Fluidized Bed after Super Saturator

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Procedure

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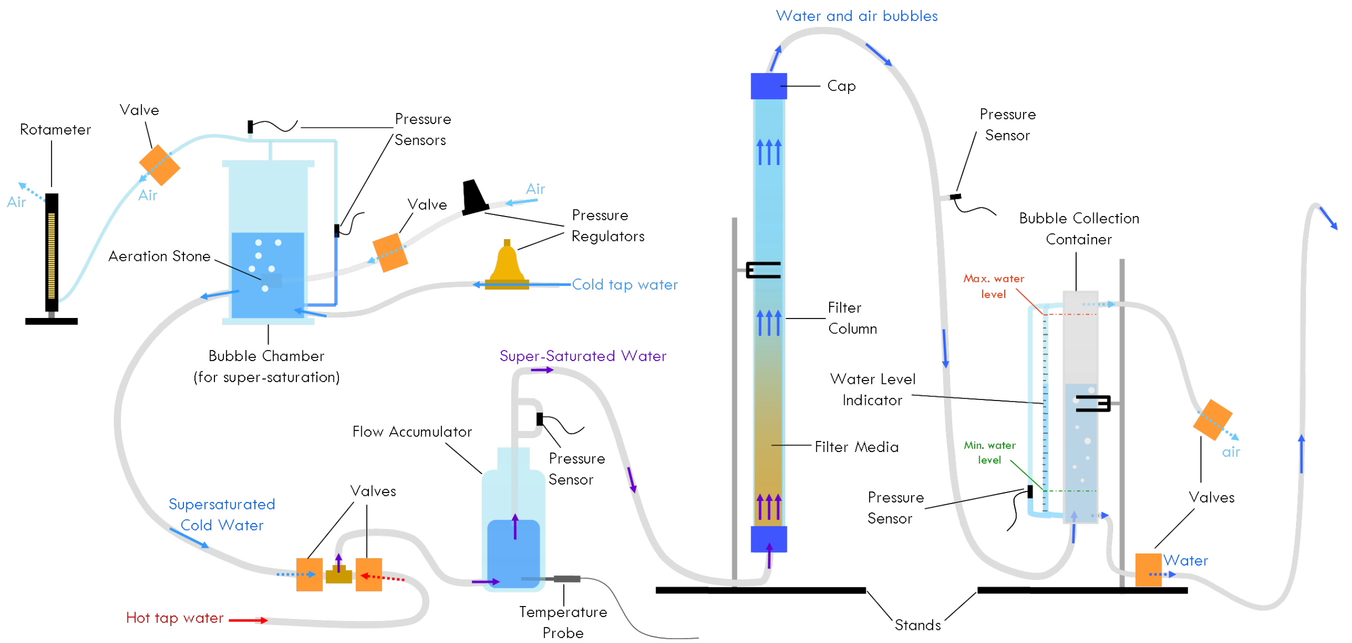

Figure 1. Experimental setup showing the super saturator, fluidized bed, and bubble collector.

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Table 1: Filter media types and sizes

Filter Media	Sieve Size	Diameter (mm)
Glass Beads	50	0.297-.42
Sand	40	0.42-.59
Sand	30	0.84-1.18

The experimental setup consists of a vertical clear PVC pipe that is 125 cm long with a 2.5 cm diameter. This is the filter column, and it is partially filled with the filter media. The filter media used were size 50 glass beads and sands with sieve sizes 30 and 40. These are summarized in #Table 1 at the right.

Tap water is sent upward through the filter column. The tap water cannot be guaranteed to be super-saturated with gases already, so the aeration apparatus previously used in the aeration method has been implemented to supersaturate the cold water before it is fed through the filter column. The aeration chamber is kept under 1 atmosphere of pressure while the water is bubbled by an aeration stone. Air is allowed to leave the aeration apparatus through a valve controlled by ProCoDA Software and a rotameter, which restricts the air flow to maintain pressure inside the chamber.

From the bubbling chamber, the super-saturated cold water joins hot tap water and flows through 1/4" tubing into the flow accumulator, which uses a pressure sensor, temperature probe, and two valves (one for hot water, one for cold water) controlled by ProCoDA Software to regulate the water's flow rate (which is altered to achieve the desired level of suspension of the filter media in the vertical column) and the water's temperature (which is set to 20°C, and can be changed to mimic water temperatures in Honduras).

The mixed water passes from the flow accumulator and into the filter column through 1/4" tubing, suspending the filter media in the column. After flowing through the suspended filter media, the water and any bubbles that formed in the process pass through 3/8" tubing into the bubble collector.

A pressure sensor is located in the 3/8" tubing between the filter column and the bubble collector. This sensor measures the pressure inside the system as cm of head. For the setup to truly mimic the open-to-atmosphere conditions of a grit chamber, the height of the final outlet of water from the system must be adjusted until this pressure sensor reads zero.

The bubble collector is made of a 3.8 cm- diameter PVC pipe that is sealed at both ends. Water and bubbles from the glass filter column enter the chamber through 3/8" tubing that connects the top of the glass filter column to the bottom of the bubble collector. Inside the chamber (which is initially filled with water before each experiment), bubbles float to the surface while the water flows out through 3/8" tubing attached the bottom of the bubble collector. A 1/4" tube attached to the top of the bubble collector allows air to enter and leave. This tube as well as the water outflow tube at the bottom are both controlled by valves that are opened and closed by ProCoDA Software, which uses a pressure sensor to monitor the water level inside the chamber. The water level inside the chamber can be visually monitored through an additional 1/4" clear plastic tube that is attached to the top and bottom of the bubble collector.

At the start of an experimental run, the bubble collector chamber is nearly filled with water, the air valve at the top of bubble collector is shut, and the water outflow valve at the bottom of the bubble collector is open. As bubbles enter the bubble chamber and gather at the top, the water level in the chamber slowly sinks. When enough bubbles have entered the chamber to lower the water level as far as possible, the outflowing water valve is shut and the air valve is opened, allowing the chamber to refill. When the water level in the chamber reaches the maximum level again, the air valve shuts and the water valve opens, and the process begins again. The chamber can be drained by opening both valves at the same time. The system continues running during all of these processes in order to keep conditions as constant as possible.

The Process Controller Method we are using to run this setup can be downloaded here.

The rate at which the water depth changes during a run is the same as the rate that air is being added to the collector, and so this is proportional to the rate that dissolved gases are being removed from the super-saturated water. Our data can be used to find the volume of dissolved gases removed per liter of water that flows through the system, allowing us to compare the relative effectiveness of each sand size, flow rate, and bed depth combination.

Results and Discussion

For each sand grain size, the change in water level was recorded over a period of time. Usually, the experiment was left to run for several hours. Water level vs. time was plotted for each of these runs. #Figure 2 serves as an example, showing the raw data for a run using glass beads in the filter column. Runs with the other filter media share the same patterns. Where the graph is slanted downward, the water level inside the bubble collector is sinking due to bubbles of gas leaving the water inside it. The steep upward climbs in the graph occur when the bubble collector has been completely filled with air and has to refill with water in order to continue the run. The data behaves fairly linearly, so after each run, a linear trendline is fitted to the data in Excel, as shown by the red line in #Figure 2.

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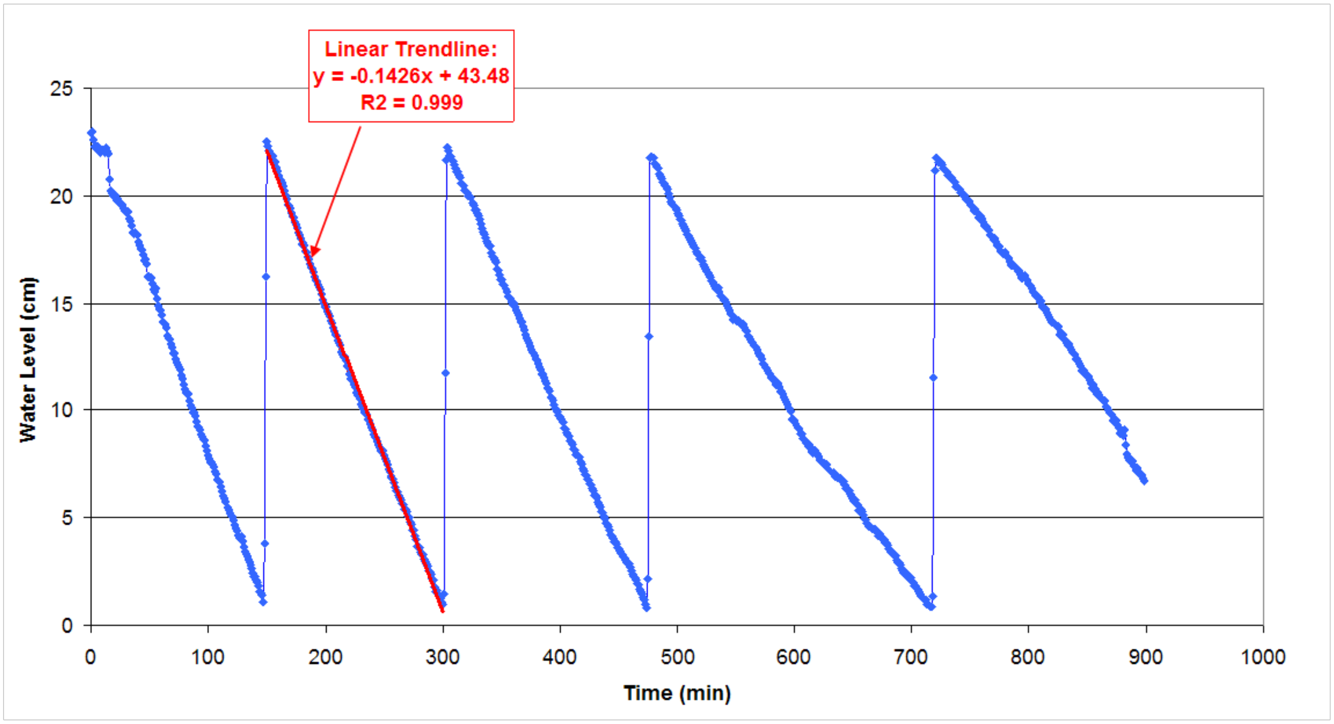

Figure 2: Water level in bubble collector vs. time, using Glass Beads as filter media. Flow rate: 180 mL/min, Bed Expansion: 50%

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Table 2: Properties of trendlines fitted to water level vs. time data. Bed Depth: 60cm, Expansion: 50%.

Filter Media	Flow Rate (mL/min)	Slope (cm/min)	R^2 value
Glass Beads	185	.1426	.999
Sand 40	345	.1541	.9992
Sand 30	500	.1423	.9915

The slope of this trendline represents the rate of change of the water level inside the bubble collector as water runs through the filter. The slopes found for the filter media tested are summarized in #Table 2, along with the R^2 value of the linear fit. All of the R^2 values are very close to one, which means that the data is in fact nearly linear and can be accurately represented by the equations given by Excel. For each run shown in the table, the filter bed was 60 cm deep and expanded by 50%.

The the rate of change of the water level can be converted to an equivalent rate of change in gas volume by multiplying the trendline's slope by the cross-sectional area of the bubble collector:

$$\frac{\Delta Volume}{\Delta Time} = slope * \pi * r_{collector}^2$$

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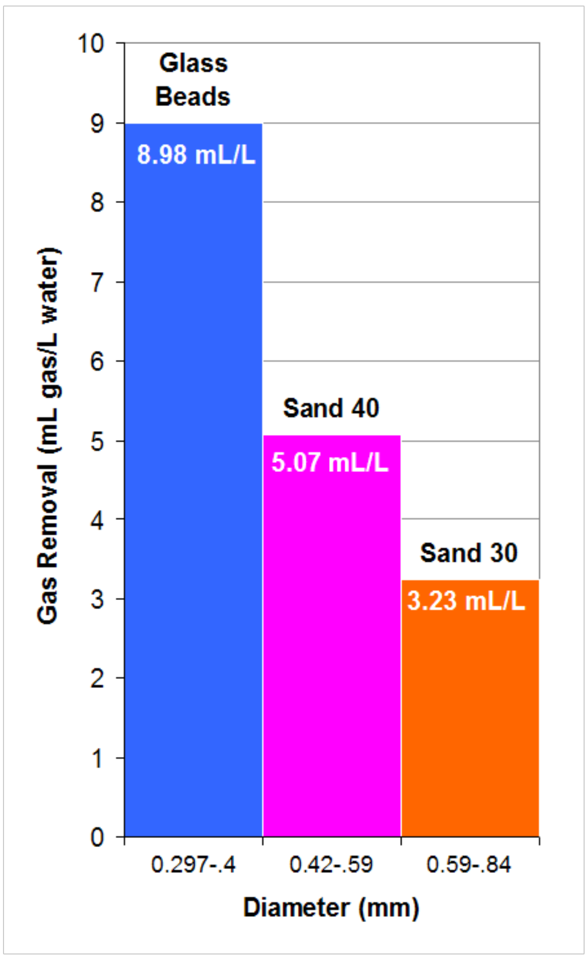

Figure 3: Dissolved gas removal for various filter media. Bed Expansion: 50%

To determine how much gas is removed per liter of water sent through the filter column, that volume rate of change is then divided by the flow rate of water in L/min.

$$\frac{mL\ gas\ removed}{L\ water\ treated} = \frac{\frac{\Delta Volume}{\Delta Time}}{Q_{water}}$$

This was done for each sand, and the results are plotted in #Figure 2.

In addition to sand grain size, filter bed depth was altered for the size 40 sand. Data was recorded for the filter depths of 42.5 cm and 60 cm, both expanded by 50% at a flow rate of 345 mL/min. The results are shown in #Figure 4. The deeper bed depth had a steeper slope, and therefore removed more dissolved gases per liter of water than the shallower depth, as summarized by #Figure 5

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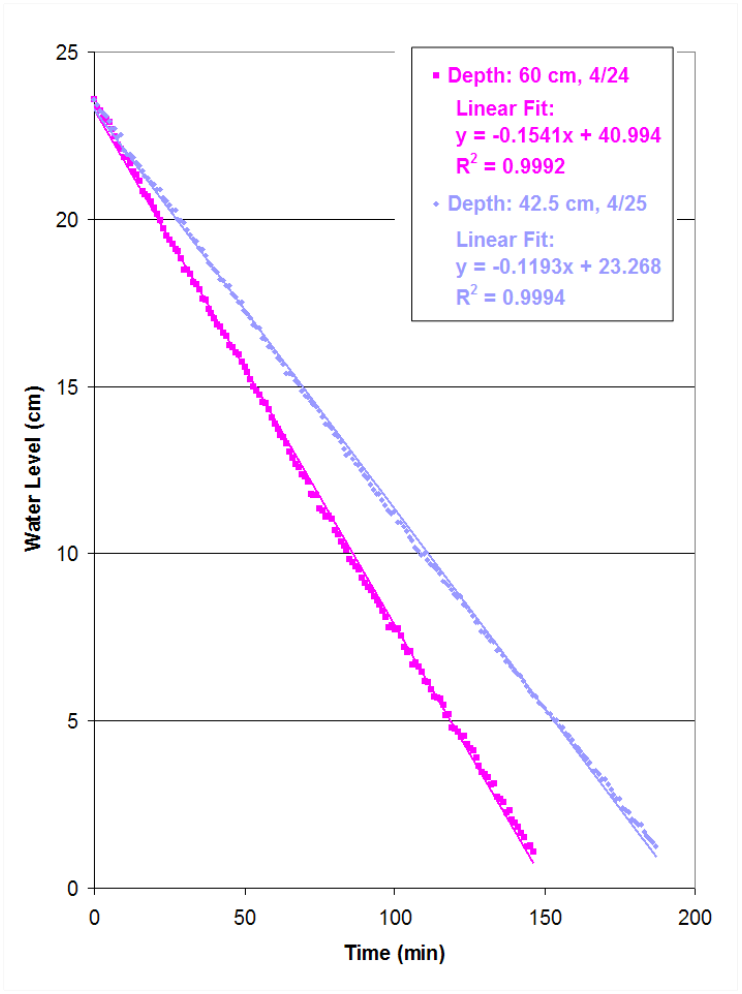

Figure 4: Water level in bubble collector vs. time, using Sand 40 as filter media. Flow rate: 345 mL/min, Bed Expansion: 50%

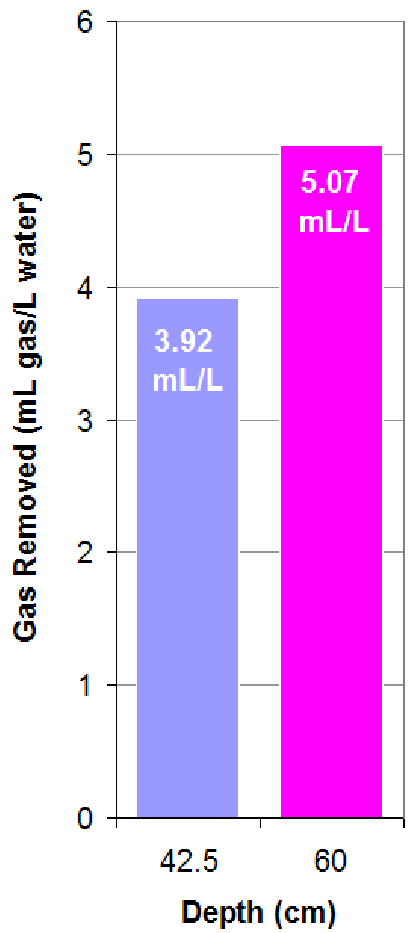

Figure 5: Dissolved gas removal for Sand 40 at different depths. Bed Expansion: 50%

Click here to download the results from this experiment (Excel workbook).

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Figure 6: Theoretical bubble formation potential as a function of the air pressure that the water equilibrated with prior to returning to atmospheric pressure.

The results from the laboratory tests can be compared with a model of the bubble formation potential (Figure 6). The model predicts that if the water had been previously exposed to air at two atmospheres of absolute pressure, that the bubble formation potential would have been 18 mL/L.

Conclusions

It is evident from the data collected that the glass beads removed more air per liter of water than the two sands, and that the smaller sand size was more effective than the larger. This makes sense since smaller grain sizes have a larger surface area to volume ratio, and thus per volume, provide more surface area on which bubbles can form. However during the experiments, we noticed that the glass beads tended to float to the top of the column with the bubbles that formed around them. Though the beads could not leave the column because of a screen at the top, in an actual grit chamber, they would float out into the rest of the plant, resulting in significant sand loss over time. So although the beads' size was the most effective at gas removal, we concluded that they were just too small to be realistically implemented at the treatment plants. The smaller sand grains, however, were not as easily lifted away by the bubbles and thus provide a more feasible solution.

In addition to sand grain sizes, we also experimented with the effects of sand bed depth on gas removal and found that greater bed depths resulted in better gas removal. Again, this is likely due to the larger amount surface area provided. However, we would like to minimize the amount of sand required to obtain an acceptable gas removal rate in order to minimize the cost of implementation. Thus, further experimentation with this parameter is required to determine the optimal sand bed depth for the sand grain sizes tested.

The team's future research plans are to further explore the effects of sand bed depth, flow rate, and bed expansion on gas removal. After more data has been collected, the team will focus on mathematically modeling the process on MathCAD and implementing a sand filter at the Pilot Plant.