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An Alternative for Sustainable Domestic Wastewater Treatment in Bangkok

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Abstract: Concerns have been raised on sustainability of conventional linear domestic wastewater treatment system in developing countries where Bangkok is not an exception. This paper aimed to unveil basic facts on characteristics and organic degradation potential of domestic wastewater in Bangkok with simple laboratory experiments and wastewater quality survey of two typical treatment plants considering existing local traditions. The results showed greywater-like qualities of domestic wastewater in Bangkok as a result of continued use of septic tanks and tradition of using water in defecation instead of toilet paper, and high organic degradation potential in tropical condition. The domestic wastewater characteristics, climatic conditions and existing local traditions in Bangkok can be better utilized by introducing low-cost, closed-loop natural treatment system with source separation instead of continuing the conventional linear system for sustainability.

Key words: Domestic wastewater, organic strength, organic degradation potential, sustainability, tropical condition.

Introduction

Sustainability has been a key factor in domestic wastewater management in the developing world (Matsui, 1999; Mgana, 2003; Volkman, 2003; Mara, 2004). Serious concerns have been raised on the sustainability of conventional highly-mechanized domestic wastewater treatment system that requires large capital investments and high operation and maintenance costs while more than 300 million urban residents in the developing countries have no access to sanitation (Rose, 1999; Volkman, 2003). Therefore, critical evaluation of the conventional treatment system in existing local conditions, and investigation on low-cost, closed-loop natural treatment alternatives to them with nutrient recovery are highly important for sustainable domestic wastewater management.

Traditionally, water is used in defecation instead of toilet paper in Thailand and other Asian countries. Toilet-flushed wastewater is first collected in septic tanks and the septic tank supernatant along with house-hold greywater is treated in conventional treatment facilities or discharged to water bodies in Bangkok and other urban areas in Thailand. The trends have continued in spite of large investments being made on conventional treatment facilities. With the existing trends and climatic conditions (high annual average rainfall and temperature) in Bangkok, the authors speculate for reduced organic strength of domestic wastewater reaching to treatment facilities. Unsustainability of conventional linear systems and prevailing conditions in Bangkok demand for investigations on alternative domestic wastewater treatment methods.

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This paper aims to unveil some fundamental facts on domestic wastewater characteristics and its organic degradation behaviours with simple laboratory experiments and water quality survey of two typical treatment plants (Sri Phraya: SP and Huay Kwang: HK) in Bangkok, and suggests possible alternative to the conventional linear treatment techniques being adopted.

Materials and Methods

Wastewater Quality Survey

Organic contents in terms of BOD_5 and COD in the influents to SP and HK wastewater treatment plants were compared based on the data obtained from the plants. Nitrogen and coliform bacteria in the influents were analyzed and compared both in dry and rainy seasons. The measurement days were selected based on the local climatic conditions (dry and wet periods) in Bangkok.

Laboratory Experiments

Simple bench-scale laboratory experiments with typical Thai domestic wastewater obtained from the outlet of a sewerage pipe in Ruamrudeea, a residential area in Bangkok, were carried out to assess organic degradation behaviours and effects of mixing, dilution and toilet paper addition in the wastewater. All the experiments were carried out in a dark constant temperature room at 30°C.

Organic degradation and dilution effect

The wastewater samples were kept in two twenty-litre capacity plastic containers. One container was mixed with a vertical stirrer (100 rpm, Re ≈ 12,700) while the other was not. The organic degradation behaviours were monitored by measuring selected parameters (BOD_5, COD, nitrogen, coliform bacteria) during three weeks. Similar experiment was conducted with two-three- and five-folds and without dilution of the wastewater samples. But, none of the samples was mixed.

Effects of toilet paper addition

Oven-dried (105°C) commercial grade toilet paper and influent to SP were used to estimate possible impacts of toilet paper addition in domestic wastewater. Four sets of containers (five litres capacity) were filled with the same volume of wastewater (four litres). Five, fifteen and twenty-five grams of toilet paper (1.25, 3.50 and 6.25 g/L, respectively) were fed into the first three containers while the fourth was without toilet paper. None of the samples were mixed, and organic byproducts and bacterial population were monitored during four weeks period.

Analytical Methods

Parameters like pH, DO, ORP, BOD_5, COD, TSS and total Kjeldahl nitrogen (TKN) were analyzed according to the Standard Methods (APHA, AWWA and WPCF, 1995). Allylthiourea (0.5 mg/L) was used to prevent nitrification in BOD_5 measurement. HACH Spectrophotometer (DR/2000) was used for nitrogen (NO_3^-, NO_2^-, NH_4^+) analyses. Total sulfide, total sugar and acetic acid were measured using DR/2000 spectrophotometer, Anthron method and Shimadzu gas chromatograph, respectively.

Total and fecal coliform bacteria (TC and FC) were enumerated using pour-plate technique and Chromagar®. Populations of cellulolytic bacteria (CLB), sulfate-reducing bacteria (SRB) and acid producing bacteria (APB) were enumerated using MPN method. Aerobic heterotrophic bacteria (HTB) were enumerated with spread-plate technique.

Results and Discussion

Wastewater Characterization

Typical domestic wastewater qualities in Bangkok have been reported in literatures (Giri, 1999). Annual average BOD_5, COD and temperature of influent to SP in 1997 were 59.0 mg/L, 96.0 mg/L and 29.2°C while BOD_5 varied between 78.0 and 43.0 mg/L. The annual average values for HK influent in 1996 were 252.0 mg/L, 424.0 mg/L and 29.0°C, and BOB_5 values were in between 358.0 and 166.0 mg/L. The influents had significant difference in total suspended solid (TSS) content. The annual average TSS values in the influents were 4.0 and 174.0 mg/L, respectively. The average BOD_5, COD and TSS values in the wastewater samples collected from Ruamrudeea in Bangkok were 241.5, 320.6 and 32.0 mg/L, respectively.

Nitrogen contents in SP and HK influents at eight different occasions both in dry (May to June) and wet (Sept. to Nov.) seasons are shown in Table 1. Significant difference can be observed in nitrogen contents in the two seasons. Concentrations were relatively bigger in dry period in both influents. The highest ammonium concentration in HK influent in Oct. 20 might have been the result of flushing action due to rain. Ammonium concentrations in HK influents were significantly bigger than in SP influents. Nitrite concentrations were below 0.2 mg/L in HK influent while they were bigger in SP. Nitrate concentrations were bigger in HK influent than in SP. The scenario indicated relatively fresh nature of HK influent that contained direct toilet flush, and aged nature of SP influent which mostly contained septic tank supernatant and household greywater. Average values of ammonium, nitrite and nitrate nitrogen in the wastewater samples collected from Ruamrudeea were 32.0, 0.02 and 0.9 mg/L, respectively.

Coliform bacteria counts in the two influents are shown in Table 2. SP and HK influents were similar in terms of TC counts. About one-log order difference in FC counts was observed between the two influents. However, TC and FC counts in HK influent were similar. The one-log order big TC counts in HK influent can be attributed to influence of human excreta. FC to TC ratio in SP and HK influents varied from 0.18 to 0.35 and 0.42 to 0.60, respectively, in this study. Average TC and FC counts in wastewater samples from Ruamrudeea were 6.6×10^6 and 1.3×10^6 CFU/ml, respectively, which were about one to two-log orders higher than observed in SP and HK influents.

Typical BOD_5, TSS and TKN values for greywater reported in literatures range from 33 to 290, 21 to 250 and 1 to 40 mg/L respectively, while the values for untreated domestic wastewater range from 100 to 500, 100 to 360 and 16 to 75 mg/L respectively (Henze et al., 2001; Veneman et al., 2002; Dept. of Env., 2002). The typical FC numbers observed in greywater and untreated domestic wastewater range from 10^5 to 10^6 and 10^6 to 10^8 respectively (Veneman et al., 2002; Dept. of Env., 2002). Based on these data, domestic wastewater in Bangkok can be placed into weak to medium range in terms of organic strength (Metcalf and Eddy, 1995; Henze et al., 2001). The wastewater qualities were similar to typical greywater rather than sewage.

Organic Degradation Potential

BOD_5 degradation behaviour of the wastewater from Ruamrudeea in tropical condition is shown in Figure 1. More than 80% BOD_5 degraded during the first seven days period. Organics, both in dissolved and suspended solid forms, had similar contributions to BOD_5. Total nitrogen removal varied between 12% and 23% (Figure 2), which were comparatively smaller than BOD_5 removal. Similar results were obtained with ammonia nitrogen and TKN removal (not shown). Coliform bacteria reductions on the seventh day (Figure 3) were significantly higher for non-mixed samples, which varied from 97% to 99%. Mixing enhanced BOD_5 and nitrogen removal had negative impact on coliform removal. Removal rate constants (*k*) of BOD_5 and coliform bacteria were evaluated assuming first-order reaction kinetic for the first five days period. The values for BOD_5 were between 0.29 and 0.33 per day. Compared to BOD_5,

Table 1: Nitrogen Concentration in Influents (mg/L)

Analysis date	*Sri phraya (SP)*			*Huay kwang (HK)*			*Remark*
	NH_4–N	*NO_2^-–N*	*NO_3^-–N*	*NH_4–N*	*NO_2^-–N*	*NO_3^-–N*	
25 Sept. 1998	10.3	0.6	2.5	49.7	< 0.2	< 0.2	
29 Sept. 1998	13.7	< 0.2	< 0.2	45.1	< 0.2	< 0.2	
20 Oct. 1998	8.2	< 0.2	0.5	146.1	< 0.2	< 0.2	After rain
04 Nov. 1998	11.9	0.2	1.1	42.0	< 0.2	< 0.2	
27 May 1999	15.5	0.7	3.1	53.6	< 0.2	7.8	Rainy
08 June 1999	22.8	0.5	1.4	63.7	< 0.2	5.7	Rainy
10 June 1999	25.8	0.8	2.1	59.5	< 0.2	6.0	Rainy
16 June 1999	24.9	1.8	1.8	65.5	< 0.2	4.4	

Table 2: Coliform Bacteria in Influents (CFU/mL)

Analysis date	*Sri phraya (SP)*		*Huay kwang (HK)*		*Remark*
	Total	*Fecal*	*Total*	*Fecal*	
25 Sept. 1998	1.2×10^5	4.1×10^4	7.7×10^5	3.8×10^5	
29 Sept. 1998	1.4×10^5	3.7×10^4	8.1×10^5	3.5×10^5	
20 Oct. 1998	1.9×10^5	3.4×10^4	4.8×10^5	2.0×10^5	After rain
04 Nov. 1998	1.7×10^5	4.0×10^4	5.6×10^5	3.1×10^5	
27 May 1999	1.6×10^5	5.3×10^4	5.9×10^5	3.0×10^5	Rainy
08 June 1999	1.7×10^5	5.6×10^4	6.9×10^5	3.6×10^5	Rainy
10 June 1999	1.7×10^5	5.9×10^4	7.1×10^5	4.3×10^5	Rainy
16 June 1999	1.9×10^5	5.9×10^4	6.8×10^5	4.0×10^5	

k values for coliform bacteria were quite high, which varied from 0.27 to 0.96/day. The *k* values for TC (0.60 to 0.96/day) were higher than for FC (0.27 to 0.89/day).

Effect of wastewater dilution was distinct mainly in nitrification. Decrease in ammonia nitrogen and TKN were significantly faster in case of two-fold dilution after two weeks (not shown). Nitrite nitrogen concentrations in the samples are shown in Figure 4. Similar trends were observed in nitrate nitrogen also (not shown). Although nitrification began earlier in five-fold dilution, maximum nitrification occurred in two-fold dilution among the four cases considered. With respect to the first-order BOD_5 degradation rate (*k*) for the first five days, two-and five-fold dilutions had similar values (about 0.27/day), which were bigger than in two other cases.

From these simple experimental results, it is apparent that organic degradation potential of domestic wastewater in Bangkok is high, and suitable dilution may enhance treatment efficiency. Thus, high annual average rainfall and temperature, and least influence of industrial activities on domestic wastewater qualities in Bangkok can be important clues for low-cost sustainable wastewater treatment system in place of conventional linear system.

Effects of Toilet Paper Addition in Wastewater

Total sulfide contents in the wastewater samples with different amounts of toilet paper are shown in Figure 5. The case without toilet paper showed some amount of sulfide in the beginning, but it disappeared later. Sulfide concentrations decreased with increasing toilet paper amount in other three cases, which could be the result of incomplete mineralization with relatively bigger amounts of toilet paper. Significant sulfide concentrations were observed even with partial mineralization of cellulose in the wastewater samples during the experiments.

Concentrations of acetic acid, which is a major intermediate product of cellulose decomposition, are shown in Figure 6. Unlike total sulfide, the concentrations increased with increasing toilet paper amount in the

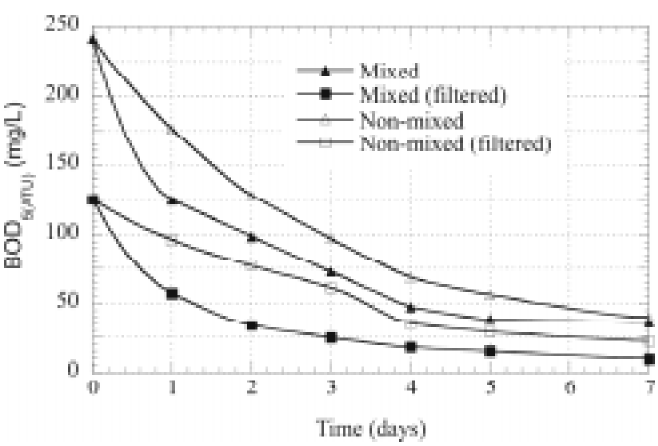

Figure 1: BOD_5 concentration profiles.

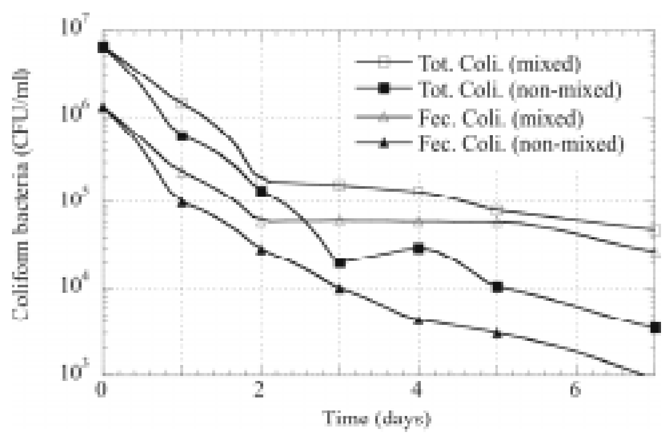

Figure 3: Reduction in coliform bacteria number.

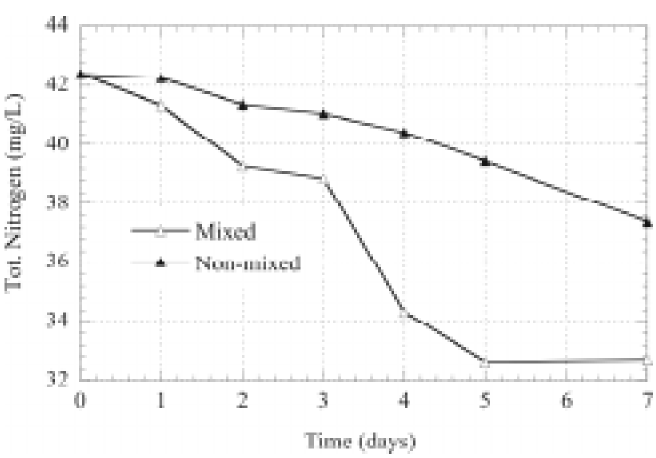

Figure 2: Total nitrogen concentration profiles.

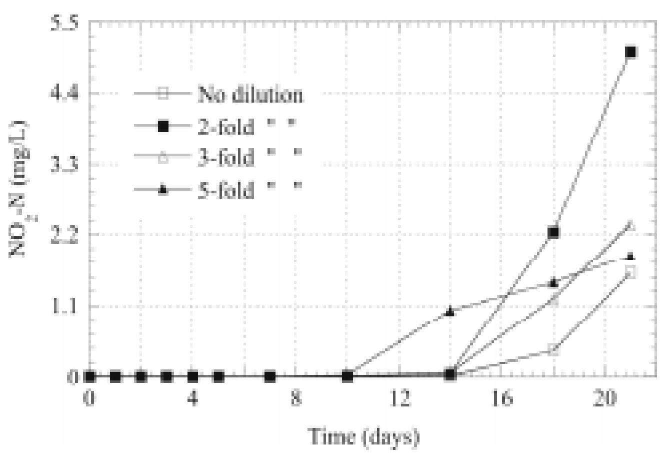

Figure 4: Dilution effect in nitrification.

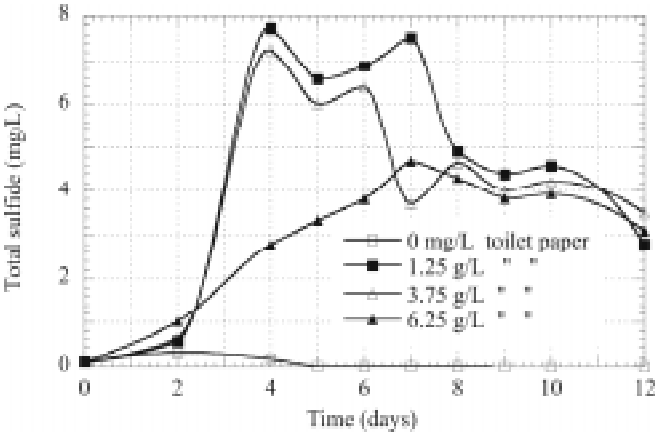

Figure 5: Sulfide produced in cellulose decomposition.

wastewater. APB, SRB and HTB number (MPN/ml) increased while CLB number and pH values decreased with increasing toilet paper amount (not shown). Total sugar produced during cellulose decomposition (not shown) also increased with toilet paper amount, but the concentrations in the sample with 3.75 g/L toilet paper were bigger than in the sample with 6.25 g/L toilet paper in the later part of the experiment.

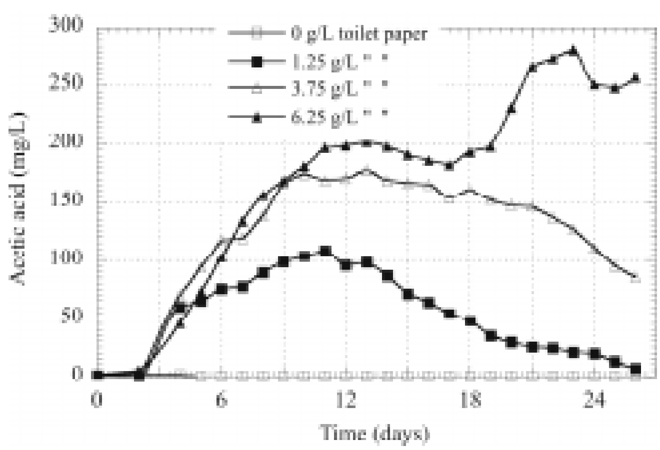

Figure 6: Acetic acid produced in cellulose decomposition.

Although the amounts of toilet paper used in the experiments were not based on real scenario, the results did indicate production of undesirable and complex organics, and considerable delay in organic degradation as a result of cellulose decomposition in domestic wastewater. Hydrogen sulfide is a major byproduct of cellulose decomposition that has negative consequences in wastewater treatment.

Sustainable Domestic Wastewater Treatment

Sustainability is a key-point in domestic wastewater treatment in developing countries (Brauer et al., 2001; Mgana, 2003; Volkman, 2003). Bangkok is not an exception where huge amount of money is being invested for conventional sewerage treatment system while its sustainability has remained questionable. Concept of source separation and treating domestic wastewater components according to their qualities has become very important recently for sustainability (Otterpohl et al., 1999; Matsui, 1999; Gunther, 2000; Vinneras, 2002).

The results presented so far indicate greywater-like quality of domestic wastewater in Bangkok and high organic degradation potential in tropical condition. Cases of conventional domestic wastewater treatment facilities in Bangkok running quite below their design capacities have also been learned recently. Continued use of septic tanks, tradition of using water in defecation in place of toilet paper and high organic degradation potential in tropical condition could have been the reasons for this. It has been unveiled that nutrient recovery in conventional linear system is costly in terms of exergy consumption (Hellstrom, 2003). Given these scenarios, it is apparent that low-cost, closed-loop natural treatment system can be a better alternative to conventional linear system in Bangkok for sustainability.

Conclusion

Domestic wastewater in Bangkok has greywater-like qualities with high organic degradation potential in tropical condition. The low organic strength of domestic wastewater in Bangkok can be attributed to continued use of septic tanks and tradition of using water in defecation instead of toilet paper. The existing situation in Bangkok can be better utilized for sustainable domestic wastewater treatment by introducing low-cost, closed-loop natural treatment system with source separation instead of continuation of conventional linear system whose sustainability has remained questionable in the developing world. This will start a new era in sustainable domestic wastewater management. Nevertheless, detailed investigation is needed.

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