Baffled Septic Tank with Anaerobic Filter (BASTAF) and Vertical Subsurface Flow Constructed Wetland for Domestic Wastewater Treatment in Vietnam

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Abstract: The decentralized wastewater management utilizing existing infrastructure and low-cost natural treatment processes has a large potential in Vietnam. Centralized wastewater collection and treatment systems are often not affordable. Currently the septic tank is the most common on-site wastewater treatment facility in Vietnam. Nevertheless it has a limited treatment performance. The Improved Septic Tank, also known as Baffled Septic Tank with or without Anaerobic Filter (BASTAF or BAST) 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 3-chamber BAST followed by Anaerobic Filter significantly increased the removal efficiencies in terms of BOD, COD and TSS in comparison with a conventional septic tank of the same size. Average treatment efficiencies of 80–90% in terms of BOD, COD and TSS can be achieved. Another component of the study showed that post-treatment of BASTAF effluent in a 2-stage vertical flow constructed wetland (CW) planted with locally available macrophytes allowed the achievement of level A, Vietnamese standard for wastewater discharge in terms of COD, BOD₅, TSS, TN, NH₄-N and T-P. Results of this study are now being implemented in different provinces in Vietnam.

Keywords: Anaerobic filter, baffled septic tank, constructed wetland, Vietnam, wastewater

INTRODUCTION

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 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.

An individual 4- or 5-members family septic tank is usually a 1.5–2.5 m³ (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 m³ septic tank loaded with domestic sewage in the tropics is about 70% TSS and 50% COD. In Vietnam, most of septic tanks receive black water only (i.e. toilet wastewater), while gray water (wastewater from kitchen, bath and laundry) is discharged into the combined sewer system or directly to the environment. While centralized wastewater management systems are still not available in most of urban and rural areas in Vietnam, efficiently working on-site treatment facilities can play a very important role for environmental pollution mitigation. In addition, it can save considerable amounts of money in future off-site wastewater management works: less flush water is needed for transport of solids in the sewer lines, while the screens, grit removal and primary sedimentation tanks at the wastewater treatment plants can be resized or omitted. Furthermore, since the sludge is of a purely domestic origin it can be suitable for agricultural reuse (Van Buuren et al., 2001).

Unfortunately, the previous study conducted by the Institute of Environmental Science and Engineering (IESE), Hanoi University of Civil Engineering shown that many septic tanks installed in Vietnam show limited treatment efficiencies and do not contribute as much as expected to the water pollution control in urban environments. Many septic tanks were inadequately designed (both capacity and shape) and improperly constructed (inappropriate material, permeable, unstable). National wastewater discharge standards can not be met with conventional septic tanks (Nguyen et al., 2006).
The overall objective of the study was to investigate technical alternatives to the conventional septic tank 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. Besides, the viability of constructed wetland as a low-cost treatment method for the septic tank effluent for meeting the national discharge standards was studied. Using constructed wetland systems for wastewater treatment in Vietnam was still new concept and not well studied.

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 the treatment of septic tank effluent in 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 (black water) by introducing vertical in-tank baffles. Introduction of baffles resulted in an increase in the contact between wastewater and the active biomass (sludge) which consequently leads to an improvement in 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 (0.45–100 g COD/l) over a large range of loading rates (0.4–28 kg COD/m³*d) and with high solids concentrations. However most of the studies on ABR have been looking at industrial wastewater treatment at 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 obtained in South Africa (Dama et al., 2002) and Thailand (Koottatep et al., 2004a). Still there are 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 component (3) of the study is the investigation of 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
Laboratory-scale experiments were carried out at the Water and Wastewater Treatment Technology laboratory of the Institute of Environmental Science and Engineering (IESE), Hanoi University of Civil Engineering, Vietnam, at an ambient temperature of 13.6–29.5 °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. The setup A should ensure 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 developed by the corresponding author with 60-mm diameter, a specific surface of 200 m²/m³ and a porosity of 98%, were used as anaerobic filter material filled in the last two columns of A.
Figure 1: Laboratory scale experimental units of the Baffled Septic Tank and reference Conventional Septic Tank. (Key: A - baffled septic tank (BAST); B - 2-compartment conventional septic tank (ST); 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 series of experiments were conducted within 4 years (1999 - 2003). The experiments were set up to determine the impact on the treatment performance of (a) the introduction of up-flow chamber(s) and its number, (b) the hydraulic retention time (HRT), (c) the effect of an anaerobic filter stage, and (d) the up-flow velocity. The 14 experiments (which were lasting for 4 – 10 weeks each) are presented in Table 1.

Table 1: Laboratory-scale experiments conducted on improved septic tank design

<table>
<thead>
<tr>
<th>System</th>
<th>Configuration</th>
<th>HRT (h)</th>
<th>Up-flow velocity (m/h)</th>
<th>Number of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 ST</td>
<td>2 UFC</td>
<td>48</td>
<td>0.06</td>
<td>95</td>
</tr>
<tr>
<td>2 ST</td>
<td>2 UFC</td>
<td>72</td>
<td>0.04</td>
<td>14</td>
</tr>
<tr>
<td>3 ST</td>
<td>2 UFC</td>
<td>48</td>
<td>0.06</td>
<td>16</td>
</tr>
<tr>
<td>4 ST</td>
<td>2 UFC</td>
<td>24</td>
<td>0.13</td>
<td>16</td>
</tr>
<tr>
<td>5 ST</td>
<td>2 UFC</td>
<td>12</td>
<td>0.25</td>
<td>19</td>
</tr>
<tr>
<td>6 BAST</td>
<td>6 UFC</td>
<td>48</td>
<td>0.19</td>
<td>306</td>
</tr>
<tr>
<td>7 BAST</td>
<td>6 UFC</td>
<td>72</td>
<td>0.13</td>
<td>22</td>
</tr>
<tr>
<td>8 BAST</td>
<td>6 UFC</td>
<td>48</td>
<td>0.19</td>
<td>34</td>
</tr>
<tr>
<td>9 BAST</td>
<td>6 UFC</td>
<td>24</td>
<td>0.38</td>
<td>27</td>
</tr>
<tr>
<td>10 BAST</td>
<td>6 UFC</td>
<td>12</td>
<td>0.75</td>
<td>46</td>
</tr>
<tr>
<td>11 ST</td>
<td>2 SC</td>
<td>48</td>
<td>0.06</td>
<td>15</td>
</tr>
<tr>
<td>12 STAF</td>
<td>2 SC + 1 AF</td>
<td>48</td>
<td>0.09</td>
<td>15</td>
</tr>
<tr>
<td>13 BAST</td>
<td>3 UFC</td>
<td>48</td>
<td>0.09</td>
<td>15</td>
</tr>
<tr>
<td>14 BASTAF</td>
<td>2 UFC + 1 AF</td>
<td>48</td>
<td>0.08</td>
<td>15</td>
</tr>
</tbody>
</table>

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. Samples were taken in average 3 times per week between a period from July 1999 to November 2003.

Peristaltic pumps were used to provide a constant inflow towards the units. For each column samples were collected from the influent, the effluent and the sludge in the bottom. Three digital gas volume counters were used for measuring the volume of biogas generated in different experimental series 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 (black water) was used as the wastewater source for this study. Wastewater from toilets of Hanoi University of Civil Engineering (HUCE) was collected in a 1,000 liter stainless steel storage tank before it was screened and 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 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 black water used during the experiments were 505 mg/l, 250 mg/l, 196 mg/l and 284 mg/l of COD, COD\textsubscript{filtered}, BOD\textsubscript{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\textsubscript{filtered}, BOD\textsubscript{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, over the period from 2000 to 2006, 20 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. Those units were serving individual houses, administrative buildings and neighborhoods in urban and rural areas, receiving either domestic black water, a mixture of grey and black wastewater, or combined sewer flow. The number of users connected to the pilot treatment units varied from 4 to 360. For this paper, the monitoring results for the 2 BASTAFs P-01 and P-20 will be presented. BASTAF P-01 has been designed for receiving black wastewater from a 4-users-family in a living quarter of Hanoi city. BASTAF P-20 has been designed for receiving combined domestic, food processing and live-stock breeding wastewater produced by 25 households in a peri-urban village of Hanoi. Both BASTAFs have been designed based on the findings from laboratory-scale experimental results and with an average HRT of 2 days.

![Figure 2: Scheme of the full-scale BASTAFs P-01 and P-20 installed in Hanoi.](https://iwaponline.com/wpt/article-pdf/5/4/wpt2010100/382761/100.pdf)

**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 performed at IESE. The study focused on the evaluation of the treatment performance using two different filter materials and on 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 3). For cells A1, A2 and A3 gravel with a diameter of 1.5–2 cm was used as filter media. For cells B1, B2 and 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 a 5 cm layer of construction quartz sand (effective size d\textsubscript{10} = 0.8 mm, uniformity coefficient UC = 1.7) was added to support physically the plant growth.

The cells were set to run in 3 parallel lines: B1–A1, B2–A2 and B3–A3. A mixture of various local plants were evenly planted in each cell, including cattail (*Typha orientalis*), common reed (*Phragmites communis*) and an ornamental plant named “prosperous tree” (*Dracaena fragrans*).
The BASTAF effluent was fed from a 1,500 L–volume regulating tank to the cells B1, B2 and B3 intermittently by 3 dosing pumps and 3 tipping baskets. When the basket is full, it turns over, pouring wastewater to the cell surface. Each cell was fed 3 times per day, equaled to the loading rates of 20–60 l/day per cell or 2.2–6.6 cm/d.

Daily composite samples were taken once a week and samples were analyzed for temperature, pH, DO, Conductivity, TDS, COD, TSS, TP, PO$_4^{3-}$, TN, N-NH$_4^+$, N-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 removal. The average removal efficiencies observed in the 14 experiments are summarized in Table 2.

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 (Error! Not a valid bookmark self-reference.).

Hydraulic retention time (HRT)

Based on 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 increase in HRT led to a significant increase in removal rate of COD and TSS in both the septic and 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 4). In the range of 12 to 48h an increase in HRT also led to the stabilization of the treatment process as indicated by the standard deviation of the COD and TSS removal rates. Therefore BAST reactors with an effective HRT of 48h are recommended.

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

<table>
<thead>
<tr>
<th>System Configuration</th>
<th>HRT (h)</th>
<th>COD Mean s.d.</th>
<th>BOD₅ Mean s.d.</th>
<th>TSS Mean s.d.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 ST 2 UFC</td>
<td>48</td>
<td>55.7 9.4</td>
<td>-</td>
<td>47.4 18.1</td>
</tr>
<tr>
<td>2 ST 2 UFC</td>
<td>72</td>
<td>57.8 10.9</td>
<td>-</td>
<td>68.9 25.8</td>
</tr>
<tr>
<td>3 ST 2 UFC</td>
<td>48</td>
<td>58.4 10.2</td>
<td>-</td>
<td>54.6 15.2</td>
</tr>
<tr>
<td>4 ST 2 UFC</td>
<td>24</td>
<td>48.5 16.3</td>
<td>-</td>
<td>44.0 12.1</td>
</tr>
<tr>
<td>5 ST 2 UFC</td>
<td>12</td>
<td>48.0 16.0</td>
<td>-</td>
<td>35.0 8.6</td>
</tr>
<tr>
<td>6 BAST 6 UFC</td>
<td>48</td>
<td>72.0 5.7</td>
<td>-</td>
<td>70.4 10.7</td>
</tr>
<tr>
<td>7 BAST 6 UFC</td>
<td>72</td>
<td>71.8 6.0</td>
<td>-</td>
<td>68.0 11.6</td>
</tr>
<tr>
<td>8 BAST 6 UFC</td>
<td>48</td>
<td>76.1 8.6</td>
<td>-</td>
<td>78.0 9.6</td>
</tr>
<tr>
<td>9 BAST 6 UFC</td>
<td>24</td>
<td>65.7 5.4</td>
<td>-</td>
<td>61.0 8.7</td>
</tr>
<tr>
<td>10 BAST 6 UFC</td>
<td>12</td>
<td>58.0 15.1</td>
<td>-</td>
<td>65.2 10.3</td>
</tr>
<tr>
<td>11 ST 2 SC</td>
<td>48</td>
<td>66.9 9.1</td>
<td>57.9 22.7</td>
<td>79.3 10.6</td>
</tr>
<tr>
<td>12 STAF 2 SC + 1 AF</td>
<td>48</td>
<td>85.1 6.8</td>
<td>69.2 9.4</td>
<td>84.7 7.5</td>
</tr>
<tr>
<td>13 BAST 3 UFC</td>
<td>48</td>
<td>84.1 5.8</td>
<td>71.7 13.1</td>
<td>86.4 9.7</td>
</tr>
<tr>
<td>14 BASTAF 2 UFC + 1 AF</td>
<td>48</td>
<td>86.3 7.4</td>
<td>74.2 11.4</td>
<td>90.8 6.4</td>
</tr>
</tbody>
</table>

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; Mean = mean value; s.d. = standard deviation

Figure 4: Impact of the HRT on the treatment performance of ST and BAST (Experiments 1–10).
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 as also observed in other studies (Barber et al., 1999, Koottatep et al., 2004a). Figure 5 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.

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 outcome of experiments 1–10.

The anaerobic filter significantly increased the removal efficiency of the conventional septic tank (compare ST vs. STAF, Figure 6). This effect was less significant in the baffled septic tank, where the BASTAF showed only slightly higher COD, BOD₅ 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, BOD₅ and TSS removal efficiencies of 86.3%, 74.2% and 90.8%, respectively.

Figure 5: Cumulative COD (a) and TSS (b) removal efficiency along the reactor length (experiments 5 to 10).
Figure 6: Average COD, BOD$_5$ and TSS removal efficiencies observed in Experiments 11–14 (all at HRT = 48h).

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

<table>
<thead>
<tr>
<th>Name</th>
<th>System</th>
<th>Sampling location</th>
<th>COD$_{tot}$</th>
<th>BOD$_5$</th>
<th>TSS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>mg/l</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P-01</td>
<td>BASTAF</td>
<td>In Mean</td>
<td>2,840</td>
<td>971</td>
<td>1,367</td>
</tr>
<tr>
<td></td>
<td></td>
<td>s.d.</td>
<td>3,696</td>
<td>1,086</td>
<td>1,411</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Out Mean</td>
<td>290</td>
<td>181</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>s.d.</td>
<td>130</td>
<td>100</td>
<td>28</td>
</tr>
<tr>
<td>P-20</td>
<td>BAST</td>
<td>In Mean</td>
<td>2,512</td>
<td>1,356</td>
<td>3,695</td>
</tr>
<tr>
<td></td>
<td></td>
<td>s.d.</td>
<td>979</td>
<td>560</td>
<td>1,846</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Out Mean</td>
<td>295</td>
<td>150</td>
<td>195</td>
</tr>
<tr>
<td></td>
<td></td>
<td>s.d.</td>
<td>132</td>
<td>50</td>
<td>86</td>
</tr>
</tbody>
</table>

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 after 3 years of operation were observed in the household BASTAF P-01. 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 7). 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 mg/l (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\% ($\sim$ 1–1.4 $\log_{10}$ units). These values do not meet the Vietnamese effluent standard for wastewater TCVN 5945-2005, Class A. No difference in removal efficiency was observed for wetland cells filled with different materials.

a)

![Graph a)](https://iwaponline.com/wpt/article-pdf/5/4/wpt2010100/382761/100.pdf)

b)

![Graph b)](https://iwaponline.com/wpt/article-pdf/5/4/wpt2010100/382761/100.pdf)

c)

![Graph c)](https://iwaponline.com/wpt/article-pdf/5/4/wpt2010100/382761/100.pdf)

**Figure 7:** 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).
The two-stage wetland system had much higher removal efficiencies (Table 4). The quality of the effluent regarding COD, BOD₅, TSS, T-N, N-NH₄⁺ and T-P met the Vietnamese effluent standards TCVN 5945–2005, class A. However, the Fecal Coliform removal efficiency in two steps wetland was only 95–97% (~ 1.3–1.4 log₁₀ 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 (Koottatep T. et al., 2004b). 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 research is needed to maximize the performance of the system, for example the determination of the maximum hydraulic loads that can be applied, the most cost efficient substrate to be used in the beds and the operational conditions that would result in an improved bacteria removal.

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

<table>
<thead>
<tr>
<th>Sample location</th>
<th>COD</th>
<th>TSS</th>
<th>NH₄-N</th>
<th>TP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>In</td>
<td>214.4</td>
<td>189.6</td>
<td>42.3</td>
<td>5.6</td>
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<tr>
<td>S.d.</td>
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<td>48.4</td>
<td>5.6</td>
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<tr>
<td>Out</td>
<td>34.8</td>
<td>6.8</td>
<td>1.8</td>
<td>1.6</td>
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<tr>
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<td>14.0</td>
<td>5.1</td>
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</table>

Note: Values represent mean values for 20 months and 3 replicate experimental units. Time period for experiments: March 2004 - April 2006.
CONCLUSIONS

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 80-90% removal of COD and TSS, especially in regions characterized by a 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 for houses connected to the communal sewer and in case 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 consequently to reduce the risk of clogging these post-treatment systems.

Reduced treatment performances were observed after two years of operation. This 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 improvement in treatment efficiency 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 m³/m²*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 by a non-ponding setup, an increase of HRT or the use of a finer filter media might provide opportunities to improve microbial removal efficiency.

ACKNOWLEDGEMENTS

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REFERENCES


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**IWA - BORDA Conference on DEWATS, Surabaya, 03/2010**

**Baffled Septic Tank with Anaerobic Filter (BASTAF) and Constructed Wetland (CW) for Domestic Wastewater Treatment in Vietnam**

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Antoine Morel**, Karin Tonderski***

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** SANDEC, EAWAG, Switzerland. antoine.morel@eawag.ch
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1. INTRODUCTION

- Septic tank (ST) is the most common domestic w/w pre-treatment method in Vietnam.
- Most STs receive blackwater (from WC) only.
- Normally: low treatment efficiencies.
- Reasons:
  - inadequately designed (capacity, shape, etc),
  - improperly constructed (structure, materials, lining, etc),
  - poorly maintained (no or long desludging interval, wrong additives).
- Treatment performance of ST depends on many factors:
  - composition and type of the wastewater, temperature, HRT, tank design and features of maintenance, etc.

This study:
- To examine possibilities to upgrade ST system by simple means:
  1. Lab experiments on improved septic tank BASTAF
  2. Field experiments on BASTAF.
2. MATERIALS AND METHODS

Component (1):
Laboratory research on baffled septic tank (BAST)

Research questions:
- Optimal design configuration?
  - number of baffles
  - hydraulic retention time
  - up-flow velocity
  - use of anaerobic filter (AF) and addition of polishing stages, etc.
- Applicability in a Vietnamese context?

- Real toilet wastewater from University’s campus
- Inlet COD ~ 500 mg/l.
  - COD\textsubscript{filtered} ~ 250 mg/l.
  - BOD\textsubscript{5} ~ 200 mg/l.
  - TSS ~ 280 mg/l.
- Constant and intermittent flow feeding
Fourteen different experiments were conducted

<table>
<thead>
<tr>
<th>No</th>
<th>System</th>
<th>Configuration</th>
<th>HRT (h)</th>
<th>Up-flow velocity (m/h)</th>
<th>Number of samples</th>
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<td>2 UFC</td>
<td>48</td>
<td>0.06</td>
<td>95</td>
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<td>ST</td>
<td>2 UFC</td>
<td>72</td>
<td>0.04</td>
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<td>2 UFC</td>
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<td>16</td>
</tr>
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<td>19</td>
</tr>
<tr>
<td>6</td>
<td>ST</td>
<td>2 SC</td>
<td>48</td>
<td>0.06</td>
<td>15</td>
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<td>BAST</td>
<td>6 UFC</td>
<td>48</td>
<td>0.19</td>
<td>306</td>
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<tr>
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<td>BAST</td>
<td>6 UFC</td>
<td>72</td>
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<tr>
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<td>48</td>
<td>0.19</td>
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</tr>
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<td>27</td>
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</tr>
<tr>
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<td>3 UFC</td>
<td>48</td>
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<tr>
<td>13</td>
<td>STAF</td>
<td>2 SC + 1 AF</td>
<td>48</td>
<td>0.09</td>
<td>15</td>
</tr>
<tr>
<td>14</td>
<td>BASTAF</td>
<td>2 UFC + 1 AF</td>
<td>48</td>
<td>0.08</td>
<td>15</td>
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</tbody>
</table>

Component (2):
Study on full-scale BAST & BASTAF

- **20 full-scale treatment** units in
  - individual houses,
  - administrative buildings,
  - neighborhoods in urban and rural areas,
- Receiving
  - domestic blackwater,
  - a mixture of grey and black-water,
  - combined sewer flow.
- Number of users: from 4 to 360.
- Results from P-01 and P-20
Component (3): Viability of BAST effluent treatment in vertical flow constructed wetland

- Evaluation of treatment performance of different system configurations, using different filter materials, tolerance of some local plants to ST effluent.
- One and two-step vertical flow CW

6 cells: D = 0.7 m. H = 1.0 m.
- Cells A1, A2, A3: gravel, d = 1.5–2 cm.
- Cells B1, B2, B3: clay bricks, d = 3–4 cm.
- 1st series: 6 parallel cells: A1, A2, A3, B1, B2, B3
- Various local plants: cattail (*Typha orientalis*), common reed (*Phragmites communis*), some ornamental plants, including prosperous tree (*Dracaena fragrans*).
- ST effluent, dosing pumps and tipping baskets
- Hydraulic loading rates: 20–60 l/day per cell, 2–3 times daily, equal to 0.022–0.066 m³/(m²*d) or 2.2–6.6 cm/d.
- Ponding from 20 cm bellow surface for better aeration + denitrification at the same time.
3. RESULTS AND DISCUSSIONS

(1) Laboratory experiments

- Introduction of baffles and anaerobic filter significantly increased the treatment performance of conventional STs in terms of COD, BOD and TSS.
- Stable removal efficiencies

Methanococcus and Methanosarcina spp.

Optimal hydraulic retention time (HRT)

- HRT = 12 to 48h:
  - An increased HRT led to a significant increase in the removal rates of COD and TSS and stabilization of the treatment process (in both ST and BAST).
- HRT > 48h:
  - An additional increase of the HRT did not significantly increase the removal efficiency

Therefore, design HRT for BAST = 48h is recommended.

Optimal number of up-flow chambers

- The main removal takes place in the first up-flow chambers.
- BAST configuration with 2 - 4 up-flow chambers is recommended
Anaerobic filter:
  - against solids wash-out
  - BASTAF system: greatest treatment performance:
    - Average COD removal: 86.3%
    - Average BOD₅ removal: 74.2%
    - Average TSS removal: 90.8%.

ST < STAF ~ BAST < BASTAF

(2) Full-scale BAST and BASTAF

<table>
<thead>
<tr>
<th>Name</th>
<th>System</th>
<th>Sampling location</th>
<th>COD₅₅</th>
<th>BOD₅</th>
<th>TSS</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mean</td>
<td></td>
<td></td>
</tr>
<tr>
<td>In</td>
<td></td>
<td></td>
<td>s.d.</td>
<td></td>
<td></td>
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<tr>
<td>P-01</td>
<td>BASTAF</td>
<td>Mean</td>
<td>2,840</td>
<td>971</td>
<td>1,367</td>
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<tr>
<td></td>
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<td>s.d.</td>
<td>(3,696)</td>
<td>(1,086)</td>
<td>(1,411)</td>
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<tr>
<td>Out</td>
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<td>Mean</td>
<td>290</td>
<td>181</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>s.d.</td>
<td>130</td>
<td>100</td>
<td>28</td>
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<tr>
<td>P-20</td>
<td>BAST</td>
<td>Mean</td>
<td>2,512</td>
<td>1,356</td>
<td>3,695</td>
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<td>979</td>
<td>560</td>
<td>1,846</td>
</tr>
<tr>
<td>Out</td>
<td></td>
<td>Mean</td>
<td>295</td>
<td>150</td>
<td>195</td>
</tr>
<tr>
<td></td>
<td></td>
<td>s.d.</td>
<td>132</td>
<td>50</td>
<td>86</td>
</tr>
</tbody>
</table>
Highly fluctuating characteristics of the influent wastewater
Satisfactory treatment efficiencies, relatively stable
Household BASTAF P-01:
– Average removal rates: COD: 77.0%; BOD$_5$: 71.0%; TSS: 86.2%
Community BASTAF P-20:
– Average removal rates: COD: 87.9%; BOD$_5$: 87.7%; TSS: 94.1%

(3) ST effluent treatment in vertical flow CW

The One-step CW:
– Influent COD: 229.5 mg/l (mean).
– Effluent COD: 53.7 mg/l,
– Removal efficiency COD: 76.6% (mean).
– Influent TSS: 93.3 mg/l
– Effluent TSS: 13.9 mg/l
– Removal efficiency TSS: 85.2%.
– Influent NH$_4$-N: 65.2 mg/l
– Effluent NH$_4$-N: 27.3 mg/l
– Removal efficiency NH$_4$-N: 58.5%
– Influent T-P: 11.6 mg/l
– Effluent T-P: 6.1 mg/l
– Removal efficiency T-P: 48.0%
– Fecal coliform removal efficiency: 90–96% (~1–1.4 log10 units).
– Vietnamese standards TCVN 5945-2005, Class A, were not met.
The two-stage wetland system:

<table>
<thead>
<tr>
<th>Sample location</th>
<th>COD</th>
<th>TSS</th>
<th>NH₄-N</th>
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<tr>
<td>In Mean</td>
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<td>189.6</td>
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<td>1.8</td>
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<tr>
<td>Out S.d.</td>
<td>14.0</td>
<td>5.1</td>
<td>0.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>

(Values represent mean for 20 months and 3 replicate experimental units).

- The quality of the effluent regarding COD, BOD₅, TSS, T-N, N-NH₄⁻ and T-P met the Vietnamese effluent standards TCVN 5945–2005, class A.
- Fecal coliform removal efficiency in 2 steps wetland was only 95–97% (~ 1.3–1.4 log₁₀ units).
4. CONCLUSIONS & RECOMMENDATIONS

- Improved septic tanks: STAF, BAST, BASTAF
- Suitable to treat medium and high-strength domestic wastewater
- BAST configuration: 1 settling chamber + 2 to 4 up-flow chambers.
- Application: for > 10 households, where access to the tank is surely provided, and where post-treatment steps such as infiltration trenches, constructed wetlands or sand filters are foreseen.

- Sludge accumulation: especially in the first chamber. Reduced treatment performance observed after 3 years of operation shows the need of proper tank configuration and desludging.
- Movable access manholes/covers should be installed for underground tanks.
- Further researches are needed in order to maximize the performance of the CW system: maximum hydraulic loads, improvement of pathogens removal (by a provision of aerobic conditions in the wetland units, increase of HRT, etc.).
- Complete DEWAT solutions to achieve effluent standards: BASTAF + CW; BASTAFAT.
Dissemination of research results

BASTAF
HF CW
(Fish) Pond

Hanoi – new living quarter
Hanoi – village
Bac Ninh – living quarter
Bac Kan – small town
Hanoi – office bldg.

Hanoi – school
Hanoi – new apartment
Hai Phong – Island resort
ACKNOWLEDGEMENTS

- Project: Capacity building for Environmental Science and Technology in Northern Vietnam (ESTNV), CEETIA – SANDEC
  - supported by SDC, Switzerland (1998 – 2007).
- Join research on VF CW by CEETIA, Hanoi University of Civil Engineering and IFM, Linkoeping University,
- All IESE members involved in the study.
Thank you very much for your attention

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