Stacked Rapid Sand Filters: An Economical Technology for Sustainable Development

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Introduction

Project Rationale

Rapid-sand filtration is commonly used after sedimentation in surface water treatment. However, **conventional filters may not be viable** for many towns in the developing world because of the infrastructure they require. Stacked rapid sand filters may be a more sustainable process for places where clean water is an urgent public health need.

Figure 1: clean water as a public health need

Benefits compared with a conventional rapid sand filter:

- Requires **no electricity** since it is gravity driven.
- **Requires much less water** for backwashing, which can in turn be used to serve additional people
- **Less expensive infrastructure** and **easier to construct and maintain** since it eliminates the need for backwash pumps, large storage tanks, deep filter tanks, and other specialized components difficult to obtain in remote areas.
- **More viable for development projects** since all the required materials for our design (PVC pipes, sand, concrete, brick, and rebar) are relatively cheap and readily available in most places.
- **More compact** design since it eliminates the need for 6 to 8 filters working in parallel.

Process Theory

In a stacked filter, **velocity is controlled by area**. For a given flow rate, the filter can be run at a low velocity by dividing the flow among the layers, or at a high velocity by combining it.

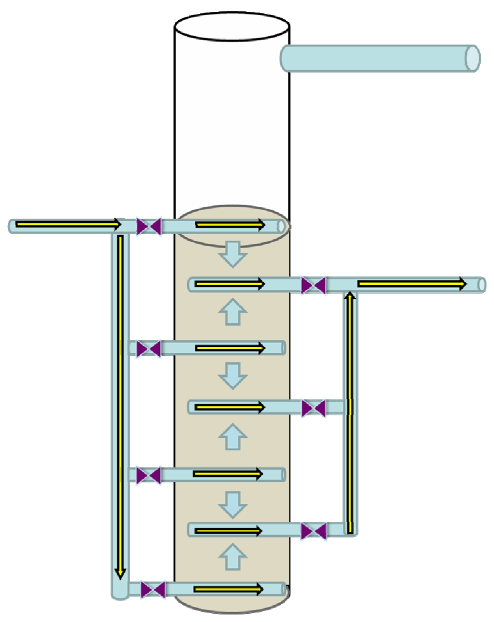

Figure 2: Filtration mode

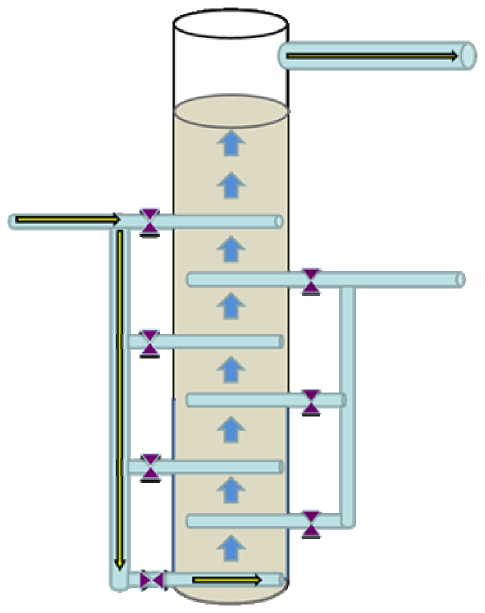

Figure 3: Backwash mode

Flow during **filtration mode:**

- Four inlet pipes carry water into filter and distribute to layers above and below
- Three outlet pipes remove water that has passed through a layer of sand
- Total flow divided among the area of the six layers

$$V_{Filtration} = \frac{Q_{Filtration}}{N_{Layer} A_{Layer}}$$

Flow during **backwash mode:**

- Backwash cleans filter from contaminants
- All flow enters the filter through the underdrain and exits through the backwash trough (outlets are closed)
- Backwash velocity is function of flow and area of one layer

$$V_{Backwash} = \frac{Q_{Backwash}}{A_{Layer}}$$

When the same flow rate Q is used in backwashing and filtration,

$$V_{Backwash} = N_{Layer} V_{Filtration}$$

Materials and Methods

A **bench-scale system** was built as shown in Figure 4

- 4-layer or 6-layer filter inside 4" PVC pipe
- Slotted pipes as inlets and outlets from the sand
- Influent dosed to 5 NTU turbidity and 1.5 mg/L alum
- Filter media: 0.5 mm sand, typical for rapid-sand filtration

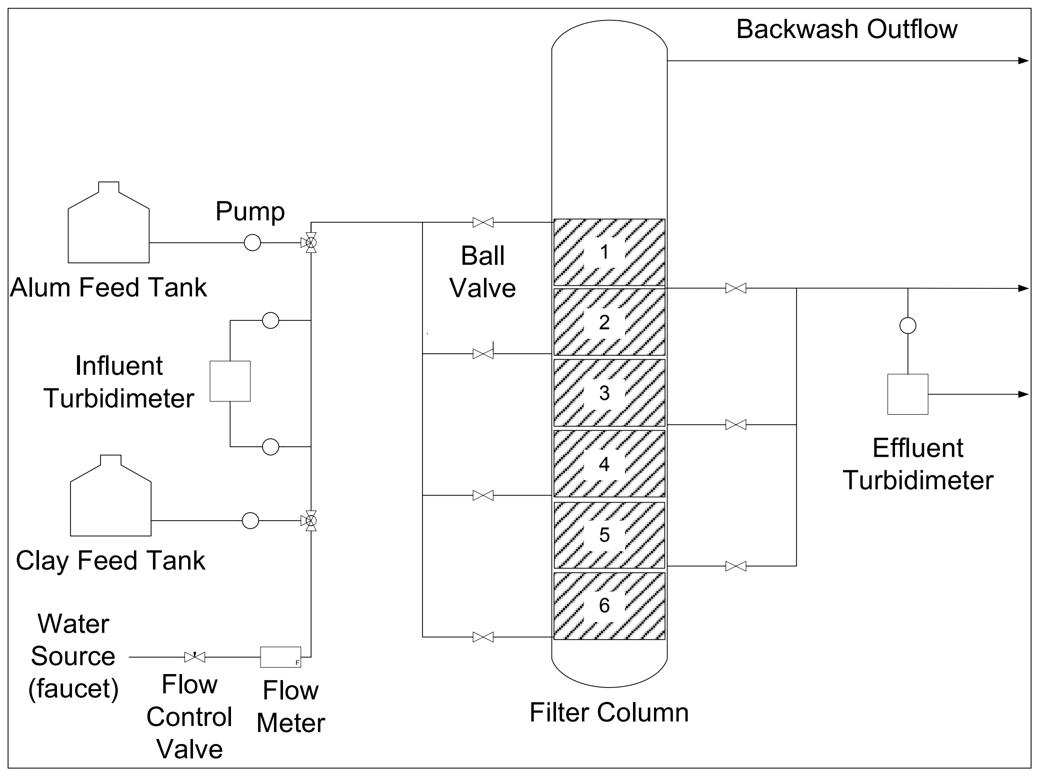

Figure 4: Process flow diagram for the bench-scale filter apparatus

Experimental trials to test the stacked filtration system

- Can each layer be effectively fluidized for backwashing?
- Does the filter produce water of sufficient quality under typical rapid-sand filtration loading rates?
- Will the performance of the filter decline if 5 NTU settled water is used in backwashing?

Results and Discussion

Backwashing and Bed Fluidization

Backwashing is possible for the stacked filtration system

- Fully fluidizing each pair of layers takes on the order of 1 min
- Typical backwash velocities (860 – 1000 m/day) were shown to be effective
- The observed bed expansion was 20-30%

Table 1: Visual observations of backwashing at two different velocities

Layers Fluidized	High Velocity (1000 m/day)		Low Velocity (860 m/day)	
	Time (s)	Bed Expansion	Time (s)	Bed Expansion
2	36.4	11%	70.1	9%
4	56.6	20%	60.9	16%
6	74.1	27%	61.8	21%

Settling the sand bed after the backwashing process

- Opening an inlet valve allows the layers below to settle
- Opening an outlet valve allows the layers above to settle
- Some excess fluidization may be observed as the bed settles

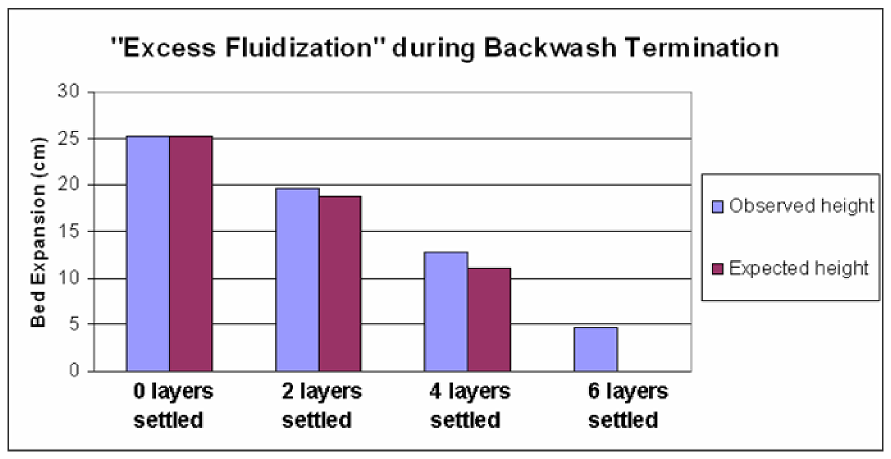

Figure 5: Excess fluidization as the bed settles, compared to the height of expansion as backwashing was initialized

Filter Performance and Turbidity Removal

The filter showed **effective performance** for turbidity removal

- Effluent turbidity remained below 0.3 NTU in more than 99% of samples once filter had ripened (meets EPA standard)
- Consistent log removal (pC*) of around 1.6- 1.7
- Acceptable performance was demonstrated at 120 m/day to 160 m/day velocity, within typical rapid sand filtration range
- The stacked filter could be backwashed with 5 NTU water (as would be done in practice) and performance did not change significantly

Table 2: Summary of filter performance study results

Test velocity (m/day)	Backwash Water Condition	Post-ripening Averages: Influent Turbidity (NTU)	Post-ripening Averages: Effluent Turbidity (NTU)	Post-ripening Averages: pC*	Samples above 0.3 NTU (%)	Length of Run (hr)
120	Clean (tap)	5	0.13	1.66	0.23%	23.8
160	Clean (tap)	5	0.15	1.64	0.58%	24.4
160	5 NTU	5	0.12	1.66	0.00%	21.0
144	Clean (tap)	10.8	0.16	1.84	4.39%	9.6
144	Clean (tap)	12.3	0.24	1.71	13.47%	9.6
144	10 NTU Raw	12.2	0.17	1.85	6.37%	9.8

Typical graphs from 15-hour performance test (144 m/day)

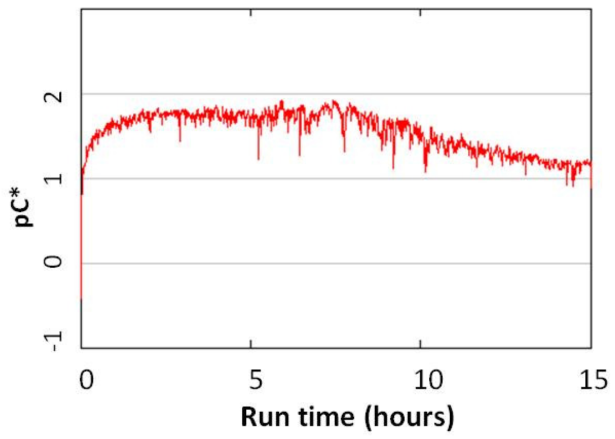

Figure 6: Graph of log removal pC* vs. time for 144 m/day run

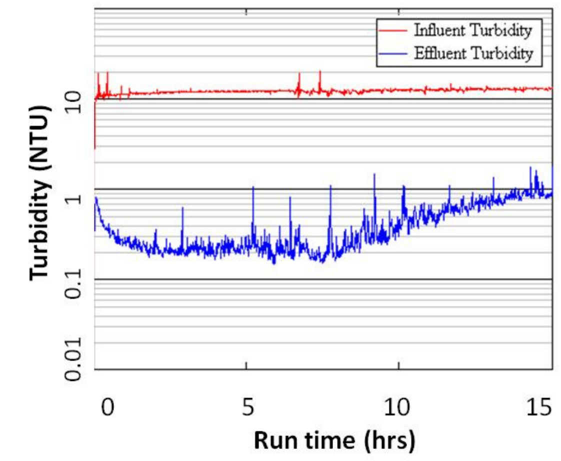

Figure 7: Graph of influent and effluent turbidity for 144 m/day run

As shown in the Figures 6-7, after a ripening time of less than 1 hr the effluent turbidity remained below 0.3 NTU for 9.6 hours of the experiment with an average effluent turbidity of 0.16 NTU. The results reflect worst case scenario where 10NTU influent is filtered. These trials suggest that a stacked filter loaded at this velocity could produce high quality water with two backwashes per day.

Future Research and Field Trials

Ongoing **future experiments** with the bench-scale system

- Tracer dye study to analyze effective residence time and distribution of flow among the layers of the filter
- Additional performance studies to refine the operating procedure and make sure the sand settles correctly
- Determine the effect of varying the filter media

Figure 8: Cuatro Communidades water plant near Tegucigalpa, Honduras, where stacked filter will be built

Full-scale design to test the system in the field

- Build a stacked filter at a 6 L/s municipal water plant
- Work through Cornell AguaClara which develops sustainable surface water treatment systems in Central America