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IMPROVED SEPTIC TANK WITH CONSTRUCTED WETLAND, A PROMISING DECENTRALIZED WASTEWATER TREATMENT ALTERNATIVE IN VIETNAM

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ABSTRACT

The decentralized wastewater management approach has a true potential in Vietnam, also in urban and peri-urban areas where centralized wastewater collection and treatment systems are often not affordable. In urban areas of Vietnam, the conventional septic tank is the most common on-site wastewater treatment facility. However, the system has a limited treatment performance, and can not provide the treatment required to reach national effluent standards and to avoid water pollution. This paper presents an innovative way to improve the treatment efficiency of septic tanks. The Improved Septic Tank, also known as Baffled Septic Tank with or without Anaerobic Filter (BAST or BASTAF), developed and studied at the Centre for Environmental Engineering of Towns and Industrial areas (CEETIA), Hanoi University of Civil Engineering, represents a valuable and promising alternative to the conventional septic tank. Results of laboratory- and pilot-scale research on BAST and BASTAF systems show that at a hydraulic retention time (HRT) of 2 days, the BAST(AF) significantly increased the removal efficiencies in terms of BOD, COD and TSS compared with a conventional septic tank without any significant increase in construction expenses. The results indicated that a reactor combining one sedimentation/equalizing chamber followed by two up-flow chambers could efficiently treat domestic toilet wastewater. Average treatment efficiencies of 80–90% in terms of BOD, COD and TSS could be achieved. The addition of an anaerobic filtration chamber filled with charcoal or local-made recycled plastic balls (VABCO-K) could further increase removal efficiencies by 10% and prevent sludge wash out. Despite its virtues, the BAST(AF) system was not able to reach the strict wastewater discharge standards of Vietnam. Therefore a second study was conducted aiming at investigating post-treatment of BAST(AF) effluent with a vertical-flow constructed wetland. The study showed that treatment of BASTAF effluent in 2-stage vertical flow constructed wetland planted with locally available macrophytes, e.g. *Typha Orientalis*, *Phragmites communis*, and *Dracaena fragrans* allowed achievement of level A, Vietnamese standard for wastewater TCVN 5945-2005 in terms of COD, BOD_5, TSS, TN, NH_4-N and T-P.

KEYWORDS

Baffled septic tank, anaerobic filter, constructed wetland, decentralized wastewater treatment, Vietnam.

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INTRODUCTION

During the last 20 years Vietnam has undergone a dramatic economic and social transformation, which has led to considerable improvements in the overall well being of the vast majority of the Vietnamese people. An important drawback of this economic evolution is the increasing pollution of the environment. The alarming state of the natural water bodies in urban areas is due to the sanitation systems in place in almost all Vietnamese cities: domestic wastewater is discharged, with rudimentary pre-treatment in septic tanks, into combined sewerage systems, open channels and natural ponds. The construction of modern centralized treatment facilities is under consideration, but financial constraints make matters difficult. It must be assumed that the (pre-)treatment of domestic wastewater on a household level will continue to be a crucial component of water pollution control in urban and peri-urban areas.

The septic tank is the most frequently applied pre-treatment system in Vietnam, as well as in most South-East Asian countries. The septic tank is a watertight, covered receptacle designed and constructed to receive domestic wastewater, in which two processes take place: settling of the solids, and decomposition of the accumulated solids by anaerobic digestion.

The septic tank is institutionally well established in Vietnam as a treatment system for domestic wastewater. According to building regulations (Ministry of Construction-MOC, 2000), houses and apartment buildings in Vietnamese cities must be equipped with a septic tank, whether they discharge wastewater to soil, surface water or a sewer line. In individual houses this is usually a 1.5–2.5 m^3 (effective volume) tank with two or three compartments. The treatment performance of septic tanks depends on many factors: the composition and type of the wastewater, the temperature, the hydraulic retention time, the tank design and the state of maintenance (Van Buuren et al., 2001). According to Polprasert et al. (1982) the expected removal efficiency of a standard 2 m^3 septic tank loaded with domestic sewage in the tropics is about 70% TSS and 50% COD. In Vietnam, septic tanks receive blackwater only (*i.e.* toilet wastewater), while greywater (wastewater from kitchen, bath and laundry) is directly discharged to the stormwater drainage channel. Since greywater can contain up to 50% of the total COD produced in a household (Büsser et al, 2006), a septic tank for blackwater treatment will reduce the total pollution load of a household by only 25%. Efficiently working on-site treatment facilities can save considerable amounts of money off-site: screens, grit removal and the primary sedimentation tanks at wastewater treatment works can be resized or omitted, which would save approximately 30% of the capital costs for the treatment. In addition, the on-site removal of solids also opens the opportunity for water conservation since less flush water is needed for transport of solids in the sewer lines. Furthermore, since the sludge is of a purely domestic origin it can be suitable for agricultural reuse (Van Buuren et al, 2001).

Unfortunately, the septic tanks installed in Vietnam show low treatment efficiencies and thus don't contribute as much as expected to the water pollution control in urban environments. In a survey conducted by the Center for Environmental Engineering of Towns and Industrial areas (CEETIA), Hanoi University of Civil Engineering between 1998 and 2002, 20 septic tanks in 4 cities (Hanoi, Vinh Yen, Thai Nguyen, and Hai Duong) were investigated with respect to design, construction, operation and treatment efficiency. The survey showed that most septic tanks were inadequately designed (both capacity and shape) and improperly constructed (inappropriate material, permeable, unstable). Most units had never been desludged, not even the septic tanks that were more than 30 years old. The survey clearly demonstrated that national wastewater discharge standards cannot be met with conventional septic tanks (Nhue Hieu Tran et al, 2003).

The overall objective of the study was to investigate technical alternatives to the conventional septic tank in Vietnam for treatment of domestic wastewater on a household and neighborhood level. Given the high institutional acceptance for the conventional septic tank, the goal was to examine possibilities to upgrade this system by simple means.

The three components of the study were: (1) Lab-scale experiments on improved septic tank design, (2) Investigations on full-scale improved septic tanks, and (3) Lab-scale studies on septic tank effluent treatment in a vertical flow constructed wetland system.

The goal of the study components (1) and (2) was to examine possibilities to upgrade conventional septic tanks for the treatment of toilet wastewater (blackwater) by introducing vertical in-tank baffles. Thanks to those baffles, the contact between wastewater and the active biomass (sludge) was increased, leading to improvement of the treatment efficiency (Langenhoff and Stuckey, 2000). According to Barber and Stuckey (1999), baffling of septic tanks was introduced around 1980 by McCarty at Stanford University, while working on anaerobic rotating biological contactors (RBC). McCarty (1981) introduced the terminology Anaerobic Baffled Reactor (ABR) for the first time in 1981. The ABR is a reactor that uses a series of baffles to force the incoming wastewater to flow under and over the baffles from the inlet to the outlet of the tank (Barber et al., 1999). In their comprehensive literature review, Barber and Stuckey (1999) concluded that the ABR is capable of treating a variety of wastewaters of varying strength (0.45–1000 g COD/l) over a large range of loading rates (0.4–28 kg COD/m^3*d) and with high solids concentrations with satisfactory results. However most of the studies on ABR have been looking at industrial wastewater treatment in lab-scale units only. Very little research has been conducted on the applicability of baffled septic systems for the treatment of domestic wastewater in low-income countries. Some promising results were produced in South Africa (Dama et al., 2002) and Thailand (Koottatep et al., 2004), but there are still important knowledge gaps, such as the optimal number of baffles, the optimal hydraulic retention time, the potential use of an anaerobic filter and addition of polishing stages, and finally the applicability in a Vietnamese context.

Assuming that no anaerobic system could reach the strict wastewater discharge standards of Vietnam, a third component of the study investigated the suitability of a vertical-flow constructed wetland for post-treatment of septic tank effluent.

MATERIALS AND METHODS

Component 1. Laboratory scale research on baffled septic tanks

The laboratory-scale experiments were carried out at the Water and Wastewater Treatment Technology laboratory of the Center for Environmental Engineering of Towns and Industrial areas (CEETIA), Hanoi University of Civil Engineering, Vietnam, at an ambient temperature of 13.6–29.5 ^{o}C. Two laboratory-scale treatment units were installed, using 6 plastic cylinders (height = 150cm; diameter = 20cm) to simulate the up-flow chambers of the baffled septic tank (reactor A), and 2 plastic up-flow cylinders to simulate a 2 compartment septic tank (reactor B) as illustrated in Figure 1. This setup ensured optimum contact between the up-flowing wastewater and the sludge accumulated at the bottom of the reactor. The up-flow velocity in both reactors was controlled in order to avoid sludge wash out. VABCO-K plastic balls with 60-mm diameter and a specific surface of 200 m^2/m^3 were used as anaerobic filter material.

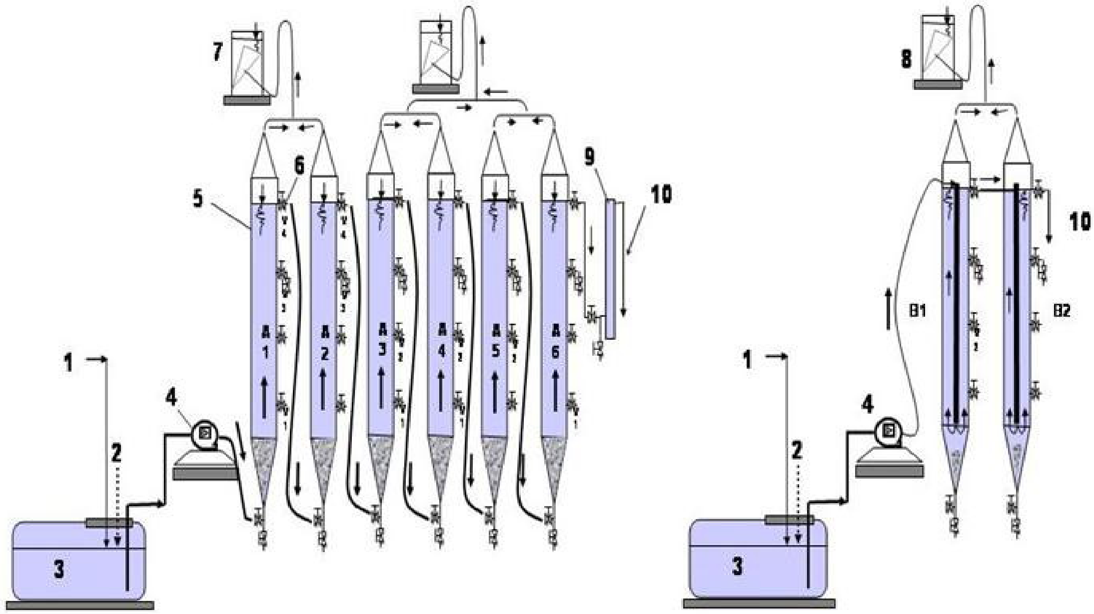


Figure 1. Lab-scale experimental units of the Baffled Septic Tank (BAST) and reference Conventional Septic Tank (ST).

(Key – 1 Raw wastewater from campus toilets; 2 – Diluting tap water; 3 – Mixing – storage tank; 4 – Dosing pump; 5 – Plastic cylinders up-flow chambers; 6 – Sampling points; 7, 8 – Gas measurement devices; 9 – Gas trapper; 10 – Effluent).

Fourteen different experiments were conducted between July 2004 and November 2005. The experiments were set up to determine the impact on the treatment performance of (a) the number of up-flow chambers, (b) the hydraulic retention time (HRT), (c) the effect of an anaerobic filter stage, and (d) the up-flow velocity. The 14 experiments are presented in Table 1.

Table 1. Laboratory-scale experiments conducted on improved septic tank design between July 2004 and November 2005.

	System	Configuration	HRT (h)	Up-flow velocity (m/h)	Number of samples
1	ST	2 UFC	48	0.06	95
2	ST	2 UFC	72	0.04	14
3	ST	2 UFC	48	0.06	16
4	ST	2 UFC	24	0.13	16
5	ST	2 UFC	12	0.25	19
6	BAST	6 UFC	48	0.19	306

7	BAST	6 UFC	72	0.13	22
8	BAST	6 UFC	48	0.19	34
9	BAST	6 UFC	24	0.38	27
10	BAST	6 UFC	12	0.75	46
11	ST	2 SC	48	0.06	15
12	STAF	2 SC + 1 AF	48	0.09	15
13	BAST	3 UFC	48	0.09	15
14	BASTAF	2 UFC + 1 AF	48	0.08	15

Note: ST = septic tank; BAST = baffled septic tank; STAF = septic tank with anaerobic filter; BASTAF = baffled septic tank with anaerobic filter; SC = settling chamber; UFC = up-flow chamber; AF = up-flow anaerobic filter

The units were fed at a constant flow using peristaltic pumps. Samples were collected from the influent, from each column, from the effluent and from the sludge in the bottom of the cones. Three gas volume digital counters were used for measuring the volume of biogas generated as shown in Figure 1.

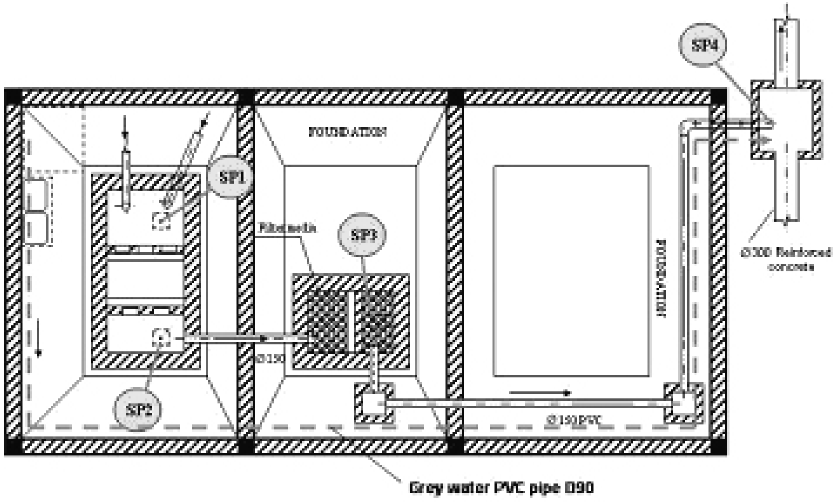
The experimental reactors were seeded with digester sludge taken from previous experiments on laboratory scale BAST in order to speed up the acclimatization process. Toilet wastewater (blackwater) was used as the wastewater source for this study. Wastewater from toilets used by students of Hanoi University of Civil Engineering (HUCE) was collected in a 1,000 liter stainless steel storage tank before it was piped to the laboratory. In order to avoid sedimentation in the tank, a rearing mechanism was introduced, accepting a certain level of anaerobic digestion in the storage tank. To avoid clogging of the system, the wastewater was filtered through a coarse filter. In order to ensure stable inlet concentrations, total COD in the raw wastewater was measured, and tap water was added if necessary in order to reach a COD concentration of approximately 500 mg/l. The average characteristics of the blackwater used in these experiments were 505 mg/l, 250 mg/l, 196 mg/l and 284 mg/l of COD, $COD_{filtered}$, BOD_5 and TSS, respectively. This corresponds to middle to high strength wastewater according to the classification of Metcalf & Eddy (2003).

Wastewater and sludge samples were analyzed in terms of COD, $COD_{filtered}$, BOD_5, TSS and pH according to the Standard Methods for Examination of Water and Wastewater (APHA-AWWA-WEF, 1998).

Component 2. Study on full-scale BAST(AF)s

Parallel to the laboratory scale research activities, pilot treatment units were installed in different locations in and around Hanoi to investigate the applicability of the baffled septic tank system in real conditions. Ten improved septic tanks were constructed. These treatment units serve individual houses, administrative buildings and neighborhoods in urban and rural areas, receiving either domestic blackwater, a mixture of grey and black wastewater, or combined sewer flow. The number of users on the pilot treatment units varied from 4 (Figure 2) and 360 (Figure 3).

a)



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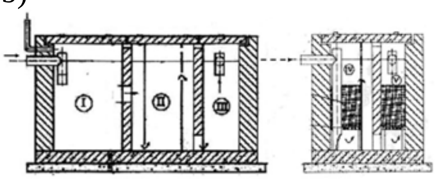


Figure 2. First full-scale BASTAF P-01 installed in Hanoi: a) plan view ; b) cross-section view.

Figure 3. BASTAF under construction for a group of 80 households in Lai Xa commune, 20 km from Hanoi centre (photo by Nguyen V. A., 2006)

The second full-scale baffled septic tank monitored serves a group of 20 households in Huu Hoa, a commune located nearby the Nhue river of Hanoi city. This system treats domestic and livestock breeding wastewaters. The 17.6 m^3 BAST consists of a sedimentation chamber followed by 4 up-flow chambers (Figure 4 a, b).

a) b)

Figure 4. Baffled Septic Tank P-20 serving 20 households in Huu Hoa Commune: a) during construction; b) construction completed. (photo by Nguyen V. A., 2006)

Component 3. Septic tank effluent treatment in a vertical flow constructed wetland system

In this component, experiments with small two-step vertical flow constructed wetlands were run at CEETIA from March 2004 to April 2006. The study focused on evaluation of the treatment performance using two different filter materials, and the tolerance of some local plants to septic tank effluent.

Six wetland cells (A1, A2, A3, B1, B2, B3) were built using stainless steel tanks of 0.7 m diameter and 1.0 m height (Figure 5). For cells A1, A2, A3, gravel with a diameter of 1.5–2 cm was used as filter media. For cells B1, B2, B3, broken clay bricks with a diameter of 3–4 cm were selected. The height of the filter media was 0.7 m, and the bottom of each unit was filled with a 22 cm deep layer of 6-8 cm gravel. On the surface of each unit, 5 cm construction quartz sand (effective size d_{10} = 0.8 mm, uniformity coefficient UC = 1.7) was added to support physically the plant growth.

a) b)

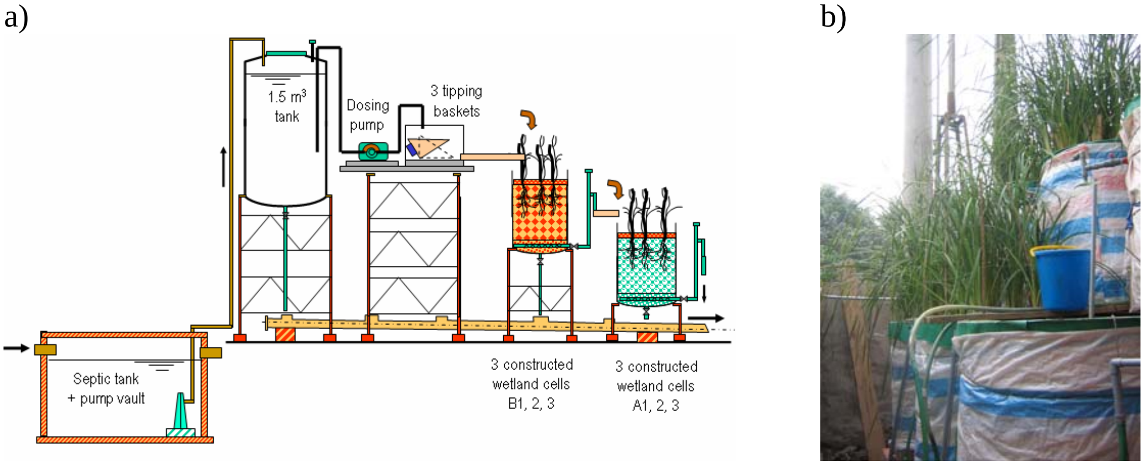


Figure 5. Vertical flow constructed wetland system: a) cross-section view; b) photo taken in July 2004.

The cells were set to run in 3 parallel lines: B1–A1, B2–A2, and B3–A3. Various plants were planted, *e.g*. cattail (*Typha orientalis*), common reed (*Phragmites communis*), and some different ornamental plants, among them the prosperous tree (*Dracaena fragrans*).

Septic tank effluent was fed through a 1,500 L–volume feeding tank to cells B1, B2, B3 by dosing pumps and tipping baskets. The loading rates were 20–60 l/day per cell applied 2–3 times daily which equaled 0.022–0.066 $m^3/(m^2*d)$ or 2.2–6.6 cm/d.

Daily composite samples were taken once per week, and samples were analyzed for temperature, pH, DO, Conductivity, TDS, COD, TSS, TP, PO_4^{3-}, TN, $N\text{-}NH_4^+$, $N\text{-}NO_3^-$, Faecal Coliform and Total Coliform according to Standard Methods (APHA - AWWA -WEF, 1998).

RESULTS AND DISCUSSIONS

Laboratory-scale experiments on improved septic tanks

The laboratory-scale experiments showed that the introduction of baffles and anaerobic filter material significantly increased the treatment performance of conventional septic tanks in terms of COD, BOD and TSS. The average removal efficiencies observed in the 14 experiments are summarized in Table 2.

Table 2. Average removal efficiencies observed in the laboratory-scale experiments on improved septic tanks.

	System	Configuration	HRT (h)		Removal efficiency (%)		
					COD	BOD_5	TSS
1	ST	2 UFC	48	Mean	55.7	-	47.4
				s.d.	*9.4*		*18.1*
2	ST	2 UFC	72	Mean	58.4	-	54.6
				s.d.	*10.9*		*25.8*
3	ST	2 UFC	48	Mean	59.8	-	68.9
				s.d.	*10.2*		*15.2*
4	ST	2 UFC	24	Mean	48.5	-	44.0
				s.d.	*16.3*		*12.1*
5	ST	2 UFC	12	Mean	48.0	-	35.0
				s.d.	*16.0*		*8.6*
6	BAST	6 UFC	48	Mean	72.0	-	70.4
				s.d.	*5.7*		*10.7*
7	BAST	6 UFC	72	Mean	71.8	-	68.0
				s.d.	*6.0*		*11.6*
8	BAST	6 UFC	48	Mean	76.1	-	78.0
				s.d.	*8.6*		*9.6*
9	BAST	6 UFC	24	Mean	65.7	-	61.0
				s.d.	*5.4*		*8.7*
10	BAST	6 UFC	12	Mean	58.0	-	65.2
				s.d.	*15.1*		*10.3*

11	ST	2 SC	48	Mean	66.9	57.9	79.3
				s.d.	*9.1*	*22.7*	*10.6*
12	STAF	2 SC + 1 AF	48	Mean	85.1	69.2	84.7
				s.d.	*6.8*	*9.4*	*7.5*
13	BAST	3 UFC	48	Mean	84.1	71.7	86.4
				s.d.	*5.8*	*13.1*	*9.7*
14	BASTAF	2 UFC + 1 AF	48	Mean	86.3	74.2	90.8
				s.d.	*7.4*	*11.4*	*6.4*

Note: ST = septic tank; BAST = baffled septic tank; STAF = septic tank with anaerobic filter; BASTAF = baffled septic tank with anaerobic filter; SC = settling chamber; UFC = up-flow chamber; AF = up-flow anaerobic filter; s.d. = standard deviation

Stable average removal efficiencies of 58.0–76.1% and 61.0–78.0% in terms of COD and TSS, respectively, could be reached, depending on the HRT in the BAST. On the other hand, the conventional septic tank reactor, with optimum configuration patterns and identical working conditions had average removal efficiencies of 48.0–59.8% and 35.0–68.9% in terms of COD and TSS, respectively (Table 2).

Optimal hydraulic retention time (HRT)

Based on the experiments 1–10, the impact of the hydraulic retention time on the treatment performance of both septic tank and baffled septic tank was estimated. The experiments revealed that in the range of 12 to 48h, an increased HRT led to a significant increase in the removal rates of COD and TSS in both the septic tank and the baffled septic tank. An additional increase of the HRT above 48 hours did not significantly increase the removal efficiency; neither in terms of COD nor in terms of solids removal (Figure 6). In the range of 12 to 48h, an increased HRT also led to a stabilization of the treatment process, as the standard deviations of the COD and TSS removal rates indicate (Table 2, experiments 6–10). Therefore, BAST reactors with an effective HRT of 48h are recommended.

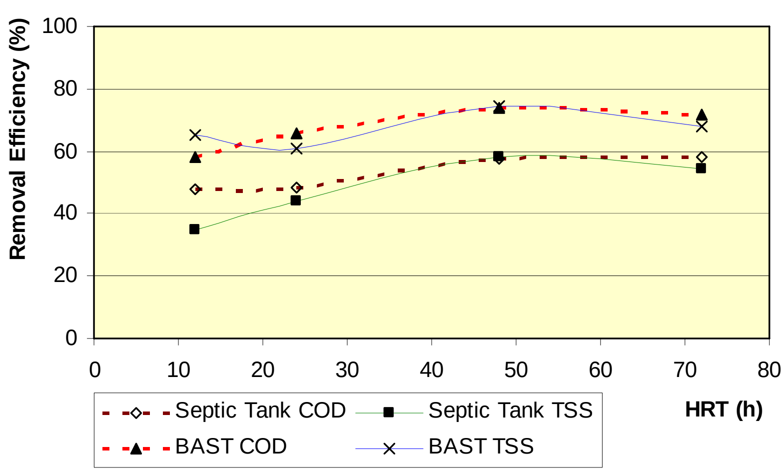


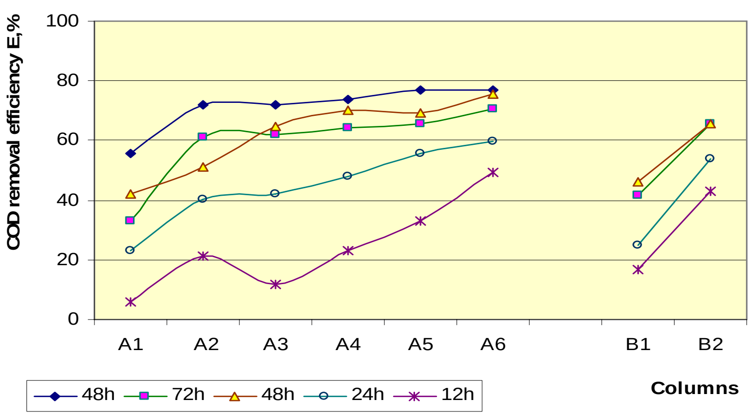
Figure 6. Impact of the HRT on the treatment performance of ST and BAST (Experiments 1–10).

Interesting observations were also made in the septic tank (experiments 1–5). The widely used standard of 2 days HRT for the tank volume design could be confirmed. A HRT of more than 2 days did not significantly increase average removal efficiencies over the 2 days HRT, while a HRT shorter than 2 days led to significantly lower average removal efficiencies (Figure 6).

Optimal number of up-flow chambers

Experiments 1 to 10 revealed that the number of up-flow chambers plays an important role in the treatment process. This has also demonstrated in other studies (Barber et al., 1999, Koottatep et al., 2004). Figure 7 illustrates the cumulative COD and TSS removal rates along the reactor length as observed in experiments 5–10. The main removal of COD and TSS takes place in the first up-flow chambers of the BAST. At a HRT of 48h or more, the last two up-flow chambers did not significantly contribute to the removal of COD and TSS. Since the number of up-flow chambers has a direct impact on construction costs, space requirement and operational complexity, it is not recommended to install BAST with more than 4 up-flow chambers.

a)



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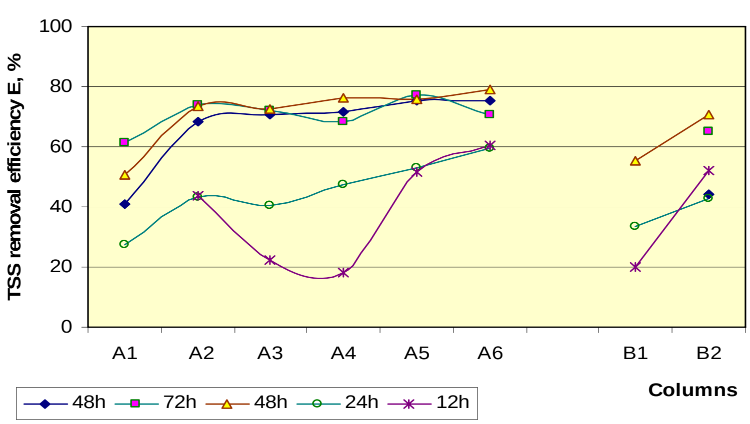


Figure 7. Cumulative COD (a) and TSS (b) removal rates along the reactor length (experiments 5 to 10).

Impact of the anaerobic filter on treatment performance

Experiments 11–14 aimed at identifying the impact of an anaerobic filter stage. Four systems were operated at a HRT of 48h following the outcomes of experiments 1–10.

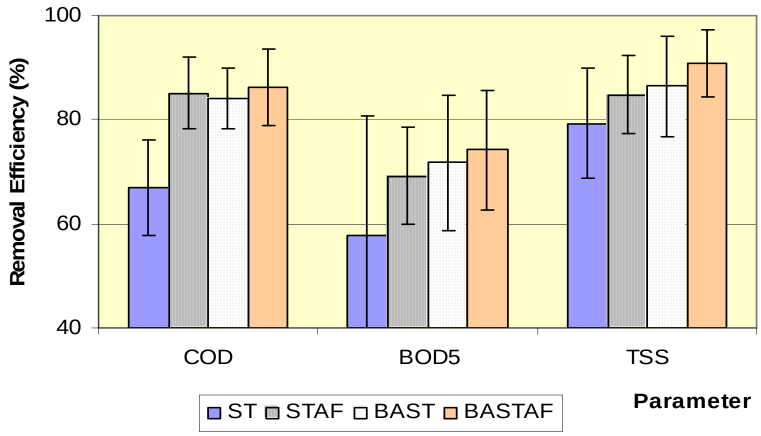


Figure 8. Average COD, BOD_5 and TSS removal efficiencies observed in Experiments 11–14 (all at HRT = 48h).

The anaerobic filter significantly increased the removal efficiency of the conventional septic tank (compare ST vs. STAF, Figure 8). This effect was less significant in the baffled septic tank, where the BASTAF showed only slightly higher COD, BOD_5 and TSS removal efficiencies than the BAST system. Here the anaerobic filter can only play the role of a barrier against solids wash out during shock loadings or maintenance failures. The BASTAF system showed the greatest treatment performance, with average COD, BOD_5 and TSS removal efficiencies of 86.3%, 74.2% and 90.8%, respectively.

Monitoring of full-scale improved septic tanks

Table 3. Treatment performance of the full-scale BASTAF P-01 and BAST P-20.

Name	System	Sampling location		COD_{tot}	BOD_5	TSS
				mg/l		
P-01	BASTAF	In	Mean	2,840	971	1,367
			s.d.	*3,696*	*1086*	*1,411*
		Out	Mean	290	181	100
			s.d.	*130*	*100*	*28*
P-20	BAST	In	Mean	2512	1356	3695
			s.d.	*979*	*560*	*1846*
		Out	Mean	295	150	195
			s.d.	*132*	*50*	*86*

Despite highly fluctuating characteristics of the influent wastewater to the full scale improved septic tanks, both systems were able to produce an effluent with relatively stable characteristics, as the comparison of standard deviations of both the influent and effluent concentrations illustrates (Table 3). The household BASTAF system (P-01) showed satisfactory treatment efficiencies, with average removal rates of 77.0%, 71.0% and 86.2% for COD, BOD_5 and TSS, respectively. This confirms the outcomes of the laboratory-scale research. The treatment performance of the community BAST (P-20) was even greater, with average removal rates as high as 87.9%, 87.7% and 94.1% for COD, BOD_5 and TSS, respectively.

These values are considerably higher than average removal efficiencies observed in conventional septic tanks in Vietnam and other regions of the world (Polprasert et al, 1982). It also demonstrates the suitability of the system to treat high-strength domestic wastewater with average COD concentrations higher than 2,500 mg/l.

Based on the above mentioned results some of the important operational issues were observed during the monitoring of the full-scale systems as follows:

- Sludge and scum accumulate in the first chamber mainly. Accumulation rates of 25 cm were observed in the household BASTAF P-01 after 3 years of operation. No scum layer was formed in the anaerobic filter chamber.

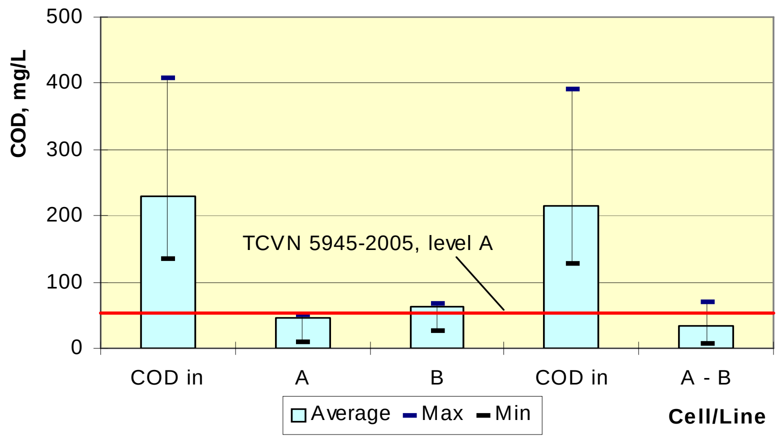
- Reduced treatment performances were observed after two years of operation, which indicated that the sedimentation chamber of the system should be desludged on a biannual basis.

Septic tank effluent treatment in vertical flow constructed wetland

With influent COD concentrations between 134.9 and 407.1 mg/l (mean value 229.5 mg/l), the effluent COD from the First step constructed wetland was 10.0–68.3 mg/l (mean value 53.7 mg/l), equal to a removal efficiency of 73.0–92.6% (mean value 76.6%) (Figure 9). Influent and effluent TSS were between 45.0–150.0 mg/l (mean 93.3 mg/l) and 5.0–19.0 mg/l (mean 13.9 mg/l), respectively, with a removal efficiency of 84.4–88.9% (mean value 85.2%). With regards to NH_4-N and T-P, the influent concentrations were between 48.2–82.1 mg/l (mean 65.2 mg/l) and 8.4–13.7 (mean 11.6), respectively. The effluent NH_4-N concentrations after the First stage were 22.2–32.4 mg/l (mean value 27.3 mg/l), and the effluent concentrations of T-P were 4.5–8.5 mg/l (mean value 6.1 mg/l). Those values represented 53.2–60.4 % (mean 58.5%) and 28.4–58.5% (mean 48.0%) removal efficiencies for NH_4-N and T-P, respectively. The Fecal coliform removal efficiency was 90–96% (~ 1–1.4 log_{10} units). Those values did not meet the Vietnamese effluent standard for wastewater TCVN 5945-2005, Class A.

The two stage wetland system had much greater removal efficiencies (Table 4). The quality of the effluent regarding COD, BOD_5, TSS, T-N, N-NH_4^+ and T-P met the Vietnamese effluent standards TCVN 5945–2005, class A. However, the Fecal coliform removal efficiency in 2 steps wetland was only 95–97% (~ 1.3–1.4 log_{10} units), leading to the fecal coliform value in the effluent from the second step of the wetlands still exceeded the Class A of the standards. The ponding regime of the wetland experimental units caused an anaerobic environment, which was probably the main reason for the small removal efficiency of the indicator bacteria. The results from laboratory scale experiments showed that adding a vertical flow wetland system to improved septic tanks resulted in an effluent that met most of the strict standards in Vietnam. However, more researches are needed to maximize the performance of the system, for example, determination of the maximum hydraulic loads that can be applied, search for the most cost efficient substrate to be used in the beds, and setting up of the operational conditions that would result in an improved bacteria removal.

a)



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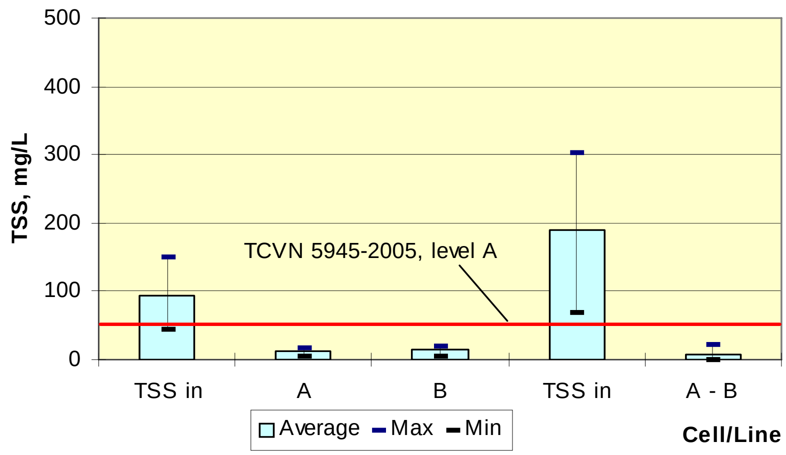
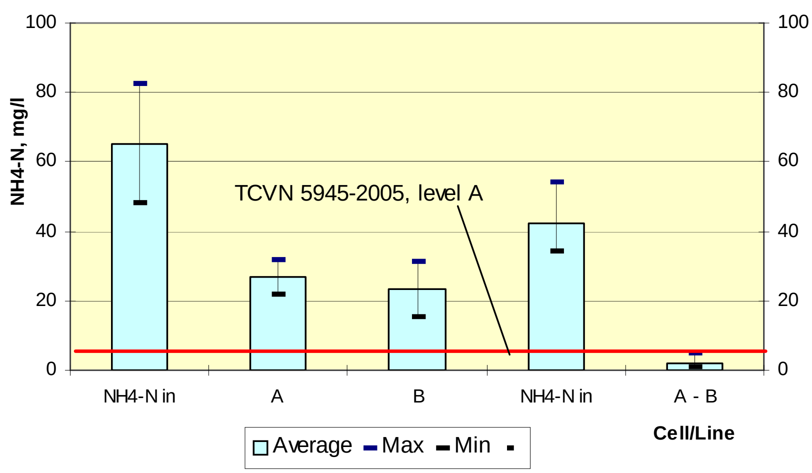
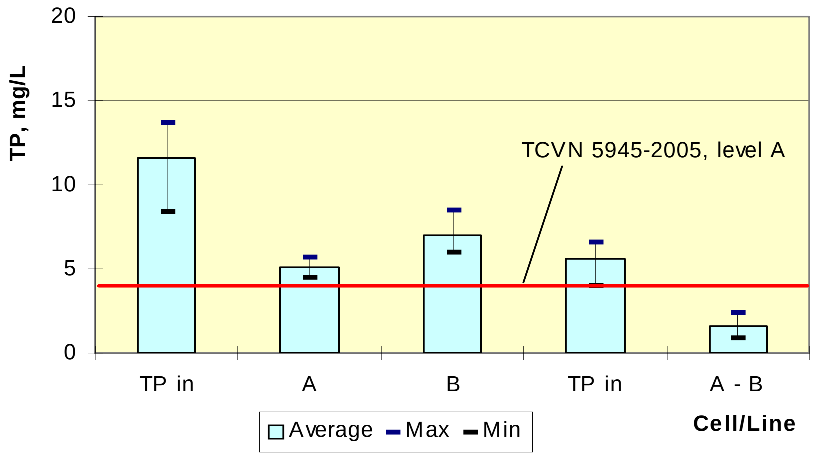


c)



d)



e)

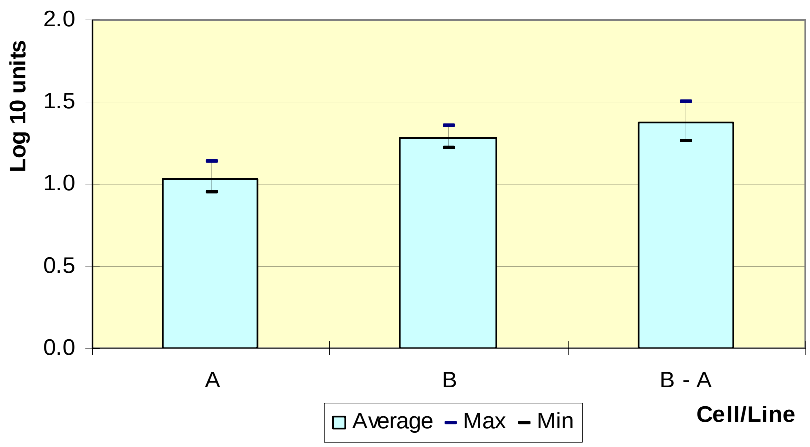


Figure 9. Vertical flow constructed wetlands filled with gravel (A) and broken bricks (B), operated in parallel or consecutively as a two stage system treating septic tank effluent. Inflow and outflow concentrations: COD (a), TSS (b), NH_4-N (c), T-P (d). Removal efficiency (log_{10} units): Fecal Coliforms (e).

Table 4. Concentrations of selected parameters in septic tank effluent before and after a two-step vertical flow constructed wetland unit.

Sample location		COD	TSS	NH_4-N	TP
		------------------ mg/L	------------------		
In	Mean	214.4	189.6	42.3	5.6
	S.d.	*61.8*	*48.4*	*5.6*	*0.9*
Out	Mean	34.8	6.8	1.8	1.6
	S.d.	*14.0*	*5.1*	*0.5*	*0.5*

Note: Values represent mean values for 20 months and 3 replicate experimental units. Time period for 1 step experiments: 10 months (April 2004–January 2005, for 2 steps experiments: January 2005–April 2006).

CONCLUSIONS AND RECOMMENDATIONS

This study clearly demonstrated the potential of STAF, BAST and BASTAF as alternatives to the conventional septic tank for the pre-treatment of domestic wastewater on a household or neighborhood level. By simple means (baffling of the septic tank or introduction of an anaerobic filter stage), the treatment performance of septic tanks could be increased to between 80 and 90% removal of COD and TSS, especially in regions with high ambient temperature throughout the year.

A minimum HRT of 2 days is recommended for improved septic tank systems. Given the similar performance of the three systems investigated (STAF, BAST and BASTAF), the selection of the system will mainly depend on the preferences of the users and the fate of the treated wastewater. The BAST system with one settling chamber and 2 to 3 up-flow chambers is recommended in houses connected to the communal sewer and when the septic tank is placed in the basement. Where post-treatment steps such as infiltration trenches, constructed wetlands or sand filters are foreseen, and where good access to the treatment system is guaranteed, it is recommended to install a BASTAF system with an anaerobic filter stage in order to minimize the discharge of solids and thus the risk of clogging these post-treatment systems.

Reduced treatment performances were observed after two years of operation, which indicated that the sedimentation chamber of the system should be desludged on a biannual basis. Since the access removable covers are often not installed on the septic tanks placed in the basement of private houses in Vietnam, it is recommended that during the tank construction those items should be installed.

Further treatment improvement of septic tank and improved septic tank effluent can be achieved using *e.g.* a two stage vertical flow constructed wetland system. However, more research is needed to identify the maximum hydraulic load that can be applied in order to minimize the area requirement of such a system. In the present study, a HLR of 0.022–0.066 m^3/m^2*d resulted in an effluent quality that met the Class A of the Vietnamese standard TCVN 5945–2005. However, the microbial quality of treated wastewater did not meet the mentioned standards. Provision of aerobic conditions in the wetland units, increase of HRT, or the use of a finer filter media might provide opportunities to improve microbial removal.

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