Computational Evaluation of Improved Anaerobic Digestion Reactor Designs

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Abstract

This modeling study was used to improve the design of the Anaerobic Digestion-Pasteurization Latrine (ADPL), a novel onsite fecal sludge treatment system that uses anaerobic digestion coupled with pasteurization to self-sustainably remove fecal pathogens [1]. The ADPL was created for communities that have either inadequate access to sanitation or sanitation that does not treat waste before entering the environment (60% of global population [2]). Theory as well as experience informs that the current design is liable to short-circuiting and therefore inefficient digestion of substrate. Two alternative reactor configurations were investigated: anaerobic baffled reactor (ABR) and horizontal anaerobic baffled reactor (HABR). These designs increase solids retention, allow selective bacteria to dominate compartments, and provide mixing effects without mechanical parts by using vertically- (ABR) or horizontally- (HABR) aligned baffle walls [3,4]. The following study used computational fluid dynamics (CFD) to evaluate these reactor configurations in order to inform future reactor designs and implementations of the ADPL.

Reactors were simulated using the CFD Module of the COMSOL Multiphysics® software, and residence time distribution (RTD) was found using "Particle Tracing for Fluid Flow". All reactors had the same outer dimensions: 1 meter (width) x 1 m (length) x 1m (height) for 2 m3 volume (Figure 1), and the impact of increasing number of compartments (N) was evaluated (N=1 in current design). Flow for each reactor was set 120 L d-1, assuming 50 people at 2.4 L person-1 day-1. RTD results were analyzed with dimensionless time □ and compared using dead space fraction V_d/V_T [5], short-circuiting factor ISC [6], Morrill Index (MI) [7], and hydraulic efficiency λ [7]. Performance classifications were based on literature [7,8].

The results for the analysis is shown in Table 1. Performance improved as the number of compartments increased. Dead space fraction decreased from 0.80 in the current design to 0.14 and 0.36 in the ABR and HABR, respectively, with only two compartments. "Excellent" hydraulic performance in three of four categories when N ≥ 2 for the ABR and N ≥ 4 for the HABR. The change in MI and dead space according to number of compartments is shown in Figure 2 and Figure 3. Improvements in MI were minimized when N ≥ 4 for the ABR and N ≥ 5 for the HABR, and improvements in dead space fraction were minimized at N ≥ 3 and N ≥ 4, respectively.

The addition of baffles dramatically improved performance, but yields were minimized

after 4 or 5 compartments for both the ABR and HABR. This number should be the target range for future studies to optimize performance while minimizing complexity and materials. Results from this modeling exercise have already been implemented. Two 2 m3 HABRs with 4 baffles were installed in Kenya in April 2016. Preliminary results show that chemical oxygen demand (COD) and total suspended solids (TSS) in the HABR effluent are 53% and 65% less than the previous reactor, respectively. More in-depth analysis and further implications will be discussed at the conference.

Reference

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Figures used in the abstract

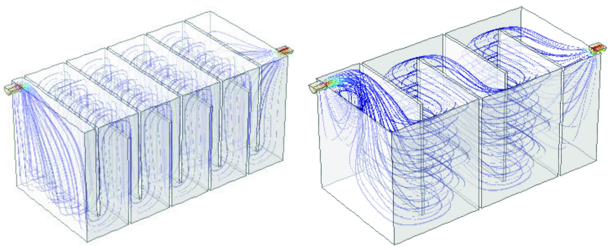

Figure 1: Reactor geometry and flow streamline for five compartment ABR (left) and HABR (right).

Model	θ_{10}	Θ_{90}	*MI*	I_{SC}	V_d/V_t	λ
CSTR	0.14	0.36	2.55	0.74	0.80	-
ABR - 2	0.70	1.30	1.86	0.83	0.14	0.43
ABR - 3	0.78	1.2	1.53	0.89	0.10	0.6
ABR - 4	0.81	1.11	1.38	0.91	0.10	0.67
ABR - 5	0.81	1.07	1.32	0.93	0.11	0.71
ABR - 6	0.77	1.03	1.34	0.92	0.15	0.7
HABR - 2	0.4	1.53	3.82	0.66	0.36	0.32
HABR - 3	0.55	1.41	2.58	0.76	0.25	0.5
HABR - 4	0.66	1.38	2.1	0.80	0.15	0.64
HABR - 5	0.72	1.23	1.70	0.85	0.13	0.69
HABR - 6	0.74	1.23	1.65	0.89	0.15	0.71
HABR - 7	0.77	1.21	1.58	0.90	0.13	0.75
HABR - 8	0.79	1.16	1.47	0.90	0.11	0.78
HABR - 9	0.78	1.14	1.46	0.91	0.13	0.77

Figure 2: Indicators of performance for each simulation with red representing "poor," yellow for acceptable, and green for "excellent."

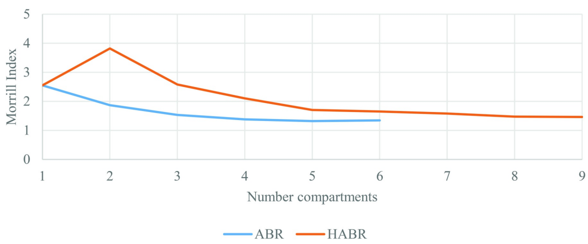

Figure 3: Morrill Index corresponding to number of compartments for ABR and HABR.

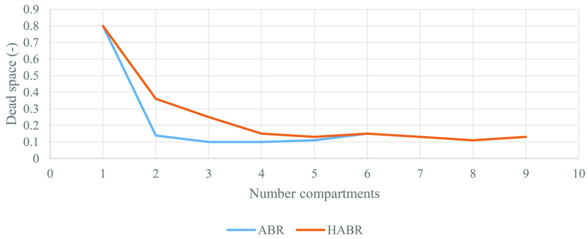

Figure 4: Dead space fraction corresponding to number of compartments for ABR and HABR.