POTENTIAL OF THE ANAEROBIC BAFFLED REACTOR AS DECENTRALIZED WASTEWATER TREATMENT SYSTEM IN THE TROPICS

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ABSTRACT

In tropical regions there have been enormous attempts in tackling urban water pollution problems by applying conventional treatment systems and centralized management approaches. However, it is apparent that these centralised approaches are not sustainable, mainly due to the substantial treatment costs, which are simply not affordable for many municipalities in developing, emerging and even industrialised countries. The Royal Thai Government invested about 1.5 billion USD for the collection and treatment of wastewater in 85 municipalities since1992, but more than 60% of these systems failed to function. The decentralized wastewater management approach enables a safe nutrient recycling at source at much lower treatment costs, can easily be adapted to the different effluent requirements and therefore is certainly a promising solution for water pollution control. Septic systems are the most common treatment units on household level in urban areas in South-East Asia; unfortunately their treatment efficiency is quite low. The anaerobic baffled reactor (ABR) could be a valuable alternative to conventional septic tanks. In this study, 3 lab-scale experimental ABR (2 baffles with and without anaerobic filter, respectively, and 3 baffles) were studied and compared to a conventional 2 chambers septic tank. The experimental units were fed with a mixture of septage and sewage in order to imitate the characteristics of toilet wastewater from households (so-called blackwater), with chemical oxygen demand (COD) and biochemical oxygen demand (BOD) concentrations of 1,000mg/L and 200mg/L, respectively. The lab-scale treatment units were operated at hydraulic retention times (HRT) of 24 and 48 hours for a period of 3 months. The baffled treatment units showed significantly higher removal efficiencies than the conventional septic tank in terms of total solids (TS), SS, COD and BOD. The 2-baffled units and the 3-baffled units showed similar removal efficiencies, amounting to approximately 65%, 85% and 85% for TS, COD and BOD, respectively. The introduction of baffles also led to a considerable stabilisation of the treatment process. The impact of influent fluctuations in terms of COD, BOD, TS and SS on the characteristics of the effluent was the lowest in the 3 baffles ABR. The introduction of an anaerobic filter in the last chamber of the ABR with 2 baffles did not show any significant impact on the treatment efficiencies in terms of COD, BOD, suspended solids (SS) and total Kjedahl nitrogen (TKN). Based on these preliminary results, a pilot-scale treatment unit was installed at the Environmental Research Station of AIT, where the treatment performance of a baffled anaerobic reactor operated at realistic conditions shall be investigated. The results presented in this paper clearly demonstrate the big potential of this technology for the decentralised treatment of domestic wastewater in urban areas; nevertheless additional research work needs to be done, including an economic evaluation.

Keywords: anaerobic baffled reactor (ABR), anaerobic filter, decentralized wastewater management.

INTRODUCTION

It has been reported by Lens *et al.* (2001) that the discharge of untreated wastewater into the aquatic environmental is worldwide the main cause of diarrhoeal diseases, with annual 3.5 billion infections, out of which 3.3 million end deadly. Developing countries are especially at stake, where public health is seriously affected by diseases directly related to inadequate wastewater management. In Africa, 80 million people are exposed to cholera and 16 million cases of typhoid infections were reported (WHO, 1996). One of the most important reasons for that grievance is the misapprehension of many governmental agencies responsible for wastewater management that the conventional, centralised wastewater management approach is the only valuable solution. These systems are very expensive and sophisticated in construction and operation and therefore neither affordable nor manageable by most municipalities in developing countries. The Royal Thai Government for instance invested about 1.5 billion USD since 1992 for the construction of wastewater collection and treatment systems in 85 municipalities, out of which more than 60% are malfunctioning (Koottatep *et al*. 2003).

The decentralised wastewater management approach on the other hand could be a valuable alternative to conventional, centralised approaches, if low-cost processes adapted to the local conditions are applied and properly maintained. The decentralised wastewater management approach includes the collection, the treatment and the disposal or reuse of wastewater from individual homes, clusters of homes, isolated communities, and institutional facilities at or near to the point of waste generation (Crites & Tchobanoglous, 1998). In most developing countries, including Thailand, the conventional septic tank with 2 chambers is the most frequent onsite treatment facility for domestic wastewater in residential areas. Although septic tanks remove COD, BOD, SS, TKN and helminth eggs to a certain extent, the technology is not able to produce an effluent which meets national quality standards. Some techniques are known to upgrade conventional septic tanks, such as introducing in-tank baffles or adding an anaerobic filter in the rear part of the treatment system. By integrating in-tank baffles, a better contact can be achieved between the wastewater and the active biomass (sludge), leading to increased treatment efficiencies (Langenhoff *et al.* 1999). Goal of this study was to examine and monitor the treatment performance of upgraded septic tanks by introducing in-tank baffles and anaerobic filter material. The impact of the number of baffles, the hydraulic retention time (HRT) and the impact of anaerobic filter material were investigated.

UNIT DESIGN AND EXPERIMENTAL SETUP

The laboratory-scale experiments were carried out at the Environmental Engineering Laboratory of AIT (Asian Institute of Technology), Thailand, at an ambient temperature of 25-30^{o}C. Four laboratory-scale treatment units with a volume of 40 litres each were constructed, using transparent acrylic plastic (unit dimensions: 64 cm long x 25 cm wide x 40 cm high). The units contained vertical hanging and standing baffles and were designed in such a way that the impact of baffles and anaerobic filter material on the treatment process could be investigated. The experimental units included (a) reactor A: 2 baffles; (b) reactor B: 3 baffles; (c) reactor C: 2 baffles with anaerobic filter; and (d) control unit: conventional septic tank with 2 chambers. The “hanging” baffles, with an opening of 3 cm above the reactor’s bottom, direct the wastewater flow to the up-flow chamber, increasing the contact between the sludge and the fresh wastewater. The anaerobic filter media, plastic with a surface area of 240 m^2/m^3, was introduced in the last chamber of reactor C, 4 cm above the reactor’s bottom and 15 cm high (Figure 1).

Both the organic loading rate (OLR) and the hydraulic retention time (HRT) were subjected to changes during the experimental phase, as shown in Table 1. The chemical and physical

characteristics of both influent and effluent were analysed according to the methods described in APHA, AWWA and WEF (1998).

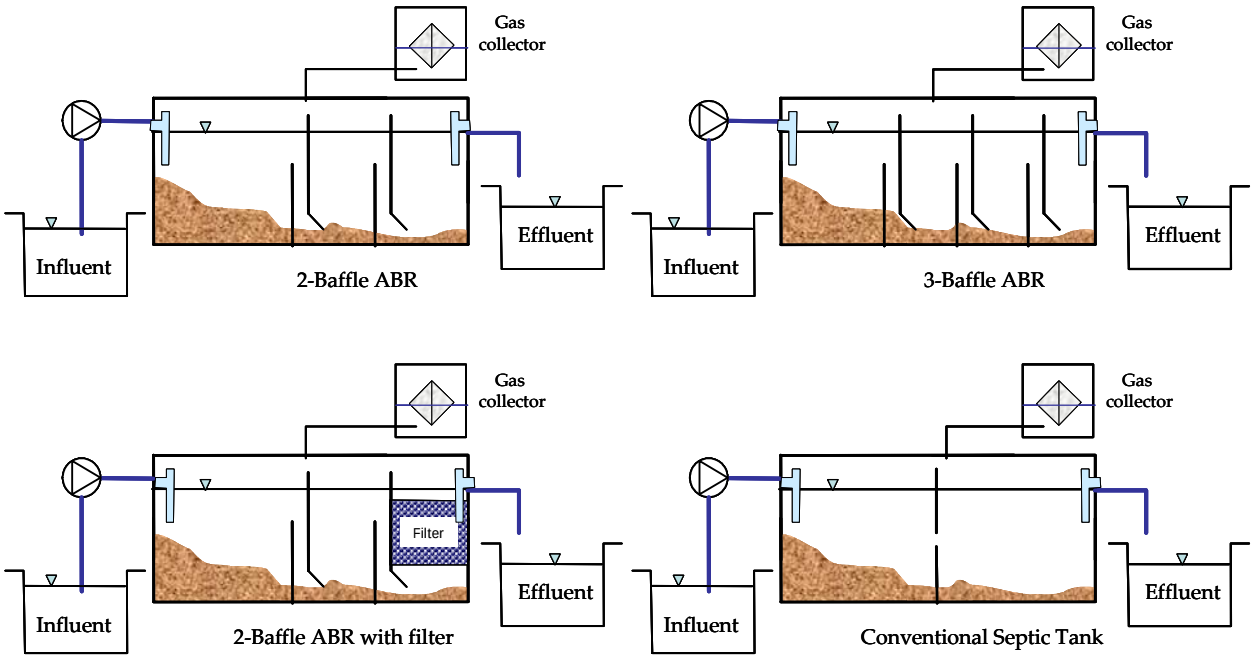


Figure 1: Scheme of the experimental setup

Table 1: Operating conditions of the experimental setup

Operating Conditions	Range
HRT [days]	24 hours: intermittent feeding for 30 min per hour 48 hours: intermittent feeding for 15 min per hour
OLR [kg BOD m^{-3} day]	0.32 – 0.64

The wastewater used for this study was a mixture of septage from Bangkok and wastewater from the AIT campus. Goal of this procedure was to produce a wastewater source possessing similar characteristics than typical toilet wastewater (also known as blackwater). The mixing ratio between septage and wastewater accounted for 1:10. The characteristics of this influent are shown in Table 2.

Table 2: Influent characteristics

Parameter	Range	Average	Standard deviation
pH	7.4 – 8.5	8.2	1.3
Alkalinity, mg/L	240 – 450	280	37
COD, mg/L	640 – 3,870	1,970	650
BOD, mg/L	200 – 1,200	625	200
TS, mg/L	610 – 2,430	1,360	352
SS, mg/L	240 – 1,600	640	330
TKN, mg/L	45 – 80	60	13
TP, mg/L	14 – 63	35	19

Note: Values are based on 46 samples, except 10 samples for alkalinity, TKN, and TP

According to Metcalf & Eddy (2003), this wastewater represents a very strong domestic wastewater, with high organic matter and solids content. The high BOD/COD ratio of 0.3 results from the mixture of septage, which presents normally very high BOD/COD ratios (0.1 to 0.2) because the solid matter is mostly degraded. With regard to the nutrient requirements

of the wastewater micro-organisms, the average BOD/TKN/TP ratio of 100:10:6 corresponds to normal domestic wastewater.

RESULTS AND DISCUSSION

Overall treatment performance

The investigations on the lab-scale units took place in the period between March 25th and July 5th 2003. Based on the experimental results obtained from this 4 months period, it could be shown that the overall treatment efficiencies in terms of COD, BOD and TS of the different ABRs were in the same order of magnitude: approximately 85%, 85% and 65%, respectively, 10-15% higher than the removal efficiencies observed in the control unit (Table 3). In terms of TKN and TP removal, the 2 baffles ABRs (with and without anaerobic filter) showed similar removal efficiencies to those obtained from the control unit, accounting for 15-25% and 48-51%, respectively. The 3 baffles ABR achieved higher TKN removal efficiencies (41%) than the other reactors, but lower TP removal rates (39%). One can postulate that anaerobic ammonium oxidation (ANMMOX), oxidizing the ammonium ions into nitrogen gas in the anaerobic conditions at the presence of nitrite concentrations from AIT sewage, might take place in the ABRs.

Table 3: Average removal efficiencies of the different ABRs

Reactor	Parameter, mg/L					
	COD	BOD	TS	SS	TKN	TP
1. 2-Baffle	86%	86%	66%	86%	15%	51%
2. 3-Baffle	85%	84%	63%	41%	41%	39%
3. 2-Baffle + Filter	85%	84%	65%	83%	22%	48%
4. Control	71%	73%	55%	71%	26%	51%

The investigations clearly demonstrated that the introduction of baffles can considerably increase the treatment performance of conventional septic tanks. The abovementioned results reflect overall average values, ignoring the different operation conditions (HRT and OLR) during the experimental phase. The following sections try to depict the effects of different HRTs in the range of 24 to 48 hours on the treatment performance of the 4 treatment units, by defining the impact of the anaerobic filter on the treatment efficiency and evaluating the sensitivities of the different units towards shock loads and effluent quality fluctuations.

Effects of the anaerobic filter on the treatment efficiency of the 2 baffles ABR

With regard to organic matter and solids, the addition of an anaerobic filter in the last chamber of the 2 baffles ABR showed very little effect on the treatment efficiencies at a HRT of 48 hours. The average pollutants removal rates observed were in the same order of magnitude for both units: BOD (86% for both units), COD (86% without filter, 87% with filter), TS (66% without filter, 67% with filter) and SS (87% without filter, 89% with filter), as depicted in Table 4. The variations in removal efficiencies were in the same range as well. The standard deviations in removal efficiencies of both units accounted for 6% to 8%. The removal of SS constituted the only exception, where higher variations were observed in the unit without anaerobic filter. Some wash-out of suspended solids was observed in the unit without anaerobic filter, where SS removal rates below 50% were measured. The anaerobic filter seems to provide an additional barrier against SS wash-out; the minimal SS removal rate observed accounted for 82%.

Table 4: Treatment efficiencies of 2 baffles ABR with and without anaerobic filter

Parameter	Removal efficiencies	2 baffles ABR with anaerobic filter	2 baffles ABR without anaerobic filter
COD	Average	87% (±6%)	86% (±6%)
	Minimal	76%	70%
BOD	Average	86% (±6%)	86% (±7%)
	Minimal	64%	57%
TS	Average	67% (±8%)	66% (±7%)
	Minimal	54%	52%
SS	Average	89% (±3%)	87% (±9%)
	Minimal	82%	44%

Note: Only 27 values between March 2003 and May 2003 were included in these statistics.

Figure 2 demonstrates that the potential of the 2-baffled units in terms of BOD and COD removal were not reached during the experimental phase at low pollution concentrations. It could be suggested that removal efficiencies higher than 95% in terms of BOD and COD could be reached when treating wastewater with higher pollution loads. The removal rate of SS on the other hand seems to be limited, since very little variations could be observed after SS concentrations in the influent had been increased. An average SS removal efficiency of 86-87% could be reached with both very weak (SS = 230 mg/L) and strong (SS = 1200 mg/L) wastewaters at a HRT of 48 hours.

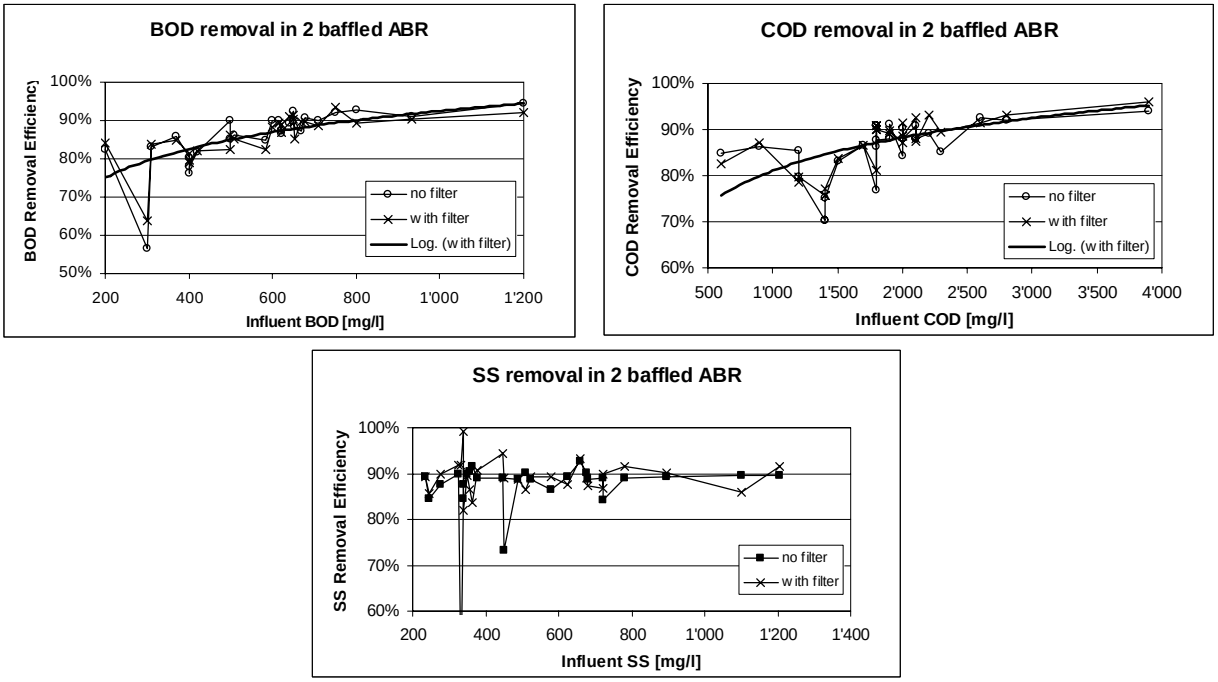
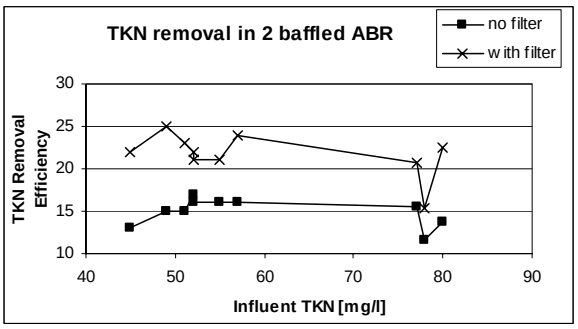


Figure 2: Removal efficiencies of BOD, COD and SS in the 2 baffles ABRs

Removal of nutrients (Nitrogen and Phosphorus): Relatively high N removal efficiencies were observed in the ABR with 2 baffles with anaerobic filter, where an average TKN removal of 22% was obtained with a standard deviation of 3%. The 2 baffles ABR without anaerobic filter showed TKN removal rates of only 15% in average. In both systems, it could be noticed that the removal efficiencies were independent of the influent TKN concentrations (Figure 3). No striking reductions in TKN removal rates were observed when the influent TKN concentration was increased up to 80 mg/L.

At low phosphorous concentrations (TP < 35 mg/L), the ABR with 2 baffles with anaerobic filter showed much higher TP removal than the unit without filter, as evidenced from TP removal efficiencies of 61% and 49%, respectively. At higher TP concentrations (TP > 35

mg/L), the removal rates in the treatment unit with anaerobic filter dropped below 45%, whereas in the treatment unit without anaerobic filter the removal rates remained at about 50%.



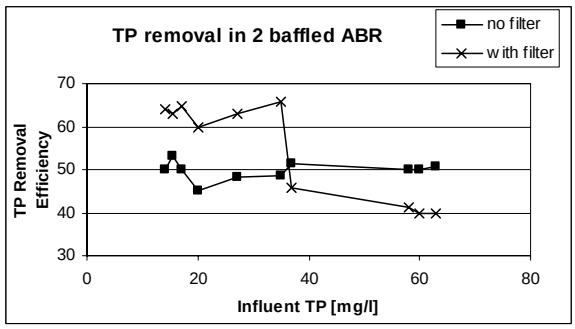


Figure 3: Removal efficiencies of nutrients (TKN and TP) in the 2 baffles ABRs

Both 2 baffles ABRs investigated, with and without anaerobic filter, showed removal efficiencies of COD, BOD, SS and TS at the same order of magnitude. With exception of reduced SS removal fluctuations, the beneficial effect of the anaerobic filter as final pre-treatment step could not be clearly demonstrated. With regard to TKN and TP removal, the anaerobic filter increased the removal efficiency by approximately 7 to 10%, although in the case of TP only at lower TP concentrations. The reason for the significant decay of the removal rates at higher TP concentrations (TP > 35 mg/L) in the unit with anaerobic filter still has to be analysed.

Effects of number of baffles on treatment performance

The results presented in Table 4 clearly demonstrated that the introduction of baffles in a conventional septic tank is leading to higher removal efficiencies in terms of BOD, COD and solids. However, no significant difference was observed between the reactors with 2 and 3 baffles, respectively. None the less different behaviours of the baffled units could be observed with regard to their treatment performance at different HRTs.

The impact of the HRT on the treatment performance strongly varied in the different septic tank constellations. At a HRT of 48 hours, the ABR with 2 baffles with anaerobic filter showed the highest removal efficiencies in terms of COD (87%), BOD (86%), TS (68%) and SS (87%). At a HRT of 48 hours, the difference of the removal rates between the baffled reactors and the conventional septic tank with 2 chambers are less distinct. This is due to the intensified sedimentation in the conventional unit at higher HRTs.

The impact of a decrease of the HRT from 48 to 24 hours was most distinctive in the conventional septic tank, with an average reduction in the COD, BOD, SS and TS removal rates of 12%, 13%, 32% and 26%, respectively (Figure 4). A similar impact of the HRT in the range 24 – 48 hours was observed in the 2-baffled reactor, with decays of 9% for COD, 14% for BOD, 26% for SS and 22% for TS removal, respectively. The 3-baffle septic tank showed the smallest reaction to a reduction of the HRT. The removal rates of COD and SS even increased by 4% and 7%, respectively, suggesting possible biomass starvation in later compartments at longer retention times.

Table 4: Treatment efficiencies of the experimental units at HRT of 24 and 48 hours

	HRT	3 baffles ABR	2 baffles ABR with AF	Conventional septic tank with 2 chambers
COD	48h	84% (±4%)	87% (±5%)	73% (±9%)
	24h	88% (±3%)	78% (±2%)	61% (±10%)
BOD	48h	86% (±5%)	86% (±5%)	75% (±9%)

	24h	74% (±6%)	72% (±4%)	62% (±9%)
TS	48h	65% (±8%)	68% (±8%)	59% (±9%)
	24h	50% (±3%)	46% (±3%)	33% (±5%)
SS	48h	73% (±11%)	87% (±6%)	76% (±7%)
	24h	80% (±7%)	61% (±12%)	44% (±13%)

Note: the first number indicates the average value; the number in the brackets represents the standard deviation.

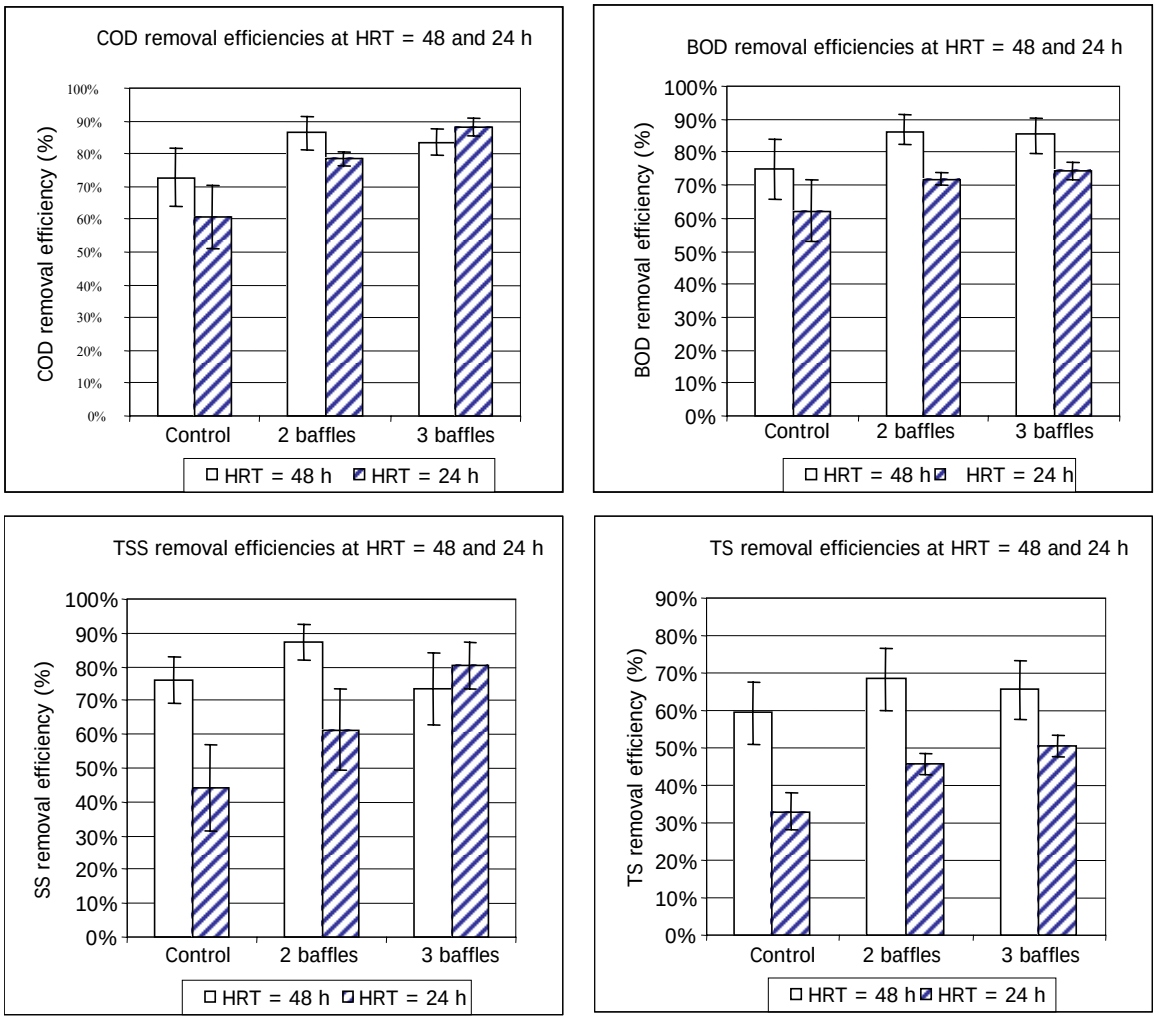


Figure 4: Removal efficiencies of COD, BOD, TS and SS in the different units at HRTs of 24 and 48 hours.

It could be observed from Figure 4 that the treatment performances of the multi-baffled units operated at a HRT of 24 hours were in the same order of magnitude than the one in the conventional septic tank operated at 48 hours. This clearly demonstrates the potential of multi-baffled units compared to conventional septic tanks.

Equalisation of influent fluctuations

In order to assess the ability of the different treatment units to equalise inflow fluctuations of COD, BOD, SS and TS, the data of a limited time period (May 25th to July 5th) was analysed. During that period, the loading rates fluctuated with a distinct peak on the 21st of June, as shown in figure 5. The different units reacted in different ways to that change of loading rates.

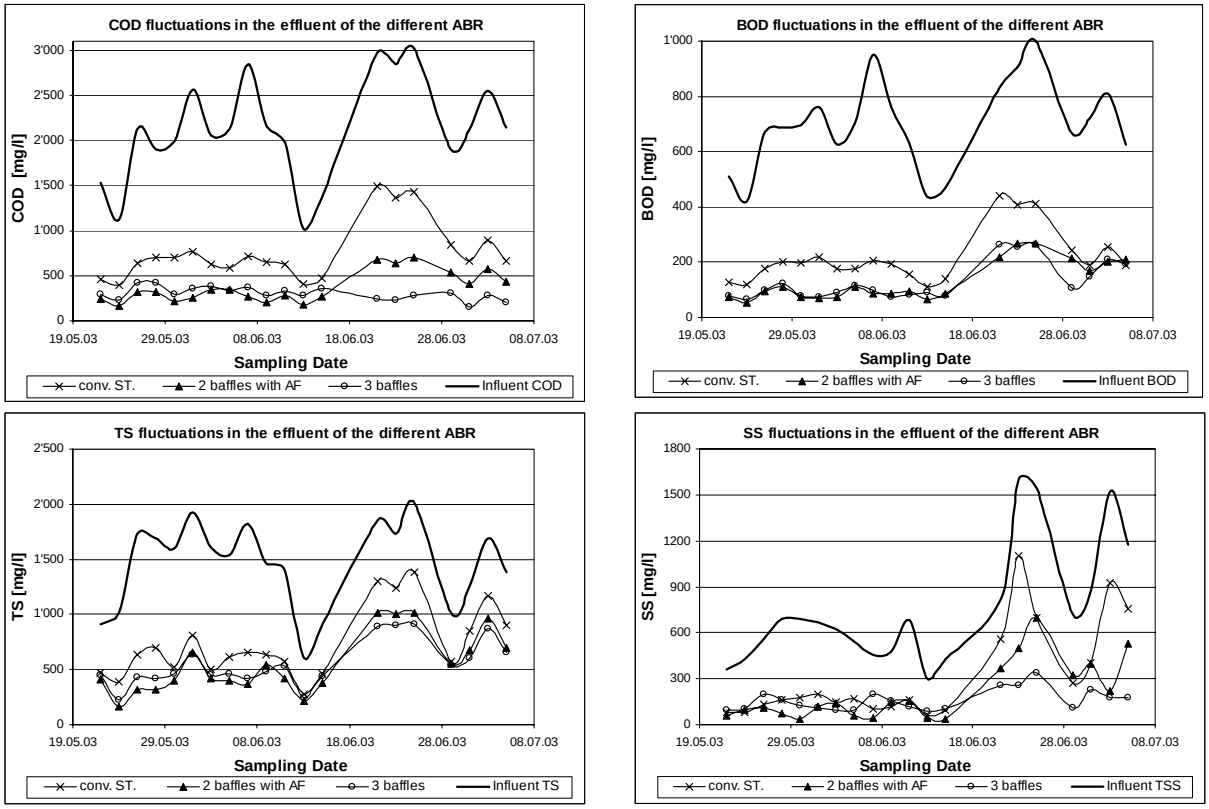


Figure 5: Reaction of the different experimental units to a rapid increase of the organic load.

COD and BOD: Figure 5 clearly shows that the 3-baffled reactor can equalise the COD and BOD fluctuations in the influent very well, as evidenced by the relatively constant effluent concentrations. It could also be observed that even a considerable increase of the COD loading rate from 0.95 g/L.d to 2.3 g/L.d (in June 2003) did not affect the treatment efficiencies of the 3 baffles ABR. On the other hand results have shown that the conventional septic tank with 2 chambers cope with COD and BOD inflow fluctuations.

Solids: The effect of TS and SS concentration fluctuations in the influent could directly be observed in the effluent of all units (Figure 5). The conventional septic tank was the weakest unit in equalising TS and SS concentrations, where a clear relation between influent and effluent concentrations could be observed. Strong wash-out effects of solids were observed in the conventional septic tank after shock-loads or a sharp increase in the SS and TS concentrations in the influent. At high SS and TS concentrations (1,600 mg SS/L and 1,740 mg TS/L), the removal efficiencies dropped to 31% and 28%, respectively.

An interesting phenomenon could be observed in the two other treatment units. The capacity of the ABR with 3 baffles to equalise SS fluctuations in the influent was higher than the capacity of the 2 baffles ABR, even if the average removal efficiencies of TS observed in the 3 baffles ABR were lower than in the 2-baffled unit with anaerobic filter. In average the 2-baffled unit could reduce SS concentrations to a higher extend than the 3-baffled unit (average removal efficiencies of 83% and 74%, respectively), but with a much higher standard deviation in the effluent (172 mg/L and 71 mg/L SS, respectively). The 3-baffled reactor showed the highest ability to equalise shock loads of TS and SS.

CONCLUSIONS AND RECOMMENDATIONS

This study denoted the evident potential of the baffled septic tank for the treatment of toilet wastewater in tropical regions and demonstrated the potentials of this system compared to the conventional septic tank. The introduction of baffles can lead to considerable increases of

the treatment performance. Fluctuations of the effluent quality are very well equalised, especially in treatment units with a high number of baffles. This is an important aspect considering the requirements towards potential post-treatment steps.

The baffled units can be operated at much lower hydraulic retention times than the conventional septic tank and still show high treatment performance (88% COD removal at a HRT of 24 hours in a 3 baffles ABR). This is very interesting from an economical point of view: the shorter the HRT, the smaller the size of the reactor.

It is not yet feasible to define the ideal design criteria for the baffled septic tank from these experimental data provided. Further research is needed with regard to wastewater with different strengths, with regard to nutrient removal and biomass starvation at low HRTs, and others. A pilot-scale study on a baffled septic tank is being conducted at AIT in order to better evaluate the potential of this innovative technology for the treatment of domestic wastewater.

In spite of the outlined potential, the upgraded septic tank systems are not able to treat wastewater with high BOD and COD concentrations to meet strict effluent standards. Therefore constructed wetlands, sand filters or other post-treatment steps might be required. The School of Environment, Resources and Development (SERD) at the Asian Institute of Technology (AIT) is investigating suitable post-treatment systems, which shall lead to comprehensive guidelines for the decentralised treatment of domestic wastewater.

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