CFD Simulation for Improving Performance of Septic Tanks

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Abstract: Onsite wastewater treatment system such as septic tanks and commercial treatment packages etc. are used to collect/treat household wastewater (grey water and black water) in developing countries and non-sewered areas of developed countries. However, in developing countries, these on-site wastewater treatment systems do not have leaching fields to treat the dissolved organic matters. Due to improper design (such as configuration, sizing and hydraulic retention time (HRT)) and limitations on operation, the removal efficiencies of organic matters, solids and pathogens have been found to be unsatisfactory and the polluted effluents are normally discharged into nearby stormwater drains or receiving water resources. Therefore, a new design approach which could minimize dead space and enhancing better contact between the influent wastewater and biomass in septic tanks should be developed to provide an improved treatment performance. “Computational Fluid Dynamic (CFD)” was applied to analyze flow hydraulics and size configuration in order to establish appropriate design and operation procedures for these on-site systems. Based on data of actual-scale septic tanks and literature data, the CFD was found to be effective in improving septic tank performance.

Keywords
Conventional septic tank; Hydraulic characteristic; Treatment performance; CFD model

INTRODUCTION

Lack of adequate sanitation facilities in most developing counties is the cause of serious water pollution and water borne diseases infection, resulting in millions of illness and deaths every year (WWAP, 2009 and UN, 2009). Centralized wastewater treatment as being practiced in most developed countries is one of the solutions to treat those wastes, but it seems to be inappropriate for developing countries because of high investment cost and requirement of skilled operation. Moreover, large investment of sewerage system and pumping associated with centralized treatment systems is one of barriers for decreasing affordability of construction of wastewater management systems (Massoud *et al.*, 2009). To come up with cost-effective and implementable solutions, onsite wastewater treatment technologies such as cesspools and septic tanks, low investment cost and easy to operate, are more applicable (Rybczynski *et al.*, 1978). For this reason, the on-site treatment system has been used as a privilege technology in a primary treatment to treat sewage or black water. Onsite treatment systems commonly used are septic tanks, cesspools and commercial treatment packages, but in developing countries these systems do not perform satisfactorily due to improper design (such as configuration, sizing and hydraulic retention time (HRT)) and limitations on operation including absence of leaching fields (Polprasert and Rajput, 1982). Therefore, onsite-treatment systems in developing countries should be designed to achieve both solids sedimentation, organic matter degradation and pathogen inactivation in the tanks. It is hypothesized that, to achieve the above purposes, a tank should be designed to have minimum dead space and better contact between the incoming wastewater and the biomass. The application of a CFD model to improve the hydraulic efficiency of a water tank was previously reported by Stamou (2008). The objectives of this study were:

(i) to investigate hydraulic efficiencies of 2 types of septic tank (rectangular and circular) by using tracer experiment and a CFD model

(ii) to evaluate and compare treatment performance of rectangular and circular septic tanks with respect to hydraulic efficiency data

MATERIAL AND METHODS

Tracer study

Tracer study was conducted with a two compartment rectangular septic tank (According to the design standard of US.EPA (2002)) and a circular septic tank by varying the HRTs at 12, 24 and 48 h and using sodium chloride and rhodamine dye as tracer chemicals. Effluent concentrations of the septic tanks were measured by a fluorometer (Bio-Tek Synergy 2 SLF ,2011, Multi-Mode Microplate Reader, USA) and a conductivity meter (mettler Toledo LE 703 conductivity). In order to evaluate the hydraulic efficiency, tracer experiments and normalized resident time distribution (RTD) (Metcalf and Eddy, 2003) were used to define hydraulic conditions in a septic tank, such as dispersion numbers. The RTD curve was plotted from the results of tracer experiment between t/T and C_t/C_0 and the mean resident time ($\bar{t}$) was determined by:

$$\bar{t} \cong \frac{\sum_i t_i C_i \Delta t_i}{\sum_i C_i \Delta t_i} = \frac{V}{v} \tag{1}$$

$$\sigma^2 = 2\left[\frac{D}{uL}\right] \tag{2}$$

Where: $\bar{t}$ was mean resident time (s), t_i was time at measuring effluent samples (s), Ci was concentration of samples at measuring effluent samples (mg/L), V was volume (L), ν was volume metric flow rate (L/s). The dispersion number is calculated from the mean resident time ($\bar{t}$) and variance of curve (σ^2). The dispersion number of 0 is defined as plug flow or no dispersion, while the value of infinity is defined as completely mixed. Short-circuiting is a portion of first appearance of tracer at the effluent and design HRTs (HRT = V/Q). If this value is less than acceptable range of short-circuiting of 0.3 or 0.4, short-circuiting will occur. Dead space is calculated by Eq. (3)

$$V_{Dead\ zone} = V_{tank}\,(1-\bar{t}) \tag{3}$$

CFD simulation

To verify the tracer study results, a CFD model for the septic tank requires specifications of the various modified geometries including hydraulic retention times (HRTs) and configurations. In this study, a commercial CFD software, Xflow (version 2014) (Lattice boltzmann method and lattice gas automata mesh-less approach) was employed for CFD calculation (2D simulation).

Validation of CFD results

The CFD results were validated with a 1000-L septic tank used for treatment of toilet wastewater (Figure 1) from a household with a flow rate of 100-300 L/d. The influent and effluent samples of this septic tank were collected for analysis of total chemical oxygen demand (TCOD), 5-day biological oxygen demand (BOD_5), total suspended solid (TSS) and *E.coli* concentrations according to APHA, AWWA and WEF (2005).

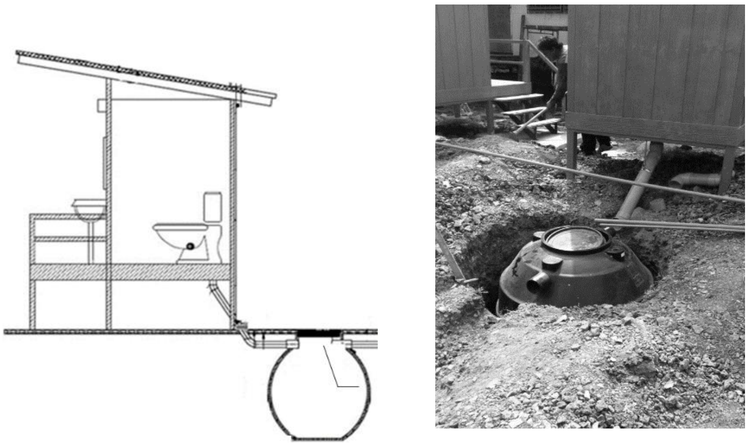
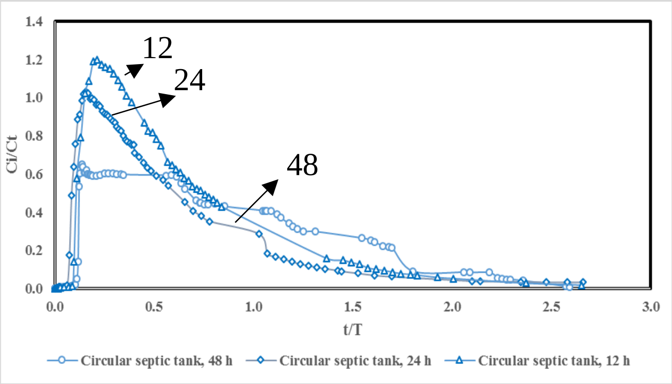


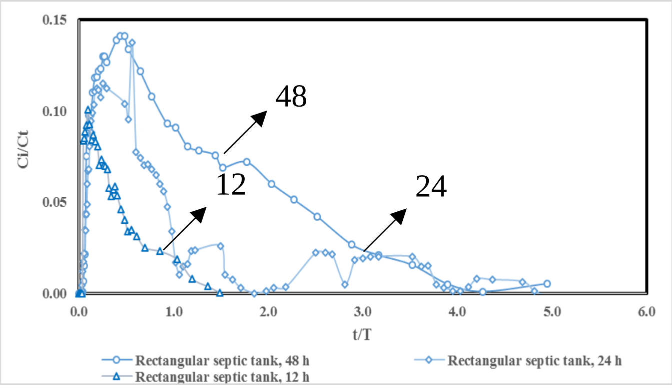
Figure 1 Actual-scale septic tank testing

RESULTS AND DISCUSSION
Tracer study and CFD simulated result

The normalized resident time distribution of a two-compartment rectangular septic tank and a circular septic tank are shown in Figure 2. The dispersion values calculated from normalized resident time distribution of both septic tanks were found to be (0.17-.032) approaching completely mixed condition (77-98%of mass recovery). The mean HRTs were found lower than the designed HRTs of 12, 24 and 48 hr, and suggesting the prevalence of complete-mix conditions. In this study, it was apparent that, due geometric effect on flow pattern, an increasing in HRT more than 48 h in a two compartment rectangular septic tank did not appear to show effects on dispersion values. While, dispersion values of a circular septic tank were found to increase from 0.17. to 0.22 with increasing HRTs and it could hypothesis that an increasing in HRT in circular septic tanks could improve the contact between the wastewater and the biomass, resulting effective biodegradation reaction and treatment performance. The short-circuit ratios of rectangular septic tank were found to be 0.030-0.050, about 50 % higher than the circular septic tank. In general, high degree of short-circuit is the cause of inefficient treatment performance and this short-circuiting effects were confirmed as shown in the data of Table 1.



(a) Circular septic tank



(b) Rectangular septic tank

Figure 2 Normalized resident time distribution

To understand hydrodynamic characteristics of the tank, the computational aided design concept by mathematical modelling was applied for upgrading septic tank performance. Figure 3 shows the CFD simulation results of a circular tank with respect to short-circuiting and dead space. Due to formation of massive re-circulation which occupied almost 60-70 % of the tank volume (Figure 3), short-circuiting was clearly evident and causing the incoming water to transit directly from the inlet to the outlet; these results were validated by the tracer study which found the actual HRTs to be shorter than the design values. Unused area or "dead space found at the zone that close to the inlet pipe of both the circular and rectangular septic tanks were found to be about 30 % of the total space. It could be hypothesized that the position of inlet pipe had significant effects on the dead space zone.

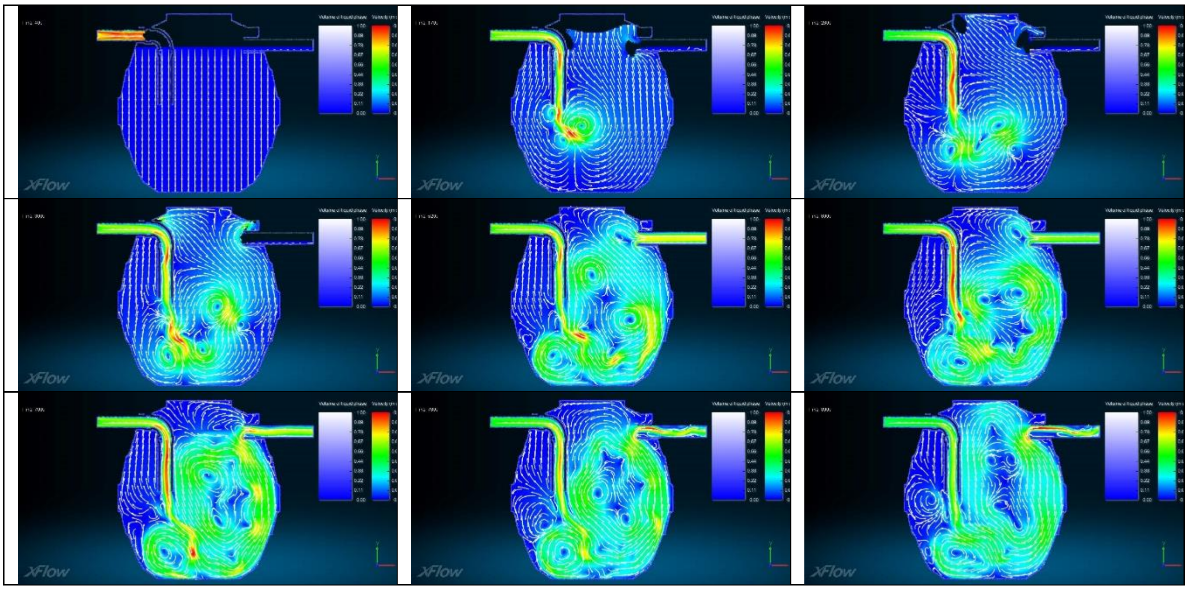


Figure 3 CFD simulated results

Treatment performance of actual scale septic tanks

As shown in Figures 2 and 3, because the circular septic tank showed better hydraulic characteristics, it was selected for implementation under actual condition. The treatment TCOD, BOD_5 and TSS removal efficiencies of the actual circular septic tank operating at HRTs of more than 2 days were found to be about 60-88, 50-79 and 87-95%, respectively, as shown in Table 1, which were more effective than the rectangular septic tanks operating under similar conditions (Polprasert and Rajput (1982), Seabloom et al. (2004), Bounds (1997), Nguyen et al. (2007) and Crites et al. (1998)). These data confirmed the CFD results (Figure 1) that circular septic tanks could provide better contact between incoming wastewater and the biomass including less short circuit than rectangular septic tanks. It is therefore recommended that, to achieve both solid sedimentation and organic matter degradation, on-site sanitation systems in developing countries should be design to with circular in shape instate of rectangular shape. It is apparent from Table 1 that E. coli reduction in both circular and rectangular septic tank were not very effective. Another study by Pussayanavin et al. (2014) and Koottatep et al. (2013) employed solar septic tanks was able to raise the septic tank temperature to be above 40 ^{o}C and resulting in more than 3 log reduction of E. coli.

Table 1 Treatment performance of actual scale septic tank

Septic tank geometries	*HRT (d)*	*Removal efficiency*				*Reference*
		TCOD	*BOD_5*	*TSS*	*E.coli log reduction*	
Circular septic tank	*5*	*74*	*53*	*91*	*0.7*	*This study*
	9	*88*	*79*	*95*	*0.5*	
	1	*76*	*84*	*72*	*-*	*Koottatep et al. (2014)*
	5	*88*	*84*	*66*	*-*	
	7	*93*	*93*	*75*	*-*	

	9	*90*	*94*	*66*	*-*	
	16	*97*	*95*	*66*	*-*	
	0.5	*-*	*52*	*-*	*--*	***Ittiusupornrat et al. (2009)***
Rectangular septic tank	*<2*	*47*	*27*	*46*	*-*	***Polprasert and Rajput (1982)***
	<2	*-*	*60*	*77*	*-*	***Seabloom et al. (2004)***
	<2	*-*	*64*	*91*	*-*	***Bounds (1997)***
	2	*-*	*58*	*-*	*-*	***Nguyen et al. (2007)***

CONCLUSIONS

Based on the results obtained from this study, the following conclusions are made.

1. The flow hydraulic of both rectangular and circular septic tanks operating under tropical conditions were found to approach completely mixed condition.
2. Due to the tank configuration, the extent of short-circuiting in rectangular septic tank was more than that in circular septic tank.
3. The CFD results were validated with data of an actual circular septic tank which showed the treatment performance to be better than the rectangular septic tank
4. To improve treatment performance, septic tank treating household wastewater should be designed with circular in shape.

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