Intermittent Slow Sand Filters for Household Use in Developing Countries: Factors Affecting Bacterial, Virus, and Turbidity Removal

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MOTIVATION:

Household water treatment has emerged as a promising approach to address unsafe drinking water in the developing world. Among low cost options, intermittent slow sand filtration (ISSF) (known as the BioSand Filter) shows great potential for affordable, sustained use at scale. This research addresses several important remaining knowledge and research gaps on ISSF performance:

- ❖ ***What is responsible for the relatively high variability in bacterial (63 to 100 percent) and turbidity (70-92 percent) removal performance encountered?***
- ❖ ***What ISSF design and operating factors could be changed to significantly improve ISSF performance?***
- ❖ ***What is the viral removal capability of the ISSF and how do design and operating factors affect it?***

RESEARCH PLAN:

ISSF factors tested:

- ➢ 2 sand sizes (d_{10} 0.17 mm, 0.52 mm)
- ➢ 3 nominal heads (10, 20, 30 cm)
- ➢ 2 residence times (short: 5 ± 2 hrs vs. long: 16 ± 4 hours)

Experimental design:

- ➢ 2 Factors (sand, head) – 6 configs. per block
- ➢ 3 repeated Blocks, each run 10 weeks

Long and short RT filter performance measured weekly for:

- ➢ Bacterial removal (Fecal Coliform)
- ➢ Viral removal (MS2 Coliphage)
- ➢ Turbidity reduction (NTU)

Fig 1. Fine (top) and coarse (bottom) sand used in ISSF testing.

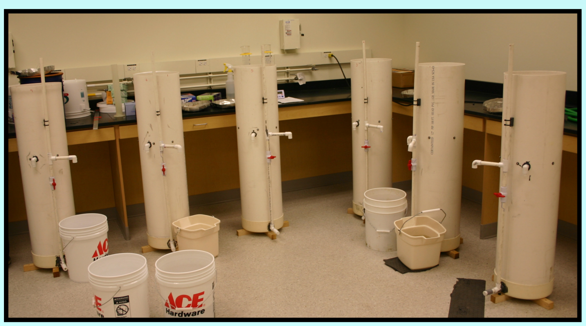

Fig 2. Intermittent slow sand filters fabricated for lab testing.

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ISSF ADVANTAGES:

- ➢ Robust design
- ➢ No recurring costs, affordable capital cost (US $15-25/unit)
- ➢ Simple operation and maintenance
- ➢ Relatively high flow rate, 3-60 L/hr
- ➢ Ability to tolerate highly turbid waters, > 100 NTU
- ➢ Fabricated with local materials and skills
- ➢ Removal of 100% *Giardia lamblia* cysts and 99.98 % *Cryptosporidium* oocysts

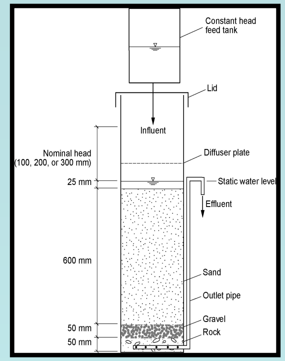

Fig 3. Experimental ISSF schematic

MATERIALS & METHODS:

Filters were tested weekly. Influent and effluent samples were collected for short and long RT operation. Samples were analyzed for fecal coliform bacteria (Standard Methods 9222 D), MS2 coliphage (Standard Methods 9224 C), and turbidity (Fig 4). Sand, head and RT effects on mean filter performance were analyzed with linear mixed models (LMM) setting block as a random effect.

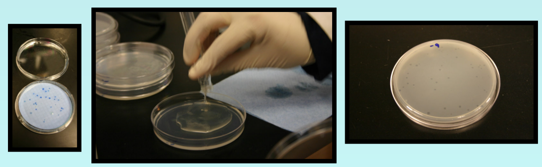

Fig 4. Membrane filtration and plaque assay for bacteria and virus enumeration.

KEY FINDINGS:

Across all 18 units, virus removal (0.5 + 0.45 log) was less effective than bacteria removal (1.43 ± 0.40 log) (Fig 5-6). Under both long and short RT, sand size and nominal head had significant effects on bacterial removal. Fine versus coarse sand, and 10 versus 30 cm head, produced marginal mean increases of 0.27 and 0.31 log, respectively, under long RT operation, and 0.13 and 0.14 log, respectively, under short RT operation (Fig 6). Turbidity in the effluent was consistently below 2 NTU for all ISSF configurations with no significant sand or head differences. Alone, long RT produced the largest significant improvement in performance on all three outcomes (Fig 5-7). Long RT operation and 10 cm head produced more consistent turbidity removal (significantly lower std dev) compared to short RT and 30 cm head. The best design and operating combination, 0.17mm fine sand, 10 cm head and long RT, produced significantly better removal on all outcomes than the worst combination of 0.52 mm course sand, 30 cm head and short RT (Fig 7).

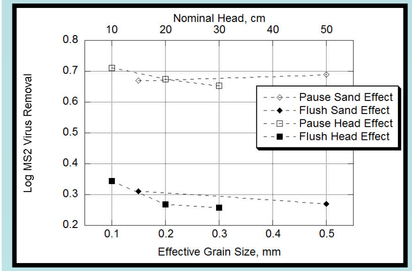

Fig 5. Mean log MS2 coliphage removal by factor level for long (Pause) and short (Flush) RT.

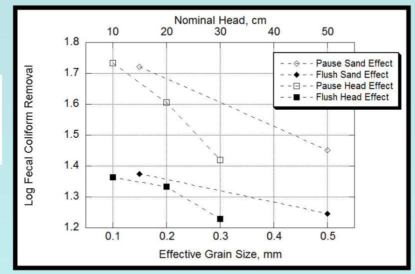

Fig 6. Mean log fecal coliform removal by factor level for long (Pause) and short (Flush) RT.

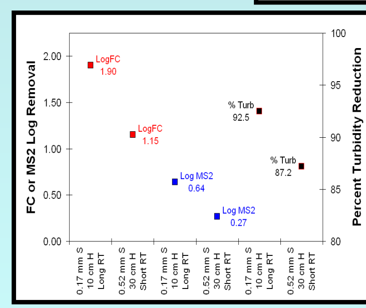

Fig 7. Comparison of mean performance of ISSF best and worst design and operating factor combinations.

RESEARCH RECOMMENDATIONS:

- ❖ ISSF bacterial, viral and turbidity removal can be significantly improved by using a smaller effective sand size of 0.17 mm, reducing nominal head to 20 cm or less, and operating filters with long RT (overnight).
- ❖ Instituting the use of a standardized fine grain size for filter installation is an important step to improve field-based ISSF microbiological performance.
- ❖ Exploring design enhancements to reduce nominal head while still allowing for a 20 L batch is another avenue for improving ISSF performance.
- ❖ Reducing the volume dosed per batch from 20 L to 10 L, in particular for daily drinking water, is a simple action that reduces nominal head and is easily implementable through user education.
- ❖ RT has proven to be critically important for achieving higher ISSF performance. ISSF users should be instructed to maintain a time gap between ISSF feedings and to reserve the overnight batch for drinking.