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# Odors in Fecal Sludge Management: Sources, Impacts, and Control using Adsorption and Biofiltration

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## BACKGROUND

Malodor nuisance is a major risk factor in fecal sludge management (FSM). Filthy and smelly latrines can motivate people to practice open defecation. The challenges of mitigating odor nuisances are significant, owing to the highly odorous nature of fecal matter, the multiple ways that odorants can be released to the atmosphere, and the very low concentrations at which these odorants cause nuisance. Yet, very little is known about the odor emissions and odor management practices in FSM.

The overall objectives of this project are to:

- Conduct a broad survey to define the landscape of odor nuisance and control in FSM
- To determine the applicability of 1) adsorption and 2) biofiltration to control fecal odors using biochars and other low-costs materials.

## SURVEY OF MALODOR LANDSCAPE

- A broad survey (20-50 questions/10-20 minutes) was developed to assess locations, causes, intensity and impacts of malodor along the chain of fecal sludge management.
- The survey was administered using Qualtrics through direct emailing, posted on SuSanA, and emailed to FSM3 participants (take a card if you wish to participate).

### Highlights of Preliminary Results

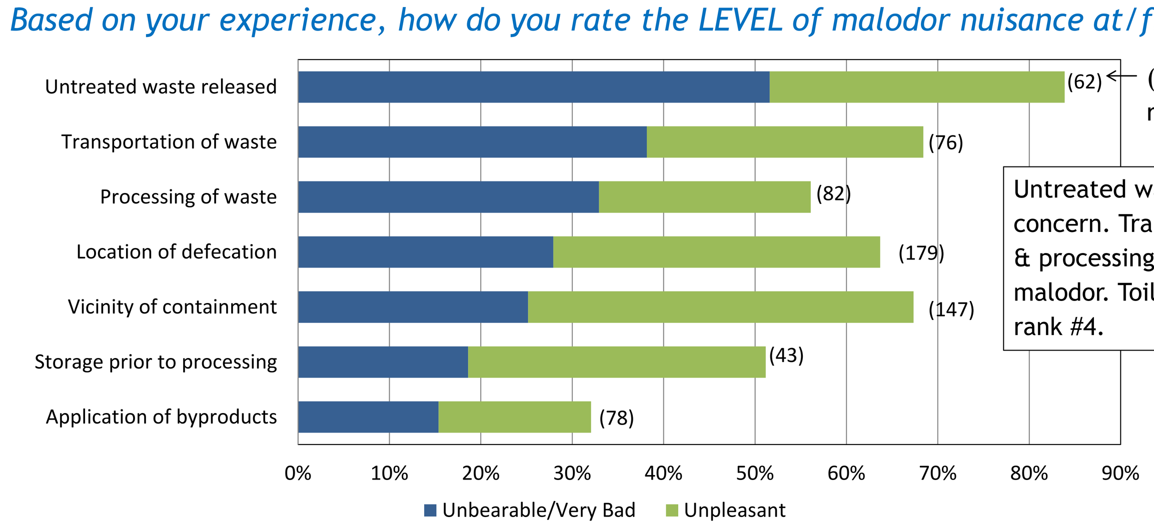
- 250 Respondents.
- Heavily weighted towards solution providers (47%) and researchers (39%). 30% of respondents described themselves as users.
- Wide range of developing countries represented: India (40), Kenya (30), Uganda (18), Bangladesh (17).
- Sanitation systems spread equally across urban, peri-urban and rural.

*How important is malodor as a barrier to toilet/latrine adoption?*

| Answer | | Response | % |
|---|---|---|---|
| Irrelevant | | 1 | 0% |
| Not very important | | 12 | 5% |
| Important | | 124 | 50% |
| Very important | | 113 | 45% |
| Total | | 250 | 100% |

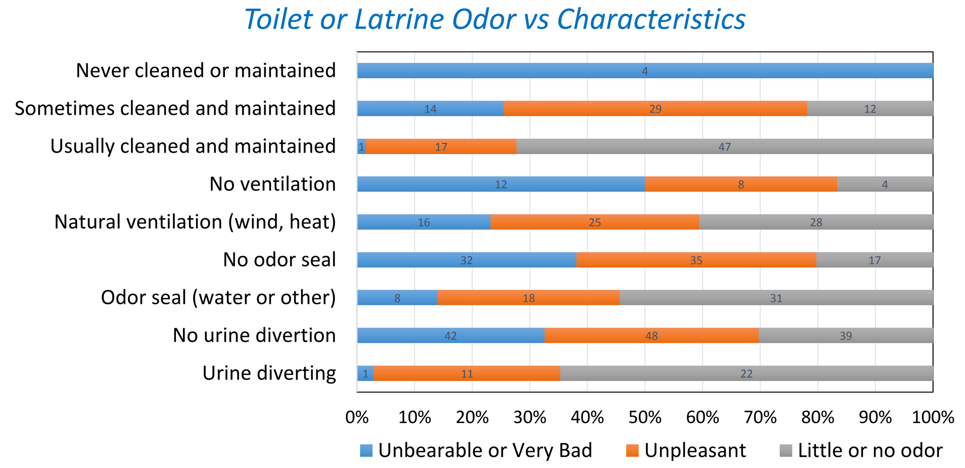
95% (Important + Very important)

*Based on your experience, how do you rate the LEVEL of malodor nuisance at/from the...*




Untreated waste is #1 concern. Transportation & processing cause malodor. Toilet/latrines rank #4.

*Toilet or Latrine Odor vs Characteristics*




Ventilation, cleaning, odor seal and urine diversion all play a role in perceived odor, with urine diversion and cleaning perhaps most influential

*What are the impacts of FSM malodor on people?*

| Answer | | Response | % |
|---|---|---|---|
| They must endure unpleasant odor | | 95 | 43% |
| Attracts flies or other bugs | | 94 | 42% |
| They choose open defecation instead | | 83 | 37% |
| Causes users to use a different latrine | | 64 | 29% |
| It deters them from maintaining or cleaning | | 64 | 29% |
| They clean or maintain more frequently | | 60 | 27% |
| They go out of their way to avoid being near | | 52 | 23% |
| They go out of their way to avoid living near | | 28 | 13% |
| None of the above | | 21 | 9% |

## ADSORPTION OF FECAL ODORS

### Static Adsorption Experiments

- A concentrated odor reconstitution solution (ORS) was made with 6 compounds commonly found in fecal odors: butanoic acid, 3-methyl butanoic acid, 3-phenyl propionic acid, p-cresol, indole, and skatole. All were dissolved in triacetine.
- Activated carbon (Norit ROZ 3) and different types of biochar produced at 900 ºC (horse manure, fecal, bamboo, pine feedstocks) of # 50 mesh or finer were added to an air bag.
- Either ORS or individual odor compounds were added (2 to 20 µl/L-air depending on the compound) to a soft paper and secured to the inside wall of the air bag. A few bags contained ORS + 1 ppm $H_2S$ .
- The bags were then filled with odor free air (30 or 40 L).
- Scentroid SM100 olfactometer (Fig. 3) was used to measure odor levels.
- Olfactometry dilution to threshold (D/T) values were in O.U./m³. These were transformed into an odor removal capacity, $q_c$.
- $q_c = \frac{\left(\frac{D}{T}_{control} - \frac{D}{T}_{experimental}\right) * V_{air}}{m_c}$ , D/T is the odor reading in O.U./m³, $V_{air}$ is the volume of air in the odor testing bag in m³, $m_c$ - mass of char (g)

| Odor Source | Control D/T (O.U./m3) | Lowest treatment D/T (O.U./m3) |
|---|---|---|
| ORS + $H_2S$ | 328 | 109 |
| ORS | 219 | 109 |
| Cresol | 80 | 48 |
| Butyric acid | 98 | 62 |
| Indole | 98 | 17 |
| 3-phenylpropionic acid | 98 | 62 |

*Table : Lowest recorded experimental D/T values for AC adsorption experiment*

*A sample bag*

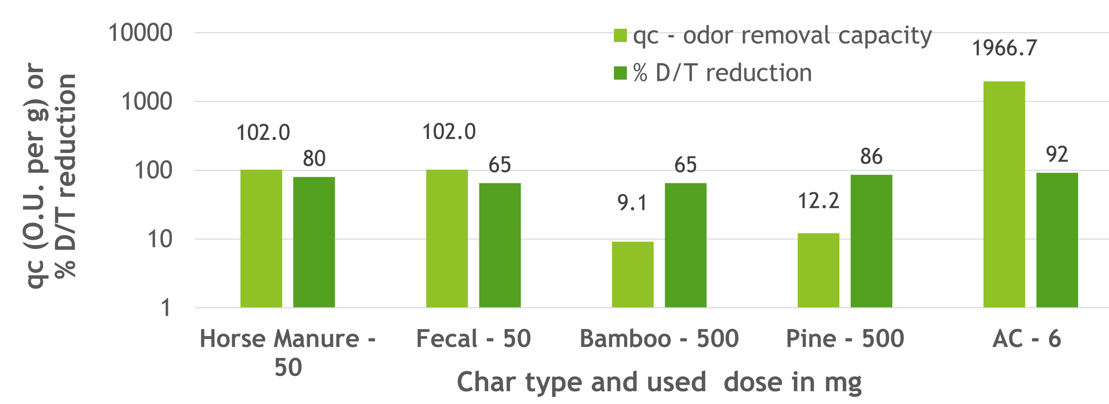



*Figure 1: Odor removal from the ORS +1 ppm $H_2S$ using AC and different biochars*

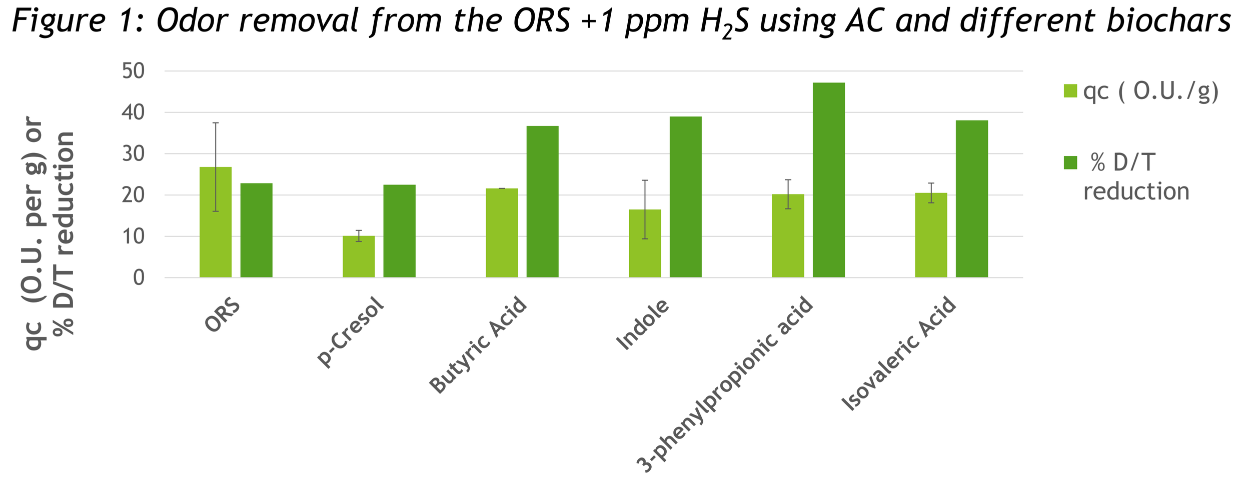



*Figure 2: Odor removal using activated carbon (AC) for individual compounds and ORS at a 50 mg char dose*

For activated carbon adsorption experiments:

- $q_c$ values were highest for the mixture (i.e., ORS) compared to individual odor compounds.
- As char dose increased (50 to 500 mg), the % D/T reduction did not improve suggesting char mass was not limiting (500 mg not shown).
- Different initial D/T levels for the odor compounds as shown in Table 1, can affect the adsorption kinetics.

Comparing activated carbon with chars:

- For the ORS solution, the 500 mg AC had a $q_c$ of 3.2 ± 1.1 O.U./g while, a 500 mg fecal char treatment has 2.7 ± 1.7 O.U./g, suggesting similar capacities.
- The presence of $H_2S$ as seen in Fig. 1 resulted in a higher % D/T removals compared to ORS only results (Fig 2) suggesting $H_2S$ as dominant odor in the mix.

### Dynamic Adsorption Experiments with the Odor Mixture + $H_2S$

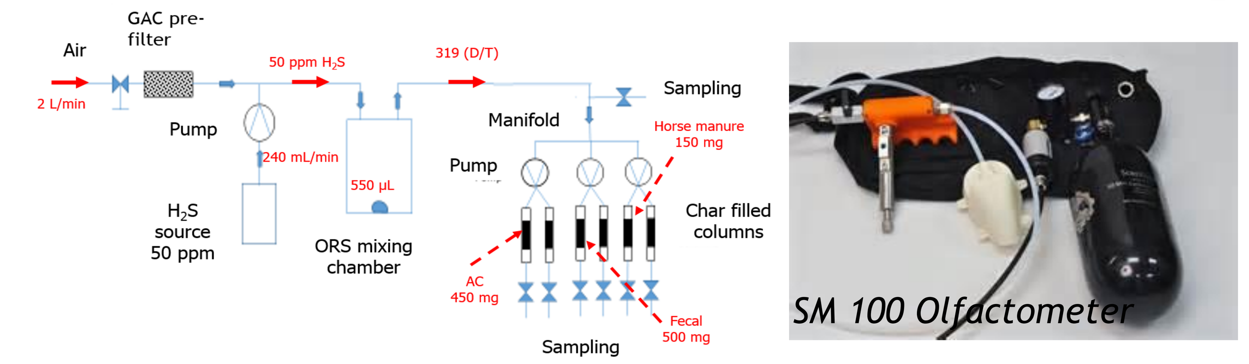



*Fig. 3 - Dynamic adsorption schematics; picture of the portable olfactometer*

- Char particles used for the dynamic tests were 0.30 to 0.59 mm
- Results indicated odor levels rising (i.e., breakthrough) much earlier than $H_2S$ levels, except for Horse Manure Char
- $q_c$ values obtained indicated an average O.U./g of 13.5 ± 4.4 for AC, 11.8 ± 3.6 for fecal char, and 34.6 ± 9.3 for horse manure char.
- $q_c$ values for dynamic adsorption were lower than for static adsorption.

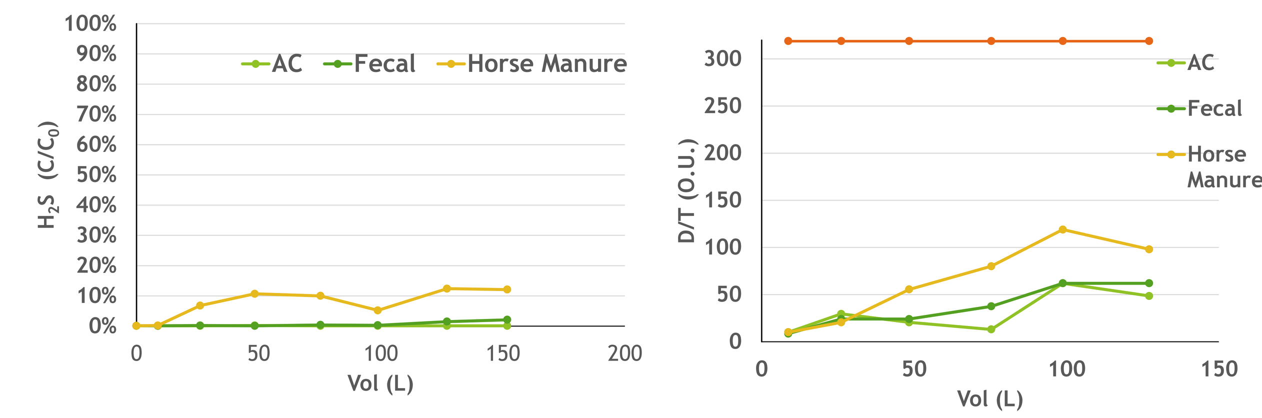



*Fig. 4 - $H_2S$ breakthrough (left), and D/T breakthrough (right) as a function of air volume passed through the adsorption columns*

## BIOFILTRATION OF FECAL ODORS

### Setup #1: Biofilter and Biotrickling Filter

Two lab-scale columns were operated continuously:

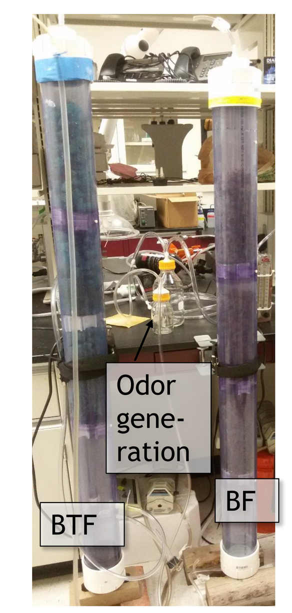
- Biofilter (BF) packed with lava rock
- Biotrickling Filter (BTF) packed with open pore polyurethane foam cubes
- Inoculated with activated sludge

Specifications:

- Packing height: 75 cm in 3 sections of 25 cm each
- Inlet flow odorous air: 10 LPM (upflow)
- Empty bed gas retention time: 12 sec. per section

Goal:

- Successfully treat the fecal odor air stream
- Quantify odor treatment rate of individual compounds in the odor mixture.




| Compound/ Mixture | Inlet D/T | Outlet D/T | Acclimation time of Biofilter (Days) |
|---|---|---|---|
| ORS | 15,000 | 0 | 7 |
| 3-phenyl propionic acid | 30,000 | 0 | 1 |
| p-cresol | 30,000 | 0 | 2 |
| 3-methyl butanoic acid | 30,000 | 0 | 3 |
| Butanoic acid | 30,000 | 0 | 7 |
| Indole | 30,000 | 0 | 2 |
| Skatole | 30,000 | 0 | 1 |

BF and BTF Results

- Complete removal of odor was obtained after a short acclimation (1-7 days) which is typical for biological systems
- Odor removal occurred in the first 25 cm section
- Odor removal rate exceeded $4.4 \times 10^6$ odor units/($m^3_{BF}$×h)
- Current work switched to a smaller BF and BTF to compare different modes of operation (with/without liquid recirculation)

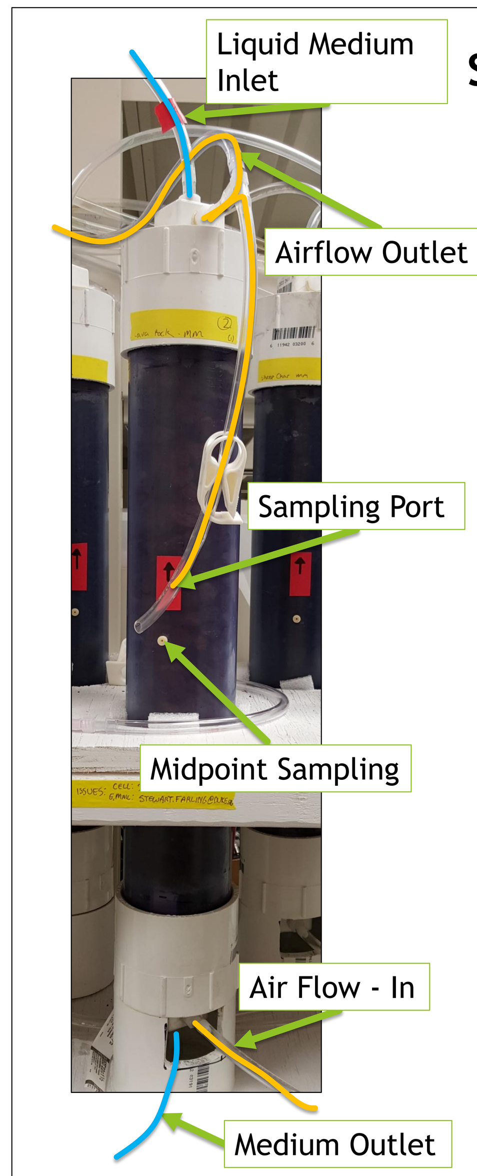
### Setup #2: Filter Packing Variations

Goals:

- Determine effects of biofilter packing and selected improvements on odor removal
- Packings include Lava Rock (LR), Zeolite, Pine char, Sheep dropping char, and Improved BF mix. All inoculated with activated sludge
- Treat slightly different odor makeup matching field latrine air samples (see right)
- Febreze (FB) addition to lava rock BF was explored - Cyclodextrins in FB are known odor scavenging compounds

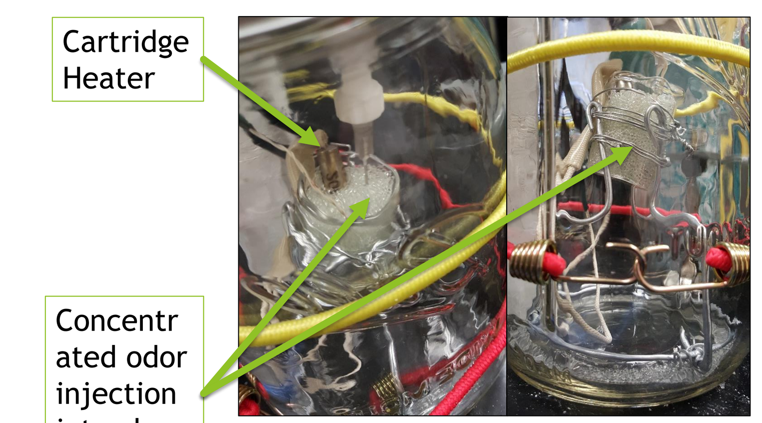
| Flowrate each column | |
|---|---|
| Odorous air flowrate | 11 LPM |
| Gas residence time | 10 s |
| **Concentrations (µg/L-air)** | |
| Hydrogen sulfide | 0.10 |
| Butyric acid | 0.0050 |
| P-cresol | 0.0030 |
| Indole | 0.00030 |

### Setup #2: Column Design and Operation




*Column Set-Up*

- Columns:
  - 40 cm packing + activated sludge at start
  - Gas retention time: 10 seconds
- Odor mixture concentrate:
  - Deionized water as solvent
  - Volatilized by cartridge heater at 150 °C over glass beads (below)
  - 0.137 mL/min flow rate
- Hydrogen sulfide:
  - Metered via mass flow controller
  - 0.10 µg/L = 72 $ppb_v$
- Main air stream:
  - Carbon filtered
  - Metered via mass flow controller




*Odor Mix Injection Chamber*

Current Results of Filter Packing Variations

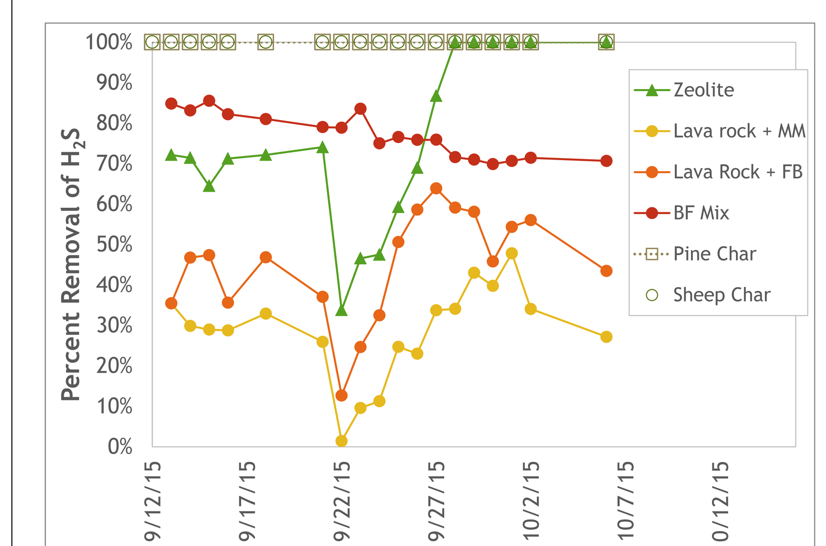



*Fig. 5 - Percentage Removal of $H_2S$*

- Biochars and zeolite remove low concentrations of $H_2S$ very well
- BF mix works well, but also has activated carbon, thus removal could be mostly adsorption
- Febreze improves $H_2S$ removal when applied
- Olfactometry results show excellent odor removal but reliable data are not yet available

## CONCLUSIONS AND FUTURE WORK

- Odors are intimately connected to fecal sludge management practices and adoption of toilets
- Malodor nuisance occur at many points along the chain of fecal sludge management
- Toilet type, design and maintenance practices have a profound impact on odor nuisances
- Activated carbon was shown to successfully adsorb individual odor compounds alone as well as in mixtures
- Cresol has the lowest adsorption saturation capacity of all odorants
- Fecal char has a comparable adsorption capacity for odors as activated carbon
- Simple biofilters and biotrickling filters are effective removing fecal odors. Biofilters packed with biochar completely removes low levels of hydrogen sulfide
- Future work will focus on obtaining reliable olfactometry data
- Higher odor levels need to be explored (increase to 1000's of D/T)
- Medium to long term plans include field testing of odor control prototypes in selected fecal sludge management settings

Acknowledgments: Bill & Melinda Gates Foundation for funding (OPP1119852)