A unit operations approach for rapid disinfection of human waste based on drying/smoldering of solid and sand filtration/uv disinfection of liquid waste

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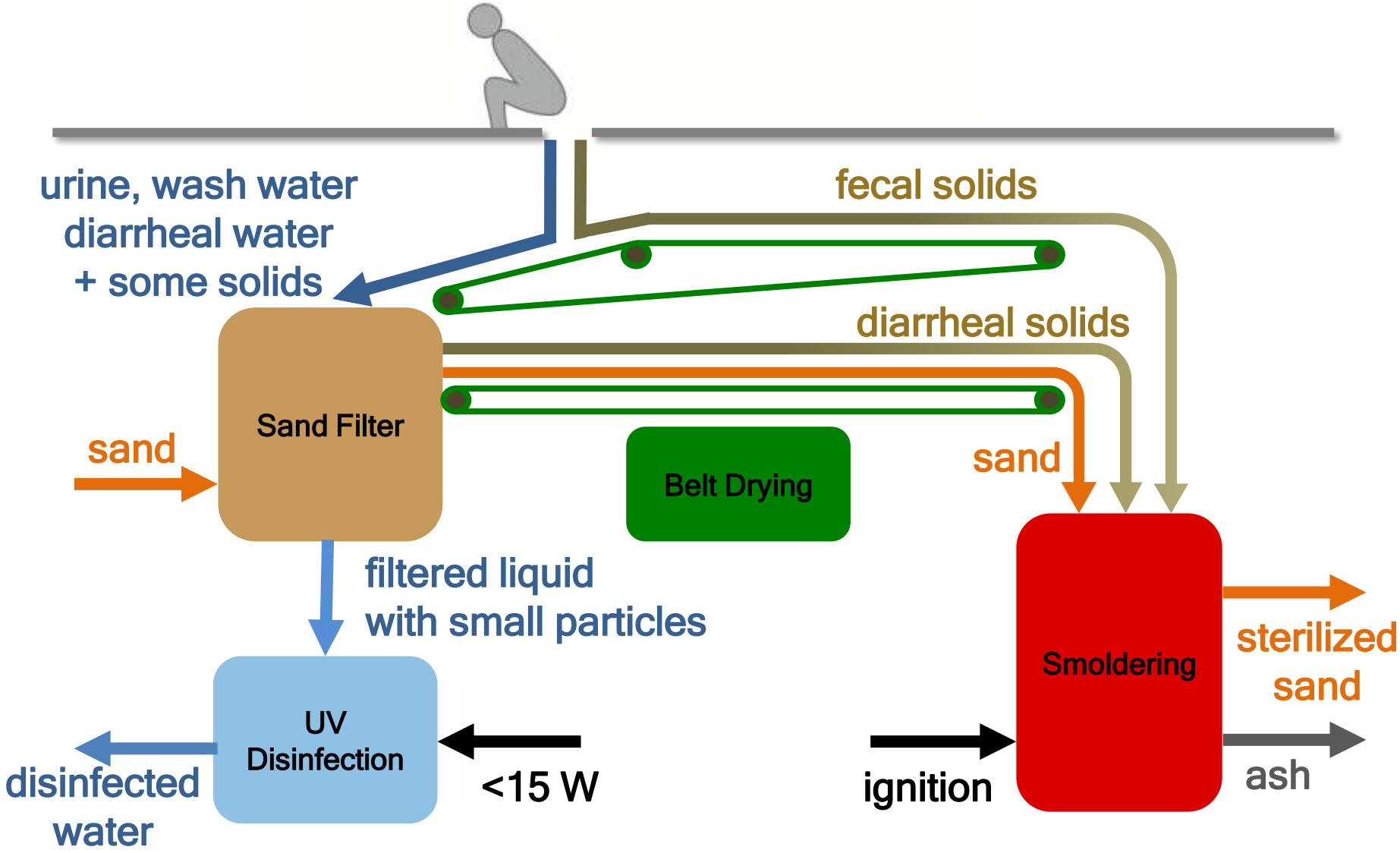
Design Objectives/Approach

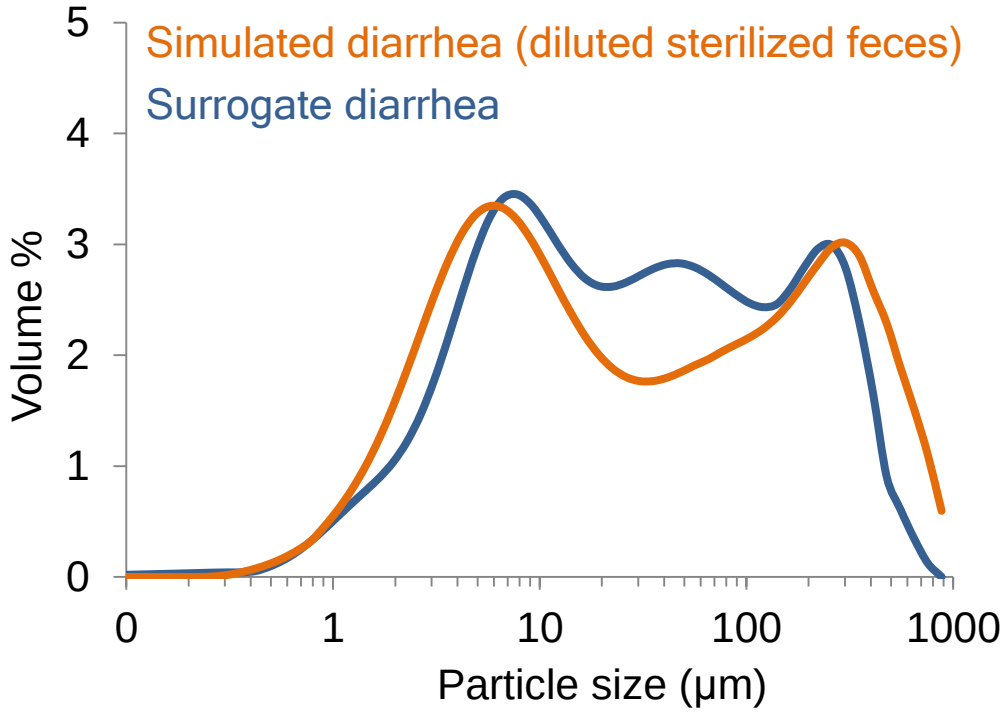
- RTTC: $0.05 per person per day; off grid (water, power, sewerage); rapid disinfection
- Contextually appropriate
  - User practices
  - Materials
  - Operation
  - Maintenance

Process Overview



Surrogate Feces & Diarrhea

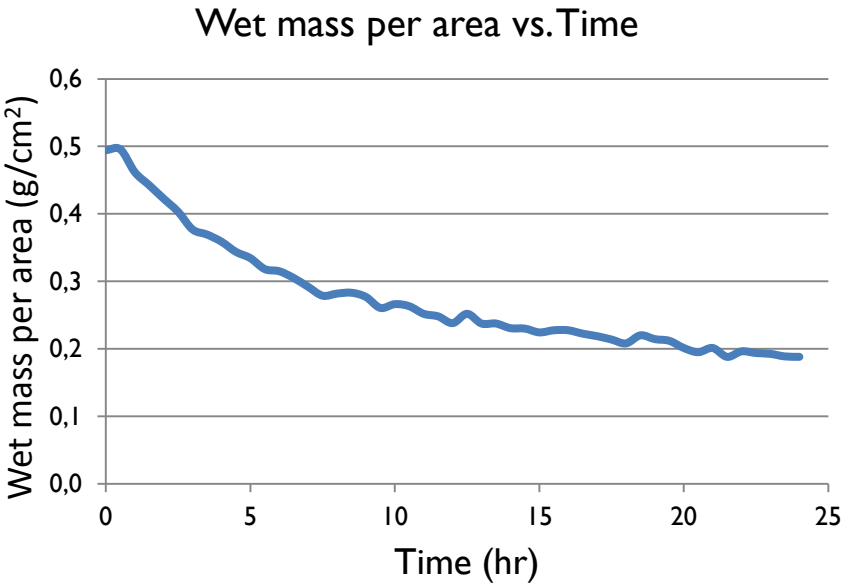
Ingredients	Representing	% Weight
Polyethylene glycol	Water-holding	20
Baker's yeast	Bacterial debris	10
Peanut oil	Fat	5
Miso paste	Proteins	30
Cellulose	Dietary fiber	15
Psyllium powder	Dietary fiber	15
Inorganic	Minerals	5

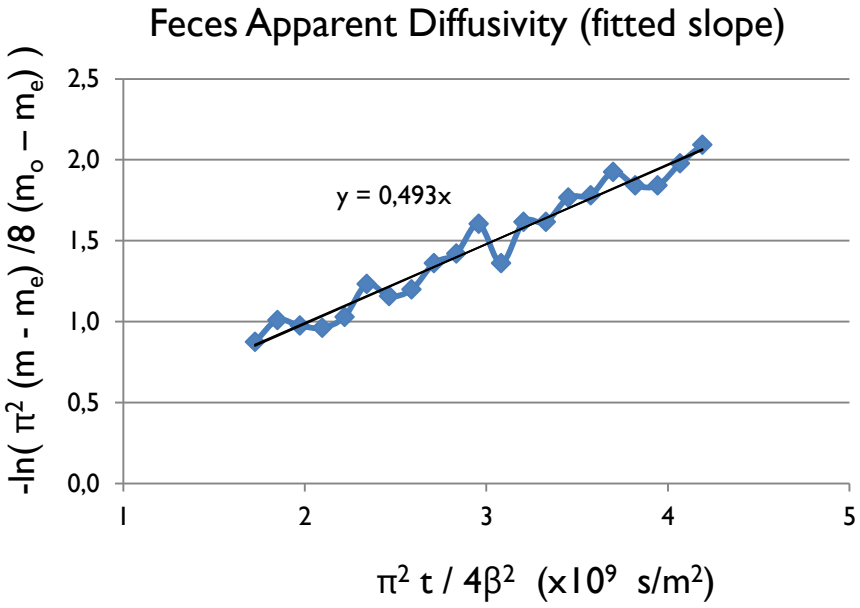


Ingredients	% Weight
Yeast	20
Ground almond	70
Cellulose	10

Literature: feces energy content: 21.5 kJ/g dry feces, range: 17.6 - 25.1 kJ/g dry feces

Drying Kinetics



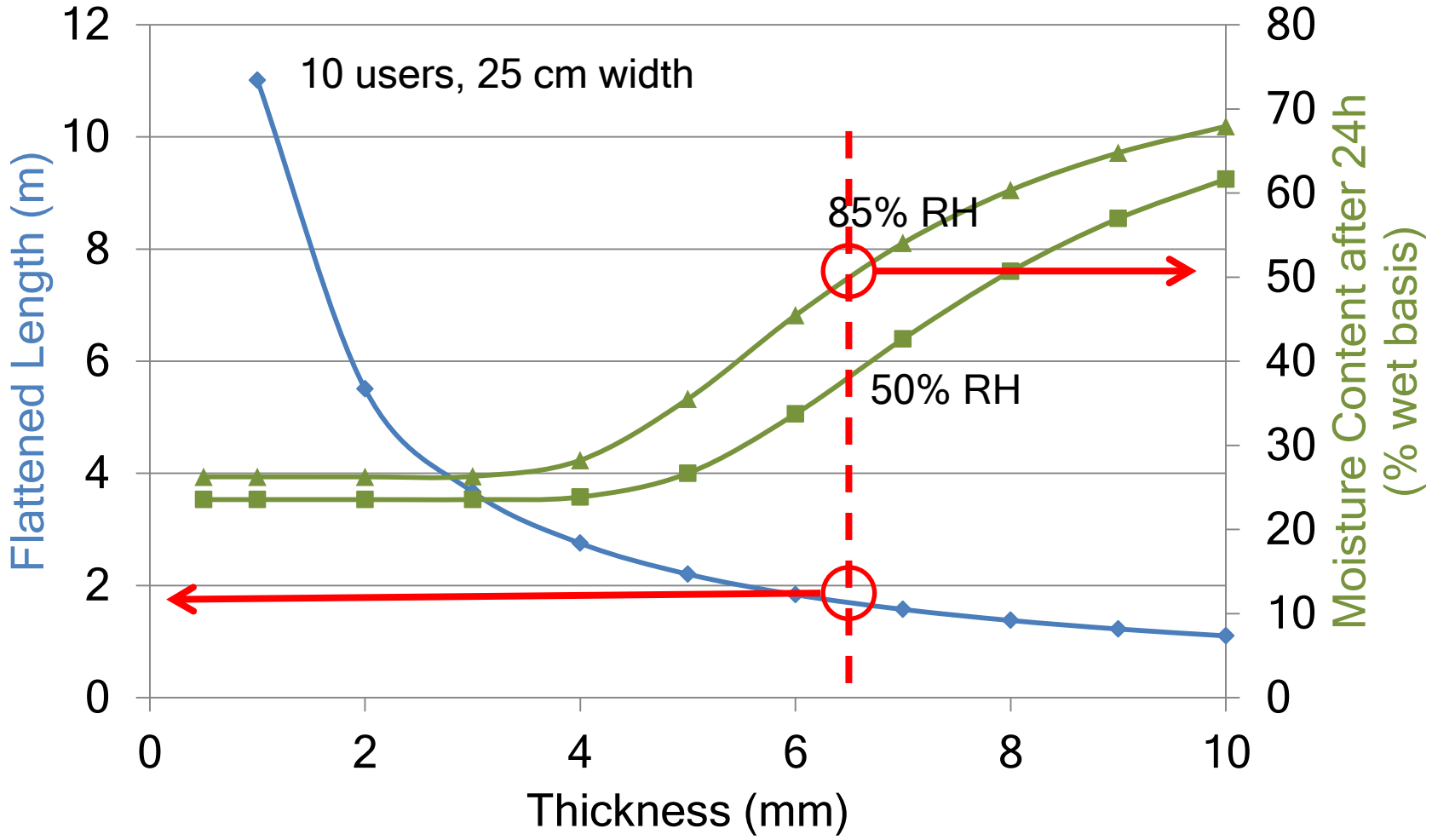


Fick's law solution:

$$D_{app} = \frac{-4\beta^2}{\pi^2 t} \ln\left[\frac{8}{\pi^2}\left(\frac{m(t) - m_e}{m_o - m_e}\right)\right]$$

m(t): wet mass at time (t)
m_o: initial wet mass,
m_e: equilibrium wet mass
D_{app}: apparent diffusivity → 4.93e-10 m^2/s

Drying to required moisture content in 24 hours is feasible with reasonable belt length.



Feces flattening and splitting to decrease thickness

Pressing after gravity drain

Flattened feces splitting on top & bottom belt

Sand Filter

Smoldering Chamber

Smoldering: surface combustion of solid fuel

- Glowing red solids → no flames
- Self-sustaining (with continuous fuel)
- Requires oxygen/fuel surface contact
  - permeability of fuel bed important

→ Key idea: mixing feces with sand to enhance permeability

Just before ignition

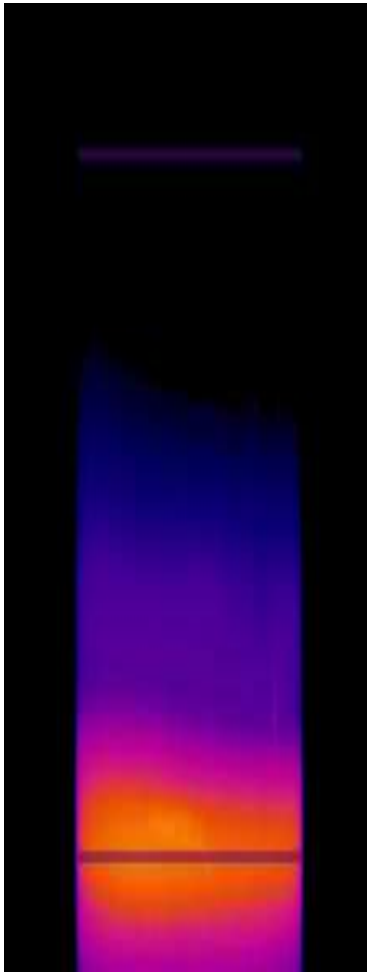
10 minutes

20 minutes

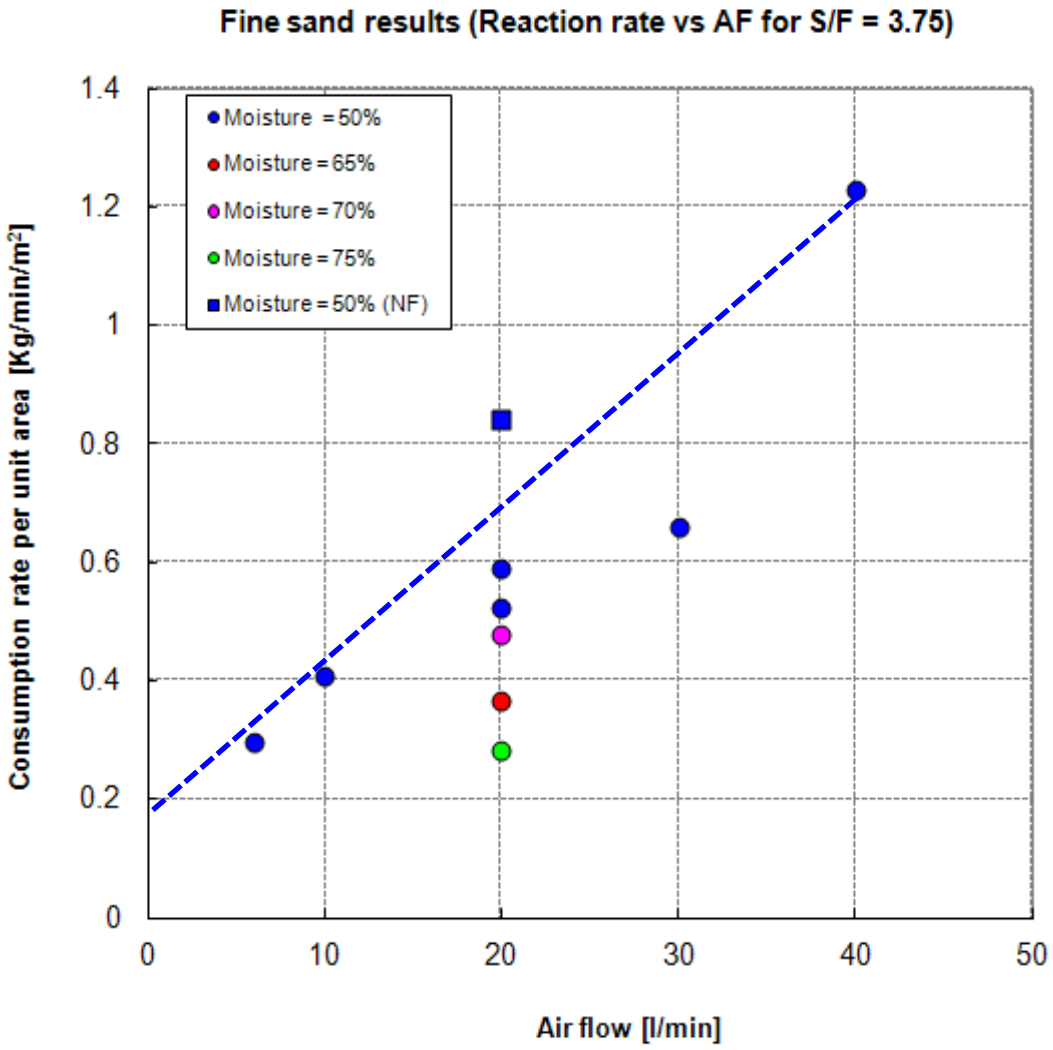
Reaction stops

Smoldering for feces destruction feasible

- Self-sustaining smoldering seen over wide conditions
  - Key: air permeability vs fuel content balance
- Permeability enhanced by:
  - Drier feces (< 0.5 moisture content ideal)
  - Higher sand/feces ratio (optimum ≈ 3.75)
  - Larger sand particles
- Variables can mutually compensate:
  - No sand: need drier feces, higher air flow
  - Higher moisture content: need higher air flow
- Peak T: 600 to 800°C
  - complete feces destruction; sterile sand remaining
- Other considerations:
  - Smoke and odor capture
  - Non-electrical ignition
  - Natural convection



Feces destruction rate: controllable by air flow

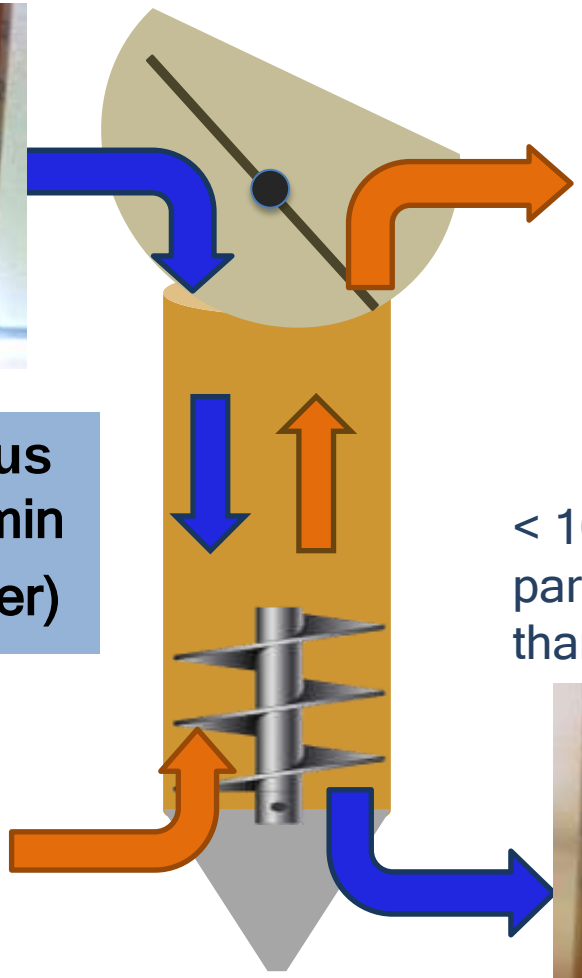


Sample design calculation:

- 3 kg/day (~10 person scale)
- If consumption rate = 0.2 kg/min/m^2
- Then: D = 11.5 cm

sand filtration: rapid bolus drainage and effective removal of particles > 8 µm

3300 mg/L particles; 2200 mg/L larger than 8 µm



Contaminated sand removal by skimmer – onto drying belt to be smoldered

Diarrheal bolus drains in < 5 min (25 cm diameter)

< 10 mg/L particles larger than 8 µm

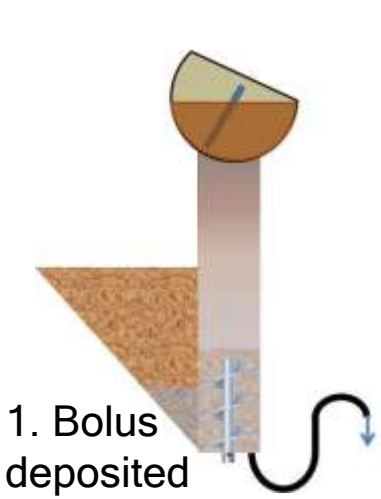
UVT < 2%

To UV reactor

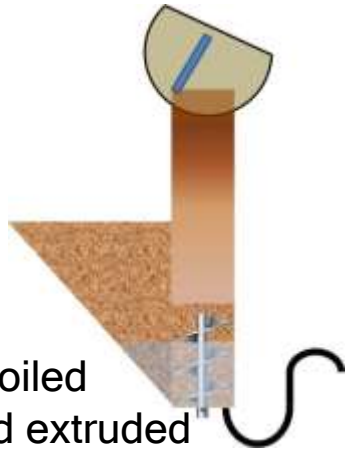
Clean sand from hopper, conveyed by auger

Stages of Sand Filtration

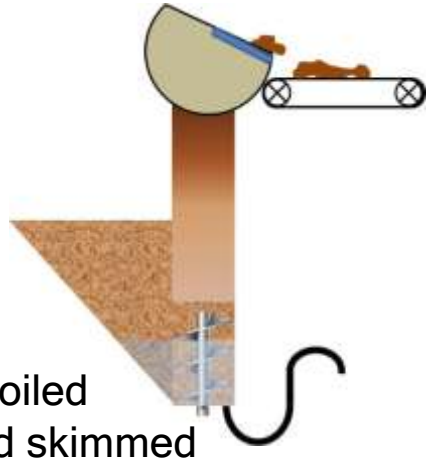
Sand extrusion



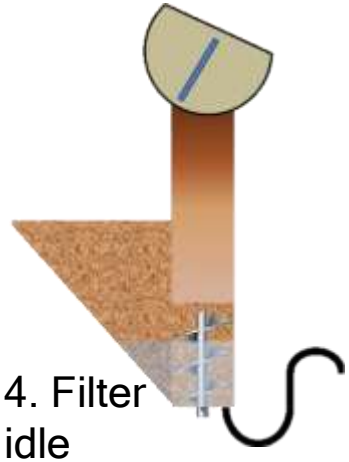
1. Bolus deposited



2. Soiled sand extruded



3. Soiled sand skimmed

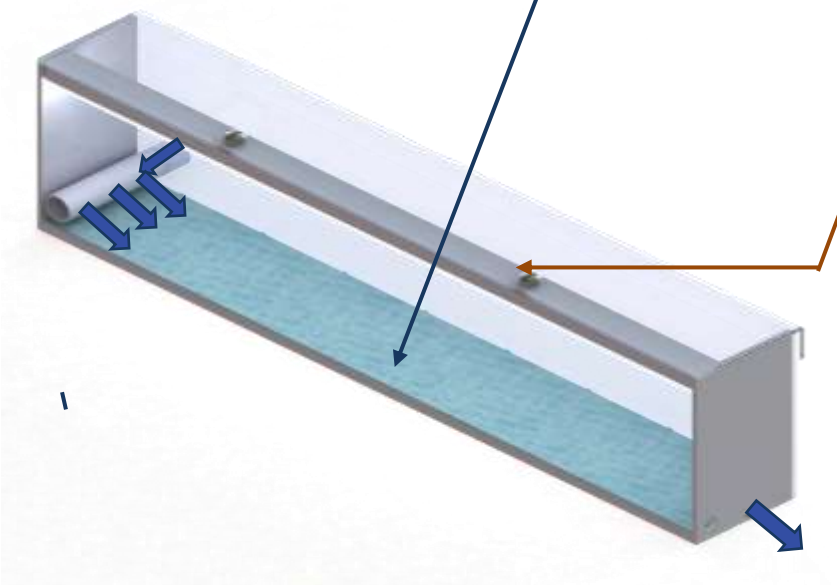


4. Filter idle

UV Disinfection

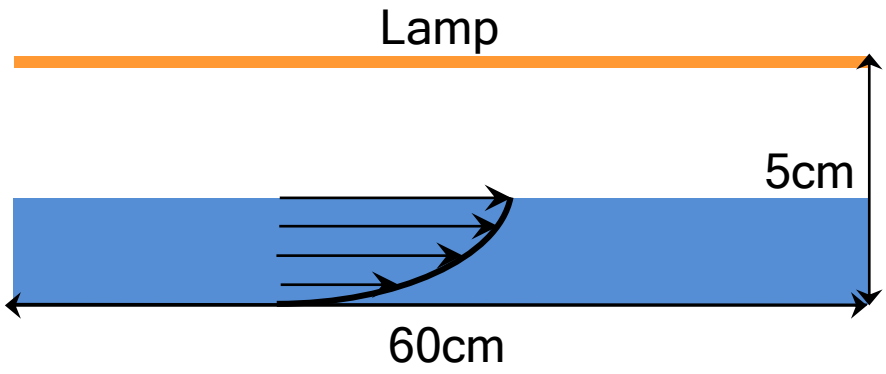
1. UV Dose ≥25mJ/cm^2

- Thin film liquid flow
- Low velocity

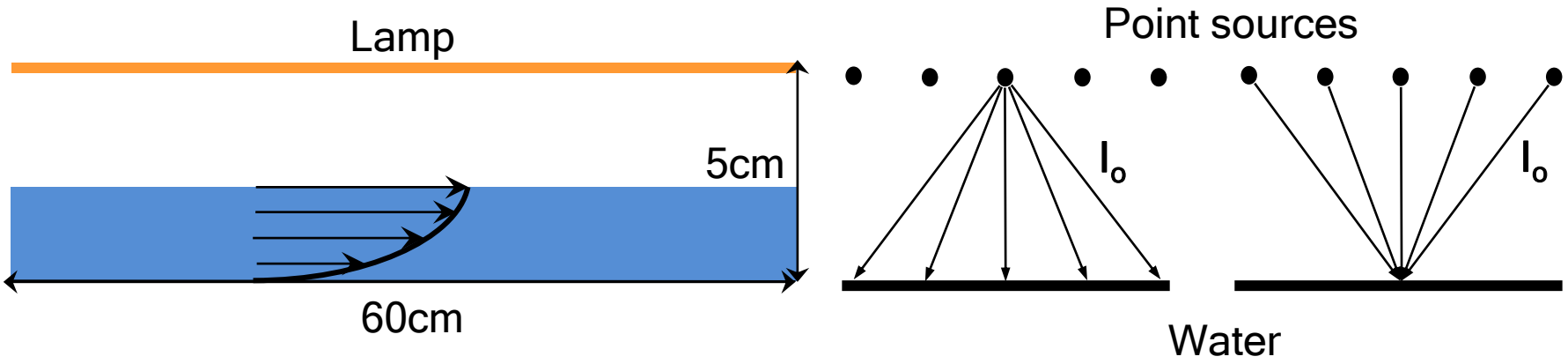


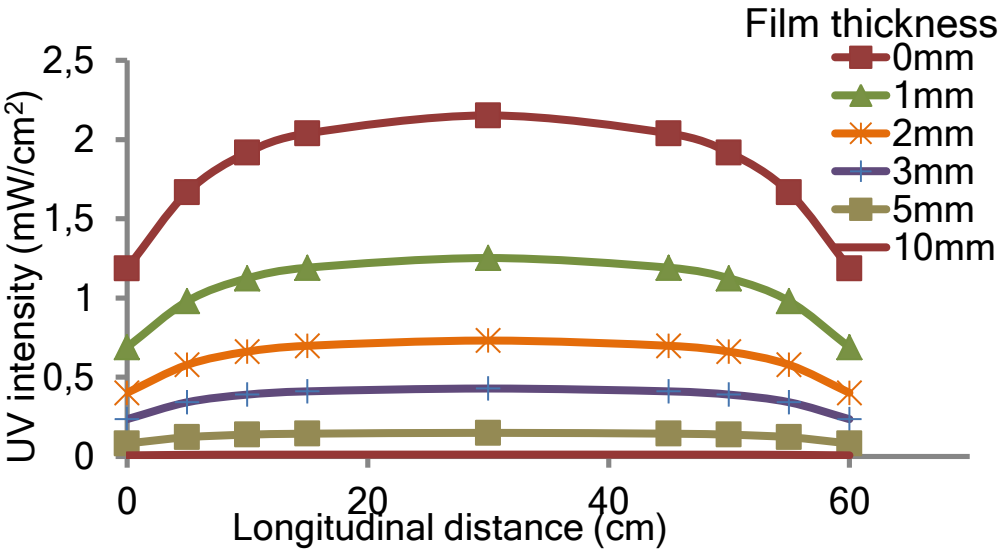
2. Minimize lamp sleeve fouling and reactor maintenance

- Suspended lamp



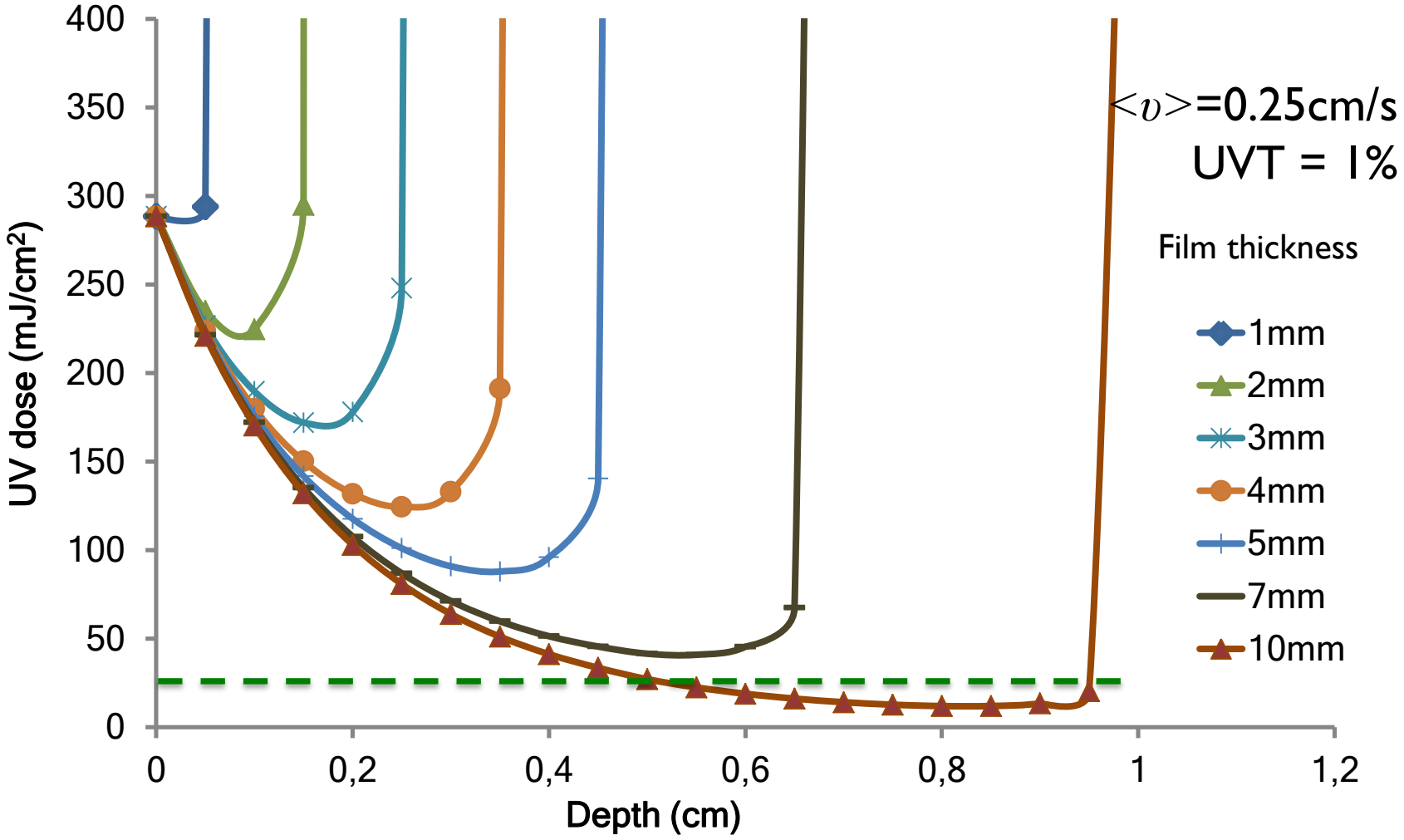
Velocity Profile and UV Intensity Modeling



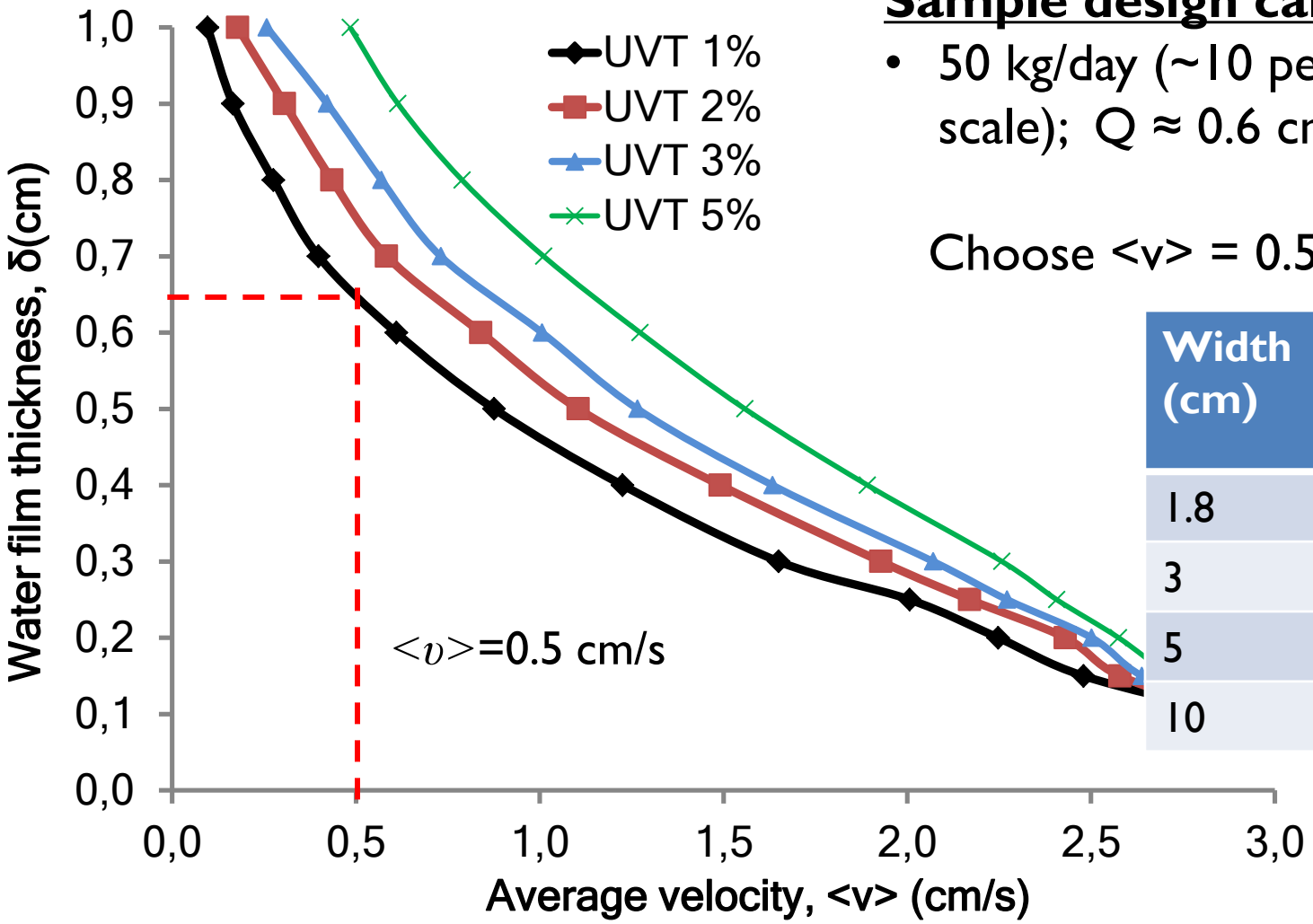


15 W lamp
30% efficiency
UVT = 1%

UV Dose Distribution



15W UV lamp easily achieves 2.5 mJ/cm²



Sample design calculation:

- 50 kg/day (~10 person scale); Q ≈ 0.6 cm³/s

Choose <v> = 0.5 cm/s

Width (cm)	film thickness (cm)
1.8	0.64
3	0.29
5	0.23
10	0.12

Proof of concept for each module

- Feces drying to required moisture content in 24 hours is feasible with reasonable belt length.
- Sustainable smoldering demonstrated over wide range of variables, and at controllable smoldering rates
- Sand filtration effectively removes particles larger than 8 µm with reasonable bolus drainage times
- 15W UV lamp should deliver enough UV dose to destroy remaining pathogens in filtrate

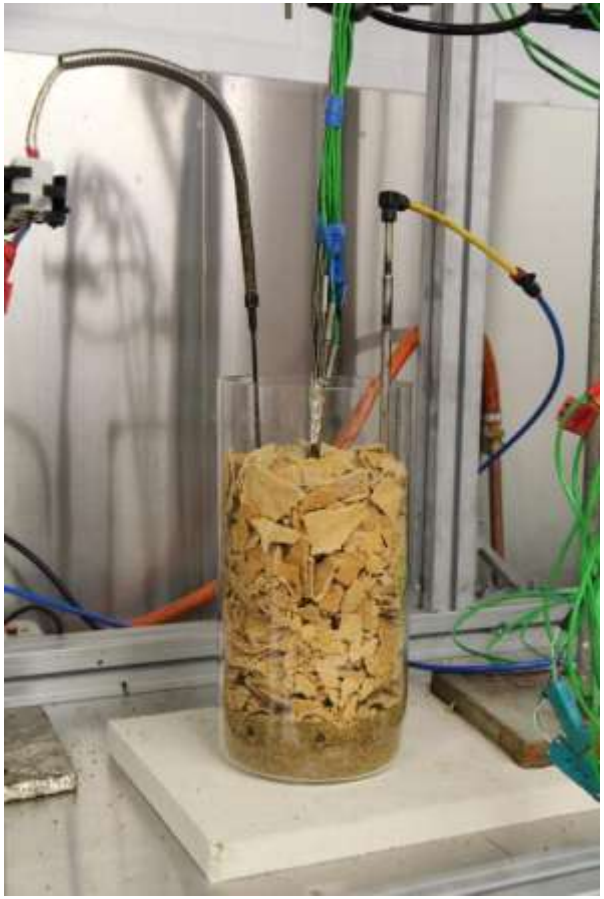
Meeting RTTC Criteria

- Rapid disinfection:
  - Solids: < 24 hours drying + hold up time in smoldering reactor
  - Liquids: fast
- Energy budget:
  - 15 W (UV lamp + possible 1.5 W fan)
  - Fuel for smoldering ignition (≤ 2 MJ; ≈ 1 person fecal output per day)
- Cost estimate:
  - Capital: $0.036 per person per day (10 person scale)
    - Prototype components local retail cost ≈ $1,350.
  - Inexpensive consumables (sand, fuel for ignition)

Understanding the Users

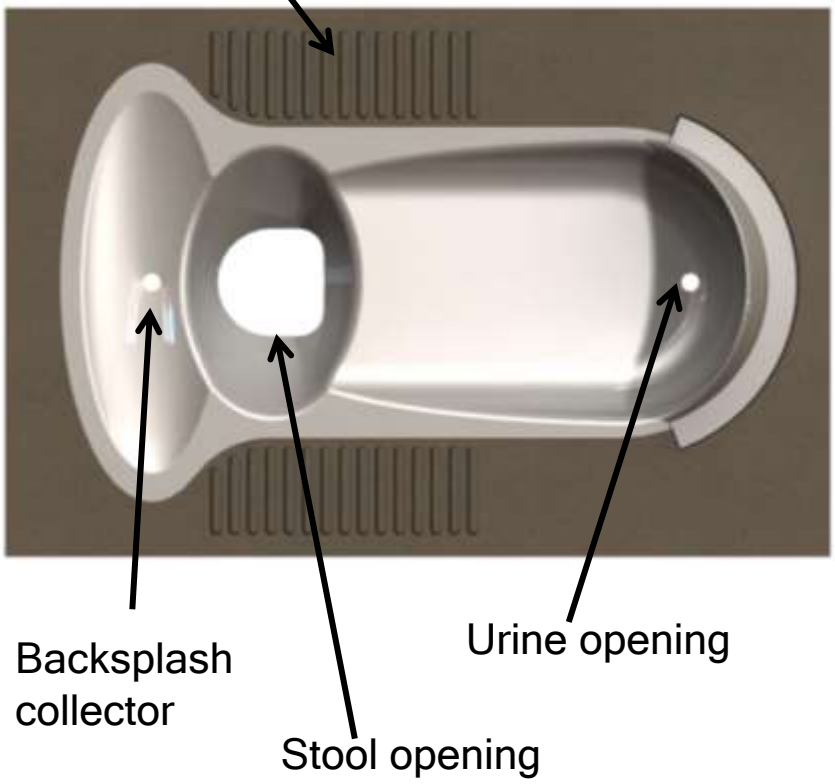
understanding the local capacity

Need to avoid this:



"Simplicity ain't simple!"

User Interface



Future Plans

- Integrate; simplify mechanical operation
- Capture/make use of heat from smoldering
- Possibly capture clean water
- Simplify user touch points
- Contain odor
- Contain smoldering emissions