Stacked Filtration Theory and Design

Stacked Rapid Sand Filtration Theory

The basic premise of the stacked filtration system is that the flow of filtration is equal to the flow of backwash so that we can use normal plant flow to backwash the filter. A conservative estimate of backwash velocity requires that it be 10 times the normal filtration velocity. We achieve this requirement by stacking layers of filtration on top of each other. Each layer, or plane, consists of a set of inlet tubes that introduce water to a layer of 20 cm of sand. The water once filtered is then collected by a set of outlet tubes. Each layer is essentially its own filtration system. When you stack the layer of filtration on top of each other, area for backwash stays the same and you can technically backwash all of them with the same backwash water. Figure 1 Basic Concept of Stacked Filtration Operation and the mathematical derivations demonstrate this relationship.

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Where

BW=Back Wash
Q=Flow rate of filtration, backwash, or entire plant depending on the subscript.
V=Velocity of either filtration or backwash depending on the subscript.
A=Area of either filtration or backwash depending on the subscript.
N=Number of any system, pipe, and etc which in this case is the number of filtration unit that receives the plant flow rate.

For our design, we chose a conservative available backwash flow rate of only half of the plant design flow rate.
We want the backwash flow rate to equal the filtration flow rate. So we arrange the first two equations for the plant flow rate and set them equal to each other.

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When we substitute the 10 to 1 relationship between backwash and filtration velocity into the above equation, we derive the following relationship with regards to area.

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With the velocity of filtration cancelling each other, we learn that in order to use the same flow rate to backwash and filter we need the area of the filtration to be 10x the time area of backwash. Consequently, if we were to have two filters, then we would need 10 filters stacked on top of each other. If we were to have four filters, like our design, then we would have 5 layers for each filtration system.

There is a tradeoff between the height of the individual filtration unit and the number of filtration units employed. When you decrease from four to two filters, the height of the individual filter essentially doubles. This relationship exists because, in order to have a geometry that allows same flow rate to filter as well as backwash, the total ratio of filtration area versus backwash area must be kept constant. Essentially, the number of filtration planes to backwash planes is set. For our example, the ratio is 10 to 1 because our backwash velocity is ten times greater than the filtration velocity. Consequently, when we select a two filter system, we reduce the number of backwash planes to two, which means that there must be a total of twenty filtration planes which now must be split between two filter units. The height of the individual filter increases as a result.

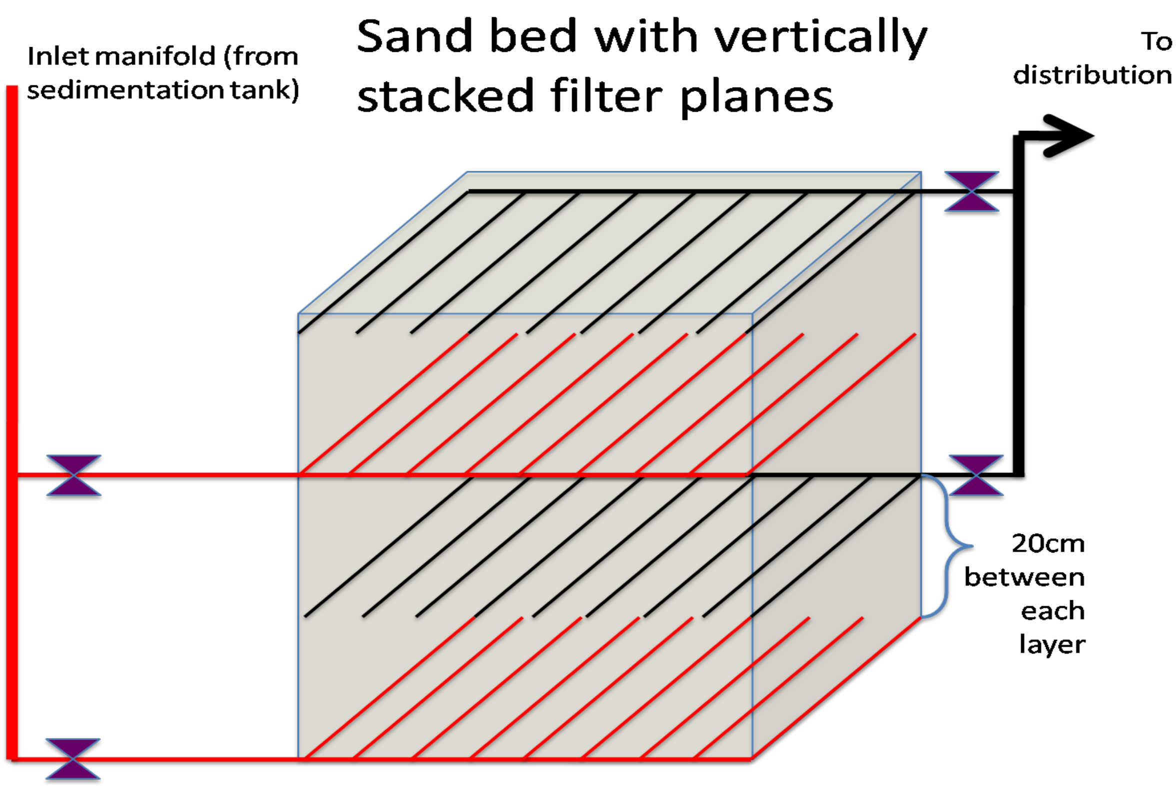


Figure 1: Basic Concept of Stacked Filtration Operation

As shown in Figure 1, there are gate valves to introduce or restrict water to the individual filtration unit. For example, if plant flow decreases to a point where one filter unit can handle the flow rate, we can shut down flow to three of the filter units so that we can perform maintenance on them.

Refer to figure 1 for the following. During backwash operations, we will first use valves to close off the water leading to the distribution tank. As shown in figure 1, we would only need to close off the valves on the outlet manifold. Then we would introduce back wash water from the sedimentation tank through the inlet tubes. As the first layer expands, we would close off the water to the top layer of influent tubes. Once the top layer expands we will close off the top inlet manifold. Now all of the backwash water will be pouring through the bottom inlet manifold. These tubes will be designed to handle that flow and, since they are purposely located at the bottom, they would be able to fluidize the entire sand bed.

IV. Assumptions

In order for our design to work, we made the following assumptions. First we assumed that 20 cm of sand will effectively filter 5-10 NTU effluent water from the sedimentation tank to lower than 1 NTU without clogging at a reasonable rate. Second, we assumed that the unfiltered water from the sedimentation tank would be able to backwash the filter so that it can continuously filter water to 1 NTU or lower standard. Third, we assumed that, as long as the distance between the filtration tubes in a layer, is small compared to the depth of a layer of sand, the flow of water coming out of the tubes will converge and form a plane of filtration. For our purposes, we assumed that a ratio of 1 to 10, comparing the distance between the tubes and the sand layer, would be small enough. One of the future challenges for the filtration team would be test this assumption. Consequently, a layer of inlet tubes sandwiched between two layers of sand would effectively have two plane areas of filtration (Figure 2). All of the assumptions will be tested as described in more detail in the Future Challenge section.

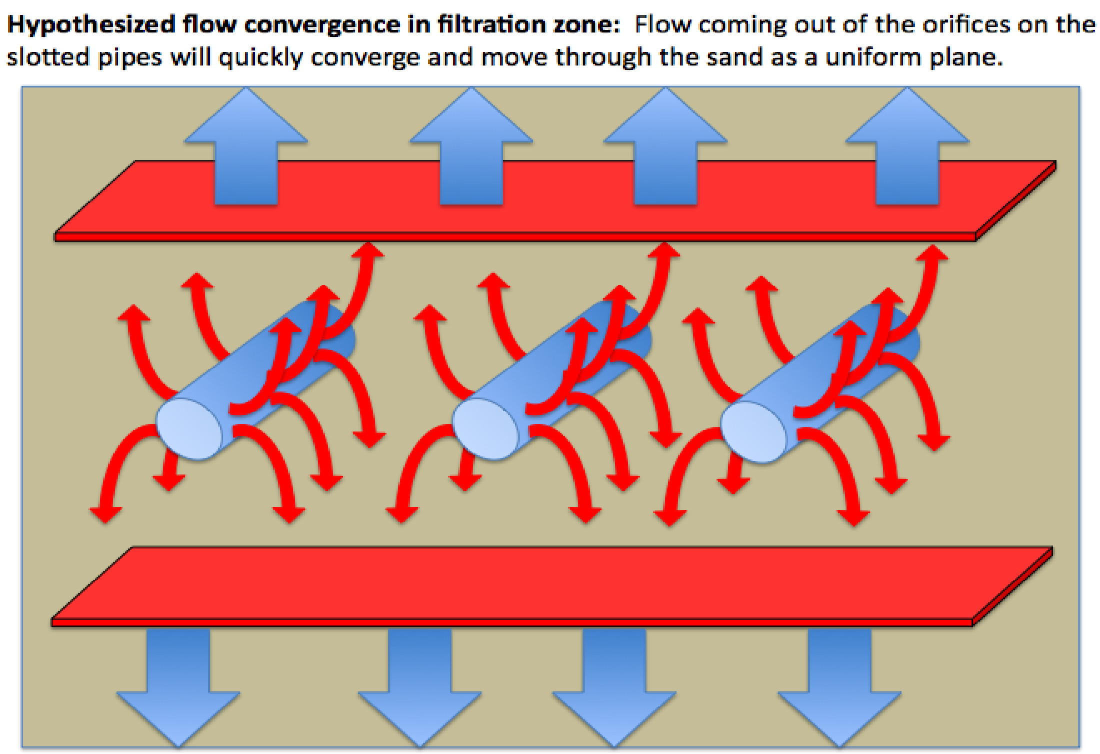


Figure 2: Plane Area Concept

IV. Methods

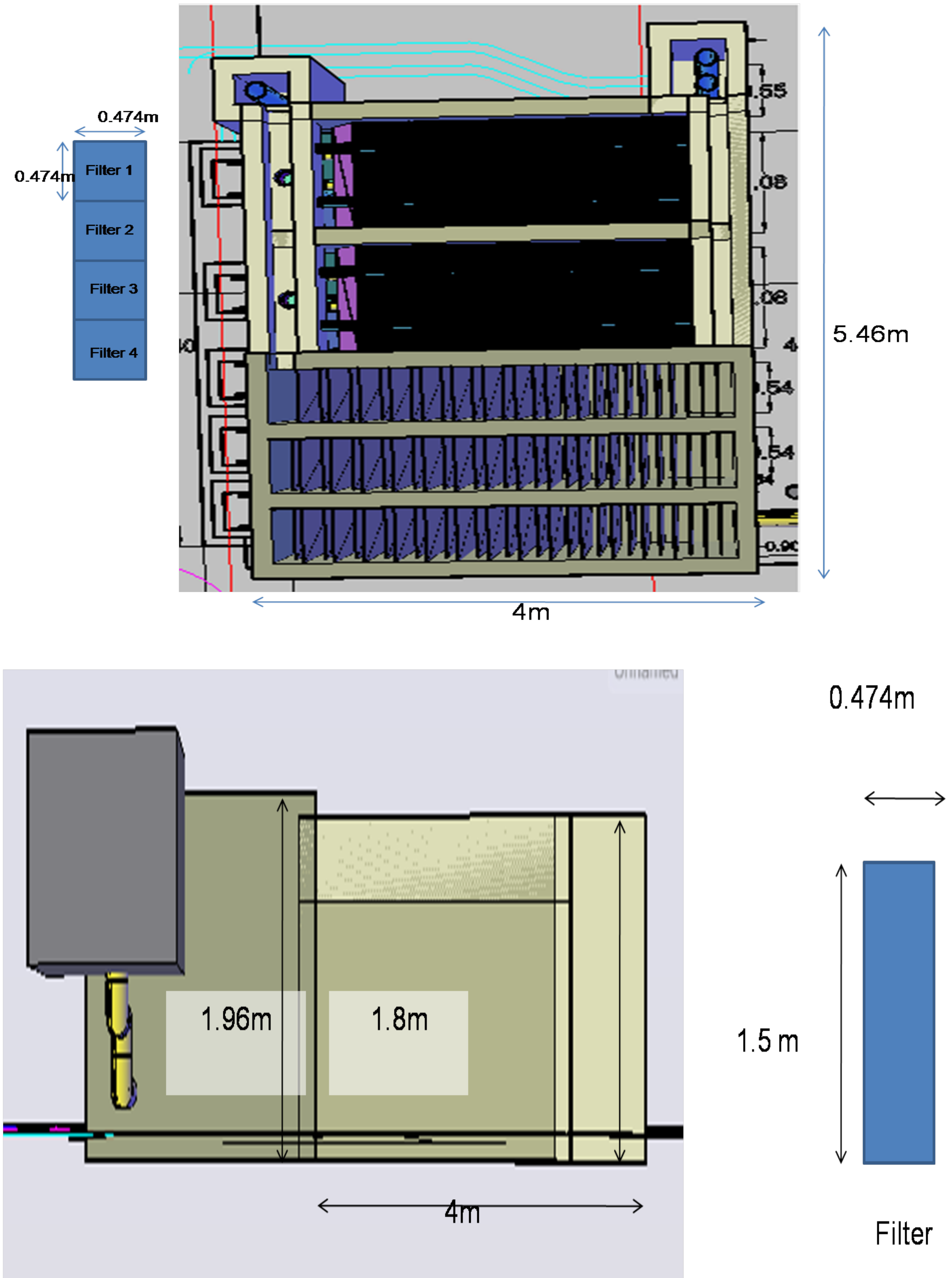
Our design process consisted of 3 major steps. First we designed the individual filter bed itself based on the relationship equations mentioned in the theory section. Second, we sized the pipe in our system so that the head loss experienced by the pipes is never greater than 10% of the head loss experienced by the sand. If the head loss in the sand is not greater than the head loss in the pipes, there will be preferential flow and not all of the pipes in the manifold will have equal flow. Third step was to design the minimum distance between the entrance pipes from the sedimentation tank to the height of the gutter to ensure proper back wash.

Results and Discussion

Our complete filtration system for Agalteca consists of a four rapid sand filtration system (Figure 5). When arranged side by side with concrete wall with a thickness of 20 cm, the total width will be 2.90 m and the total height will be 1.65 m. Each filtration unit will be 1.65 m in height and the sand portion will be square with a side of 0.47 m. Each filter will have 5 layers with each layer, consisting of a set of inlet pipes, 20 cm sand layer, and a set of outlet pipes. Please see Figure 2 Top View Comparison of Agalteca versus Stacked Filtration and Figure 3 Side View Comparison of Agalteca versus Stacked Filtration. Each layer will hold 18 perforated pipes except for the bottom inlet layer which will hold only 12 because they are bigger tubes. Such arrangement will leave 0.5 in between each upper tubes and 0.75 in between the bottom filtration tubes. This is a very conservative design because it maximizes the number of filtration tubes which we believe would do a better job of acting as a plane of filtration than less tubes. The future challenge for the filtration team is to test this assumption and find out how much space we can have between tubes and still achieve a plane like effect.

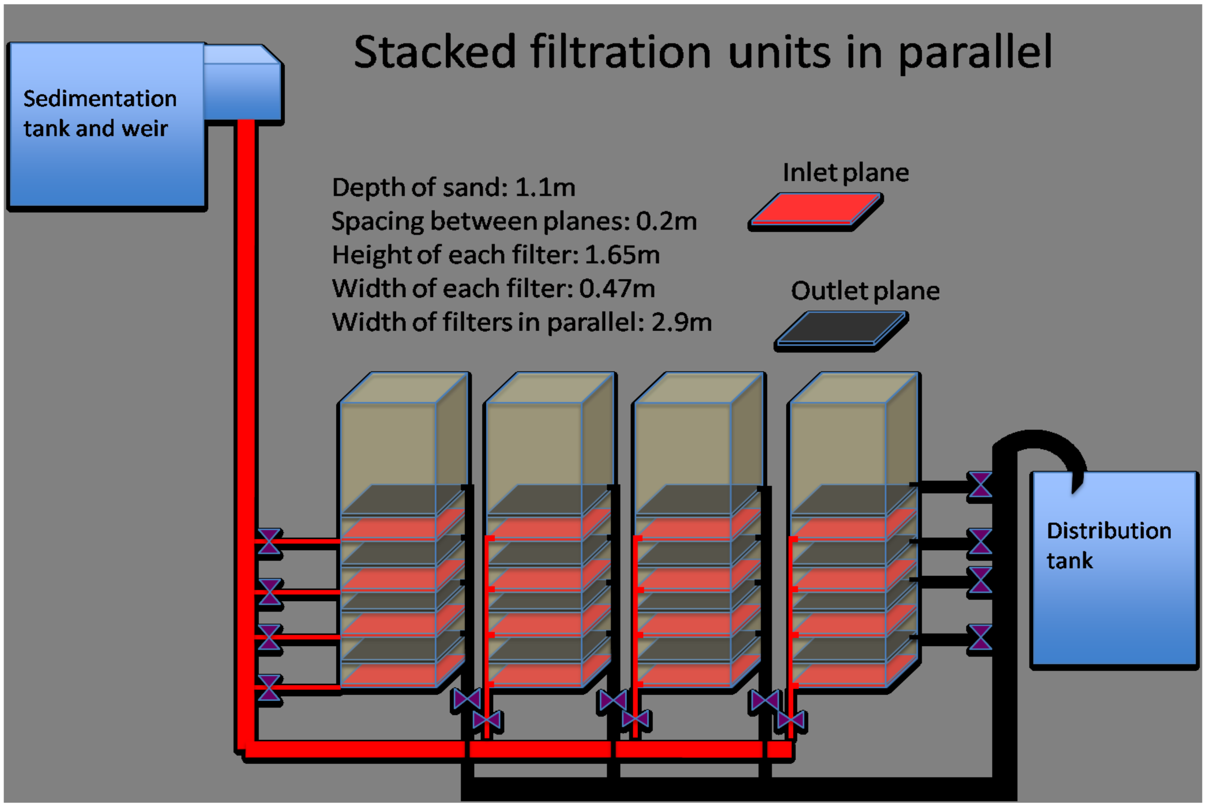
Figure 3 Top View Comparison of Agalteca versus Stacked Filtration

Figure 4 Side View Comparison of Agalteca versus Stacked Filtration



All of the inlet and outlet tubes are 0.5 inch while the bottom is 0.75 inch in diameter. All of the manifold that connects to these filtration tubes will be 3 inch in diameter. All pipes and tubes used are schedule 40. This filter is designed for sands with typical characteristics of D60 of 0.55mm, porosity of 0.4, and specific gravity of 2.65. It will filter at rate of 1.4 mm/s and backwash at 14 mm/s with the expected 30% bed expansion. The filtration system should be located so that there is at least 1.1 m distance from the entrance pipe of the sedimentation tank to the gutter and the effluent pipe of the filtration unit should be slightly higher than the sand bed where it discharges into an elevation control box on its way to the distribution tank. This will keep the filter wet even when there is no flow.

Figure 5: Vertically Stacked Filtration Design



Our design should work as long as the following assumptions hold. First, we need to effectively backwash the sand filter with unfiltered water from the sedimentation tank so that it can continue to filter water to 1 NTU or lower. If there is decreasing filtration efficiency, as evident by high effluent NTU, then this design cannot work. Also we need to know whether or not 20 cm of sand is enough to lower the effluent NTU to 1 or lower. Also we need to find the clogging time of 20 cm of sand. If the 20 cm of sand clogs too frequently then that would be a weakness of this design. Lastly we are depending on the layer of inlet tubes to function as a plane of filtration instead of tubes of filtration if the distance between them is significantly smaller than the distance to the outlet tubes. Modeling the layer of tubes as a single layer that has a top and bottom plane area of filtration has enabled us to greatly reduce the size of our system.