%	624	90	86%	265	250
8-May-03	45	7.92	35	56.7	2,836	368	87%	934	82	91%	1,815	436	76%	722	85	88%	275	250
10-May-03	47	8.11	36	43.0	2,148	302	86%	709	73	90%	1,246	444	64%	680	185	73%	255	280
12-May-03	49	7.88	36	36.9	1,843	276	85%	640	85	87%	1,290	557	57%	340	120	65%	270	285
14-May-03	51	7.96	36	12.0	600	105	83%	200	29	86%	977	493	49%	677	222	67%	300	280
16-May-03	53	7.68	35	18.9	945	156	83%	310	62	80%	845	389	54%	245	62	75%	255	280
18-May-03	55	7.54	36	24.5	1,225	316	74%	400	89	78%	827	377	54%	277	127	54%	270	260
20-May-03	57	7.60	33	34.6	1,728	272	84%	600	82	86%	1,210	481	60%	340	105	69%	275	280
22-May-03	59	7.41	34	30.5	1,526	290	81%	509	80	84%	915	446	51%	362	97	73%	255	270

Appendix 2: Daily measurements of various parameters in the three-baffled septic tank (Cont.)

Date	Day	pH	Temp (ºC)	OLR (g/d)	COD (mg/L)			BOD (mg/L)			TS (mg/L)			TSS (mg/L)			Alkalinity (mg/L	
					Inf.	Eff.	Rem%	Inf.	Eff.	Rem%	Inf.	Eff.	Rem%	Inf.	Eff.	Rem%	Inf.	Eff.
24-May-03	61	7.46	34	22.5	1,125	226	80%	420	64	85%	1,013	226	58%	429	102	76%	320	360
26-May-03	63	7.11	35	42.6	2,131	426	80%	670	100	85%	1,731	426	70%	562	200	64%	270	285
28-May-03	65	7.17	37	37.9	1,895	417	78%	689	125	82%	1,695	417	75%	687	158	77%	260	285
30-May-03	67	7.22	34	39.9	1,993	300	85%	695	80	88%	1,594	459	71%	690	126	82%	265	270
1-Jun-03	69	7.09	35	51.3	2,565	359	86%	761	76	90%	1,924	634	67%	666	113	83%	240	260
3-Jun-03	71	7.14	33	41.2	2,058	386	81%	624	90	86%	1,605	450	72%	624	99	84%	265	280
5-Jun-03	73	7.32	35	42.7	2,135	337	84%	703	115	84%	1,537	457	70%	542	96	82%	380	370
7-Jun-03	75	7.12	34	56.9	2,846	373	87%	949	98	90%	1,821	421	77%	452	195	57%	340	300
9-Jun-03	77	7.28	33	43.2	2,158	287	87%	760	75	90%	1,468	484	67%	478	153	68%	280	250
11-Jun-03	79	7.21	36	39.6	1,982	332	83%	630	84	87%	1,407	535	62%	685	115	83%	265	270
13-Jun-03	81	7.26	35	20.5	1,025	278	73%	438	89	80%	605	243	60%	301	86	71%	270	285
15-Jun-03	83	7.45	36	27.3	1,365	352	74%	470	79	83%	914	438	52%	425	102	76%	305	290
17-Jun-03	85	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19-Jun-03	87	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21-Jun-03	89	7.23	33	119.0	2,975	240	88%	831	265	68%	1,857	895	52%	814	256	69%	270	265
23-Jun-03	91	7.22	35	113.8	2,845	231	88%	904	257	72%	1,735	901	48%	1,600	255	84%	270	285
25-Jun-03	93	7.35	35	121.0	3,025	275	86%	998	263	74%	2,006	913	54%	1,543	340	78%	290	280
27-Jun-03	95	7.44	33	25.6	640	175	91%	250	54	78%	960	455	53%	1,700	407	76%	260	250
29-Jun-03	97	7.26	32	76.2	1,904	305	84%	665	109	84%	1,010	543	73%	723	109	85%	265	280
1-Jul-03	99	7.27	35	84.5	2,112	157	93%	720	150	79%	1,259	610	52%	877	230	74%	270	260
3-Jul-03	101	7.46	34	102.0	2,549	282	89%	809	208	74%	1,686	876	48%	1,523	180	88%	400	420
5-Jul-03	103	7.45	34	85.9	2,148	207	90%	625	195	69%	1,387	656	53%	1,179	177	85%	290	285

Note: date June 17- June 19, samples were not collected due to wastewater shortage

Appendix 3: Daily measurements of various parameters in the two-baffled septic tank

Date	Day	pH	Temp (ºC)	OLR (g/d)	COD (mg/L)			BOD (mg/L)			TS (mg/L)			TSS (mg/L)			Alkalinity (mg/L)	
					Inf.	Eff.	Rem%	Inf.	Eff.	Rem%	Inf.	Eff.	Rem%	Inf.	Eff.	Rem%	Inf.	Eff.
25-Mar-03	1	7.29	36	38.1	1,905	168	91%	600	95	84%	1,290	500	61%	350	135	61%	270	300
27-Mar-03	3	7.36	36	49.5	2,477	341	86%	715	92	87%	1,217	443	64%	326	35	89%	270	300
29-Mar-03	5	7.28	37	38.7	1,935	279	86%	621	85	86%	1,218	403	67%	379	41	89%	250	260
31-Mar-03	7	7.47	35	28.1	1,405	418	70%	300	130	57%	1,217	443	64%	580	78	87%	270	300
2-Apr-03	9	7.40	36	52.5	2,625	195	93%	800	58	93%	2,434	730	70%	333	185	44%	450	275
4-Apr-03	11	7.45	35	38.1	1,905	168	91%	500	50	90%	1,533	506	67%	523	59	89%	405	345
6-Apr-03	13	7.36	35	45.7	2,287	338	85%	650	50	92%	1,144	366	68%	451	121	73%	270	300
8-Apr-03	15	7.41	36	42.1	2,105	253	88%	420	77	82%	1,257	447	64%	782	85	89%	250	250
10-Apr-03	17	7.27	37	23.6	1,180	173	85%	370	52	86%	1,160	290	75%	325	33	90%	265	265
12-Apr-03	19	7.26	35	77.4	3,871	232	94%	1,200	67	94%	1,027	413	60%	446	49	89%	300	250
14-Apr-03	21	7.40	36	36.9	1,846	251	86%	500	74	85%	1,130	527	53%	723	115	84%	270	300
16-Apr-03	23	7.20	36	39.7	1,984	313	84%	654	77	88%	1,488	491	67%	1,204	125	90%	245	250
18-Apr-03	25	7.02	37	41.0	2,049	247	88%	678	62	91%	1,373	467	66%	895	96	89%	255	265
20-Apr-03	27	6.92	35	43.2	2,158	235	89%	750	59	92%	1,446	405	72%	1,102	115	90%	265	270
22-Apr-03	29	6.85	37	28.7	1,433	358	75%	400	78	81%	1,133	458	60%	235	25	89%	280	290
24-Apr-03	31	7.00	36	28.1	1,405	418	70%	400	95	76%	1,124	418	63%	351	36	90%	270	280
26-Apr-03	33	7.30	36	36.9	1,843	169	91%	620	84	86%	1,106	169	85%	356	34	90%	275	270
28-Apr-03	35	7.70	37	38.0	1,902	228	88%	620	79	87%	1,294	336	74%	377	41	89%	255	270
30-Apr-03	37	7.58	36	39.7	1,986	194	90%	650	68	90%	1,331	399	70%	489	55	89%	275	295
2-May-03	39	7.72	35	37.0	1,849	225	88%	615	62	90%	1,294	350	73%	660	49	93%	285	280
4-May-03	41	7.74	34	41.9	2,096	192	91%	670	86	87%	1,362	422	69%	510	51	90%	250	255
6-May-03	43	7.75	35	36.1	1,805	418	77%	585	88	85%	1,217	443	64%	624	66	89%	265	250
8-May-03	45	7.68	35	56.7	2,836	227	92%	934	84	91%	1,815	454	75%	722	79	89%	275	260
10-May-03	47	7.61	36	43.0	2,148	258	88%	709	72	90%	1,246	374	70%	680	77	89%	255	305
12-May-03	49	7.69	36	36.9	1,843	169	91%	640	69	89%	1,290	500	61%	340	53	84%	270	300
14-May-03	51	7.56	36	12.0	600	90	85%	200	35	83%	977	337	66%	677	66	90%	300	275
16-May-03	53	7.66	35	18.9	945	129	86%	310	52	83%	845	347	59%	245	38	84%	255	305
18-May-03	55	7.64	36	24.5	1,225	248	80%	400	88	78%	827	393	52%	277	34	88%	270	270
20-May-03	57	7.57	33	34.6	1,728	231	87%	600	59	90%	1,210	460	62%	340	42	88%	275	295
22-May-03	59	7.49	34	30.5	1,526	257	83%	509	71	86%	915	421	54%	362	31	91%	255	265

Appendix 4: Daily measurements of various parameters in the two-baffled septic tank with anaerobic filter media

Date	Day	pH	Temp (ºC)	OLR (g/d)	COD (mg/L)			BOD (mg/L)			TS (mg/L)			TSS (mg/L)			Alkalinity (mg/L)	
					Inf.	Eff.	Rem%	Inf.	Eff.	Rem%	Inf.	Eff.	Rem%	Inf.	Eff.	Rem%	Inf.	Eff.
31-Mar-03	1	7.24	35	28.1	1,405	341	76%	300	109	64%	1,217	477	61%	580	62	89%	270	280
2-Apr-03	3	7.37	36	52.5	2,625	225	91%	800	85	89%	2,434	783	68%	333	27	92%	270	280
4-Apr-03	5	7.23	35	38.1	1,905	198	90%	500	88	82%	1,533	538	65%	523	56	89%	250	260
6-Apr-03	7	7.42	35	45.7	2,287	243	89%	650	55	92%	1,144	366	68%	451	49	89%	270	280
8-Apr-03	9	7.28	36	42.1	2,105	253	88%	420	76	82%	1,257	457	64%	782	66	92%	450	260
10-Apr-03	11	7.25	37	23.6	1,180	252	79%	370	56	85%	1,160	252	78%	325	61	92%	405	295
12-Apr-03	13	7.20	35	77.4	3,871	155	96%	1,200	95	92%	1,027	343	67%	446	25	94%	270	280
14-Apr-03	15	7.20	36	36.9	1,846	185	90%	500	69	86%	1,130	447	60%	723	73	90%	250	265
16-Apr-03	17	7.07	36	39.7	1,984	257	87%	654	97	85%	1,488	521	65%	1,204	119	92%	265	265
18-Apr-03	19	6.92	37	41.0	2,049	232	89%	678	70	90%	1,373	439	68%	895	87	90%	300	260
20-Apr-03	21	6.91	35	43.2	2,158	149	93%	750	50	93%	1,446	390	73%	1,102	155	86%	270	280
22-Apr-03	23	7.02	37	28.7	1,433	330	77%	400	75	81%	1,133	430	62%	235	25	89%	245	260
24-Apr-03	25	7.00	36	28.1	1,405	341	76%	400	82	80%	1,124	341	70%	351	37	89%	255	260
26-Apr-03	27	7.18	36	36.9	1,843	169	91%	620	82	87%	1,106	169	85%	356	48	87%	265	265
28-Apr-03	29	7.28	37	38.0	1,902	209	89%	620	68	89%	1,294	285	78%	377	35	91%	280	280
30-Apr-03	31	7.34	36	39.7	1,986	169	91%	650	63	90%	1,331	373	72%	489	55	89%	270	280
2-May-03	33	7.41	35	37.0	1,849	183	90%	615	65	89%	1,294	350	73%	660	45	93%	275	270
4-May-03	35	7.30	34	41.9	2,096	158	92%	670	69	90%	1,362	490	64%	510	69	86%	255	280
6-May-03	37	7.65	35	36.1	1,805	341	81%	585	102	83%	1,217	477	61%	624	78	88%	275	290
8-May-03	39	7.75	35	56.7	2,836	195	93%	934	91	90%	1,815	363	80%	722	96	87%	285	290
10-May-03	41	7.74	36	43.0	2,148	267	88%	709	80	89%	1,246	349	72%	680	86	87%	250	250
12-May-03	43	7.68	36	36.9	1,843	169	91%	640	57	91%	1,290	447	65%	340	3	99%	265	250
14-May-03	45	7.71	36	12.0	600	105	83%	200	32	84%	977	427	56%	677	75	89%	275	270
16-May-03	47	7.57	35	18.9	945	121	87%	310	50	84%	845	372	56%	245	35	86%	255	300
18-May-03	49	7.36	36	24.5	1,225	250	80%	400	84	79%	827	383	54%	277	28	90%	270	280
20-May-03	51	7.64	33	34.6	1,728	231	87%	600	70	88%	1,210	472	61%	340	61	82%	300	280
22-May-03	53	7.60	34	30.5	1,526	248	84%	509	75	85%	915	412	55%	362	59	84%	255	265
24-May-03	55	7.40	34	22.5	1,125	168	85%	420	55	87%	1,013	168	83%	429	92	79%	270	270
26-May-03	57	7.30	35	42.6	2,131	319	85%	670	94	86%	1,731	319	82%	562	108	81%	275	290
28-May-03	59	7.33	37	37.9	1,895	322	83%	689	110	84%	1,695	322	81%	687	72	90%	255	255

Appendix 3: Daily measurements of various parameters in the two-baffled septic tank with anaerobic filter media

Date	Day	pH	Temp (ºC)	OLR (g/d)	COD (mg/L)			BOD (mg/L)			TS (mg/L)			TSS (mg/L)			Alkalinity (mg/L)	
					Inf.	Eff.	Rem%	Inf.	Eff.	Rem%	Inf.	Eff.	Rem%	Inf.	Eff.	Rem%	Inf.	Eff.
30-May-03	61	7.22	34	39.9	1,993	217	89%	695	75	89%	1,594	399	75%	690	38	94%	320	340
1-Jun-03	63	7.19	35	51.3	2,565	251	90%	761	70	91%	1,924	654	66%	666	120	82%	270	280
3-Jun-03	65	7.32	33	41.2	2,058	341	83%	624	74	88%	1,605	417	74%	624	139	78%	260	270
5-Jun-03	67	7.20	35	42.7	2,135	347	84%	703	112	84%	1,537	400	74%	542	59	89%	265	280
7-Jun-03	69	7.10	34	56.9	2,846	271	90%	949	87	91%	1,821	364	80%	452	47	90%	240	240
9-Jun-03	71	7.02	33	43.2	2,158	210	90%	760	85	89%	1,468	543	63%	478	148	69%	265	270
11-Jun-03	73	7.02	36	39.6	1,982	287	86%	630	94	85%	1,407	422	70%	685	152	78%	380	360
13-Jun-03	75	7.12	35	20.5	1,025	182	82%	438	64	85%	605	212	65%	301	42	86%	340	275
15-Jun-03	77	7.04	36	27.3	1,365	273	80%	470	88	81%	914	384	58%	425	39	91%	280	250
17-Jun-03	79	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19-Jun-03	81	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21-Jun-03	83	6.97	33	119.0	2,975	676	77%	831	220	74%	1,857	1,010	46%	814	366	55%	305	280
23-Jun-03	85	7.02	35	113.8	2,845	633	78%	904	266	71%	1,735	1,003	42%	1,600	500	69%	265	270
25-Jun-03	87	7.26	35	121.0	3,025	701	75%	998	266	73%	2,006	1,013	49%	1,543	694	55%	390	380
27-Jun-03	89	7.37	33	25.6	640	198	93%	250	60	76%	960	563	41%	1,700	765	55%	270	270
29-Jun-03	91	7.36	32	76.2	1,904	533	81%	665	215	68%	1,010	557	72%	723	325	55%	270	280
1-Jul-03	93	7.41	35	84.5	2,112	411	81%	720	170	76%	1,259	680	46%	877	395	55%	290	280
3-Jul-03	95	7.23	34	102.0	2,549	569	78%	809	201	75%	1,686	963	43%	1,523	220	86%	260	270
5-Jul-03	97	7.34	34	85.9	2,148	437	80%	625	210	66%	1,387	698	50%	1,179	531	55%	265	270

Appendix 5: Daily measurements of various parameters in the conventional septic tank

Date	Day	pH	Temp (ºC)	OLR (g/d)	COD (mg/L)			BOD (mg/L)			TS (mg/L)			TSS (mg/L)			Alkalinity (mg/L)	
					Inf.	Eff.	Rem%	Inf.	Eff.	Rem%	Inf.	Eff.	Rem%	Inf.	Eff.	Rem%	Inf.	Eff.
25-Mar-03	1	7.56	36	38.1	1,905	343	82%	600	110	82%	1,290	516	60%	350	85	76%	270	265
27-Mar-03	3	7.48	36	49.5	2,477	890	64%	715	203	72%	1,217	487	60%	326	79	76%	270	265
29-Mar-03	5	7.26	37	38.7	1,935	542	72%	621	159	74%	1,218	477	61%	379	82	78%	250	245
31-Mar-03	7	7.41	35	28.1	1,405	774	45%	300	180	40%	1,217	750	38%	580	123	79%	270	265
2-Apr-03	9	7.56	36	52.5	2,625	600	77%	800	165	79%	2,434	950	61%	333	200	40%	450	260
4-Apr-03	11	7.34	35	38.1	1,905	343	82%	500	109	78%	1,533	343	78%	523	126	76%	405	300
6-Apr-03	13	7.25	35	45.7	2,287	501	78%	650	145	78%	1,144	446	61%	451	95	79%	270	265
8-Apr-03	15	7.25	36	42.1	2,105	674	68%	420	202	52%	1,257	473	62%	782	130	83%	250	240
10-Apr-03	17	7.17	37	23.6	1,180	236	80%	370	71	81%	1,160	236	80%	325	70	78%	265	260
12-Apr-03	19	7.15	35	77.4	3,871	465	88%	1,200	142	88%	1,027	417	59%	446	88	80%	300	275
14-Apr-03	21	7.23	36	36.9	1,846	295	84%	500	86	83%	1,130	467	59%	723	165	77%	270	265
16-Apr-03	23	7.11	36	39.7	1,984	417	79%	654	125	81%	1,488	565	62%	1,204	253	79%	245	265
18-Apr-03	25	7.04	37	41.0	2,049	511	75%	678	143	79%	1,373	535	61%	895	181	80%	255	260
20-Apr-03	27	7.02	35	43.2	2,158	487	77%	750	155	79%	1,446	506	65%	1,102	215	80%	265	265
22-Apr-03	29	7.12	37	28.7	1,433	416	71%	400	104	74%	1,133	516	54%	235	67	71%	280	275
24-Apr-03	31	7.15	36	28.1	1,405	574	59%	400	169	58%	1,124	574	49%	351	78	78%	270	265
26-Apr-03	33	7.38	36	36.9	1,843	461	75%	620	128	79%	1,106	461	58%	356	79	78%	275	285
28-Apr-03	35	7.63	37	38.0	1,902	377	80%	620	113	82%	1,294	427	67%	377	82	78%	255	275
30-Apr-03	37	7.56	36	39.7	1,986	436	78%	650	119	82%	1,331	506	62%	489	105	79%	275	275
2-May-03	39	7.42	35	37.0	1,849	306	83%	615	85	86%	1,294	427	67%	660	77	88%	285	285
4-May-03	41	7.30	34	41.9	2,096	295	86%	670	130	81%	1,362	545	60%	510	110	78%	250	265
6-May-03	43	7.68	35	36.1	1,805	774	57%	585	200	66%	1,217	750	38%	624	165	74%	265	250
8-May-03	45	7.64	35	56.7	2,836	453	84%	934	140	85%	1,815	581	68%	722	159	78%	275	270
10-May-03	47	7.68	36	43.0	2,148	418	81%	709	129	82%	1,246	448	64%	680	154	77%	255	285
12-May-03	49	7.61	36	36.9	1,843	461	75%	640	144	78%	1,290	517	60%	340	80	76%	270	265
14-May-03	51	7.54	36	12.0	600	165	73%	200	50	75%	977	547	44%	677	165	76%	300	280
16-May-03	53	7.66	35	18.9	945	239	75%	310	76	75%	845	389	54%	245	78	68%	255	285
18-May-03	55	7.67	36	24.5	1,225	351	71%	400	109	73%	827	370	55%	277	92	67%	270	270
20-May-03	57	7.62	33	34.6	1,728	476	72%	600	135	78%	1,210	520	57%	340	76	78%	275	275
22-May-03	59	7.59	34	30.5	1,526	464	70%	509	128	75%	915	476	48%	362	79	78%	255	260

Appendix 4: Daily measurements of various parameters in the conventional septic tank (Cont.)

Date	Day	pH	Temp (ºC)	OLR (g/d)	COD (mg/L)			BOD (mg/L)			TS (mg/L)			TSS (mg/L)			Alkalinity (mg/L	
					Inf.	Eff.	Rem%	Inf.	Eff.	Rem%	Inf.	Eff.	Rem%	Inf.	Eff.	Rem%	Inf.	Eff.
24-May-03	61	7.60	34	22.5	1,125	394	65%	420	120	71%	1,013	394	61%	429	82	81%	320	310
26-May-03	63	7.32	35	42.6	2,131	639	70%	670	175	74%	1,731	639	63%	562	133	76%	270	265
28-May-03	65	7.03	37	37.9	1,895	700	63%	689	200	71%	1,695	700	59%	687	158	77%	260	270
30-May-03	67	6.94	34	39.9	1,993	695	65%	695	198	72%	1,594	526	67%	690	179	74%	265	270
1-Jun-03	69	6.88	35	51.3	2,565	763	70%	761	218	71%	1,924	808	58%	666	195	71%	240	250
3-Jun-03	71	7.00	33	41.2	2,058	622	70%	624	176	72%	1,605	498	69%	624	144	77%	265	265
5-Jun-03	73	7.18	35	42.7	2,135	584	73%	703	177	75%	1,537	615	60%	542	168	69%	380	365
7-Jun-03	75	7.33	34	56.9	2,846	710	75%	949	206	78%	1,821	656	64%	452	102	77%	340	280
9-Jun-03	77	7.20	33	43.2	2,158	647	70%	760	193	75%	1,468	631	57%	478	117	76%	280	250
11-Jun-03	79	7.24	36	39.6	1,982	621	69%	630	156	75%	1,407	577	59%	685	160	77%	265	280
13-Jun-03	81	7.18	35	20.5	1,025	407	60%	438	112	74%	605	278	54%	301	62	79%	270	270
15-Jun-03	83	7.18	36	27.3	1,365	466	66%	470	140	70%	914	457	50%	425	97	77%	305	265
17-Jun-03	85	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19-Jun-03	87	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21-Jun-03	89	7.08	33	119.0	2,975	1,487	50%	831	440	47%	1,857	1,300	30%	814	562	31%	270	265
23-Jun-03	91	7.07	35	113.8	2,845	1,360	52%	904	408	55%	1,735	1,243	28%	1,600	1100	31%	270	265
25-Jun-03	93	7.23	35	121.0	3,025	1,423	50%	998	413	59%	2,006	1,383	31%	1,543	695	55%	290	275
27-Jun-03	95	7.48	33	25.6	640	226	85%	250	67	73%	960	533	44%	1,700	619	64%	260	270
29-Jun-03	97	7.41	32	76.2	1,904	838	71%	665	243	63%	1,010	573	51%	723	270	63%	265	265
1-Jul-03	99	7.30	35	84.5	2,112	665	69%	720	189	74%	1,259	849	33%	877	407	54%	270	260
3-Jul-03	101	7.27	34	102.0	2,549	892	65%	809	257	68%	1,686	1,168	31%	1,523	925	39%	400	360
5-Jul-03	103	7.30	34	85.9	2,148	667	69%	625	188	70%	1,387	902	35%	1,179	754	36%	290	290

Appendix 6: Measurements of TKN (mg/l)

Days	Inf. TKN	3 baffles	%remove	2baffles	%Remove	2baff.+media	%Remove	Conventional	%remove
10	52	31	41	43	17	41	22	39	25
20	55	31	43	46	16	43	21	40	27
30	49	29	41	42	15	37	25	36	27
40	51	30	42	43	15	39	23	38	26
50	45	27	41	39	13	35	22	34	25
60	52	31	40	44	16	41	21	38	27
70	57	35	39	48	16	43	24	43	25
80	77	47	39	65	16	61	21	60	22
90	78	46	41	69	12	66	15	57	27
100	80	48	40	69	14	62	23	59	26

Appendix 7: Measurements of TP (mg/l)

Days	Inf. TKN	3 baffles	%remove	2baffles	%Remove	2baff.+media	%Remove	Conventional	%remove
10	14	9	36	7	50	5	63	7	50
20	16	9	42	7	53	6	63	7	53
30	17	10	41	9	50	6	65	8	51
40	27	15	44	14	48	10	63	10	63
50	20	11	45	11	45	10	50	10	50
60	35	19	46	18	49	12	66	16	54
70	37	22	41	18	51	20	46	19	49
80	63	44	30	31	51	38	40	31	51
90	60	42	30	30	50	36	40	30	50
100	58	40	31	29	50	34	41	29	50

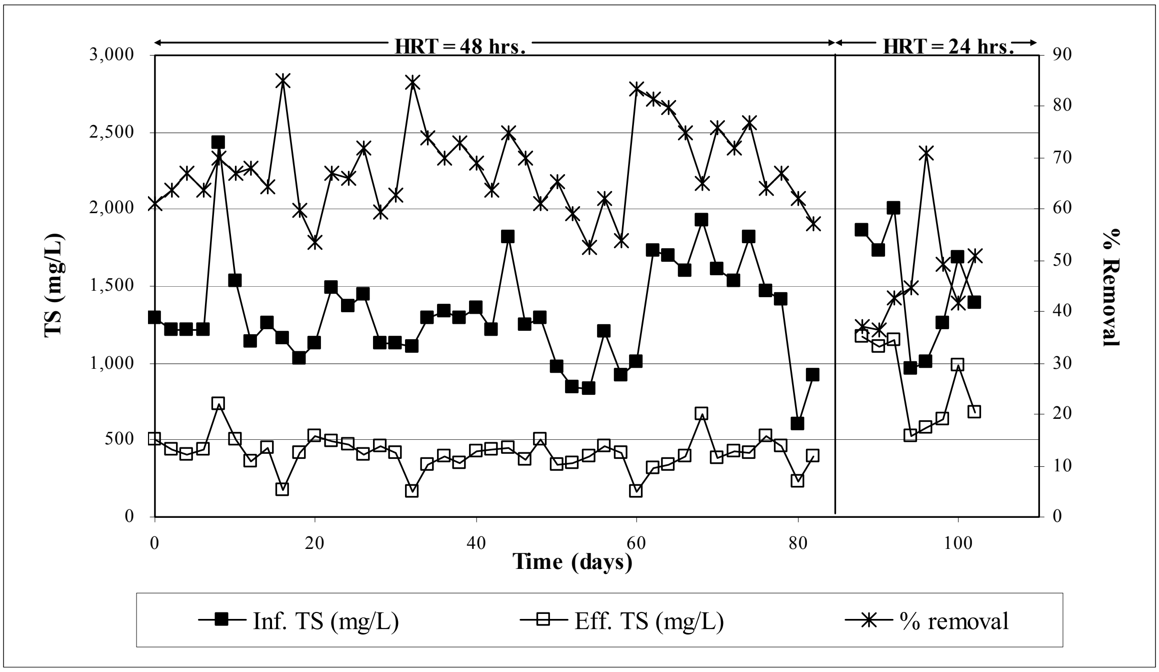
Appendix 8: TS removal in the different septic tank configurations (HRT = 48 hours)

Treatment unit	Range of Effluent TS (mg/L)	Average Effluent TS (mg/L)	Range of % TS removal	Average % TS removal
septic tank	236 – 950	511	38 – 69 %	58 %
2 baffled septic tank	169 – 730	394	53 – 85 %	66 %
2 baffled septic tank with filter media	168 –783	406	54 – 83 %	67 %
3 baffled septic tank	226 – 876	432	49 – 77 %	63 %

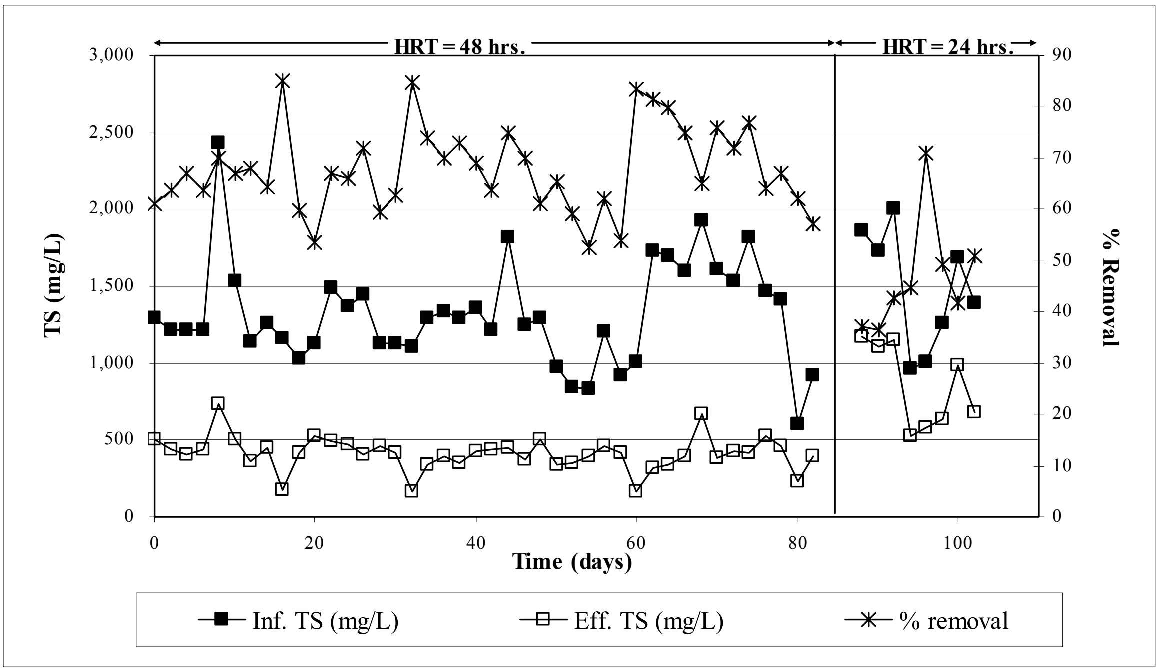
Appendix 9: TS removal in the different septic tank configurations (HRT = 24 hours)

Treatment unit	Range of Effluent TS (mg/L)	Average Effluent TS (mg/L)	Range of % TS removal	Average % TS removal
septic tank	533 – 1,383	994	28 – 51 %	35 %
2 baffled septic tank	580 – 1,170	855	36 to 71 %	47 %
2 baffled septic tank with filter media	557 – 1,013	811	41 – 72 %	49 %
3 baffled septic tank	543 – 913	731	48 – 73 %	54 %

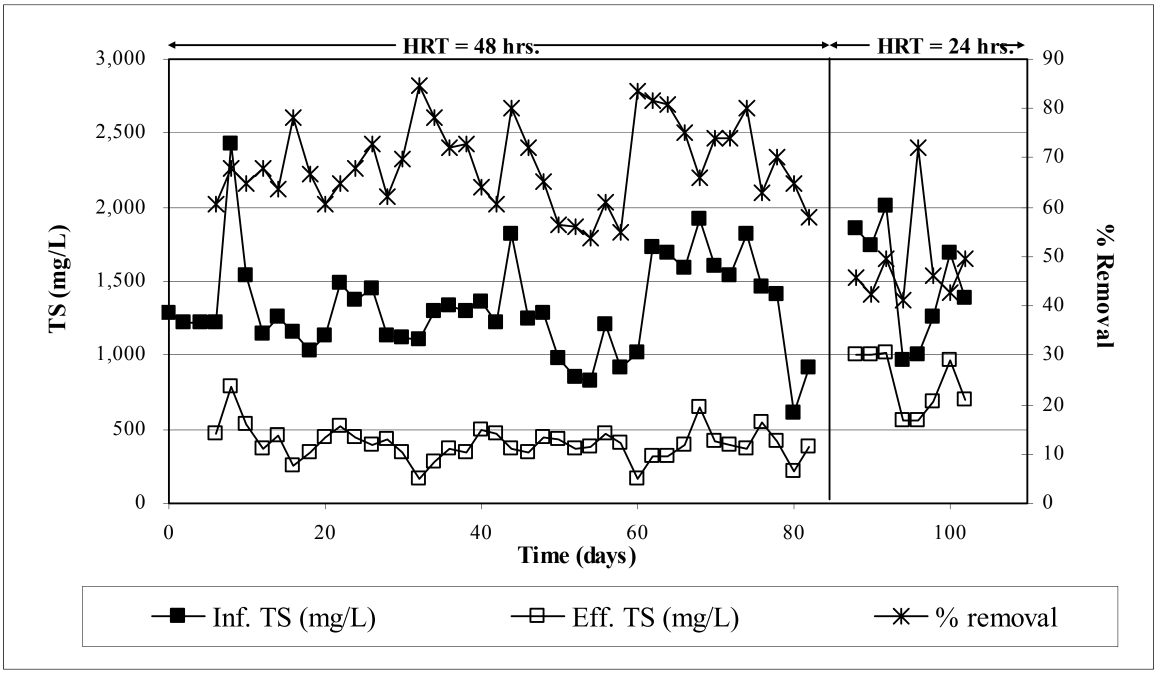
Appendix 10: TS removal in the three-baffled septic tank



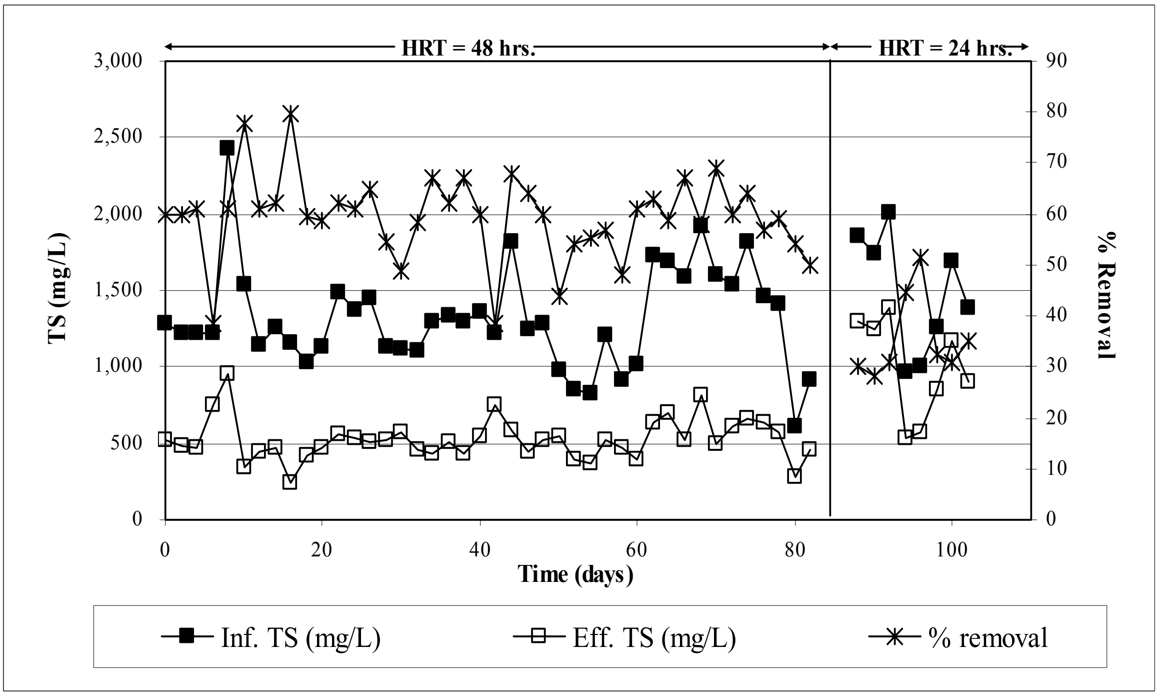
Appendix 11: TS removal in the two-baffled septic tank



Appendix 12: TS removal in the two-baffled septic tank with anaerobic filter



Appendix 13: TS removal in the conventional septic tank



Appendix 14: Sludge accumulation in the three-baffled septic tank

Time (day)	Amount of sludge accu-mulated (cm^3)	Amount of sludge accu-mulated (g)	Average sludge accumulated per day (g/d) (calculated from a 10days period)
50	11,039	3,201	14
60	11,184	3,243	7
70	11,578	3,358	11
80	12,113	3,513	16
90	12,913	3,745	22
100	14,225	4,125	38

Appendix 15: Sludge accumulation in the two-baffled septic tank

Time (day)	Amount of sludge accu-mulated (cm^3)	Amount of sludge accu-mulated (g)	Average sludge accumulated per day (g/d) (calculated from a 10days period)
50	8,260	2,395	12
60	8,660	2,511	9
70	9,420	2,732	12
80	10,100	2,929	20
90	11,150	3,379	30
100	12,850	3,988	39

Appendix 16: Sludge accumulation in the two-baffled septic tank with anaerobic filter

Time (day)	Amount of sludge accumulated (cm^3)	Amount of sludge accumulated (g)	Average sludge accumulated per day (g/d) (calculated from a 10days period)
50	8129	2,357	17
60	8620	2,500	8
70	9358	2,714	14
80	10094	2,927	19
90	11025	3,197	21
100	12159	3,526	33

Appendix 17: Sludge accumulation in the conventional septic tank

Time (day)	Amount of sludge accumulated (cm^3)	Amount of sludge accumulated (g)	Average sludge accumulated per day (g/d) (calculated from a 10days period)
50	7,080	2,395	5
60	7,125	2,500	1
70	7,500	2,714	11
80	7,700	2,927	6
90	7,950	3,197	7
100	8,250	3,526	9

Appendix 18: Average pH values

days	pH				
	Influent	3 baffle-tank	2 baffle-tank	2 baffle-tank + media	Septic tank
10	7.80	7.47	7.39	7.46	7.38
20	7.70	7.30	7.35	7.21	7.25
30	7.50	7.11	6.95	7.09	6.99
40	7.85	7.50	7.63	7.45	7.33
50	8.36	7.91	7.67	7.64	7.75
60	8.01	7.54	7.60	7.65	7.52
70	7.90	7.10	7.22	7.01	7.29
80	8.20	7.25	7.02	7.21	7.10
100	8.08	7.34	7.23	7.12	6.98
Avg.	7.93	7.39	7.34	7.32	7.29

Appendix 19: Average alkalinity values

days	Alkalinity (mg/L as $CaCO_3$)				
	Influent	3-baffle	2-baffle	2 baffle with media	Septic tank
10	292	277	286	279	271
20	285	280	280	275	269
30	270	272	281	274	266
40	266	269	272	275	272
50	269	270	280	276	272
60	278	280	290	280	279
70	277	290	287	279	271
80	284	292	299	286	282
90	308	302	303	295	289
100	286	278	276	276	274
Avg.	283	282	286	280	275

Appendix 20: Numbers of faecal coliforms observed in the influent and effluent

Time (days)	Faecal coliforms (MPN/100ml)				
	Influent	3-baffle	2-baffle	2 baffle with media	Septic tank
15	5.0×10^5	3.0×10^5	2.2×10^5	5.0×10^5	5.0×10^5
30	5.0×10^5	3.0×10^5	2.7×10^5	2.2×10^5	5.0×10^5
45	3.0×10^5	3.0×10^5	2.4×10^5	5.0×10^5	5.8×10^5
60	7.0×10^5	5.0×10^5	3.0×10^5	5.0×10^5	5.0×10^5
75	2.4×10^5	8.0×10^4	5.0×10^4	1.3×10^5	5.0×10^4