MECH 425: Engineering for Sustainable Development
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Appropriate technology project: Optimization of SODIS water treatment method by decreasing turbidity

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Objective

To determine the effectiveness of 3 different filter media at decreasing the turbidity of a sample of water.

Theory

The solar water disinfection (SODIS) method of water treatment has been shown to be effective at inactivating bacterial microorganisms in aerated water. However, microbial reductions are decreased or prevented by turbidity particles (effective usually only for <30 NTU). Effective treatment of turbid water therefore remains a challenge, as there is currently a lack of availability of simple methods for reducing turbidity of water before solar treatment (World Health Organization, 2002).

Pre-treatment technologies for removal of turbidity from water potentially include:

- Settling or plain sedimentation
- Fiber, cloth or membrane filters
- Granular media filters
- Slow sand filter

These methods will vary in their effectiveness, depending on the nature of the particles (in particular, their size and density).

<u>Settling/sedimentation</u>
Removal of settable solids can reduce turbidity but some water solids are not efficiently removed by settling, and the physical set up requirements for this method (undisturbed vessel, settling times) are often not feasible.

<u>Granular media filters</u>
Rapid granular media filters are capable of reducing turbidity and enteric bacteria by as much as 90% and reducing parasites such as helminth ova by >99%.

Consideration given to the following materials, based on cost and availability:

- Coal-based material/charcoal
- Vegetable matter
- Sand, gravel

<u>Slow sand filters</u>
Proven effective in theory but not effective in practice due to technical knowledge and maintenance requirements for communal (large-scale) filters.

Fiber, cloth or membrane filters
Fabric, paper and similar filters can be used in conjunction with coagulation processes or disinfection processes to achieve improved reduction in turbidity and (large) microbes in water.

Consideration given to the following materials, based on cost and availability:
- Paper
- Cloth (from clothing: e.g. used in India with saris)

Materials

Filters:
- Filter columns (3)
  Dimension: 25.4 cm (10 in) tall, 10.2 cm (4 in) diameter
  Volume = 2059.3 cm^3 (2.1 L)
- Screens (3), 10.2 cm (4 in) diameter
- Plastic screen (3), 10.2 cm (4 in) diameter
- Filter base with tap (3)
- Rubber piece (3), 10.2 cm (4 in) diameter
- 2.5 kg (5.5 lbs) regular sand
  - well graded, poorly sorted
  - grain size: 2mm to 0.07 mm
- 2.5 kg (5.5 lbs) Ottawa sand
  - poorly graded, well sorted
  - grain size: 0.6 mm
- 2.0 kg (4.4 lbs) silica sand
  - poorly graded, well sorted
  - grain size: 0.2 mm
- 2.0 kg (4.4 lbs) clean gravel
- 30 g (1.1 oz) bentonite clay powder
  - grain size: 0.06 mm
- At least 9 L of water

Other apparatus:
- Seven 1-L beakers
- Turbidimeter
- Stopwatch
- Weighing scale
- Oven set at 105 ^oC

Testing and analysis necessary

- Initial concentration of clay particles in the turbid sample
- Moisture content of sand
- Initial turbidity in each sample
  - Quantitatively by NTU and qualitatively by observation
- Flow rate through the filter
- Final turbidity of the filtrate
  - Quantitatively by NTU and qualitatively by observation

Procedure

1. Assemble the columns for testing. The parts are shown in Figure 1 and that assembled columns can be seen in Figure 2.

Figure 1 - Components of a filter column.

2. Prepare columns for filtering
    a. Column #1
        i. Add gravel to the bottom of the column to a depth of 5 cm (2 in) – approximately 615 g (1.4 lbs)
        ii. Add regular sand to the column, on top of the gravel, to a depth of 15 cm (6 in) – approximately 2 kg (4.4 lbs). This will bring the entire filter media to a depth of 20 cm (7.9 in)
    b. Repeat for Columns #2 and #3, replacing the regular sand with Ottawa sand and silica sand, respectively.

    The fully assembled and prepared columns are shown in Figure 2.

Figure 2 - Prepared filter columns: regular sand (left), Ottawa sand (center), silica sand (right).

3. Measure moisture content of regular sand
   a. Dry sample of sand of known mass at 105 ^{o}C overnight
   b. Record dried mass of sand
   c. Moisture content = (mass $_{initial}$ – mass $_{final}$)/mass $_{initial}$ * 100%

4. Create turbid water to filter
   a. Add 2.5 g of bentonite clay powder to 1 L of water, for a concentration of 2500 mg/L.

5. Filter the turbid water sample
   a. Pour 1 L of sample into Column #1 using a 1-L beaker
   b. Record the amount of time it takes for all of the filtrate to fill the 1-Lcatchment beaker and the volume of filtrate

6. Repeat steps 2 and 3 for Column #2 and Column #3.

7. Stir the filtrate from each column and measure the turbidity (NTU) and record all qualitative observations

8. Repeat steps 1 through 5 for subsequent tests on each column.

Recorded measurements

Moisture content of regular sand

Sample	Mass (tin) (g)	Mass (soil+tin) (g)	Mass (soil+tin) dried at 105 °C (g)	Moisture content (%)
1	13.59	31.25	31.15	0.566
2	13.55	33.33	33.22	0.556
3	13.97	31.56	31.46	0.569
				Avg = 0.564

Turbidity of effluent from sand filters

Regular sand filter:

Trial	Initial turbidity (NTU)	Final turbidity (NTU)	Flow rate[a] (mL/min)	Supernatant turbidity (1 day of settling) (NTU)	Supernatant turbidity (4 days of settling) (NTU)
1	560.0	790.0	41.4	17.44	4.67
2	981.4	665.9	30.5	17.36	-
3	736.9	1092	25.7	-	-

a – Flow rate was based on the total volume of effluent produced in the time it took to produce that volume, from the initial addition of the water sample to the column. Therefore, it depends more on the media permeability than the dimension of the output tap.

Ottawa sand filter:

Trial	Initial turbidity (NTU)	Final turbidity (NTU)	Flow rate (mL/min)	Supernatant turbidity (1 day of settling) (NTU)	Supernatant turbidity (4 days of settling) (NTU)
1	645.3	1100/no read	221.2	257.5	4.67
2	731.5	665.9	259.2	171.1	-
3	836.4	843.3	241.5	-	-

Silica sand filter:

Trial	Initial turbidity (NTU)	Final turbidity (NTU)	Flow rate (mL/min)	Supernatant turbidity (1 day of settling) (NTU)	Supernatant turbidity (4 days of settling) (NTU)
1	729.1	486.5	58.1	159.4	4.65
2	828.0	636.9	54.1	255.4	-
3	736.3	987.2	49.5	-	-

Stock influent of turbid water: supernatant following 1 day of settling = 159.3 NTU

Observations

The first trial resulted in extremely turbid effluents from each of the sand filters. The brownish colour of the regular sand effluent (Figure 3) was due to the portion of fine particles in the filter media that passed through the voids of the larger particles along with the water. This initially resulted in a high level of turbidity. The Ottawa sand filter had almost no effect on the turbidity of the sample water; the uniformly sized particles allowed for relatively easy passage of the water and with it, the clay particles. Very few clay particles were therefore retained in the media. The silica sand particles, though very small in diameter, did not retain the clay particles very well. A large amount of silica and clay was collected in the effluent and the silica began to settle quickly.

Figure 3 – Trial 1 effluent from normal sand (left), Ottawa sand (center), silica sand (right).

The collected filtrates were allowed to settle overnight. Figure 4 illustrates the observed effluent following a single day of settling. The fines from the regular sand filter media that passed through settled very well, producing a clear supernatant. The Ottawa sand effluent remained very much the same; though the turbidity reading of the supernatant showed a decrease from the initial, qualitatively there was an insignificant improvement. The silica sand also settled well, producing a clear supernatant, though somewhat more opaque than the supernatant from the regular sand effluent.

Figure 4 - Settled effluent after 1 day. Effluents are from regular sand (left), Ottawa sand (center), silica sand (right).

Unsettled samples of effluent from all three trials for each of the filters are shown in Figure 5. Trial 2 for each of the filters showed a slight improvement in observable turbidity in the immediately collected effluent. However, this did not hold once the collected effluents were allowed to settle for a day; particles that collected in Trial 2 effluents did not settle as well as the did in Trial 1. This was shown again in Trial 3, where the collected particles did not settle as well as they had in Trial 1 and 2.

Figure 5 - Unsettled effluent from each of the filters. From left to right, 1-3 are regular sand effluent; 4-6 are Ottawa sand effluent; 7-9 are silica sand effluent; and 10 is stock influent for baseline comparison.

Discussion of results

There were several inconsistencies in some of the recorded values. While the influent concentration was uniform across prepared batches (2500 mg/L of bentonite particles in water), the initial turbidity readings were inconsistent, yielding values that varied by as much as 421 NTU. This may be due to device error; however, it was found that readings of low turbidity were very accurate, as demonstrated by readings that coincided with baseline samples (a 10.0 NTU baseline sample resulted in a reading of 10.2 NTU). Therefore, the variance in readings was most likely due to the fact that the influent sample was generally extremely turbid and the device had difficulty taking measurements within this upper end of the spectrum. This applied as well to the turbidity readings for the effluent, which did not produce consistent results.

Another anomalous result was that the effluent produced from the regular sand filter in Trial 3 had a higher turbidity than the effluent from Trial 2. However, after being allowed to settle for a day, Trial 1 exhibited the most effective settling and Trial 3, the poorest. This did not follow the pattern that was expected. Settled effluent from the regular sand filter can be observed in Figure 6.

Figure 6 - Settling observed after one day in a sample of the collected filtrate from the regular sand filter. The differences in Trial 1 (left), Trial 2 (center) and Trial 3 (right) illustrate how settling occurred optimally when there were a relatively high amount of fines that passed through the filter with the sample turbid water (Trial 1).

There are two possible explanations for this, depending on the behaviour of the clay particles relative to the fines in the sand filter media:

1) The large passage of fines from the filter media (as evidenced by the brownish, opaque colour of the effluent shown in Figure 3) may have meant that most of the sand fines passed through to the collected effluent in Trial 1, leaving progressively fewer remaining fines in the filter media. By the time Trial 3 occurred, there would have been significantly fewer fines remaining in the filter media and the clay particles could easily pass through the voids left by the absence of the sand fines. This would only happen if the filter functioned such that clay particles were carried down the column with the sand fines and passed through with the effluent, where they later settled due to the larger sand particles' density and associated settling velocity.
2) The passage of the sand fines left voids that were too large to retain the clay particles, thereby producing a more turbid effluent. This would happen only if the filter functioned such that the clay particles were retained in the filter media pore spaces.

The results observed for the other two sand filters suggest that the first explanation is correct. The Ottawa sand particles were too large to pass through the screen at the bottom of the filter, which allowed for the passage of the clay particles. With their low density, small size and negative charge, they did not settle well on their own. This is supported by the lack of settling that occurred even after 4 days, at which point the Ottawa sand effluent was observed to still be very similar to the stock influent, which settled very little. The silica sand on the other hand, was fine enough to pass through the screen at the bottom of the filter, resulting in a large amount of fines in the effluent and with them, the clay particles. These collectively settled well, as the silica particles were larger than the clay particles and therefore forced them to settle.

This theory is further supported by observing the clarity in the supernatant of the collected effluent from the regular sand filter (Trial 1) as compared to the supernatant of a sample of the turbid influent, shown in Figure 7. Both samples were allowed to settle for one day. This shows that in order for the clay particles to settle, there must be a relatively large amount of fines in the filter media to pass through to the collected effluent, which induce the settling of the clay particles.

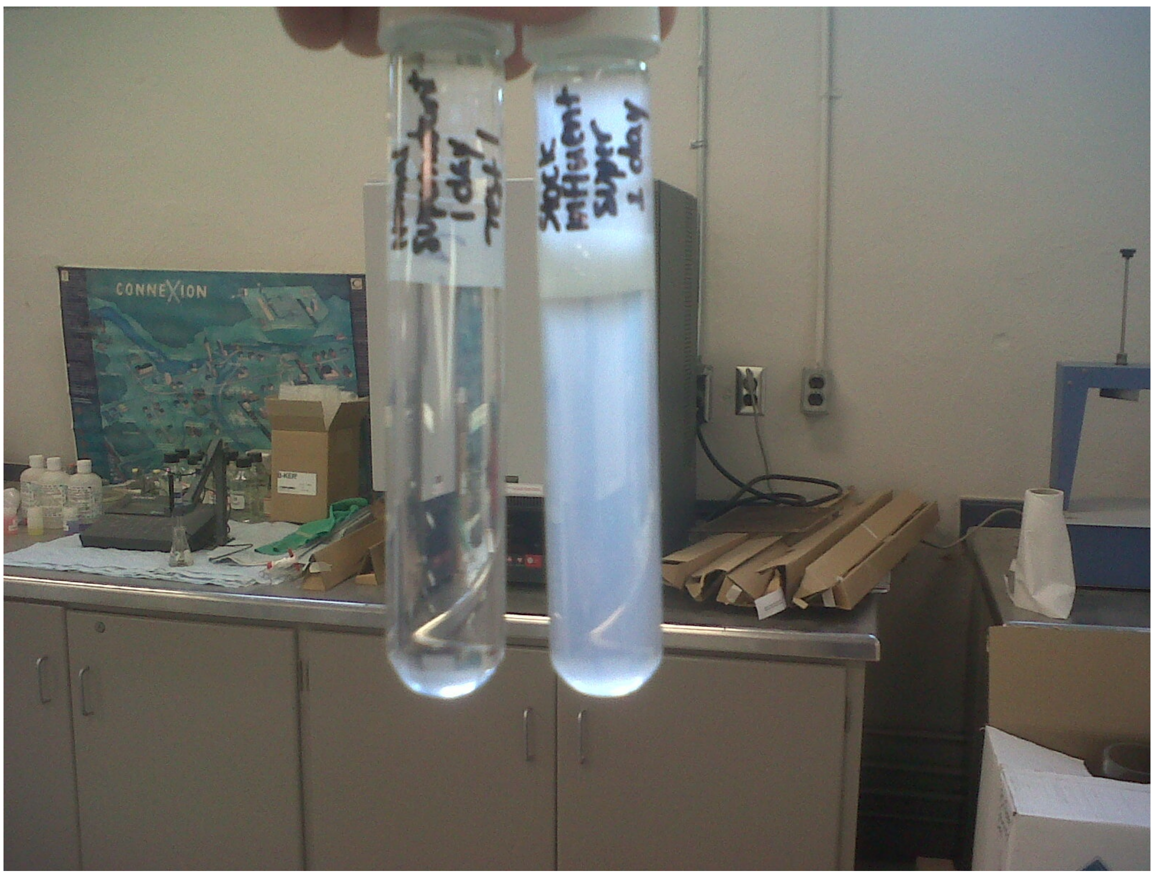

Figure 7 - Supernatant collected from Trial 1 effluent from the regular sand filter (left) and stock turbid water influent (right). Samples were allowed to settle for one day before supernatant was collected.

Despite the variability in readings in the upper range of turbidity, the qualitative observations suggest meaningful findings. In particular, the results from the regular sand filter suggest that filtering water with this media may be an effective means by which turbidity can be significantly decreased. Though the unsettled effluent produced from the regular sand filter in Trial 1 was extremely turbid (even more so than the influent), it settled very effectively after one day. This produced a very clear supernatant that could be poured or siphoned off for SODIS treatment, which requires water of <30 NTU turbidity in order to be effective. The silica sand produced a similarly high-quality supernatant, though only after settling for 4 days.

These results demonstrate the importance of using a filter media that contains both small and fine particles. The Ottawa sand, with uniformly sized particles, did not effectively retain the clay particles and furthermore, allowed for their passage into the effluent, where they had no larger particles to induce their settling. The filter media must therefore contain some fines to force the settling of the smaller, lighter clay particles. It was found that of the three media types, the normal sand functioned best in this regard.

Application to homemade household filter

Of the three media types chosen for comparison, the regular sand yielded the most promising results. This is positive, as this sand – of mixed small and fine particles – is fairly typical of many regions in the world. The results of the silica sand filter also suggest that a silty sand, with a slightly more uniform grain size distribution as compared to the regular sand, may be used as filter media in regions where sand has not been produced due to glacial retreat as it was in many parts of Canada (eg. desert areas), where sand has a relatively wide distribution of particles.

The bench scale results suggest that a similarly constructed filter in the field will yield favourable results. The 2.1 L volume of the columns used in the lab is almost identical in size to a 2 L beverage bottle, which could be used to construct the filter.

One downside to the observed results is the decrease in settleability of the collected effluent as trials progress. Based on these results, it is expected that as the filter is re-used, the collected effluent will produce increasingly turbid water that will not settle effectively in a practical amount of time. It is recommended that ballasted flocculation is explored as a means of inducing the settling of small particles in turbid water, using readily sourced materials such as sand. The effectiveness of this in the context of a household filter system will have to be researched further.

Sources:

“Managing Water in the Home: Accelerated Health Gains from Improved Water Supply”, World Health Organization, Geneva (2002)