Computational Evaluation of Improved Anaerobic Digestion Reactor Designs

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Introduction:

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**). 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.

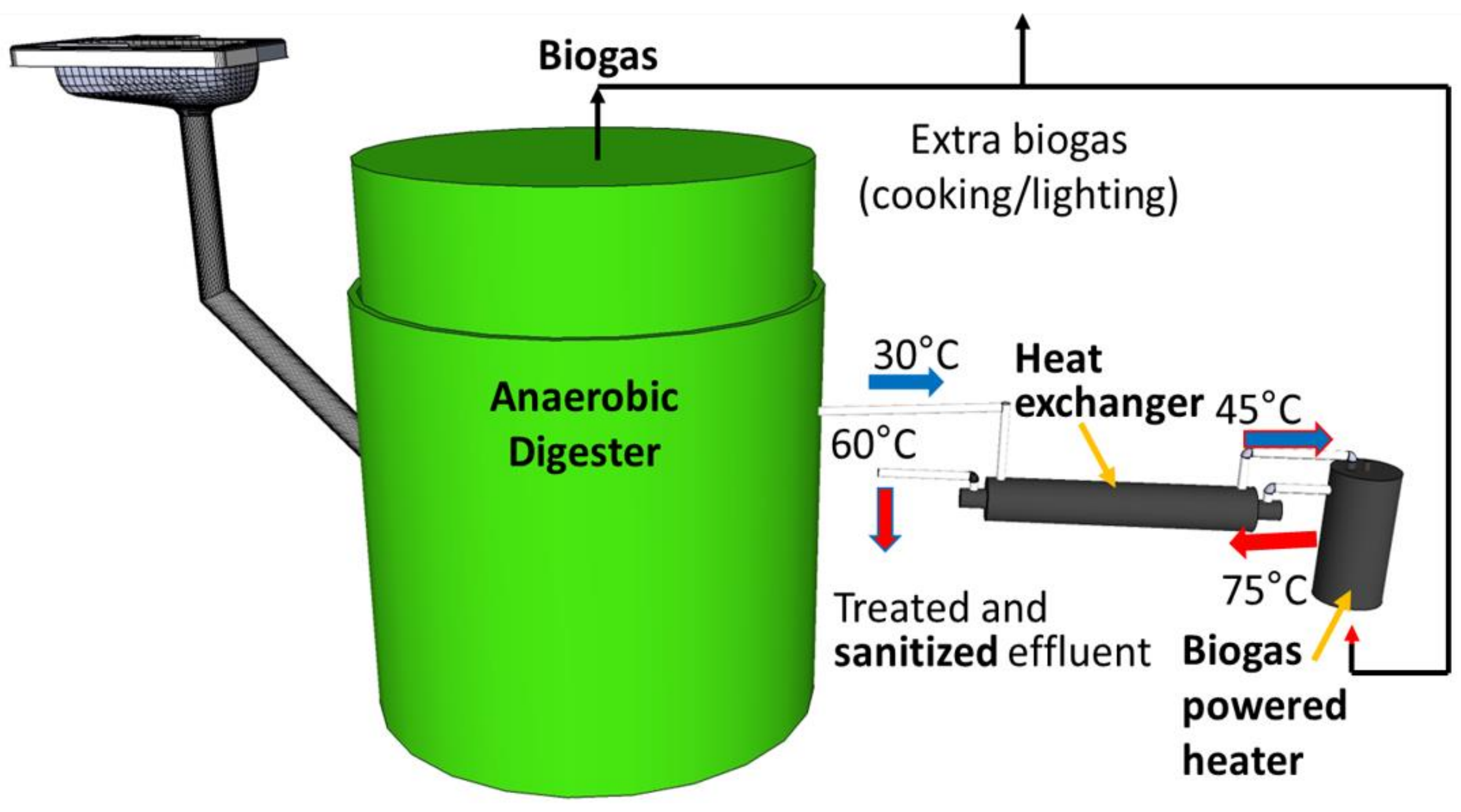


Figure 1. Concept flowsheet for ADPL.

Computational Methods:

COMSOL CFD was used to determine residence time distribution (RTD). All reactors had the same outer dimensions with flow of 120 L d^{-1} (~50 people). RTD results were analyzed with dimensionless time Θ and compared to indicators [3] using dead space fraction V_d/V_T [4], short-circuiting factor I_{SC} [5], Morrill Index (MI) [6], and hydraulic efficiency λ [6].

$$\rho(\mathbf{u} * \nabla)k = \nabla * \left[\left(\mu + \frac{\mu_{\mathrm{T}}}{\sigma_k}\right) * \nabla k\right] + P_k - \rho\epsilon \; ;$$

$$\rho(\mathbf{u} * \nabla)\epsilon = \nabla * \left[\left(\mu + \frac{\mu_{\mathrm{T}}}{\sigma_\epsilon}\right) * \nabla \epsilon\right] + C_{\epsilon 1}\frac{\epsilon}{k}P_k - C_{\epsilon 1}\rho\frac{\epsilon^2}{k} \; ;$$

$$\epsilon = \mathrm{ep};\ \mu_{\mathrm{T}} = \rho C_\mu \frac{k^2}{\epsilon}$$

$$\frac{d(m_p\mathbf{v})}{dt} = \mathbf{F_t}$$

Efficiency	Θ_{10}[3]	Θ_{90}[3]	*MI*[3]	λ[7]
Poor	<0.2	>2.3	>10	≤ 0.5
Compromising	0.2-0.4	2.0-2.3	5.0-10	
Acceptable	0.4-0.5	1.5-2.0	2.5-5.0	0.5-7.5
Excellent	>0.5	<1.5	<2.5	>0.75

$$MI = \frac{\theta_{90}}{\theta_{10}}$$

$$\lambda = \left(1 - \frac{V_d}{V_T}\right) * \left(1 - \frac{1}{N}\right)$$

$$I_{sc} = \frac{\theta_{16}}{\theta_m}$$

$$\frac{V_d}{V_T} = 1 - \theta_m$$

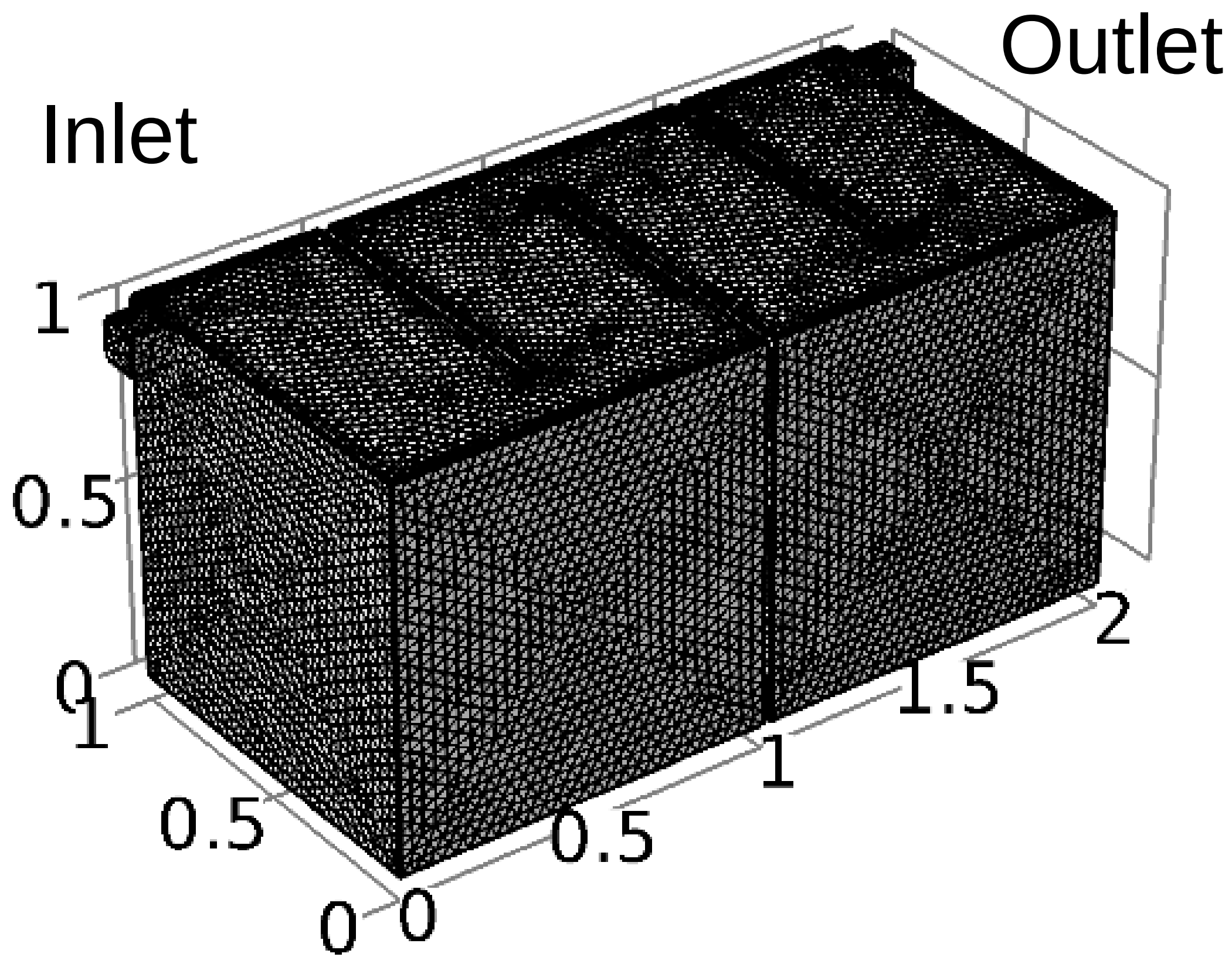


Figure 2. Reactor geometry and mesh. Example here is HABR-4, HABR reactor with 4 compartments.

Results:

Performance indicators improved quickly in the increase in number of compartments, but improvements because less significant after 4 compartments. For example, dead space decreased from 0.80 to .14 and .15 in the ABR-3 and HABR-3.

Model	Θ_{10}	Θ_{90}	*MI*	λ	V_d/V_T
CSTR	0.14	0.36	2.55	-	0.80
ABR - 3	0.78	1.20	1.53	0.6	0.14
ABR - 4	0.81	1.11	1.38	0.67	0.10
ABR - 5	0.81	1.07	1.32	0.71	0.10
ABR - 6	0.77	1.03	1.34	0.7	0.11
HABR - 3	0.55	1.41	2.58	0.5	0.15
HABR - 5	0.72	1.23	1.70	0.69	0.15
HABR - 7	0.77	1.21	1.58	0.75	0.13
HABR - 9	0.78	1.14	1.46	0.77	0.13

Table 1. Performance indicators for selected reactors

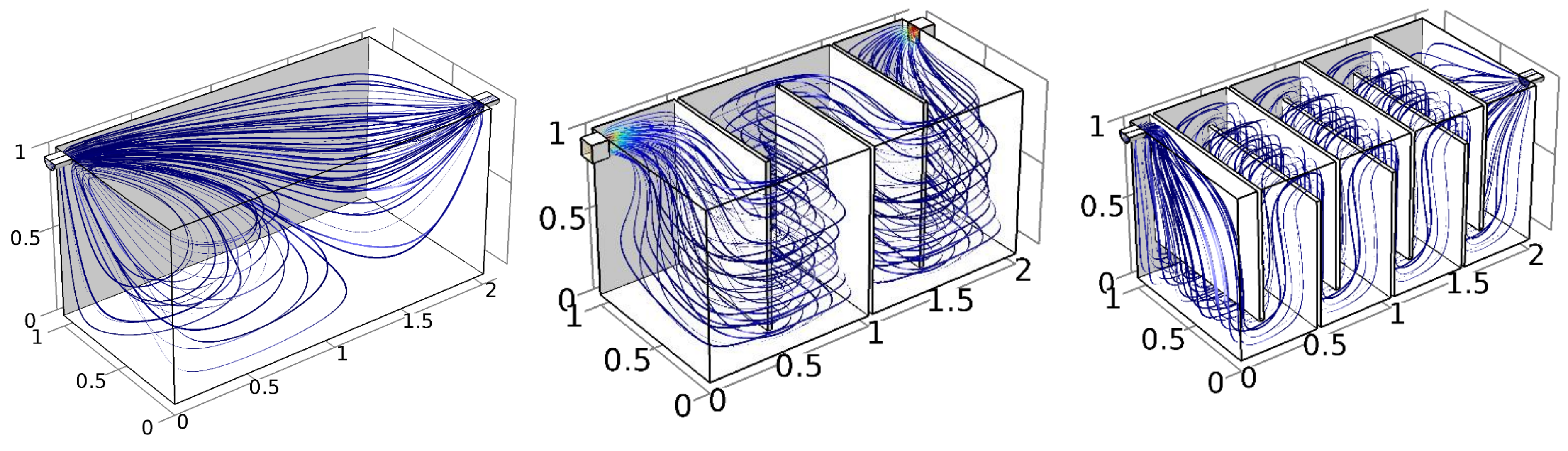
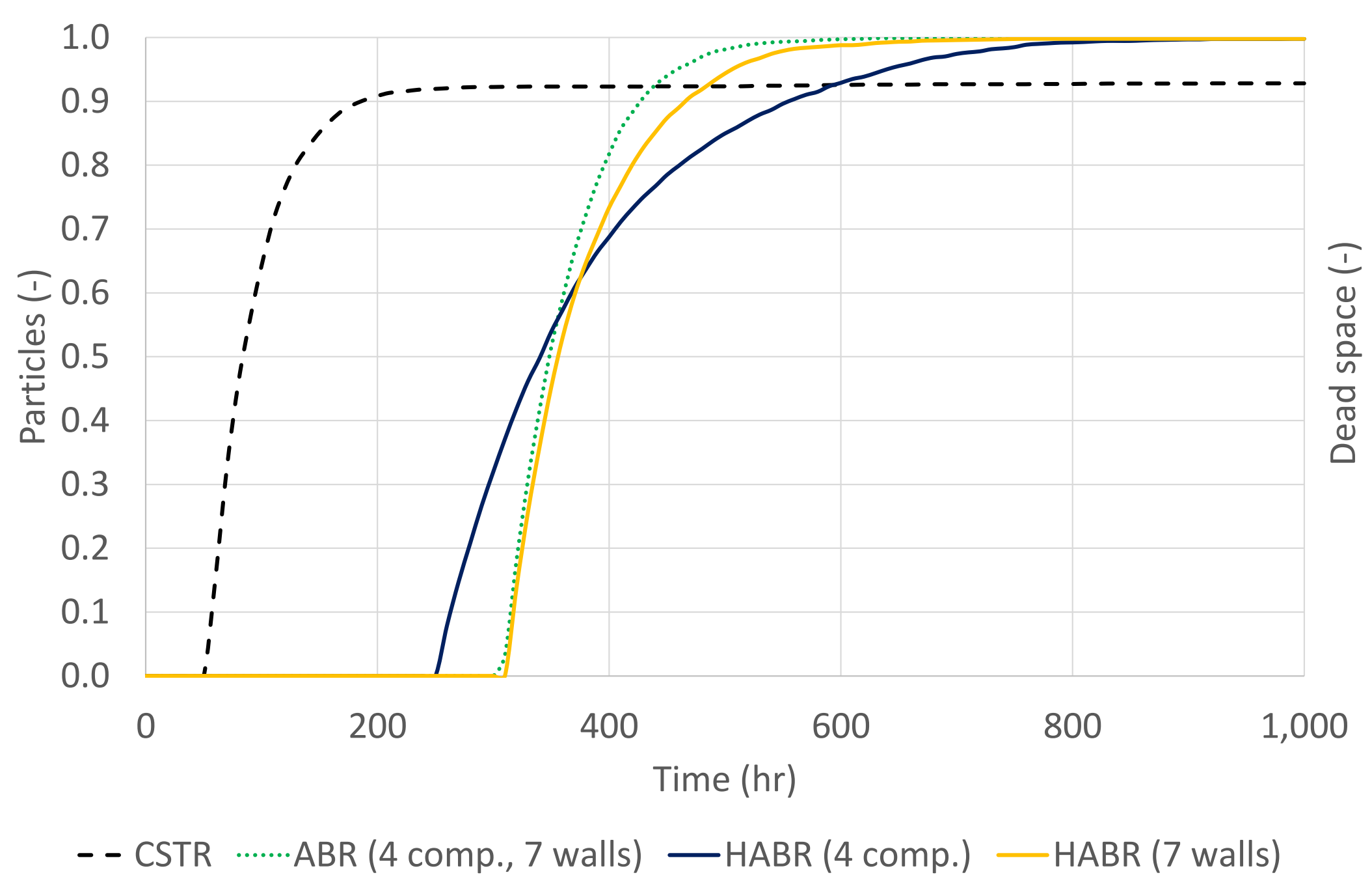


Figure 3. Flow streamline for CSTR, HABR-4, and ABR-4 (in order).



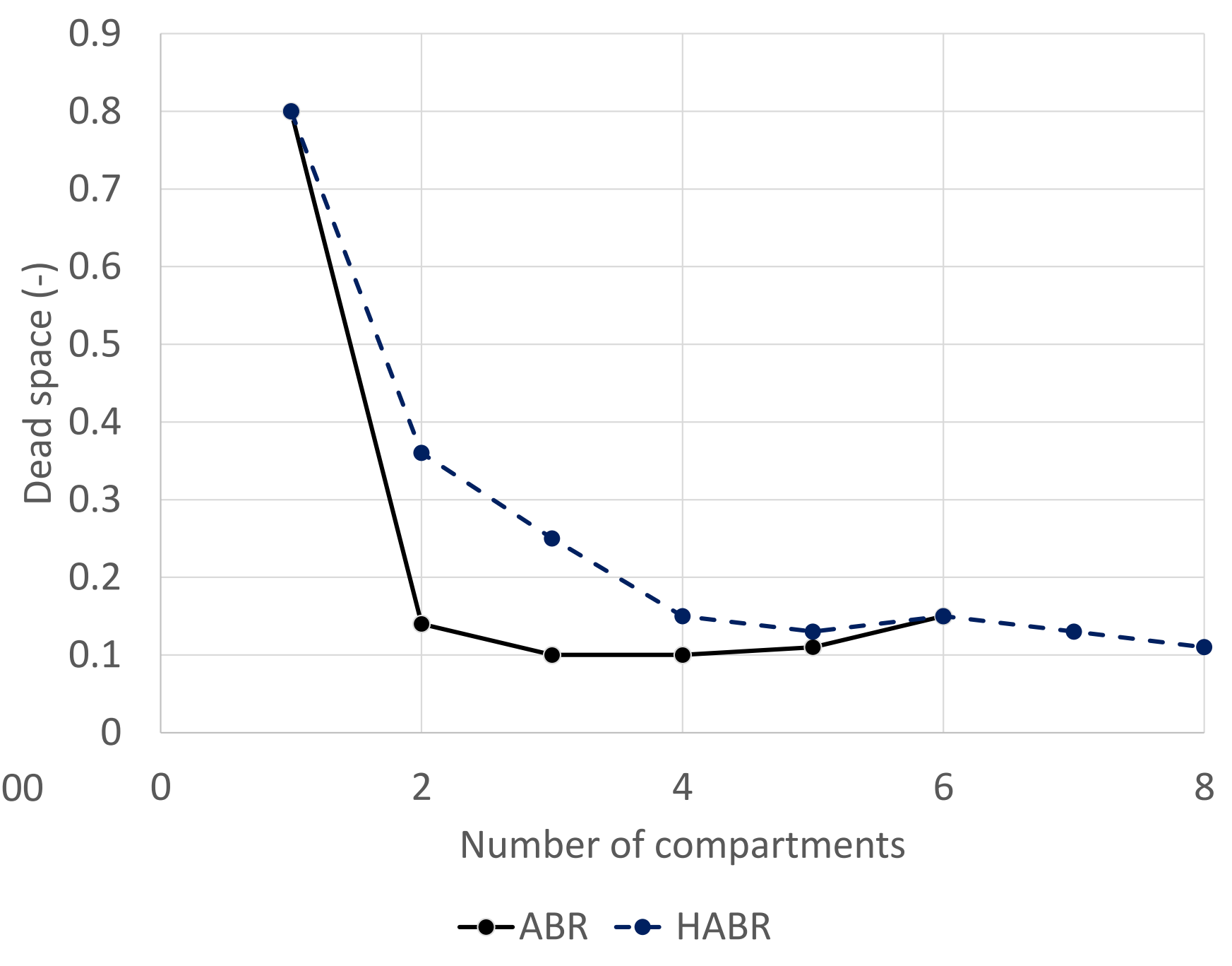


Figure 4. RTD for selected reactors (left)

Figure 5. Dead-space fraction according to number of compartments (right).

Conclusions:

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. Future modeling work to optimize baffle configuration and incorporate biological reactions will focus on this number. Results from this modeling exercise have already been implemented. Two 2 m^3 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

References:

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