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ORIGINAL ARTICLE

Hydraulic Conditions of Up-Flow Thermophilic Septic Tank (UTST) for Treatment of Blackwater

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Abstract: Septic tank is one of on-site systems that is commonly used to treat blackwater. Septic tanks are currently modified to improve the operation and design to achieve better performance. Up-flow thermophilic septic tank (UTST) is a case of septic tank improvement by supplementing the heat and up-flow feeding mode to improve the septic tank performance. This study aims to investigate the treatment performance and the hydraulic conditions of a laboratory-scale UTST. The average COD removal efficiencies of the laboratory-scale UTST operating at 8, 16, 24 and 32 h and the temperature of 50 °C were 53, 67, 77 and 75%, respectively. The results showed that the UTST operating at the HRT of 24 h could remove COD and BOD_5 better than those operating at 8, 16 and 32 h. Consequently, the intermittent feeding mode was conducted with the HRT of 24h to compare the treatment performance of different feeding modes. The experimental results showed that the intermittent feeding mode could remove COD and BOD_5 better than the continuous feeding. The average COD and BOD_5 removal efficiencies of the intermittent feeding at 24h HRT were 87 and 79%, respectively, with significant differences ($p < 0.05$). These results suggested that hydraulic conditions could affect the treatment performance of UTST. The characteristics of hydraulic patterns such as residence time, dead zone, short circuiting and mixing can influence the reactor performance. Therefore, the hydraulic conditions in the UTST at the optimum HRT of 24h were studied by using NaCl as a tracer chemical with a single shot impulse. The normalized resident time distribution (RTD) curves of the tracer study indicated that the dispersion numbers of the continuous and intermittent feeding were 0.203 and 0.326, respectively, representing the reactors approaching the completed-mix pattern. Application of the experimental results for design and operation of full-scale UTST for effective pollution control was discussed.

Keywords: Hydraulic Condition, Up-Flow Thermophilic Septic Tank, HRT, Blackwater

1. Introduction

Most people in developing countries are being served by on-site sanitation facilities such as septic tanks and cesspools which are generally used in both urban and rural areas to treat blackwater (a combination of feces, urine and flush water). These septic tanks are operated without drainage fields, therefore, the liquid effluent is still highly polluted, and can leak to nearby soil, groundwater or surface water. The pollution problems caused by poor performance of the septic tanks require new techniques to improve the blackwater treatment efficiencies.

Up-flow thermophilic septic tank (UTST) is a modification of solar septic tank in which the up-flow feeding mode can improve the contact between anaerobic accumulated sludge and blackwater, hence better organic matter degradation (Luostarinen and Rintala, 2005 and 2007; Zeeman and Lettinga, 1999). Therefore, the UTST could improve the treatment performance and treat higher organic loading rates than the conventional solar septic tank.

A previous study of the performance of UTST treating blackwater (Prapasriket, 2018) found that the UTST was effective in organic removal, pathogen inactivation and methane production. The UTST integrated the conventional septic tank with thermophilic condition and up-flow feeding mode. Although Pussayanavina et al. (2014) reported that the thermophilic septic tank to remove COD and BOD_5 better than the conventional solar septic tank, UTST with up-flow feeding mode is expected to have better treatment performance. Therefore, study on hydraulic conditions of the UTST should be useful for reactor design and operation to achieve high treatment performance.

Tracer study is one of the parameters commonly used to determine the hydraulic conditions of a reactor such as dead zone, dispersion and short-circuiting. The main objective of this study was to investigate the effects of hydraulic conditions on the treatment performance of a laboratory-scale UTST treating blackwater.

2. Materials and methods

2.1 Reactor configuration

The laboratory-scale of UTST was made of Polyvinyl chloride (PVC) cylinder having a diameter of 0.2 m and height of 0.9 m (Figure 1), or the total volume of 27 L, but the operating volume was maintained at 22 L. There was another PVC pipe (5 cm in diameter) with a length of 0.7 m installed in the UTST for influent feeding and creating up-flow feeding mode. The UTST was equipped with a gas-solid (GS) separator and gas collection chamber. The UTST reactor was operated at 50°C by an electric heater with a temperature sensor.

2.2 Reactor operation

The experiments were investigated at different HRTs of 8, 16, 24 and 32 h. The blackwater was mixed with tap water to maintain the TCOD concentrations of 1957-4982 mg/L and the organic loading rates (OLRs) within the range of 1.7-3.0 kgCOD/(m^3-d). The UTST was allowed to acclimatize until steady-state conditions, based on relatively stable effluent COD concentrations (Polprasert et al., 1992), were reached. After that, the UTST was operated of different HRTs by changing the influent flow rates. The optimum HRT was considered based on the highest treatment performance of UTST treating blackwater. The treatment performance of the UTST between continuous and intermittent feeding modes was compared using the optimum HRT. The intermittent feeding mode was related to the people's behavior in using the toilets (Butler et al, 1995). The times of influent feeding were divided into three periods as shown in Table 1 (Augsorntung, 2015 and Chaiwong, 2016)

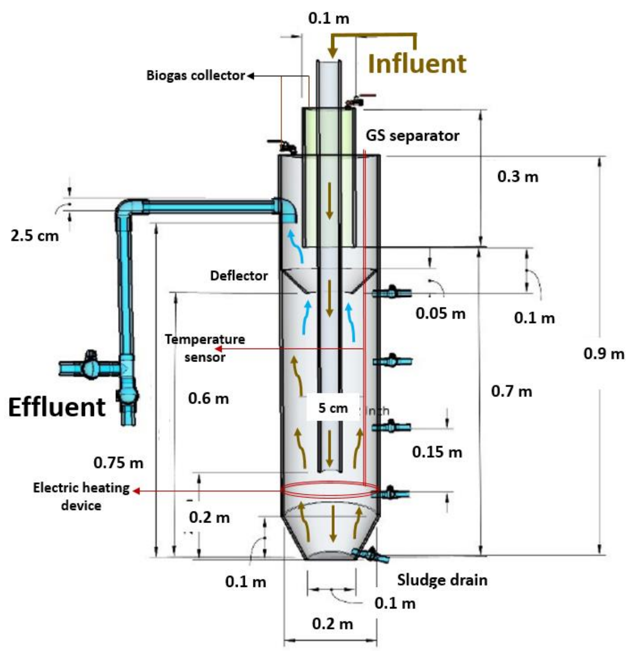

Figure 1. Detail of a laboratory-scale UTST

2.3 Tracer experiments

Sodium chloride (NaCl) was selected as a tracer chemical because it is non-biodegradable, low-cost and environmentally friendly (Eamrat, 2014). Tap water containing 500 mg/L of NaCl was introduced into the reactor by pulse input and the effluent samples which were collected every 5 minutes and NaCl concentrations were analyzed by using a conductivity meter (Mettler-Toledo Inc, Seven2Go S3 Portable Conductivity Meter). The data of the effluent NaCl concentrations were used to determine the normalized resident time distribution (RTD) according to the procedure shown in section 2.4 (Levenspiel, 1999).

The operating condition of the tracer study of the UTST under continuous and intermittent feeding modes are shown in Table 1.

Table 1. Operational conditions of tracer study

Feeding modes	Feeding period	Feeding Time (h)	Flow rate (L/h)	Tracer chemical
Continuous	All day	24	0.92	NaCl
Intermittent	6 am – 7 am	1	12	
	12 pm – 1 pm	1	3	
	6 pm – 7 pm	1	7	

2.4 Calculations of tracer data

Equation (1) shows the calculation of the mean residence time or actual hydraulic retention time (t)

$$t = \frac{\int_0^\alpha tCdt}{\int_0^\alpha Cdt} = \frac{\sum_i t_i c_i \Delta t_i}{\sum_i c_i \Delta t_i} = \frac{V}{v} \quad (1)$$

Where: t_i= time at measuring effluent samples (s), C_i = concentration of samples at measuring effluent samples (mg/L), V = reactor volume (m^3), v = flow rate (m^3 /s)

Dead space or dead zone in the reactor was calculated by Equation (2).

$$\frac{V_d}{V_t} = 1 - t \quad (2)$$

Where: V_d = dead volume (L), V_t = total volume (L)

The dispersion number (D/$\mathcal{U}$L) was calculated by determining the shape of the tracer curves as it passes the exit of the system. The dispersion number of 0 indicates ideal plug flow pattern, whereas the infinity number means completely-mixed pattern (Metcalf & Eddy, 2003). Equation (3) and (4) show the calculation of variance and dispersion number, respectively.

$$\sigma^2 = \frac{\int_0^\alpha (t-\bar{t})^2 Cdt}{\int_0^\alpha Cdt} = \int_0^\alpha \frac{t^2 Cdt}{Cdt} - \bar{t}^2 \quad (3)$$

$$\sigma_\theta^2 = \frac{\sigma_t^2}{t^2} = 2\left[\frac{DL}{\mu^3}\right] \quad (4)$$

Where: $\bar{t}$ = mean resident time (s), σ^2 = the spread of curve or variance, D or D/ $\mathcal{U}$L = the dispersion coefficient

2.5 Analytical methods

The influent and effluent samples were collected by grab sampling every 1-3 days for analysis of COD (total, soluble), BOD_5 (5-day biochemical oxygen demand) and TKN (Total Kjeldahl Nitrogen) concentrations. The main parameters were analyzed according to procedures described in Standard Methods (APHA et al., 2012).

3. Results and discussion

3.1 Effects of hydraulic retention times on treatment performance at continuous feeding

The removal efficiencies of COD (TCOD and SCOD) and TKN at various HRTs operation (Table 2) revealed that the longer HRT provided, the higher organic removal. According to Farajzadehha et al. (2012), long HRT operation in anaerobic wastewater treatment could lead to longer contact between wastewater and sludge that resulted in better decomposition of organic matter. From statistical analysis, the TCOD, SCOD and BOD_5 removal efficiencies at the HRTs of 24 and 32 h were not significantly different which were probably due to sufficient contact time between influent blackwater and the microorganism in the UTST reactor. Therefore, for cost effectiveness reason, the HRT of 24 h was considered to be optimum for the design and operation of the UTST reactor for organic removal. Due to the anaerobic condition prevailing in the UTST reactor, the TKN removal efficiencies for all the HRTs were relatively low, suggesting requirement of additional treatment units, such as constructed wetland or drainage system, for further TKN removal from the UTST effluent samples. The relatively higher TKN removal efficiencies at the HRT of 32 h may be resulted from solids sedimentation and anaerobic conversion of organic nitrogen to nitrogen gas.

Table 2. Treatment performance of the UTST operating under continuous feeding at various HRTs

Parameters		Continuous feeding (HRTs)			
		8 h	**16 h**	**24 h**	**32 h**
TCOD	% removal efficiency	53±5.5	67±10.5	77±8.1	75±7.4
SCOD	% removal efficiency	38±13.6	23±15.1	41±12.0	51±7.6
BOD_5	% removal efficiency	42±5.5	53±3.0	76±0.5	73±0.6
TKN	% removal efficiency	6±0.5	9±4.4	6±4.2	20±1.5

3.2 Comparison of UTST performance under continuous and intermittent feedings

The removal efficiencies (%) of organic matters at 24 h HRT operation of the UTST under continuous and intermittent feedings are shown in Table 3. In general, the intermittent feeding resulted in better organic removal than those of the continuous feeding. It could be hypothesized that the intermittent feeding caused more solid sedimentation, hence better treatment performance than the continuous feeding. According to Vrieze, et al. (2013), the pulse feeding mode of organic matter can encourage higher functional stability in anaerobic digestion. Therefore, the UTST reactor under intermittent feeding, which represents actual people's behavior in toilet using, should be effective in treating organic matter in the blackwater.

Table 3. UTST treatment performance under continuous and intermittent feedings

Parameters		Continuous feeding	Intermittent feeding
TCOD	% removal efficiency	77±8.1	87±4.1
SCOD	% removal efficiency	41±1.2	60±20.7
BOD_5	% removal efficiency	76±0.5	79±0.7
TKN	% removal efficiency	6±4.2	8±2.1

3.3 Tracer study results

The results of hydraulic evaluation were determined as normalized RTD by plotting between C_t/C_0 and t/T according to Levenspiel. (1999). As shown in Figure 2, it indicated the relatively higher hydraulic dispersion in the intermittent feeding than the continuous feeding. However, the values of D/uL (Table 4) of these two feeding modes suggested that they are in the moderate-high dispersion condition (Metcalf & Eddy, 2014).

From Table 4, the actual hydraulic retention times of the continuous and intermittent feedings were found to be 31 and 26 h, respectively. The higher retention times than that of the design hydraulic retention time probably come from dead spaces in the reactor which were determined to be 23 and 8% for the continuous and intermittent feedings, respectively. Further investigation on this aspect is recommended. To further improve treatment performance of the UTST reactor, additional researches on reactor design and operation to reduce dead space should be done such as increasing the ratio of height/diameter and frequency of sludge drain, etc.

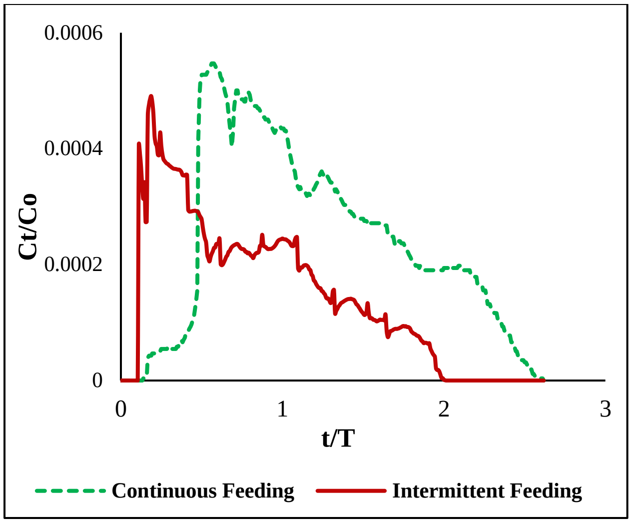

Figure 2. Dispersion curve of the UTST reactor at HRT of 24h on continuous and intermittent feeding

Table 4. Hydraulic characteristics of UTST reactor using NaCl at HRT of 24h

Values	Unit	Feeding Modes	
		Continuous	Intermittent
t	h	31	26
σ_θ^2	-	0.233	0.531
D/uL	-	0.203	0.326
Dead space	%	23	8

4. Conclusions

The experiments on UTST reactor treating blackwater were conducted to investigate its efficiency on organic and TKN removal. Under the continuous feeding and temperature of 50°C, the HRT of 24h was found to be optimum, resulting in the TCOD, SCOD and BOD_5 removal efficiencies of 77, 41 and 76 %, respectively. Due to the anaerobic condition prevailing in the reactor, the TKN removal efficiency was only 6 %. Probably due to solid sedimentation, the intermittent feeding mode, representing people's behavior in toilet using, resulted in better organic removal than the continuous feeding mode. The tracer study results showed the dispersion numbers to be 0.203 - 0.326 or moderate-high dispersion and the dead space values to be 8-23 %. To further improve treatment performance, more researches on design and operation of the UTST reactor should be done to reduce dead space values in the UTST reactor.

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