Sand Source and Testing Methods - Research Report

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Abstract

The Sand Source and Test Methods sub-team is new to AguaClara this semester. Our main sources of research come from the known SRSF sand constraints, which dictate that no sand should be able to slide through the 0.2 mm slots in the PVC pipe, the sand should be hard and not prone to dissolution in acid, the backwash velocity required to expand the filter bed by 30% should be very close to 11 mm/s, and the sand bed must not have significant stratification after backwash. In addition to the constraints provided by the SRSF, the filter sand used must also satisfy American Water Works Association guidelines (AWWA). We are using American Water Works Association (AWWA) media constrains along with the American Society for Testing and Materials guidelines(ASTM International) to compile a series of test methods for filter sand. We intend to determine which of these constraints apply to the SRSF design. Furthermore, progress towards local sand acquisition is varied between the sites in India and Honduras as of September 2013. In India, sand is currently taken from the Barakar river and the only modifications made are sieving it for correct size on site, using two large rectangular mesh sheets that are shaken by two people. The two sieve sizes currently in use are No. 60 and 30, which correspond to particle sizes of 0.25 mm and 0.5mm respectively. There is also potential access to laboratories in the Universities and NGOs nearby. In Honduras, on the other hand, there is not an established sand mine industry and sand will likely be taken from river beds near the site. Transporting this sand from the river to the site is easy, but testing will be done in the apartments without the use of laboratory equipment that is difficult to transport.

Introduction

Part of the goal of AguaClara is to design drinking water treatment systems that utilize local materials and labor to operate and construct. One of the materials that is essential to run AguaClara Stacked Rapid Sand Filters is the silica sand used as filter media. Currently in Honduras, there is a budget allotted by Agua Para el Pueblo (AAP) to import sand from the United States. In order

Table 1: Sample Size based on Total Number of Bags

Number of Bags		
Minimum	Maximum	Sample Size
2	8	2
9	15	3
16	25	5
26	50	8
51	90	13
91	150	20
151	280	32

to reduce costs and increase overall independence of the system, AguaClara is looking towards using local sand sources. A local source may come from sand mines within the country, from riverbeds, or other raw sources near the construction site. Whatever the source, it is important that we ensure that the sand is compatible with the SRSF filters being used, as well as with the guidelines provided by the AWWA for filter media. To determine this, there are standard tests to perform on the sand to assess whether it is suitable as filtration media and compliant to the SRSF design.

The motivation for this team is to make the filtration construction process more locally based and to provide a streamlined method to test potential sand sources. Our current goals include identifying filtration media standards as well as standard tests to determine if a certain sand source is suitable, and if not, to alter the local sand to produce suitable media. We will first perform the tests we discover in the lab, and then will work to modify them so that they can be easily repeated on site. We will also attempt to produce suitable sand from an unsuitable source, and communicate with AguaClara alumni in the field to gain a better understanding of the specific needs of each location, and how the tests we find can be modified.

1 Literature Review

1.1 AWWA Filter Media Standards

These standards helped us compile a list of properties that the sand source must fulfill before use in the filter. In addition to standards in filter characteristics, AWWA lists standards for the testing sample size, they are listed in table 1 below:

The size of a bag is not a set measurement, but set by the distributor. While some tests require a sample based on the total number of bags, other tests have independent sample sizes.

1.2 ASTM C40, ASTM C117, ASTM C127, ASTM C146, ASTM E11

Using Cornell Engineering Library, we have collected some ASTM testing methods. These resources help us to identify the specific tests for the filter media specifications outlined in the AWWA b100-09 publication.

1.3 Sand Size Analysis for Onsite Wastewater Treatment Systems

This is a fact sheet that outlines a uniformity coefficient and effective size test. It gives some background on why both properties are important in filter systems, followed by a detailed procedure and necessary calculations. This test follows the ASTM testing standards.

1.4 Water Treatment Unit Processes: Physical and Chemical, By David W Hendricks

This book is very helpful in Backwash Velocity relationships and calculations. If gives the backwash velocity equation, as well as many example calculations. Furthermore, is gives many graphical and analytical explanations of the relationship between backwash velocity and other properties.

1.5 Water Treatment Unit Processes: Physical, Chemical and Biological, By David W Hendricks

This book is gives insight into bed fluidization and bed expansion. It gives many way to calculate bed expansion and explains the relationships between bed expansion and backwash velocity.

1.6 Hydrogeology Journal

A 1997 paper by Moujin Xu and Yoram Eckstein indicated a negative correlation between porosity and Uniformity Coefficient through experimental data. This relationship allows us to modify porosity by changing the Uniformity Coefficient.

2 Methods

2.1 Laboratory Testing

2.1.1 Effective Size and Uniformity Coefficient Test

The effective size and uniformity coefficient test are one single test involving sieving of the sand. It is relatively straight forwards and can easily be performed in any environment. Uniformity coefficient will further be used in the backwash velocity and bed expansion calculations. These properties are significant because they can easily be altered such that the sand sample fulfills the necessary qualifications.

2.1.2 Acid Solubility Test

Before putting sand into the filter, it is crucial to ensure it does not have high limestone composition. Ideally, we are looking for silica sand. We do this by performing the acid solubility test outlined below. This test is easy to perform and very reliable. Limestone dissolves in acid, and thus would not be suitable to filter contaminated water.

2.1.3

2.1.4 Porosity Test

Testing for the porosity of the sand is useful for backwash velocity and bed expansion calculations. There are no direct specifications for the porosity of the sand. The porosity of the sand can be used to alter our backwash velocity and bed expansion due to its inverse relationship to uniformity coefficient.

2.2 Theory

2.2.1 Silica Content Test

The ASTM Silica Content Test for Glass sand requires melting the sand, something that we do not have the equipment for in Honduras or India. Not only is this test impractical, it is also unnecessary. If the sand has a composition unsuitable for use in a rapid sand filter, it will be detected in the acid solubility test.

2.2.2 Backwash Velocity

Using a wide variety of equations, we have found a way to calculate the minimum fluidization velocity, or the minimum necessary backwash velocity for a specific bed of sand. The minimum fluidization velocity is necessary to calculate the bed expansion. This value is dependent on the uniformity coefficient, and thus can be adjusted by changing the uniformity coefficient. We heavily rely on Mathematica, a program created by Wolfram Alpha, to perform calculations and graph relationships.

2.2.3 Bed Expansion

The bed expansion is dependent on the relationship between the backwash velocity and the settling velocity of the sand. Using a variety of equations, we were able to calculate a bed expansion as a function of velocity, and thus solve for the relationship between bed expansion and porosity as well. Once again, the formulas and relationships are calculated with the help of Mathematica.

3 Analysis

After reviewing each of the specifications for the sand, we have found a way to either test for these characteristics or performed the necessary theoretical calculations. After performing each test, we further devised ways to make them less complicated, reproducible, and still accurate. We heavily considered the environments in which the test would be performed in the future, and modified them accordingly.

3.1 Testing Techniques and Methods

To standardize our tests, we have devised some testing techniques and methods as outlined below. These techniques will be consistent through all of our experiments and procedures. These were created to ensure that each experiment could be performed in the environment that they will be implemented in. These techniques not only simplify the tests and remove unnecessary steps, but also standardize these modifications.

3.1.1 Sample Size

Most ASTM tests that require sample sizes based on the total number of bags; instead, we will set a sample size of 100g because there is no outside bag size to compare to, and each plant varies on the total amount of sand required. Standardizing the sample size will also simplify the test process and materials list.

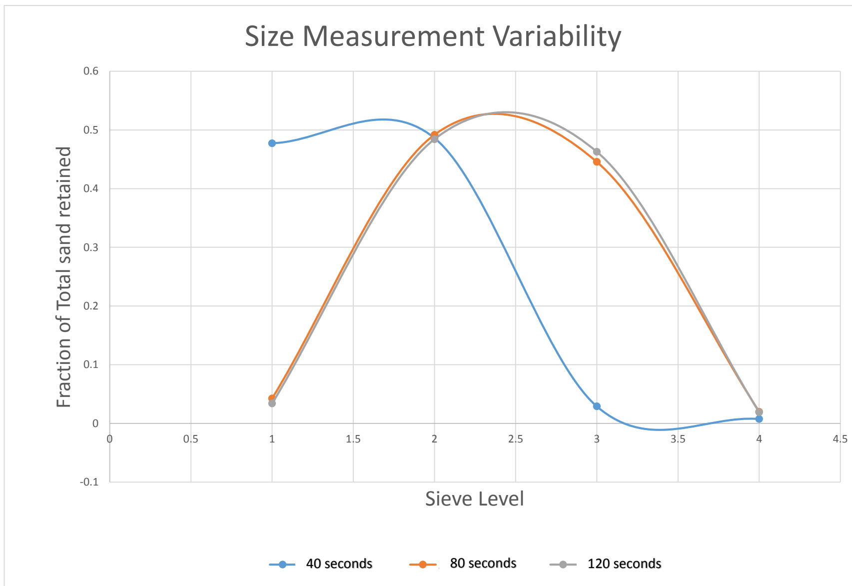
3.1.2 Cleaning the Sand

Although ASTM testing protocol requires the sand sample to be washed and dried many times before any tests are done, we found it to be unnecessary; with AguaClara LFSRSF technology, the sand will be cleaned in the filtration process. Furthermore, in the field we will not have the equipment to properly wash and dry the sand in an easy or efficient way, thus it is important that our sand samples mimic the sand samples that will be tested on site. For the same reason, we will not perform the clay and organic matter tests specified by AWWA standards. Both of these correspond to ASTM tests for the purity of glass sand or conventional rapid sand filters. These two requirements do not apply to the SRSF system. Unlike traditional systems that require a clean filter to produce clean water for the initial backwash, a stacked rapid sand filter is able to backwash as soon as the filter is in place. Because of this distinction, both the clay particle test and organic matter test are not required for SRSF filter media.

3.1.3 Sieving Time

Sieving the sand is required for modify the particle size to fit AguaClara specifications and to calculate the uniformity coefficient and effective size of the sand.

Figure 1: Changes in Effective Size with Shaking Time



We used small circular sieves to determine the uniformity coefficients and effective sizes for the test samples. These small sieves recommend 5 to ten minutes of shaking to separate so that the difference after another minute is less than 1% of the sand volume. We measured the percent on each sieve at 40 second intervals to verify the accuracy of our results based on these standards.

Based on this experiment, after only 80 seconds the values do not change considerably, so 5 minutes of shaking satisfies the requirement than the percent of the sand passing to the next lower sieve does not change by more than 1%. We found that the change in percent decreased as the volume decreased, so with the larger sieves used to sort large volumes of sand, we recommend pouring the sand into the sieves continuously as the sieves shake.

3.2 Testing Procedures and Results

Filter media specifications include a number of material properties; such as hardness, acid solubility, specific gravity, and silica content. Other physical properties of our sample that affect performance in the filters are grain shape

Table 2: Acid Solubility Test Results

Sample Type	Percent lost by Mass	Pass?
Aquarium Sand	0.3%	Yes
Size 20 Sand	10.35%	No

and uniformity coefficient. The effective size of the sand will determine the velocity necessary to expand the filter bed the desired amount, while the uniformity coefficient will affect the amount of stratification after backwash. We are working to find a balance between tests that can be performed simply but produce yields of usable size and desired properties. We expect to determine a relationship between effective size and uniformity coefficient that yields affective behavior during the backwash process. Our test methods should allow AguaClara filters to use local sand for SRSF filters instead of importing sand.

3.2.1 Acid Solubility

Because sand will not have to be cleaned before use in the filters, the only remaining quality of sand is its durability in filters. Filter media hardness ranges from anthracite to silica on the Moh's Hardness Scale, so hardness itself does not determine lifetime of media. The composition of media may also vary, so single composition sand does not perform better or worse than a mixed-media filter. Though the current filter media used in AguaClara filters is silica sand, the test for silica sand is too complicated for our purposes and the result has no defined effect on filter performance. Therefore, the best measure of media durability is the 30 minute Acid Solubility Test as defined in AWWA C-100 standards. This test specifies that after 30 minutes in 1:1 hydrochloric acid solution, there must be less than a 5 percent change in the mass of a suitable sand. We performed this test on aquarium sand and Size 20 sand from an unknown source.

As seen in Table 5, One of our samples passed, while the other did not. This indicates that the Size 20 sand has low durability and would not be suitable filter media.

3.2.2 Uniformity Coefficient and Effective Size Tests

The test performed for both of these properties is straightforward and fairly simple. They are easy to replicate and do not need any machinery, making them easy to perform in the field. Furthermore, as seen form the test, effective size and uniformity coefficient can be easily manipulated. If the sample of sand does not fit the standards that SRSF filters require, it is quite simple to sieve out the unwanted sizes. All this would require is a No. 70 sieve (mesh size of 0.210 mm) to sieve out any sand particles less than the required 0.2 mm, as well as a maximum mesh size to sieve out the larger particles. The maximum mesh size can be determined using the desired backwash velocity and effective size.

The procedure is as follows: to test the effective size and uniformity coefficient, begin with 100g of dried and washed sand. Then measure the masses of each sieves. Stack the sieves from the largest No. to the smallest No. (the largest sieve No. has the smallest mesh size, and the smallest sieve No. has the largest mesh size). Place a pan at the base of all the sieves, and a lid on the top of all the sieves. Lift the lid, and pour the 100g sample of sand into the sieve at the top of the stack (this topmost sieve should have the smallest sieve No.). Replace the lid, and begin vibrating, jolting, and shaking the sieves. The sand should be mixed until less than 1% of the sand by weight will not pass any individual sieve during an additional minute of mixing. Roughly 5 to 10 minutes of continuous mixing fulfills this requirement. Next, record the mass of each sieve and its accumulation of sand. Calculate the percent retained using the following formula:

$$\%Retained = \frac{SampleWeight}{DryWashedSand} * 100$$

Next, calculate the percent of the sand sample to pass through each individual sieve.

$$\%Passing = \%PassingLastMesh - \%Retained$$

Initially, begin with the percent passing for the sieve with the largest mesh size (and smallest sieve number) at 100%. Below are the results of this test on three different sand samples.

The effective size and uniformity coefficient can now easily be calculated. The effective size is equivalent to the grain size of a sample through which 60 percent of the sample passes; we call this value d_{10}. This value can easily be found using the graph.

$$EffectiveSize = d_{10}$$

The uniformity coefficient is the ratio of grain sizes. It is the grain size through which 60 percent of the sand sample passes (d_{60}) divided by the grain size through which 10 percent of the sand sample passes (d_{10}). These values can be found using the above calculations and graph.

$$UniformityCoefficient, UC = \frac{d_{60}}{d_{10}}$$

$$EffectiveSize = d_{10} = 0.390mm$$

$$UC = \frac{d_{60}}{d_{10}} = \frac{0.590mm}{0.390mm} = 0.661$$

$$EffectiveSize = d_{10} = 0.195mm$$

Table 3: Aquamere Sand: Effective Size and Uniformity Coefficient Results

Sieve No.	Sieve Size (mm)	Sample Weight (g)	% Retained	% Passing Last Mesh	% Passing
4	4.75	0	0	100	100
10	2.00	0	0	100	100
20	0.850	0	0	100	100
40	0.425	85.71	85.71	100	14.29
60	0.250	11.97	11.97	14.29	2.32
70	0.212	0.700	0.700	2.32	1.62
Base Pan	0	1.34	1.34	1.62	0.280

Figure 2: Aquamere Sand: Effective Size and Uniformity Coefficient Graph

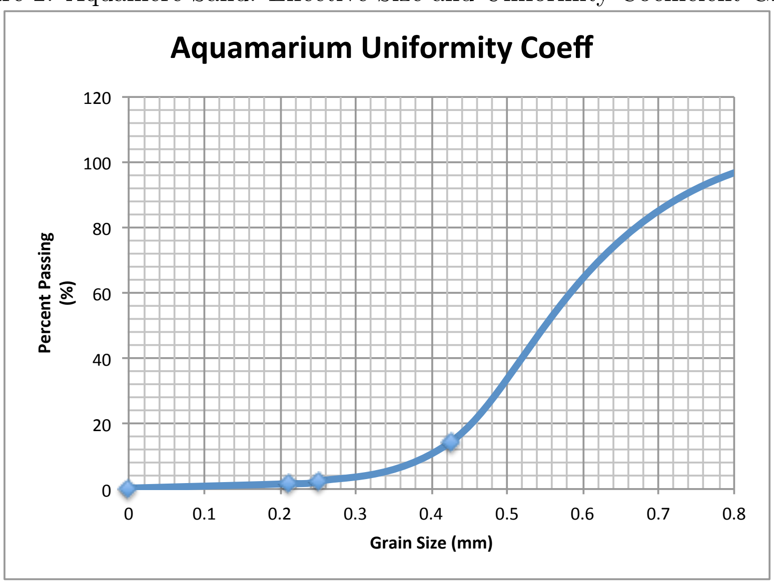


Table 4: Playground Sand: Effective Size and Uniformity Coefficient Results

Sieve No.	Sieve Size (mm)	Sample Weight (g)	% Retained	% Passing Last Mesh	% Passing
4	4.75	0.	0.	100.	100.
10	2.00	0.04	0.0377	100.	99.96
20	0.850	0.02	0.0189	99.96	99.94
40	0.425	19.89	18.8	99.94	81.18
60	0.250	63.31	59.7	81.18	21.45
70	0.212	10.97	10.3	21.45	11.10
200	0.075	10.59	9.99	11.10	1.113
Pan	0.	0.07	0.0660	1.113	1.047

Figure 3: Playground Sand: Effective Size and Uniformity Coefficient Graph

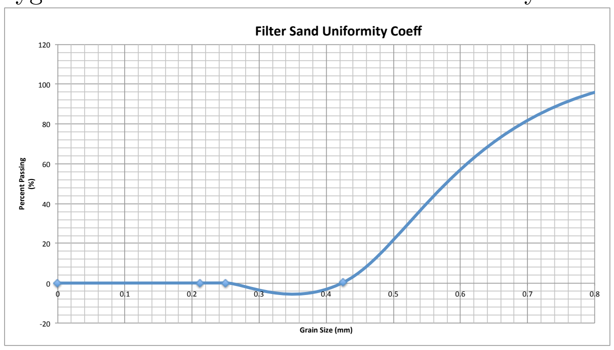


Table 5: Filter Sand: Effective Size and Uniformity Coefficient Results

Sieve No.	Sieve Size (mm)	Sample Weight (g)	% Retained	% Passing Last Mesh	% Passing
4	4.75	0.	0	100	100
10	2.00	0.02	0.020	100	99.98
20	0.850	0.06	0.060	99.98	99.92
40	0.425	100.08	99.6	99.92	0.3383
60	0.250	0.50	0.498	0.3383	0.1592
70	0.212	0.03	0.0299	0.1592	0.1294
200	0.075	0.04	0.0398	0.1294	0.08955
Pan	0.	0.02	0.0199	0.08955	0.06965

Figure 4: Filter Sand: Effective Size and Uniformity Coefficient Graph

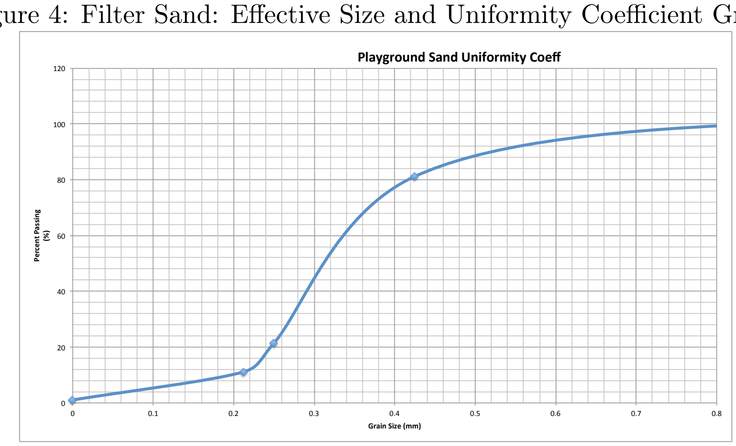
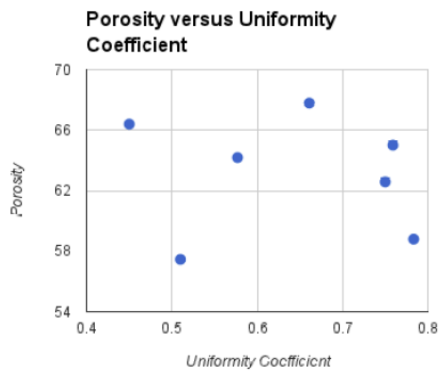


Figure 5: Uniformity Coefficient



$$UC = \frac{d_{60}}{d_{10}} = \frac{0.195mm}{0.338mm} = 0.577$$

$$EffectiveSize = d_{10} = 0.463mm$$

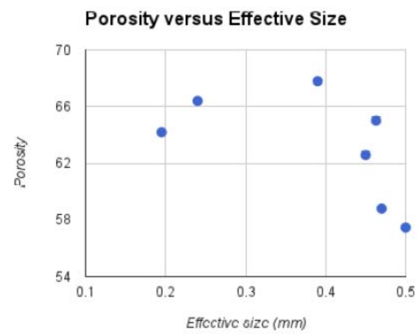
$$UC = \frac{d_{60}}{d_{10}} = \frac{0.463mm}{0.610mm} = 0.759$$

3.2.3 Porosity

One property of sand that may influence the relationship between backwash velocity and the resulting bed expansion is the porosity of the sand, which describes the ease at which water moves through the sand bed. While we cannot easily correct for the porosity of the sand, we can use sieves to change the effective particle size. Our hypothesis based on observation was that finer sand would have lower porosity, and therefore increase the backwash velocity necessary to reach a certain bed expansion. Also, sand with a lower uniformity coefficient would have a higher porosity than sand with a greater uniformity coefficient, which would imply that pore spaces of larger particles are more easily filled by smaller particles. Xu and Eckstein's 1997 paper in the Hydrogeology Journal support this. We tested the porosity of 7 sand samples of varying uniformity coefficients and effective sizes. Sample seven is a mix of size 20 sand and playground sand, which have the greatest and least effective sizes respectively.

As shown in figures 5 and 6 above, our tests reveal no clear tends.

Figure 6: Effective Size



Our Laboratory results for the porosity of sand samples as it varies with effective size and uniformity coefficient indicated that there is not a relationship between porosity and sand size, or that the types of sand we are using are not varied enough to reveal a trend. Therefore, for our purposes, porosity is not currently a valuable characteristic of sand.

3.3 Theoretical Calculations

3.3.1 Backwash Velocity Calculations

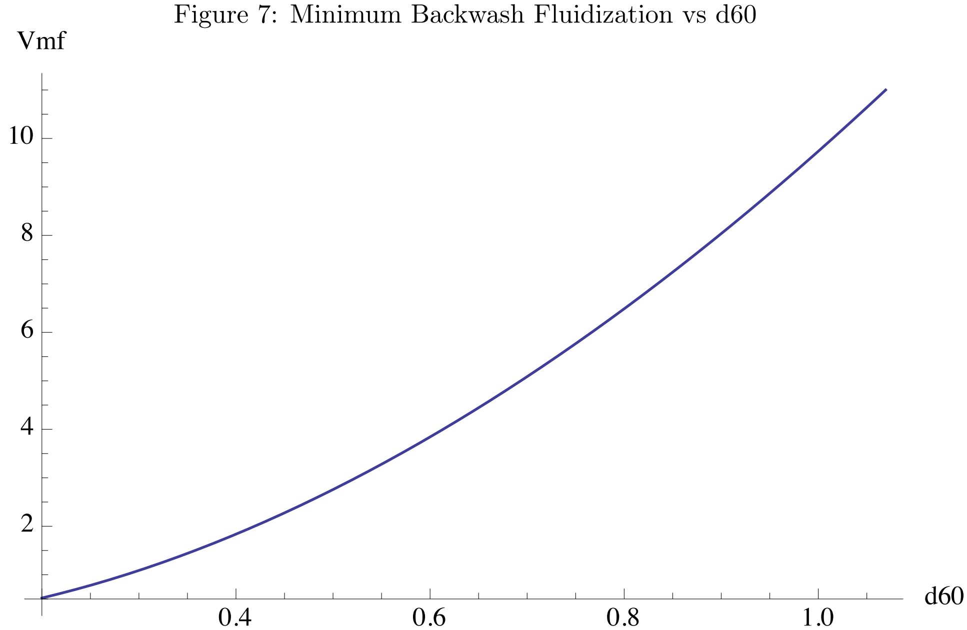
$$v_{mf} = \frac{3.2193 \cdot 10^{-11} (d_{60})^{1.82} [\gamma_w^2 (SG(medium) - 1)]^{0.94}}{\mu^{0.88}}$$

Where v_{mf} is the minimum superficial velocity at which fluidization occurs (m/s), $d_{60}$is the size of sand (mm) that 60% of the sand sample is finer than, γ_w is the specific weight of water (N/m^3) SG(medium) is the specific gravity of the sand, and μ is the dynamic viscosity of water (Ns/m^2).

$$v_{backwash} > v_{mf}$$

The backwash velocity must be greater than the minimum superficial velocity. As demonstrated in the equation above, the $d_{60}$of the filter sand greatly effects the minimum required backwash velocity. Thus, if needed, the sand can easily be sieved to adjust to the d_{60} needed to obtain the desired backwash velocity of 11 mm/s. Assuming approximately room temperature (20 $^\circ$ C): $\gamma_w = 998.7 \frac{kg}{m^3}$, $SG(medium)_{standard} = 2.648$, $\mu = 0.001005264 \frac{N \cdot s}{m^2}$. The maximum d_{60}required for a 11 mm/s backwash velocity can then be solved for. Using Wolfram Mathematica solver, we found $d_{60} < 1.06939mm$. This criterion can be easily met through sieving.

Figure 7: Minimum Backwash Fluidization vs d60



In India, they are currently using sand such that $d_{60} = 0.4mm$. This meets the necessary criteria. Thus, by plugging this value back into the equation and solving for the minimum backwash velocity, you get a value of $v_{mf} = 1.83701$. Therefore, the desired backwash of 11.0 mm/s is attainable.

We then solved for the maximum d_{60}necessary to obtain a backwash velocity of 11 mm/s, and found that $d_{60_{max}} = 0.06939mm$.

The graph below demonstrates the relationship between the minimum backwash fluidization and the d60.

3.3.2 Bed Expansion Calculations

The bed of a filter expands proportional to the superficial velocity, and is given by the equation

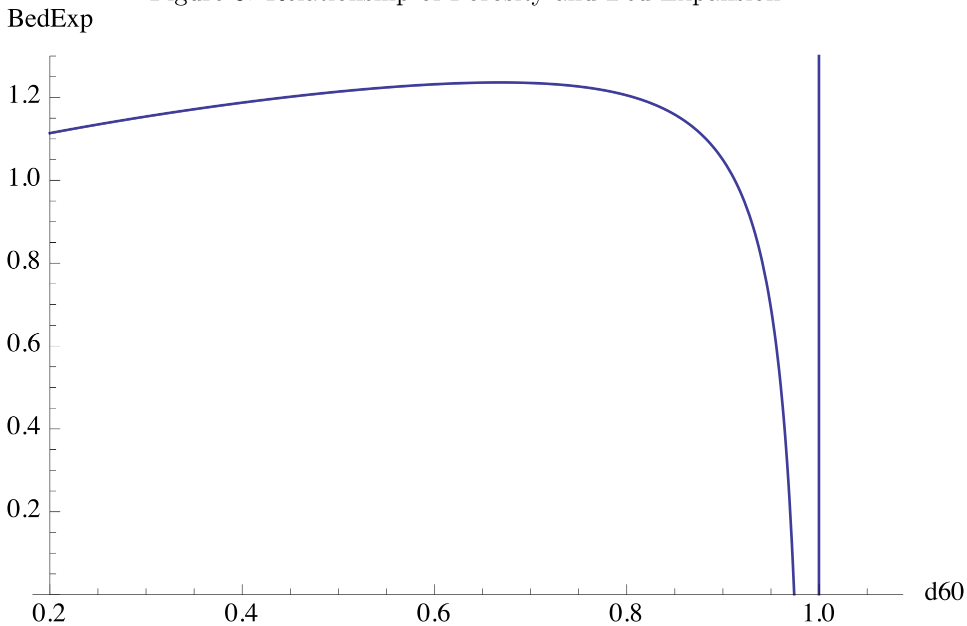
$$BedExpansion = \frac{h_o}{h} = \frac{1-\varepsilon}{1-\varepsilon_o}$$

where $h_o$is the depth of the expanded bed (m), h is the depth of the bed before expansion (m), $\varepsilon$is the porosity of the filter media, and $\varepsilon_o$is the porosity of the filter media during expansion.

$$\varepsilon_o = (\frac{v_{backwash}}{v_{settling}})^{0.22}$$

where $v_{backwash}$is the backwash velocity (mm/s) and $v_{settling}$is the settling velocity. We are looking to solve for a bed expansion of 30% at a backwash velocity

Figure 8: Relationship of Porosity and Bed Expansion

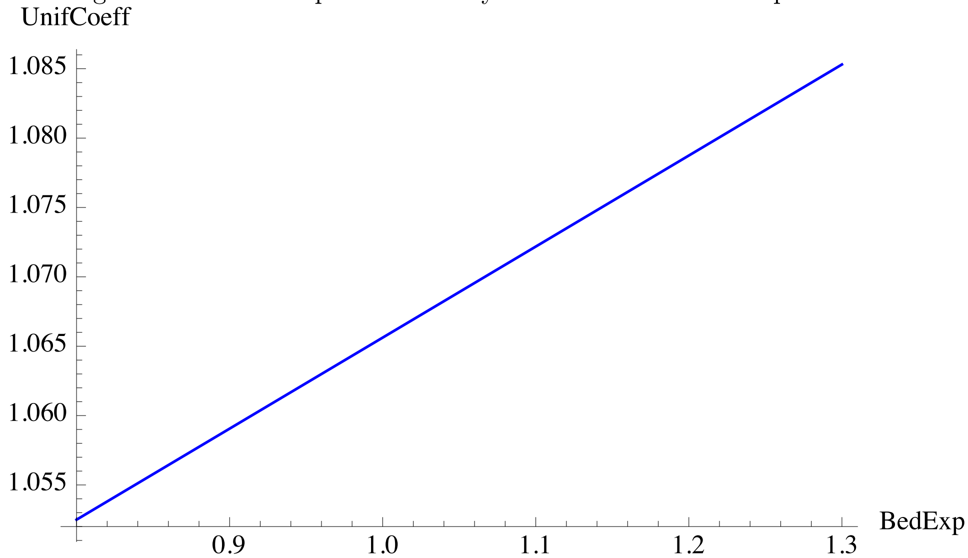


of 11 mm/s. Therefore, our BedExpansion = 1.3 and $v_{backwash} = 11mm/s$. A $v_{settling}$value that was calculated by the LRSF theory team as 8.24 mm/s. Although this value will vary depending on many properties of both the filter and the sand, for the sake of our calculations we take $v_{settling} = 8.24mm/s$. Therefore, since this is a very rough estimate, we then solved for a relationship between bed expansion and the d60 rather than for any quantitative values. To do this we used both the bed expansion formulas above as well as the backwash velocity formulas presented in section 3.3.1.

Notice that because we used a backwash velocity of 11 mm/s, the graph is invalid for $d_{60} > 1.1mm$. Lastly, knowing that porosity and uniformity coefficient are inversely related, we found the relationship between uniformity coefficient and bed expansion:

As would be expected from prior relationships, the uniformity coefficient and the bed expansion are inversely related. Thus, if we test a sample of sand and the bed expansion is too high, we propose you continue to increase the uniformity coefficient until you are satisfied with the new bed expansion. While this is not the most accurate or time efficient solution, given the lack of on-site technology, and thus information, this is the best that can be offered.

Figure 9: Relationship of Uniformity Coefficient and Bed Expansion



4 Conclusions

The Stacked Rapid Sand Filters used by AguaClara water treatment plants have different requirements than traditional filters. These differences result from the backwash process and the access to laboratory equipment in Honduras and India. The procedure for sand testing that we recommend for use in evaluating river sand in Honduras results from three main considerations: the current sand acquisition practices in India, characteristics important to filter function, and characteristics that can be modified.

4.1 Testing Potential Sources

The Acid Solubility Test determines whether a sand source is suitable for filter media. If a sand source passes this test, it may be treated for use in the stacked Rapid Sand Filters. If the sand does not pass, there is not an easy way to change the composition of the sand, so another source should be found.

4.2 Treating Viable Sources

Before the sand can enter the filter, it must be sieved for size. As in India, we recommend using No. 30 and No. 60 sieves which result in an effective size of approximately .4 millimeters. After the sand is sieved, Uniformity Coefficient and porosity tests may be performed on samples to provide parameters for the minimum backwash velocity and approximate bed expansion. Both uniformity coefficient and porosity are characteristics than can be modified through sieving.

However, given the expected effective size, these parameters are not likely to be violated.

5 Future Work

5.1 Experimentation

Our plan of action in the futureis to modify the test procedures that we have developed. We want to see how effective and practical these tests are in the field; specifically to determine the applicability of the backwash equations to the SRSF system.

5.2 More Precise Calculations

We also still want to work on making our calculations as precise as possible. Right now they are still largely based on assumptions. Some areas where more data is needed are with settling velocity and porosity for greater ranges of uniformity coefficients. Also, we do not have data from India regarding the acid solubility, hardness, uniformity coefficient, or other characteristics of the local sand currently in use.

5.3 Communication

We plan on continued communication with the field sites about the different situations in India and Honduras. We want to know what the sand sources will be like, what the experimentation area will be, and what materials they have access to. We want to ensure that our test procedures are as easy and practical for their specific purposes as they can be.

5.4 Modification

After learning more about the situation of where and how the sand will be tested we want to modify our original tests to make them the most effective. We want to simplify our tests as much as we can without losing the integrity of the results. We will also be working to see what properties can be altered to adhere to the necessary guidelines.