The Anaerobic Digestion Pasteurization Latrine: Operation in 3 countries and looking ahead

Aaron Forbis-Stokes[1,2]

Graham Miller[1], Brandon Hunter[1], Patrick O'Meara[3], Felix Kiptoo[3], Marc Deshusses[1]

[1]Duke University, Dept. of Civil & Environmental Engineering, Durham, NC, USA

[2]Triangle Environmental, Durham, NC, USA

[3]Wataalamu Repair & Maintenance, Eldoret, Kenya

Duke University

Triangle Environmental Health Initiative

Wataalamu Repair & Maintenance

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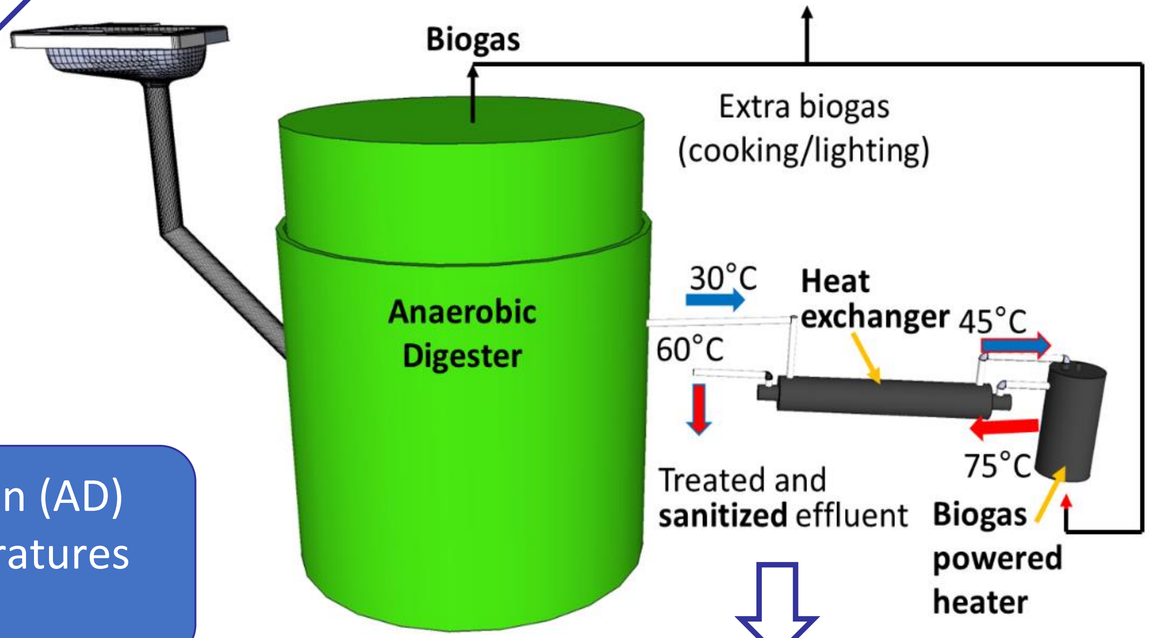
Background

The ADPL: A Self-Sanitizing Toilet

Minimally diluted fresh excreta
Gravity flow, flow pattern controlled by use



Anaerobic digestion (AD) at ambient temperatures
No mixing

Biogas from AD powers effluent pasteurization system

Energy from excreta used to inactivate its own pathogens

Effluent reuse
fertilizer, toilet flush water

Self-contained and simple system…

Target 10-40 users (scalable)…

Peri-urban or rural settings

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History – From lab to 6 units in 3 countries

2012	2013	2014	2015	2016	2017	2018




2012-2018: Lab development & ongoing research

Kenya Field 1

Kenya Field 2

Kenya Field 3

Philippines Prototype

Philippines Field 1

Philippines Field 2

India Field 1

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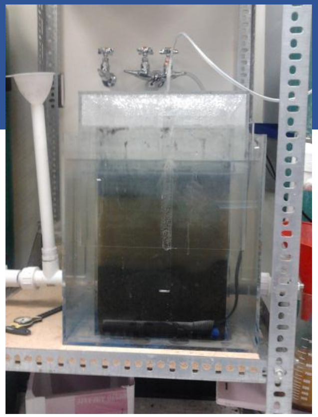
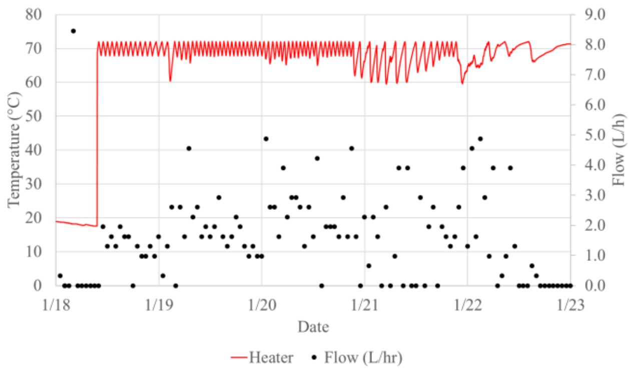
High-level findings through FSM4

- FSM2: Lab studies with simulant excreta
  - Biogas yield of 0.3-0.4 L_{biogas}/g_{COD}
  - 65-75% of biogas produced required for pasteurizer
- FSM3: Initial field studies
  - Digester produces enough gas for pasteurizer
  - Controls required to adjust to daily usage patterns
- FSM4: Continued development
  - Sustained pasteurization with low-cost controls
  - Improved digestion with multi-compartment reactor
  - Lab biological filters improve effluent quality





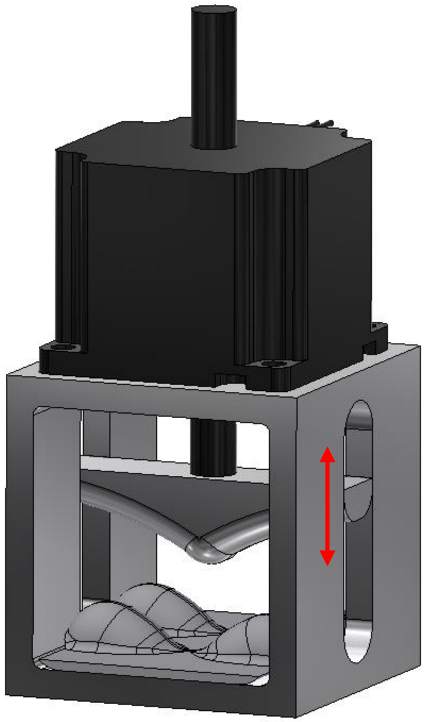
Continued research and development

Pasteurization Improvements

Goal: **Equalize daily flow** for improved efficiency

15% increase in heat-exchange
25% reduction in biogas used

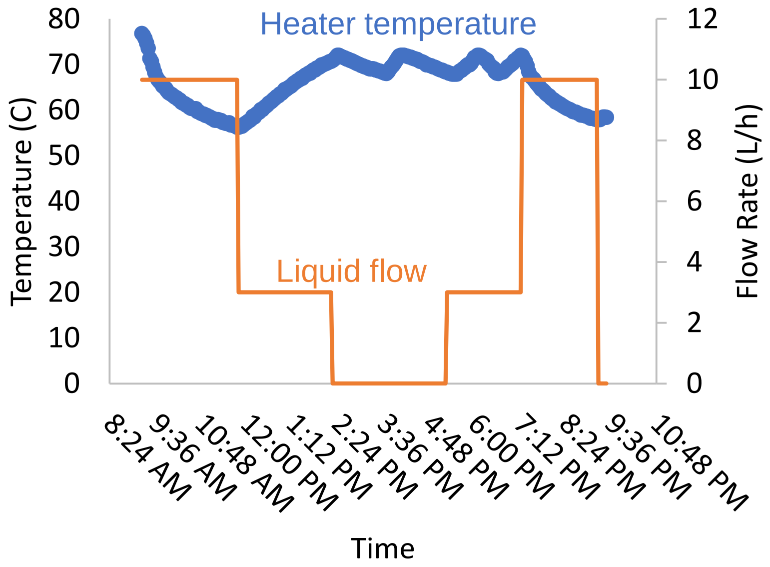
Pinch valve – open/closes flexible tubing digester outlet tubing



Before Improvements

Variable Flow (No pinch valve)

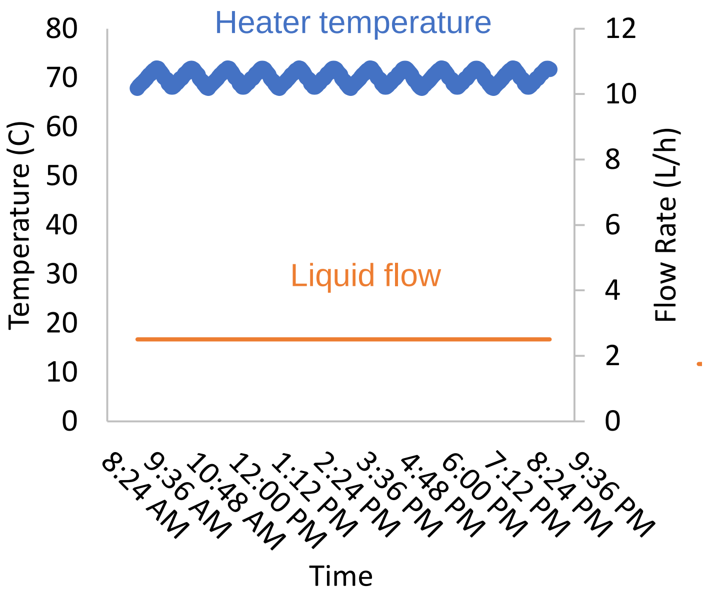
- Heater temp readings >65 °C = 58%



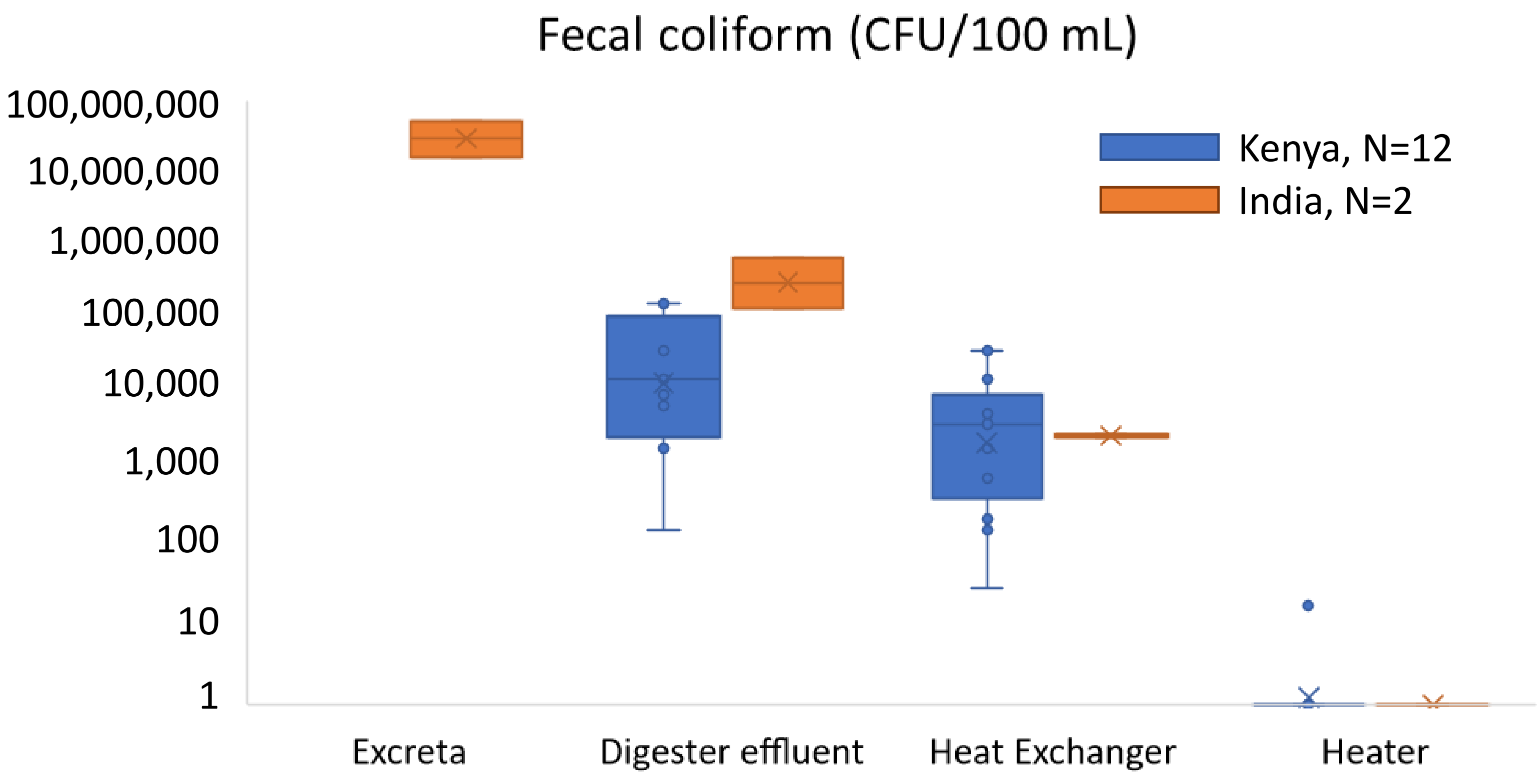
After Improvements

Steady Flow (with pinch valve)

- Heater temp readings >65 °C = 100%



Pathogen Inactivation – Fecal coliform

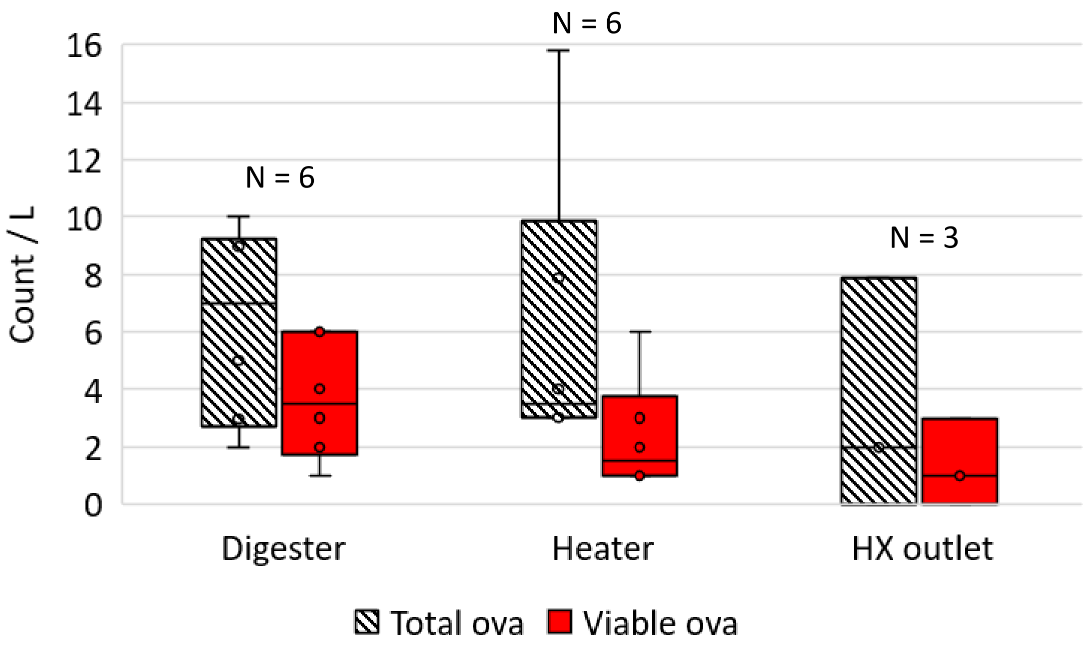


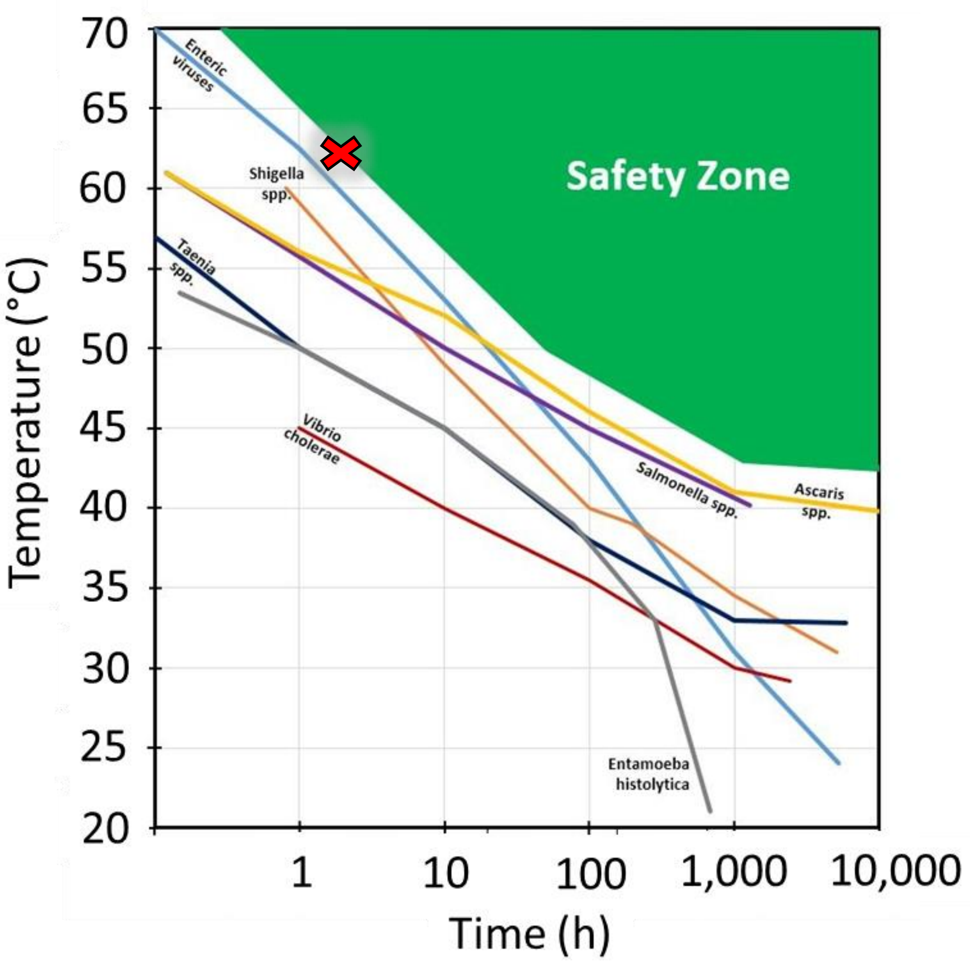
Results from Heater setpoints 68-72 °C & 62-66 °C

Non-detectable FC in all but 1 sample (@ 68-72 °C)

Lower setpoint temperature saves 16% biogas

Pathogen Inactivation - Ascaris





Viable ova in effluent **despite operating in "Safety Zone"** of Feachem et al. chart (right)

Study by Feachem et al, World Bank, 1983
Image by R. Saini, U.Toronto, 2014

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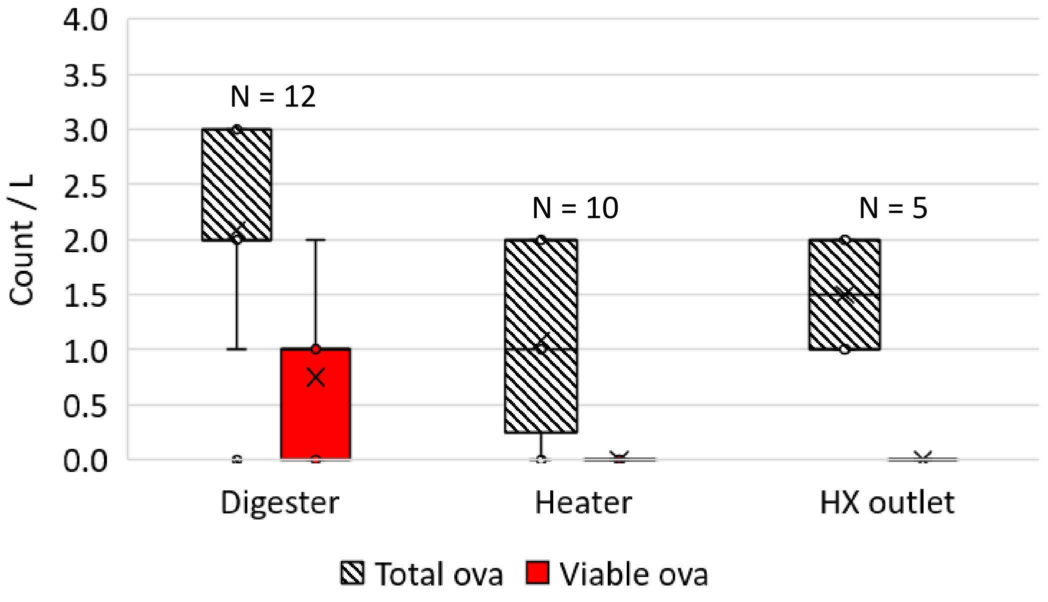
Pathogen Inactivation - Ascaris

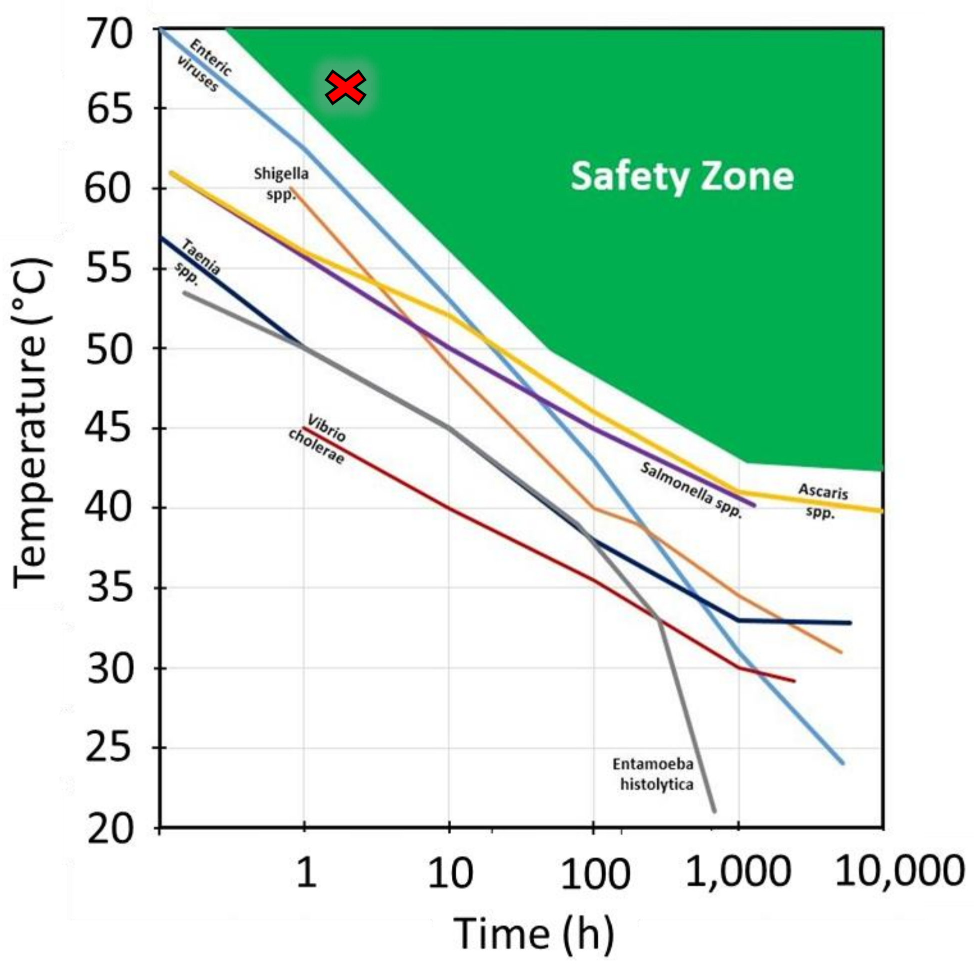


No viable ova in effluent

- Limited log reduction, low counts in digester

Impact of solids on pasteurization?

- Previous studies in water, not sludge



Study by Feachem et al, World Bank, 1983
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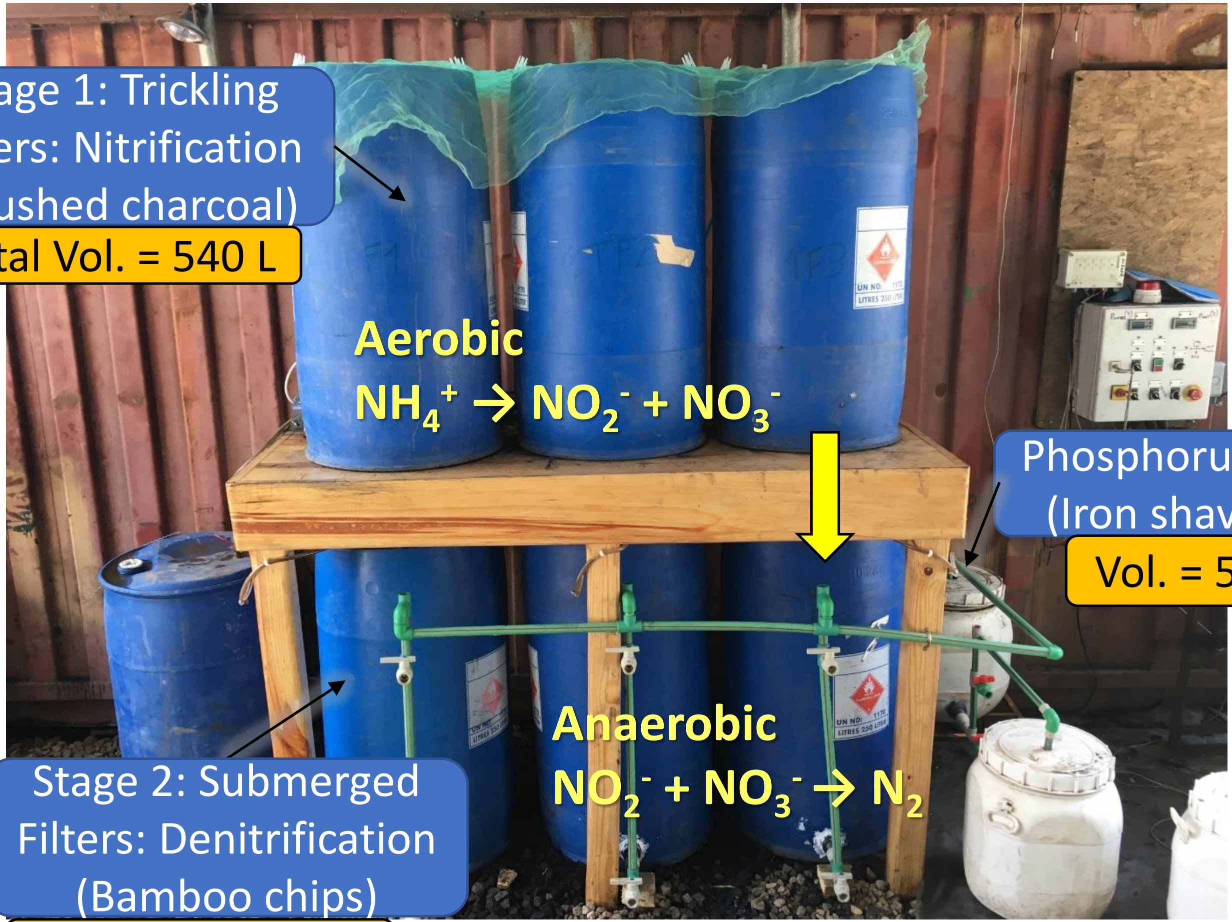
Biological filters for effluent polishing - Madagascar



<u>Phase I (Weeks 1-8)</u>	<u>Phase II (Weeks 9-16)</u>
Flow = 71.3 L / d	*Flow* = 35.6 L / d
Inlet N = 4,700 mg N / L	*Inlet N* = 4,800 mg N / L
Trickling Filter 79% NH_3-N Reduction	*Trickling Filter* 90% NH_3-N Reduction
Submerged Filter 82% NO_2/NO_3-N Removal	*Submerged Filter* 89% NO_2/NO_3-N Removal
Phosphorus Filter 47% Removal	*Phosphorus Filter* 9% Removal

Cumulative findings

Lessons Learned – Anaerobic Digester

Biogas:
0.25-0.42 L_{gas}/g_{COD}
25-42 L_{gas} / p / d

Inlet:
~42,500 mg COD / L
(1 L flush)
0.6-1.8 $kg_{COD}/m^3/d$

Outlet:
1,900-7,400 mg COD / L
70-85% COD removal

Desluding:
Kenya – 60% removed 2x in 6 years

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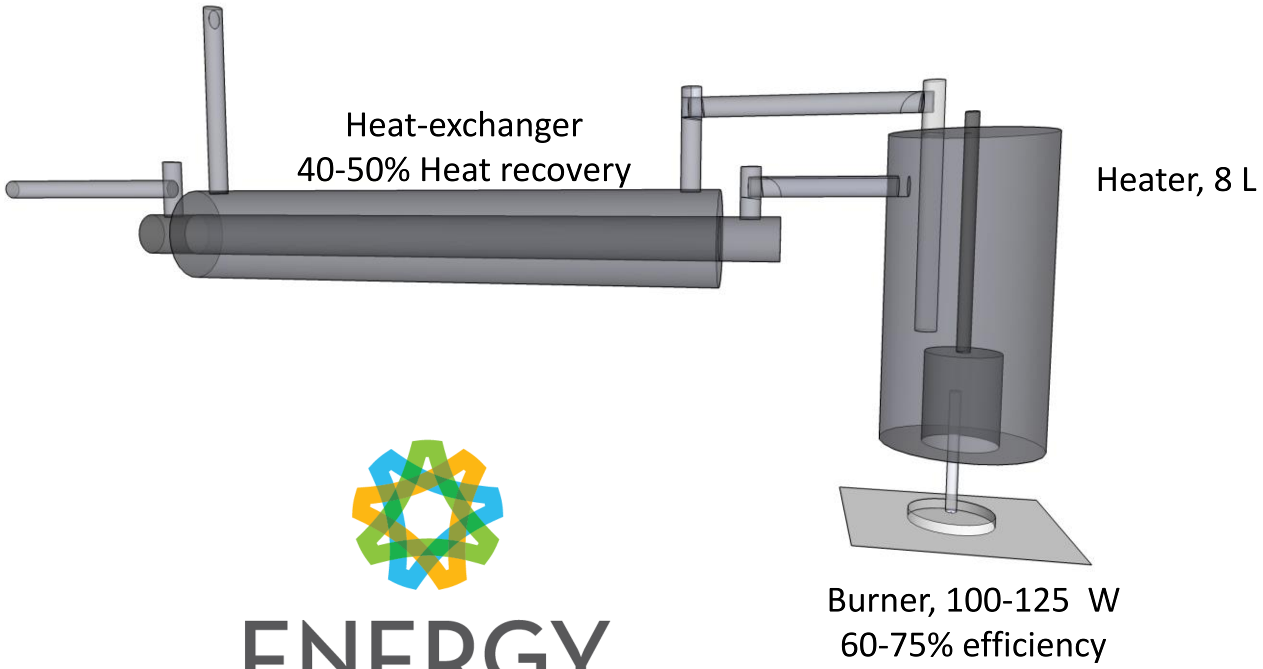
Lessons Learned - Pasteurization

- Max 3 L water per person / energy balance
- >65 °C & >1 hr for FC and Ascaris inactivation
- Must minimize heat loss to environment
  - 8 L oversized, will reduce to save losses
- Maximize burner efficiency – air:gas mixture



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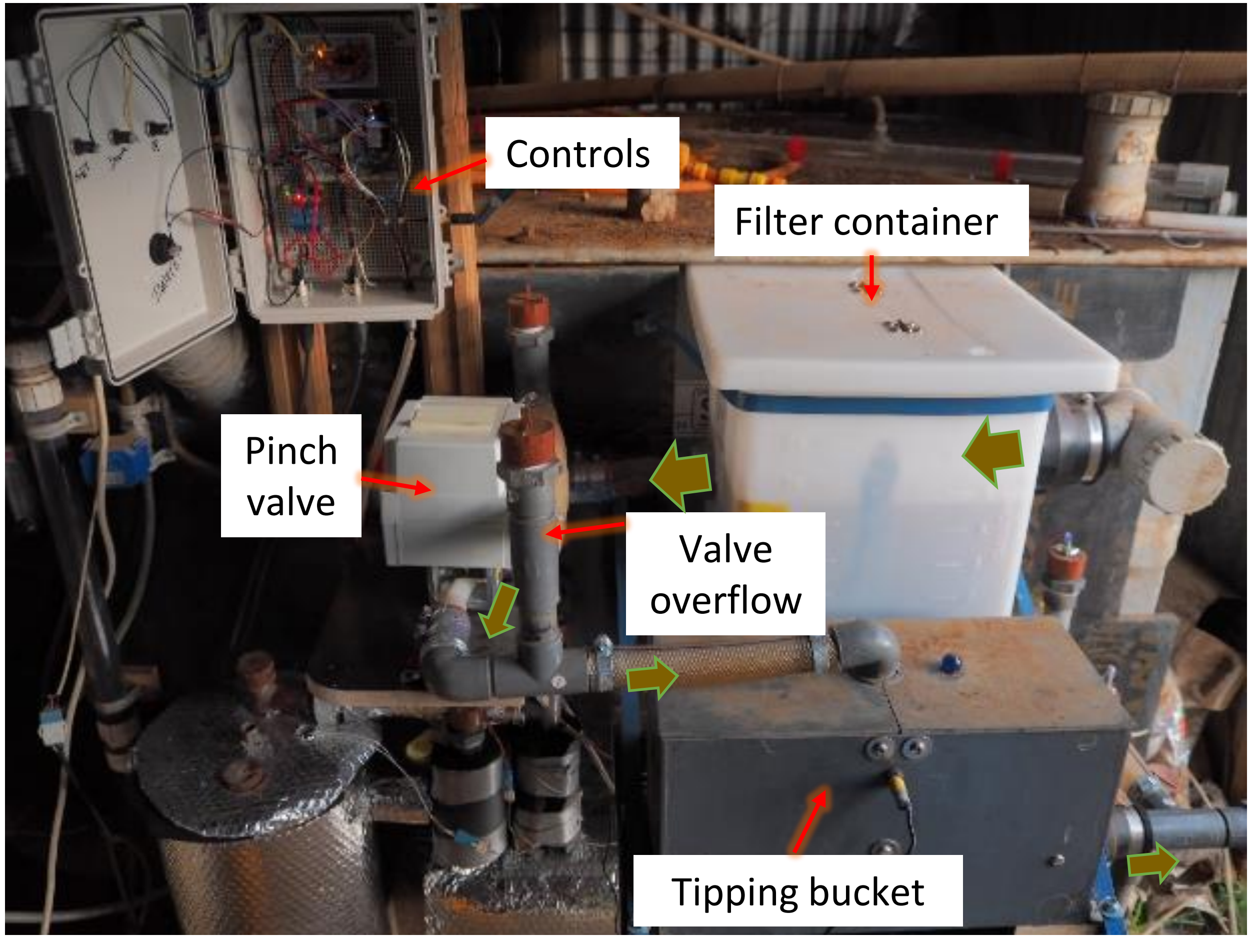
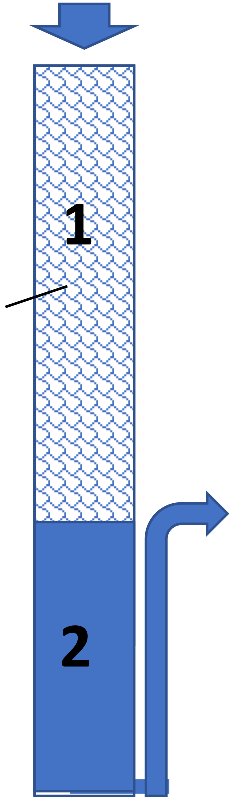
Lessons learned - Controls

- Necessary for efficiency
    - Flow equalization
    - Match heat demand to heat use
- Remote data access and monitoring
- Low cost (<$200) and added robustness



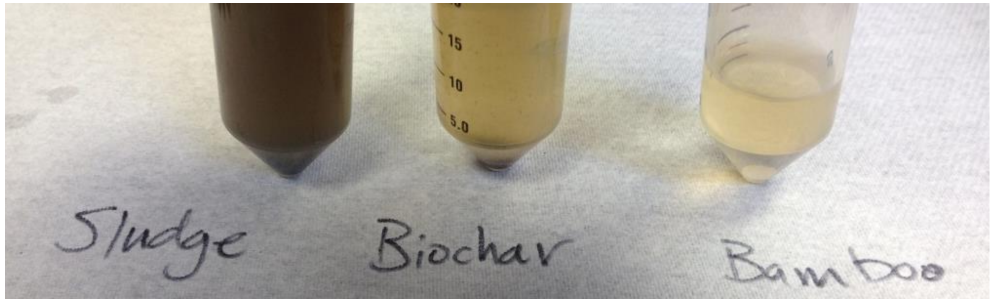
Lessons learned – Biological filtration



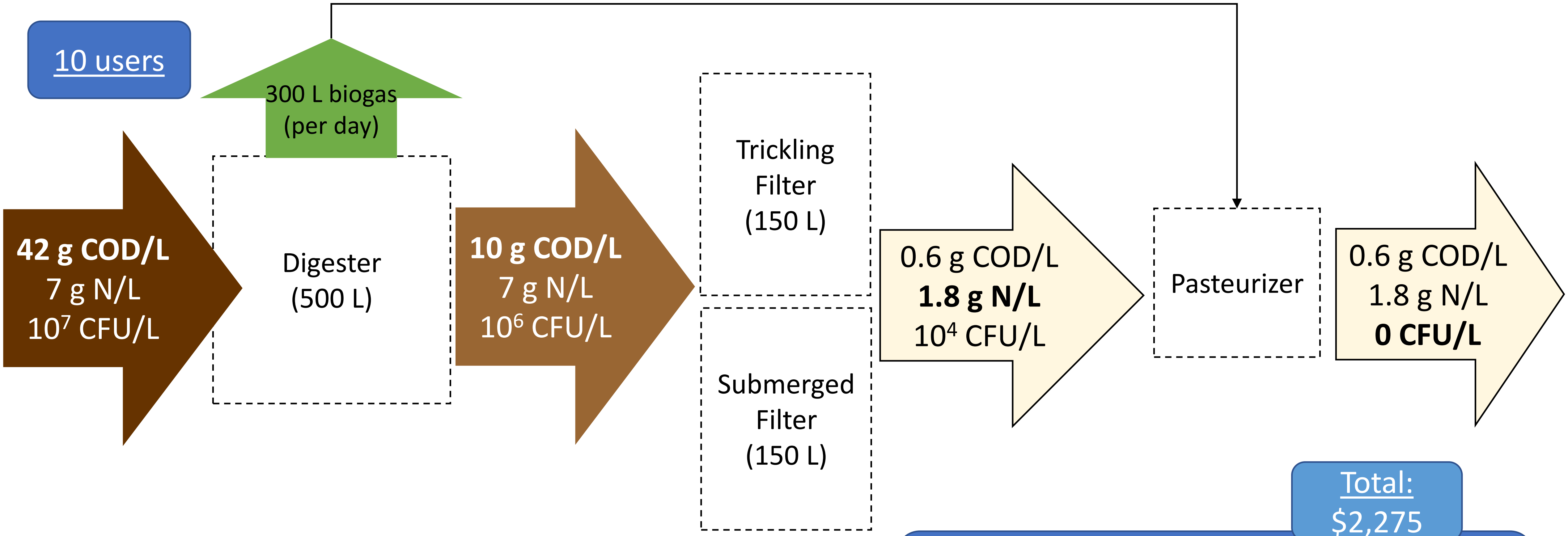
Nitrifying Trickling Filters:
0.10-0.25 kg N / m^3 / d removal rate
79-90% NH_3-N removal

Denitrifying Submerged Filters:
0.03-0.16 kg N / m^3 / d removal rate
66-89% NO_2/NO_3-N removal

Combined:
69-82% COD removal
77-99% Turbidity removal
49-63% Total N removal
41-89% Total P removal



Bringing it all together



Total: $2,275

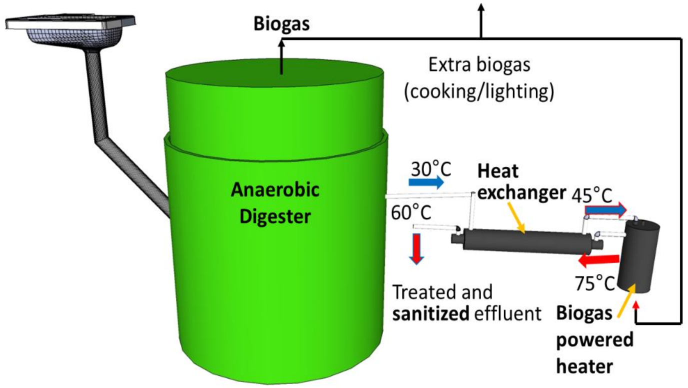
System costs:

- Structure = $500
- Reactors = $1450
- Pasteurization = $120
- Controls = $205

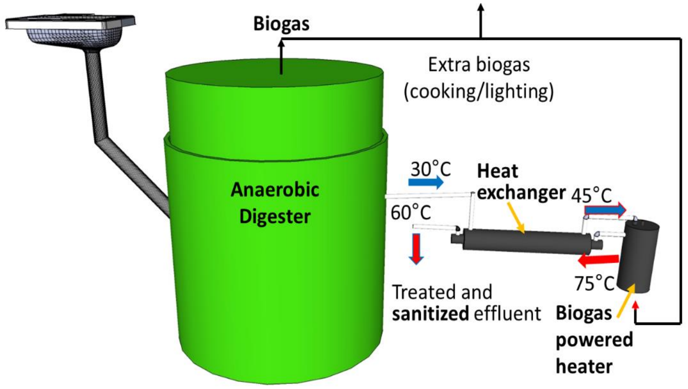
Performance compared to ISO standards

Parameter	ISO 30500	ADPL
COD (mg/L)	150	✗
TSS (mg/L)	30	✗
E. coli (CFU/L)	100	✓✓
Ascaris suum (#/L)	1	✓
Total Nitrogen (% load reduction)	70	✓
Total Phosphorus (% load reduction)	80	✓
pH	6-9	✓✓
Odor		✓

Next steps: Research project → product development



Next steps: Research project → product development



Single-family modular sanitation product

ANA
BRINGING SANITATION TO THE WORLD

Easily manufactured

Cost-competitive

Effective off-grid treatment

Contact Information:

Duke UNIVERSITY

Prof. Marc Deshusses
marc.deshusses@duke.edu
Professor of Civil & Environmental Engineering
www.sanitation.pratt.duke.edu

TRIANGLE ENVIRONMENTAL HEALTH INITIATIVE

Aaron Forbis-Stokes, Ph.D.
aaron@triangle-environmental.com
Sanitation Technology Consultant
www.triangle-environmental.com

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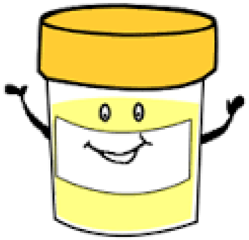
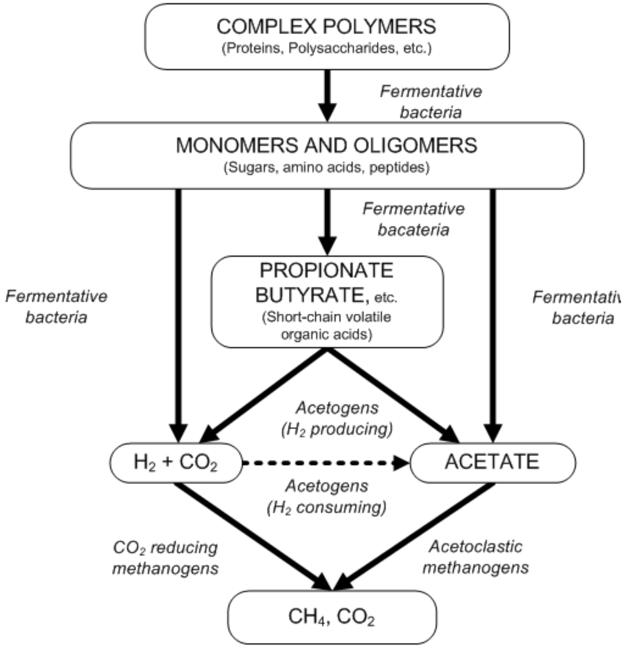
Appendix

Process Fundamentals

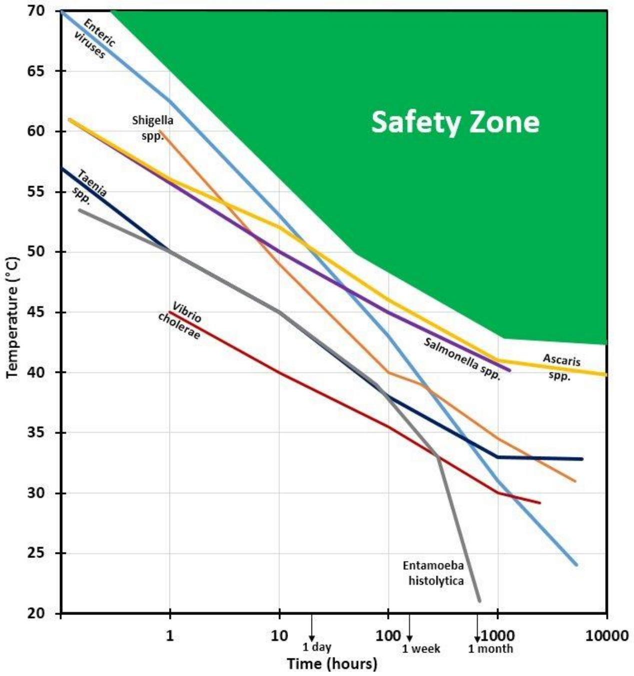
Feedstock



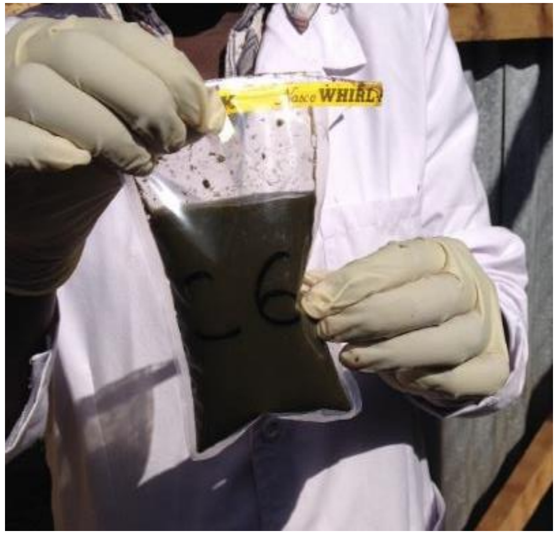
Anaerobic Digestion

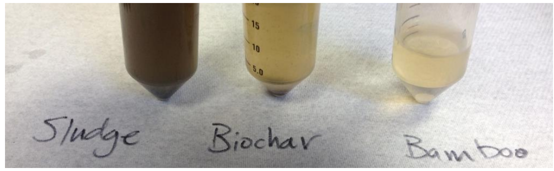


Pasteurization

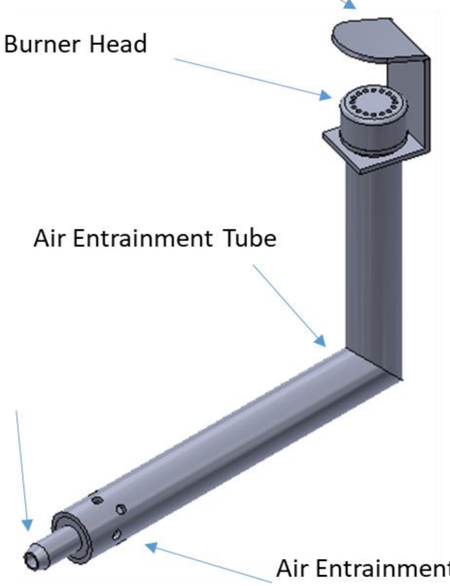


Output





CSU Key findings

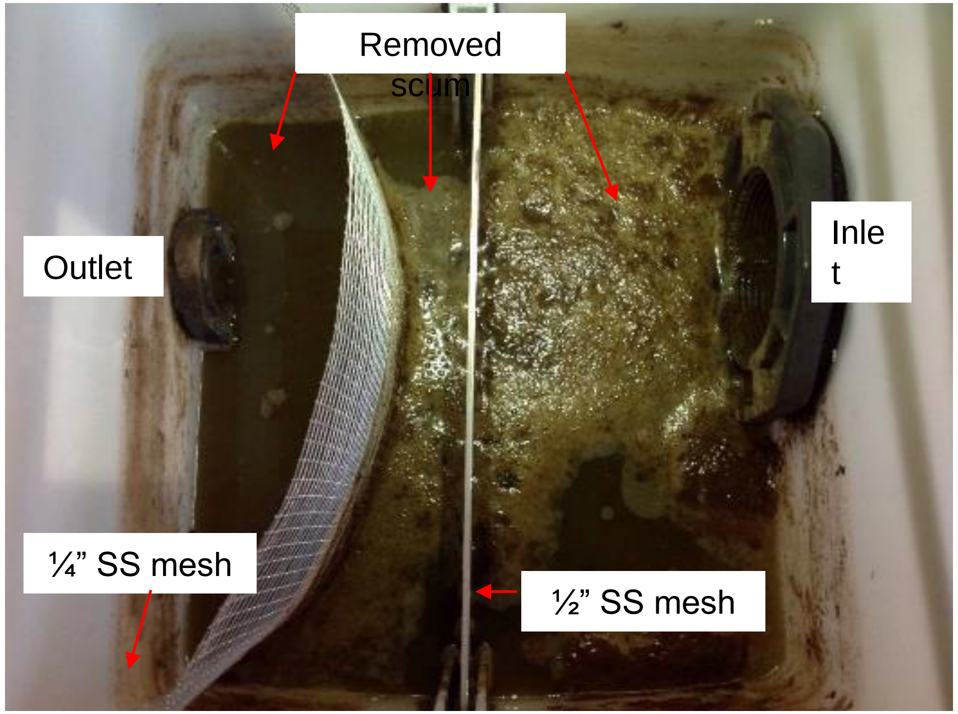


Burner findings:

- Maximum Firepower (@ 350 $\frac{cm^3}{min}$ Flowrate): 125.23 W
- Minimum Required Heating of Effluent: 69.14 W
- Minimum Required Heat Transfer Efficiency: 55%
- At a 7kg water-weight heater (@ 400 $\frac{cm^3}{min}$ Flowrate): 142.86 W
  - **Standard Bunsen Burner: 115 W**
    - 80% efficiency
  - **P2 Burner @ 3" Cavity Placement: 142W**
    - 99% efficiency
  - **19% Boost in Efficiency.**
- Turbulator findings:
- turbulator provided an additional boost in power up to a 20.6% increase in measured heat gain
- too many turns caused too much of a pressure drop in the exhaust tube which would cause the flame to go out

Kenya System Upgrades: Effluent Filter

- Prevents unexpected large particles (hair extensions, wiping materials, etc.) from clogging downstream piping
- Brush allows for screen cleaning
- Allows additional settling of smaller suspended particles
- Translucent material provides visual display of available head upstream of pinch valve
- Long-term operation will be monitored for screen clogging and solids deposition and serve to fine tune maintenance requirements and reduced heating system down-time



Previous Ascaris studies