Stacked Rapid Sand Filter Backwash ↑

Location: HLS 160 Right Bench

Skills: fluids, fabrication, Process Controller, Mathcad

Introduction

Backwashing filters to remove captured solids is an old method, but it may be poorly understood. The range of sand size in typical filters may be too large to allow full fluidization of the entire filter bed. The minimum fluidization velocity for the largest sand in the bed may be so high that it would cause the finer sand to wash out of the filter.

Many municipal water treatment plants use air to agitate the sand bed to achieve effective cleaning. The addition of air is a difficult requirement for small communities because of the need for an air compressor and electricity. It is possible that municipal water treatment plants adopted the use of air precisely because the sand size distribution was too broad to allow fluidization of the coarse sand without loss of the fine sand.

In recent studies, the AguaClara team has found significant bed segregation in a sand bed that has a uniformity coefficient $(U_C = \frac{D_{60}}{D_{10}})$ of 1.4 and an effective size (D_{10}) of 0.45. This uniformity specification is tighter than is often used for rapid sand filters and thus it suggests that traditional specifications for filter sand are inadequate. Đuriš, et al. (2013) report that a fluidized bed will be completely mixed if the sieving ratio of the largest to smallest sieve opening was less than about 1.5. This ratio of largest to smallest sieve size of 1.5 represents a narrower size distribution than an uniformity coefficient of 1.4.

The form that this characterization should take is somewhat unclear at present. Traditionally, size distributions are characterized by a uniformity coefficient . This may not be a useful characterization of particle size distribution (PSD) for this purpose, however, because it is the presence of the largest particles that most limits the fluidization of the bed. According to Obata, et al. (1982) and Asif (2013), the minimum fluidization velocity of a multicomponent bed is determined by the harmonic mean of the minimum fluidization velocities of all components, with weight given according to the fraction of the total that they represent. This suggests that larger particle sizes, like D_{80} or D_{90}, should be important. However, this analysis doesn't take into account the potential for bed segregation. If the bed segregates by size during backwash then the ability to fluidize the bed is only a function of the largest size of the sand that is at the bottom of the bed. Therefore, the primary deliverable of this study is to develop a consistent way to interpret PSD data to determine the fitness of a particular sand as filtration media.

Traditionally, an expansion ratio of 1.3 has been selected for backwash, but this is for an entire bed. What is more important is the minimum expansion ratio needed in any given size of sand to achieve effective cleaning. For example, in a sand bed with one half of the sand composed of very large sand grains and one half composed of small sand grains, this overall expansion ratio could correspond to no expansion in the large sand grains ($\Pi Exp = 1$) and a dramatic expansion in the fine sand grains ($\Pi Exp = 1.6$). It is likely that the small sand grains in this case would be well cleaned, but it is doubtful that any cleaning would happen in the layer of larger particles. In a less extreme example, an expansion ratio of 1.3 might mean vigorous mixing in the fine portion of a bed, but only mild agitation in the coarser fraction of the bed. Thus, it is important that a minimum expansion, corresponding to a minimum vigor of fluidization, be achieved in the coarsest significant fraction of the bed for the purpose of cleaning it. The minimum expansion needed in the large particles will then dictate the expansion needed for the bed, overall. As far as sand choice, it is important that the sand be uniform enough that this minimum expansion not require excessive filter column heights. As such, the problems of minimum expansion and optimal PSD are highly interrelated.

Tasks and Goals

There are several aims for this study.

- Develop rational guidelines for the selection of sand for SRSFs. As the nominal upflow velocity for backwash in SRSFs has been set at 11 mm/s, the goal is to find the size characteristics of a sand that will completely fluidize and effectively backwash at this upflow velocity without having an excessive expansion ratio. Ideally the sand will be sufficiently uniform that it will not segregate during fluidization.
- Develop an understanding of what is required to achieve effective cleaning of the sand when air scour and surface wash are not possible.
- Work with filter sand suppliers to find out if they have the capability to provide sand that has a size distribution that is appropriate for SRSFs.

The stacked rapid sand filter would be better if there were minimal sand size segregation from top to bottom. This would make the 6 sand layers be close to identical. If the constraint suggested by Đuriš, et al. (2013) prevents segregation during backwash and if we can either purchase or produce sand meeting those specifications, then the big questions are the best expansion ratio for effective cleaning and the best method to produce sand with the target size distribution.

Tasks to specify sand for an SRSF

- Develop methods to grade sand to meet the 1.5 ratio between largest and smallest sand grain size. It is possible that it is only a matter of setting the two sieve sizes (falls through x sieve and is retained on y sieve) or it may be desirable to use hydraulic sieving based on fluidization segregation. Develop a meaningful way to interpret the sand size distribution for selection purposes. A simple way to do this would be develop a ratio of largest significant size to smallest significant size. This would require determining what constitutes a significant fraction of the bed. Speculatively, it seems unlikely that the largest 2% of particles would be significant in a modestly sized filter, but the largest 10% could be important. Perhaps the ratio will be around $\frac{D_{95}}{D_5}$ or $\frac{D_{90}}{D_{10}}$. Currently, the significant fraction has been understood as the average size of the largest and smallest sixths (16.7%) of the sand, as these correspond to the bottom layer and top layer of the filter, respectively.
- Develop an experimental apparatus that will allow measurement of sand size distribution in a fluidized sand bed. (use the Đuriš, et al. (2013) method or develop a new method)
- Test various samples of sand in backwash to see if the Đuriš, et al. (2013) ratio of 1.5 is correct.
- Select the optimal expansion ratio for cleaning. Select a sand sample that remains completely mixed during backwash and conduct further testing on cleaning efficiency. Determine if higher expansion ratios or lower expansion ratios result in better cleaning. We need a method to assess “cleaning efficiency”. Efficiency can be measured based on the m of water that pass through the

filter bed while cleaning it or based on the amount of dirt that remains attached to the sand after cleaning. Dirt remaining after cleaning could be measured by extracting a 100 gm sample of sand from the top of the filter bed and placing it in a 1 L plastic bottle with 500 mL of water. The sample could then be shaken vigorously in a consistent manner and then the water turbidity could be measured. The turbidity of the water immediately above the fluidized bed as a function of the height of water that passed through the bed during backwash could be used as a measure of efficiency of water use during cleaning. According to notes from the Physical/Chemical Processes course, the optimal expansion ratio is 1.5 $\frac{Expanded\ Bed\ Height}{Original\ Bed\ Height}$. As this is higher than our current specification of 1.3 for AguaClara treatment plants, it would be valuable to understand the tradeoffs in selecting an expansion ratio. Increased expansion ratio will require deeper filters.

- Select and test an optimal sand size range for SRSF that can be backwashed at 11 mm/s.
- Assess whether a different backwash velocity should be used for future SRSF.
- Develop a protocol for testing a sand hydraulically to see if it meets the specifications.
- Experiment with the use of short sloped baffles (like short plate settlers) between the sand bed and the backwash waste effluent pipe. These baffles would provide opportunities for sand grains to slide and roll against each other and thus could enhance cleaning. These baffles could also potentially help prevent loss of sand during backwash. This task addresses the issue that rapid sand filters normally use air scour during backwash to get better cleaning. We can't easily inject air into our filters without electricity and thus we want to understand what is required to get good cleaning of the sand without using air. It is possible that conventional rapid sand filters had poor cleaning during backwash without air because the sand didn't properly fluidize because the uniformity coefficient was too high. Thus it is possible that be setting the right criteria for sand selection that you will already solve the cleaning problem. Adding these baffles may also improve cleaning.

The final task for this team is to determine if fluidization in an SRSF can fail due to excessive slot area. The hypothesis is that if the slot area is very large compared with the cross sectional area of the pipe, that flow distribution between slots will be poor and that could lead to zones of fluidization and sedimentation.

References

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