Group 6 Research Report

A New Approach to Aerator Design

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Abstract

The team was tasked with the challenge of developing a compact aeration system catered toward the issues experienced in Ocotal, Nicaragua. Although inspired by a venturi aeration system, the team eventually developed an open U-tube apparatus that produced bubbles and promoted oxygen residence. However, the scale at which the experiments were performed and the method in which water was introduced into the system proved troublesome. The team concluded that split-flow interface introduction was a promising path and requires more investigation at higher flows and less size constraints.

Please refer to Group 6 CEE 4530 Final Presentation for videos of various experiments performed.

Introduction

The problem that the team will seek to solve is the aeration situation of the Ocotal plant in Nicaragua. The facility that currently stands in Ocotal will be replaced by an AguaClara plant and is assumed to contain an aerator in the treatment train. However, available head is not sufficient to power a traditional cascade style aerator. Therefore, more investigation is needed in order design a performing aerator that may be catered to the plant's constraints.

Monroe recommended that the plant operators count the LFOM as an aeration system and that they enhance the performance of the LFOM as an aerator by extending the LFOM tube to the bottom of the flocculator so that it carries the entrained bubbles deeper. The core idea is that one wants to maximize the residence time of the bubbles in the water because it was learned from the aeration lab that 97% of the oxygen was still in the bubbles when they escaped from the reactor.

Initially, a venturi system was proposed for the introduction of oxygen without the need for active air pumping. A venturi works by providing a constriction in a flowing fluid, increasing velocity and decreasing pressure at the point in which the channel narrows. This decreased pressure promotes the inflow of oxygen from the atmosphere as a result of the produced vacuum effect.

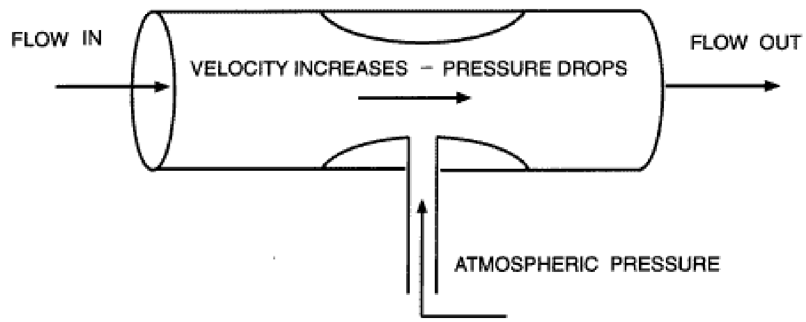

Figure 1: The venturi system creates a pressure difference within the piping which causes air to flow into the fluid and thus aerates the system.

While a venturi may replace the free fall cascade effect of the LFOM, it may prove difficult to keep the bubbles in suspension for a long time throughout the length of the reactor. Thus, the team experimented with various air injection systems such as an air stone and eventually a high pressure jet.

In order to align with the mission of AguaClara, it would be invaluable to invent a hydraulically driven aerator in which the gravitational potential energy is utilized to power the system, and does so with great efficiency.

Objectives

The driving hypothesis behind this research proposal is that a hydraulically-driven aeration system can perform at comparable efficiencies to that of an electrical powered plant. By modeling various scenarios of oxygen introduction and bubble sequestration, the team hopes to achieve an acceptable aeration rate.

Experimental Plan

Experiments to test the efficiency of the aerator will be tested on a benchtop scale tentatively using a PVC tube reactor. In order to test the efficacy of aeration, DO probes will be placed at the influent and effluent stream of the water flow in order to gauge the performance of the system.

The team intends to fine tune the experimental setup based on what is learned from experimental trials. Below are questions that the team seeks to answer:

1. What determines the required residence time?
2. What is important about the geometry of this proposed reactor?
3. Should flow be horizontal or vertical up or vertical down?
4. What determines the optimal velocity of the water?
5. Is there a way to make a reactor more compact?
6. Is there a way to break up large bubbles into smaller bubbles?

Key Design Parameters

1. System flow rate
2. Reactor length
3. Reactor diameter
4. Headloss (orifices, peizometric, etc.)

Timeline of Tasks/Experiments

- 4/16: Develop a working benchtop system to begin flow and constriction tests
- 4/23: Present a robust model of the benchtop model regarding flow aeration
- 4/30: Manipulate the model in order to maximize bubble retention and overall aeration performance
- Final presentations of the experiments and results

Possible Hurdles/Challenges

- Access to data to compare the efficiency of a hydraulic system to the already-implemented aerator in Ocotal
- Developing a consistent testing system for the reactor's performance
- Providing an appropriate amount of water for the experiments

Resources Needed to Conduct Experiments

1. Electric drill
2. Peristaltic pumps (600 RPM)
3. PVC piping (from AguaClara lab)
4. 2 DO probes (if time permits DO testing)
5. Plastic sheets
6. sulfite and cobalt items to deoxygenate water (if time permits DO testing)
7. push-to-connects (adapters as well)

Expectations/Anticipated Results

The team expects that a working model for aeration system will perform relatively well; however, it is unlikely that the team will be able to reach the point of development to produce an elegant prototype given the time constraints for the project. It is expected that the team will find valuable data to give insight into the value of pursuing this type of research.

Procedures

The team moved through a series of preliminary steps before beginning the fabrication. To begin, there were several calculations to perform to understand the effects of specific constraints and how these parameters influence expected performance. After calculations, the team created a **schematic** for the anticipated experimental setup. This experimental plan was modified significantly as a result of several experiments that revealed new insights. These included the following:

1. **Aeration stone experiment** to observe the efficacy of sequestering bubbles introduced from an aeration stone.
2. Testing the efficacy of a **active aeration** into the system by means of pumping
3. **Air diffusion** testing
    - Closed system: plugged
    - Open to the atmosphere
4. **Analysis of dual-interface interactions** through varying water flow methods
    - Sidewall introduction of water into the surface
    - Direct impingement of the stream into the surface
5. **Split-flow** to maximize the sequestering of bubbles while still allowing a sizeable exit velocity for expended bubbles
    - Large orifice nozzle
    - Small orifice nozzle

Preliminary Calculations

The team began with a simple experiment through an aeration stone similar to the aeration lab done earlier in the semester. The purpose of this was to observe how large the average bubble was. By determining the diameter of a bubble, one could then find the resulting upflow velocity in a fluid (in this case water). This relationship can be described by the following relationship:

$$ Vt = \sqrt{\frac{4g}{3Cd}\frac{\rho_{particle}-\rho_{H2O}}{\rho_{H2O}}} $$

With this upflow velocity known, the team then knows the minimum downward velocity needed within the apparatus to retain bubbles in the system. After a short trial of the aeration stone with a airflow of 200uM/s, the diameter of the average bubble was about 4 mm.

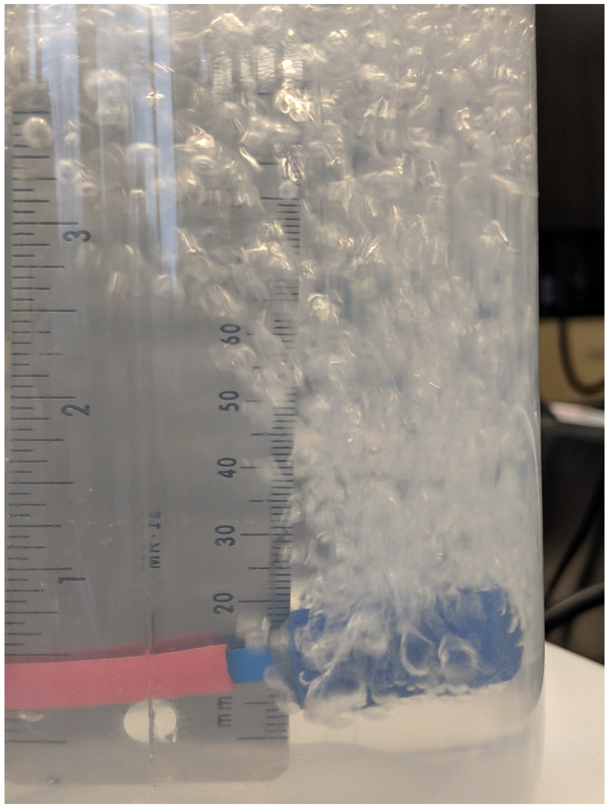

Figure 2: The aerator stone at an airflow rate of 200 uM/s made bubbles about 4 mm in diameter. This bubble size was used to calculate the upflow velocity.

This method of sizing bubbles based on observations proved to be difficult due to a lack of a precise measurement device to directly calculate the diameter of the bubbles. To circumvent this issue, the team recorded video of the bubbles being produced by the aeration stone and placed a ruler behind the stone for reference of scale. By stopping the video at random intervals and recording the size of a select number of bubbles, an average bubble size was calculated for the system.

Below are the calculations that followed this known value.

```
from aide_design.play import*
import Environmental_Processes_Analysis as EPA
import importlib
importlib.reload(EPA)
import scipy
from scipy import special
from scipy import stats
from scipy.optimize import curve_fit
```

```
import collections

d_bubble = 4*u.mm #diameter of the bubble
rho_air = 1.225*u.kg/u.m**3 #density of air
rho_water = 997*u.kg/u.m**3 #density of water
Cd = .6  #drag coeff (several iterations with Reynolds number were performed to get thi
Nu = 9.554*(10**-7)*u.m**2/u.sec  #viscosity at 22 C
Vt = -np.sqrt((4*pc.gravity*d_bubble*(rho_water-rho_air)/(3*Cd*rho_water)))
Re = (Vt.to(u.m/u.s)*d_bubble.to(u.m))/Nu
>> Re = 1235 #this is a good Reynolds number to correlate with the drag coeff of 0.6
>> Vt = 0.295 m/s

d_tube = 0.5*u.inch
A_tube = pc.area_circle(d_tube)
Q = -1*Vt*A_tube
Q.to(u.mL/u.s)

>>Q_needed = 37.378 mL/s
```

With this flowrate known, it was necessary to understand which dimensions were appropriate for the apparatus. If the headloss is too high, the apparatus would not experience the flow rates necessary to keep the bubbles down and maximize residence. Below are the calculations that were performed to investigate minor headloss in the push-to-connects and major headloss in a 1 meter long tube (the apparatus will be composed of this).

```
#headloss Calculations through a different push-to-connects
pi_orifice = .62 #empirically known vena contracta coefficient
d_orifice_1 = .17*u.inch
headloss_1 = pc.head_orifice(d_orifice_1, pi_orifice,Q )
headloss_1
d_orifice_2 = .25*u.inch
headloss_2 = pc.head_orifice(d_orifice_2, pi_orifice,Q )
headloss_2
l = 1*u.m

d_pipe = 1*u.m
headloss_major = pc.headloss_fric(Q,d_pipe,l,Nu,.01*u.mm)
headloss_major
```

It was found that the 0.25 inch push-to-connect was appropriate for the experimental apparatus in order to avoid significant headloss in the system. Furthermore, headloss due to friction in the tube was not significant enough for issues to arise.

Initial Schematic

Figure 3 is a schematic of the teams anticipated apparatus at the beginning of the experimentation phase.

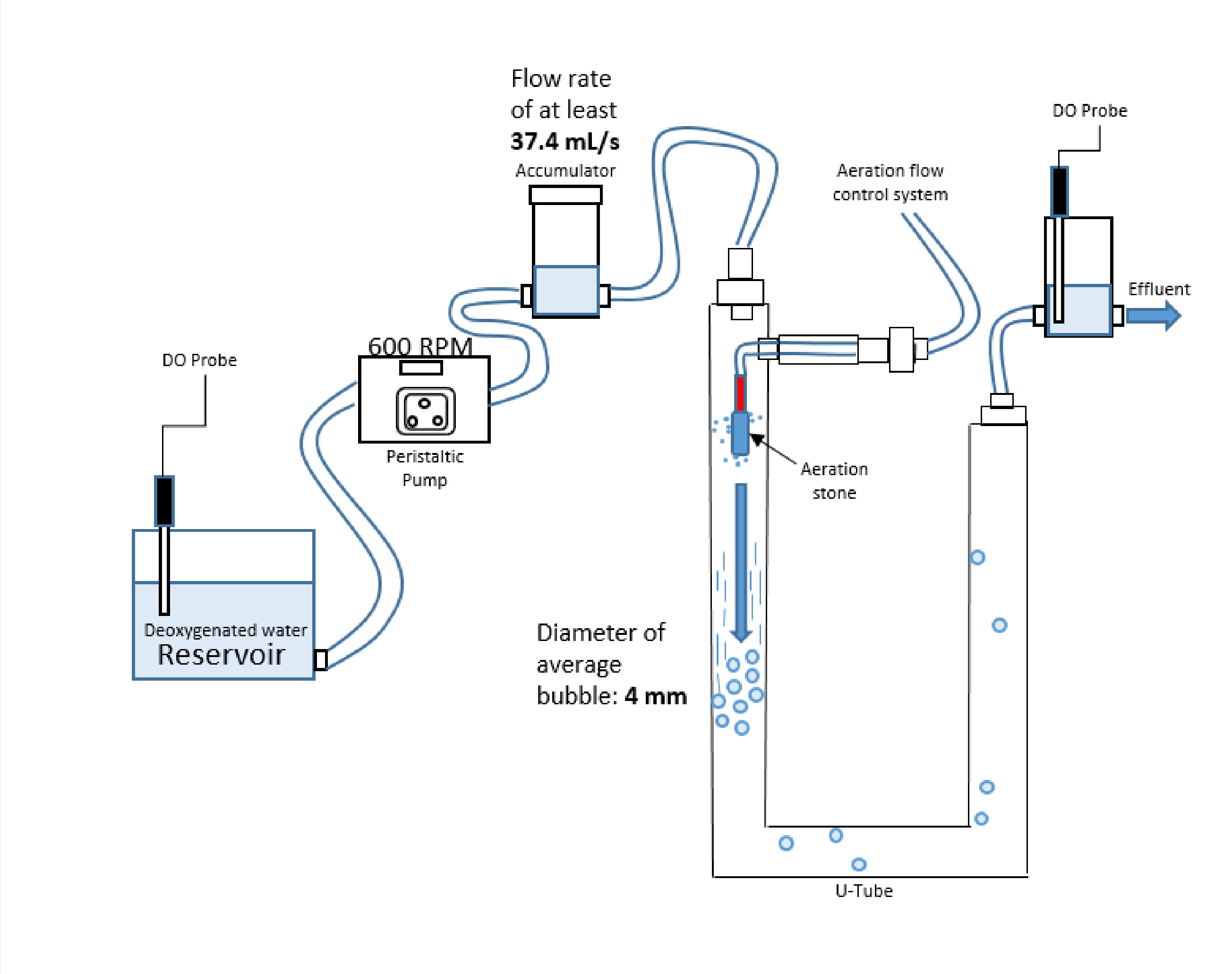

Figure 3: The initial schematic for aeration experiments

It consisted of a U-tube composed of 1 inch diameter clear PVC piping which each side 4 feet tall. Deoxygenated water (with DO tracked through a DO probe) would be supplied from an independent reservoir. This water would then be pumped from the reservoir to the U-tube with a 600 RPM peristaltic pump capable of pushing 37.4 mL/s of water. The accumulator before the U-tube functions as a "cushion" from the pump to create a steady flow rather than pulses.

Within the U-tube, the aeration stone would introduce air into the system. This aeration system used would be identical to the one used in the aeration lab performed earlier in the semester as seen in **Figure 4**.

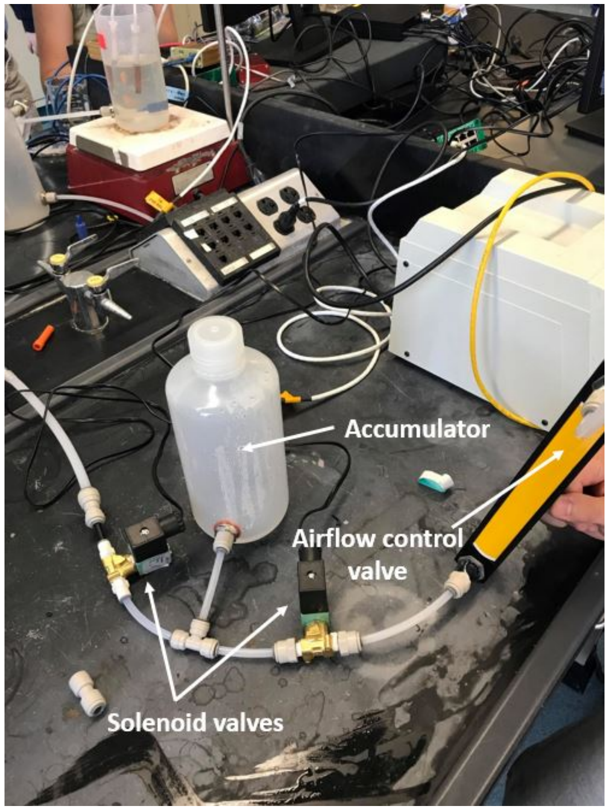

Figure 4: The aeration setup was initally identical to the aeration lab performed earlier in the semester. Solenoid valves were operated through ProCoDA to achieve a desired airflow rate and the accumulator provided the necessary pressure.

Bubbles of 4 mm would be pushed down into the depths of the U-tube and therefore aerate the influent. The aerated water would then leave the system and enter another reservoir where DO would be measured again.

Experiments and Analysis

Initial Experimental Apparatus

Before the team could implement DO probes and accumulators into the system, the behavior of the bubbles and the overall functionality of the apparatus as a means of sequestering bubbles had to be tested first. The following are the subsequent experiments to investigate this aspect. These experiments lead the team to ask more questions than it did to help answer others. As a result, the DO probes and accumulators were never implemented into a final fabricated design.

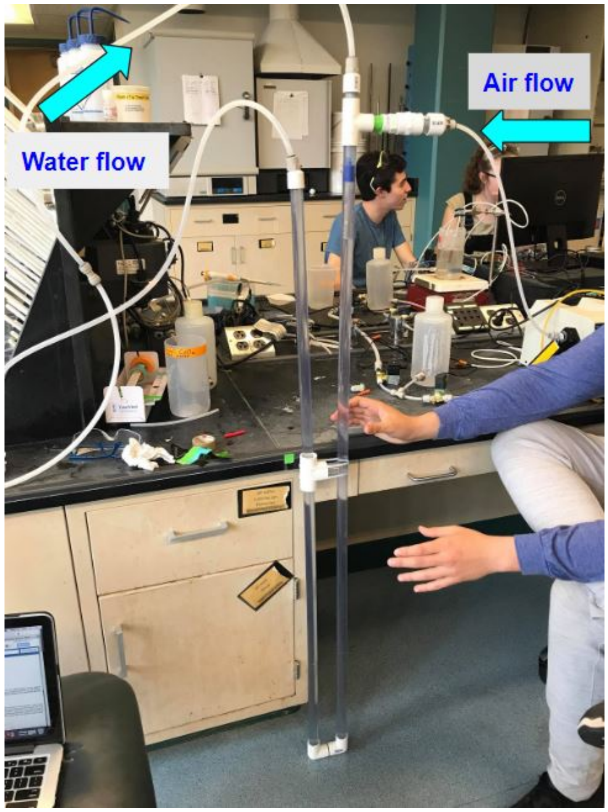

Figure 5: The overall apparatus deviated from the initial schematic. There were no DO probes and no accumulators. Water was supplied into the top of the apparatus and kept bubbles from the aeration stone from rising out of the top.

Aeration Stone Experiment

The ultimate success of this experiment would be determined by the extent with which a selected size of bubbles remain in the system for extended residence times, while exiting the system after their oxygen had been depleted during the oxidation of the influent water.

In this trial, the aeration stone was set directly in the path of the influent water stream. The theory behind placing the aeration stone in the flow of water was that this method would allow for the bubbles to become immediately sequestered within the reactor without having to worry about losing any of the bubbles to the surface of the air-water interface.

Contrary to the theory, the aeration stone created a variety of issues with the experimental trials. The presence of the aeration stone impeding the flow created an obstacle that would require an unrealistic flow rate of water in order to bypass the impedance that the aeration stone presented. Due to the obstruction, a great deal of back-pressure was produced, making it impossible to provide consistent airflow into the system, even with a set pumping speed with ProCoDA.

The presence of the aeration stone additionally produced an unexpected interface of bubbles which inhibited bubbles of the team's selected size from forming. As a result, it was concluded that an alternative means of aeration would be necessary in order for this experiment to be successful.

The team decided to switch to the active pumping of air with a peristaltic pump rather than controlling solenoid valves through ProCoDA. The idea behind this was that the continual pumping of air would be able to combat the high pressures that the aeration stone was experiencing.

Figure 6: The solenoid valves were replaced with a peristaltic pump which actively forced air from the aeration stone. This was implemented in order to combat the high pressures that the aeration stone was experiencing and the resulting inhibition of bubble introduction.

Air Diffusion

In the previous trials of forced aeration using an aeration stone, it was decided that an alternative means of aeration would need to be investigated due to the problems it presented. Even with a peristaltic pump introducing air, the aeration stone experienced backup and water ended up in the accumulator. The following trials were conducted in order to determine if forced aeration would be necessary, or if passive aeration could achieve the desired result.

The first trial analyzed the system closed to the atmosphere by plugging the aeration port where the air was initially pumped through the stone. After running the experiment, the system eventually became full with water and no air was introduced into the reactor.

Figure 7: The aeration portion of the apparatus was plugged in order to investigate whether air was being introduced into the system by passive introduction. However, without active aeration, no air was introduced.

The second trial involved opening the reactor to the atmosphere by allowing for air to enter into the reactor through the air port, pulled in by the negative pressure produced from the flow rate of the influent water. This was successful, but the positioning of the snorkel tube was critical to maintaining consistent performance. Furthermore, at higher flow rates, the snorkel tube acted like a "water gun" as the high pressures forced water out the aeration stone rather than into the apparatus. As a result, the team concluded that it would be possible to passively aerate with the reactor being open to the atmosphere and to use the force of the influent water to produce the size of bubbles required for optimal aeration.

Figure 8: Opening the aeration port to the atmosphere with a snorkel tube allowed water to be introduced through the aeration stone at moderate flow rates. However, if pressure become too high, the aeration stone experienced backflow of water rather than an inflow of air.

Analysis of Dual-Interface Interactions

The first attempt at flowing water into the system as a reactor open to the atmosphere was to position the influent tube such that water would run along the tube until reaching the surface of the water. Under these conditions, bubbles were produced and the results were consistent between trials. However, the flow lost too much energy to the walls of the reactor, and thus produced a low density of bubbles which would not be sufficient for aeration.

Since the flow along the walls of the reactor did not contain enough energy to disrupt the surface of the water, it did not produce a sizeable quantity of bubbles. The team's solution to this was to aim the influent stream at the center of the water's surface to direct the greatest amount of energy into a concentration target. This method produced a high number of bubbles, but a complicated interface developed as a result of unexpected flow and wall interactions. The series of interfaces were as follows: the water flowing at the surface of the water created a great deal of bubbles with large diameters, which then led to a void space of air in which the water flowed along the walls, until it reached the final interface at a uniformly filled tube of water.

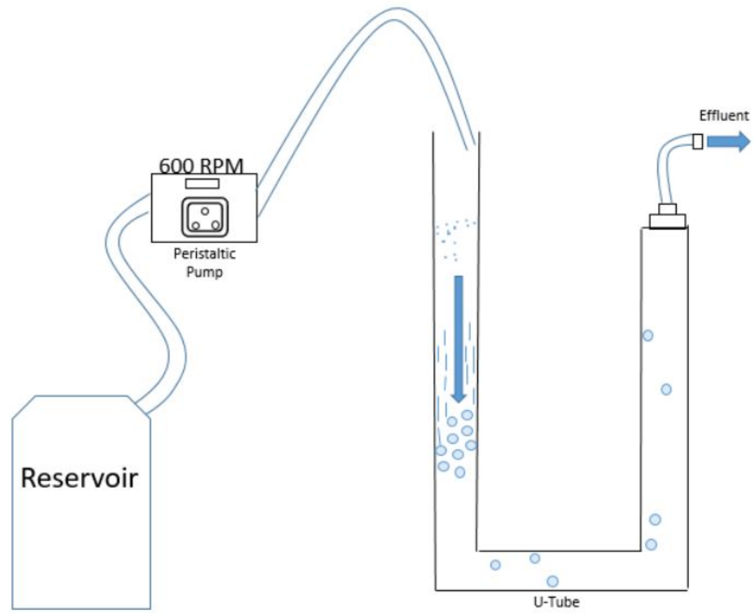

Figure 9: Flowing water along the sides of the reactor did not produce a sufficient amount of bubbles. Aiming the water directly at the surface of the water produced a complex multi-interface interaction within the reactor which led to inconsistent and poor results.

In both trials, bubbles were formed, but a variety of problems ensued as a result of these methods. Most bubbles were lost to the surface, and in the case of the direct flow to the surface of the water, a strange interface resulted which disrupted the experiments. Given these results, the team decided that the introduction would need to be refined, and to do so, a combination of flow methods would be necessary to produce the best results.

Split-Flow

In order to refine the water introduction method, the team decided to split the influent. By doing this, one part of the flow was dedicated to producing bubbles directly at the air-water interface while the rest of the flow provided the remaining flowrate needed to sequester the rising bubbles. This direct flow consisted of a nozzle in order to achieve a finer flow and thus produced smaller bubbles. The supplementary flow was referred to as the "bulk flow" and contained a valve which allowed the team to manipulate how much water was flowing through it. By constricting this flow more, a finer and faster flow could be introduced through the nozzle and therefore create a higher number of smaller bubbles.

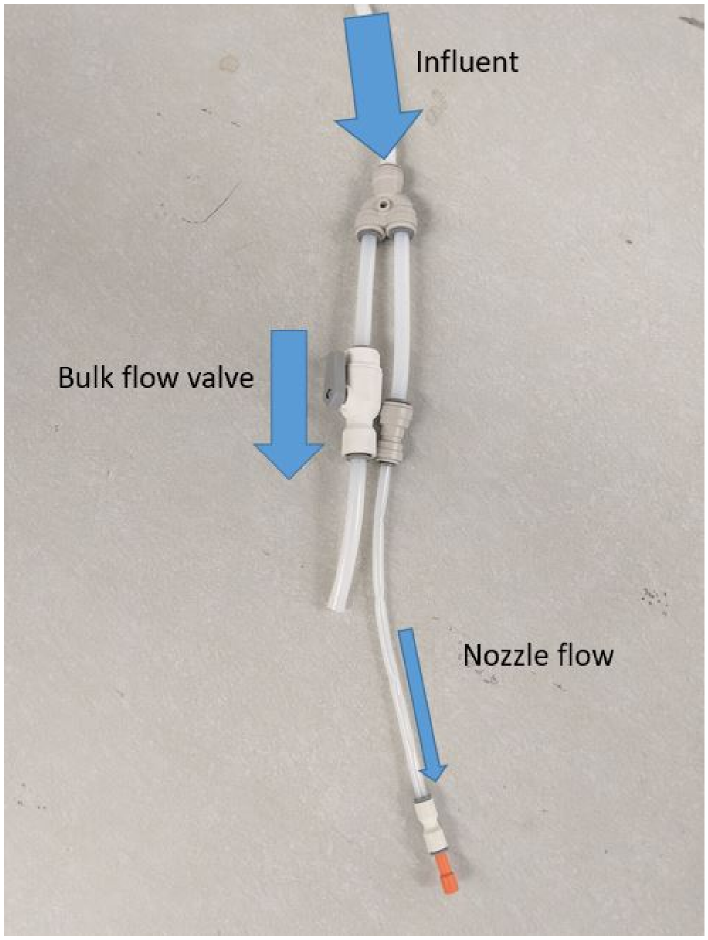

Figure 10: Splitting the flow enabled a balance of sequestering bubbles in the reactor with long residence times while producing a large quantity of bubbles sufficient to the optimal size constraints.

This method of water introduction seemed most successful. The initial nozzle size created sufficient bubble sizes that were finer than previously seen in other experiments and in greater number. However, the team wished to see the effects of a smaller diameter nozzle.

After making the nozzle smaller, it was clear that the team was on the correct path of investigation. Bubbles were even smaller and were made in greater quantities. Finding the "sweet spot" of the bulk flow valve created a unique balance between bubble production and sequestration. However, the system was still not efficient enough. The bulk flow failed to keep all bubbles that were formed down in the apparatus due to bubbles being produced at a greater rate than the bulk flow could be supplied.

The team concluded that the scale in which the experiment was being performed was insufficient for the issue being investigated. Higher flow rates were needed to achieve a desired number of bubbles in the effluent. Furthermore, when the constricted flow was pushed to an absolute maximum, the water pumping system could not handle the pressure in the split-flow system. This caused a system blowout where peristaltic tubing failed to resist the pressurized flow. Also, the limited space characteristic of the apparatus' inner diameter caused unwanted wall interactions observed in other experiments.

Since the lab space could only supply a 600 RPM pump capable of producing a maximum of about 36 mL/s, future experiments may need to be performed with a sump pump (or necessary equipment) in order to achieve necessary flow rates.

Conclusion

The team found that the best method of achieving both desirable bubble formation and sequestration was through a split-flow method. Unlike the other experiments performed, the split-flow experiment produced finer bubbles and a denser concentration of bubbles in the effluent branch of the U-tube. The team believes that complications in this design lay in the overall scale in which the apparatus was being tested. To successfully sequester all formed bubbles and maximize retention time, this experiment must be performed at high flow rates that the resources of the Environmental Research Lab could not make available. Also, the apparatus itself must be larger in order to avoid the unwanted wall interactions observed throughout experiments.