Team Third Photo, Spring Semester 2018

Julian Claudio

With help from Michael Sandoval, Dillon Kidd, Alastair Crowe, Ben Roberts, and Ty Gunnlaugsson.

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The purpose of this image is to show the flow characteristics inside of a straight, circular section of glass tube. This team third picture was taken on the same test stand that I used for the team first video. Over the semester, my team and I had a lot of time to improve our visualization technique and also improve our skills at capturing the flow with high speed cameras and with DSLR cameras.

Before explaining the setup of the flow, I will first explain the images purpose and the post processing involved with the image. Below is the original image:

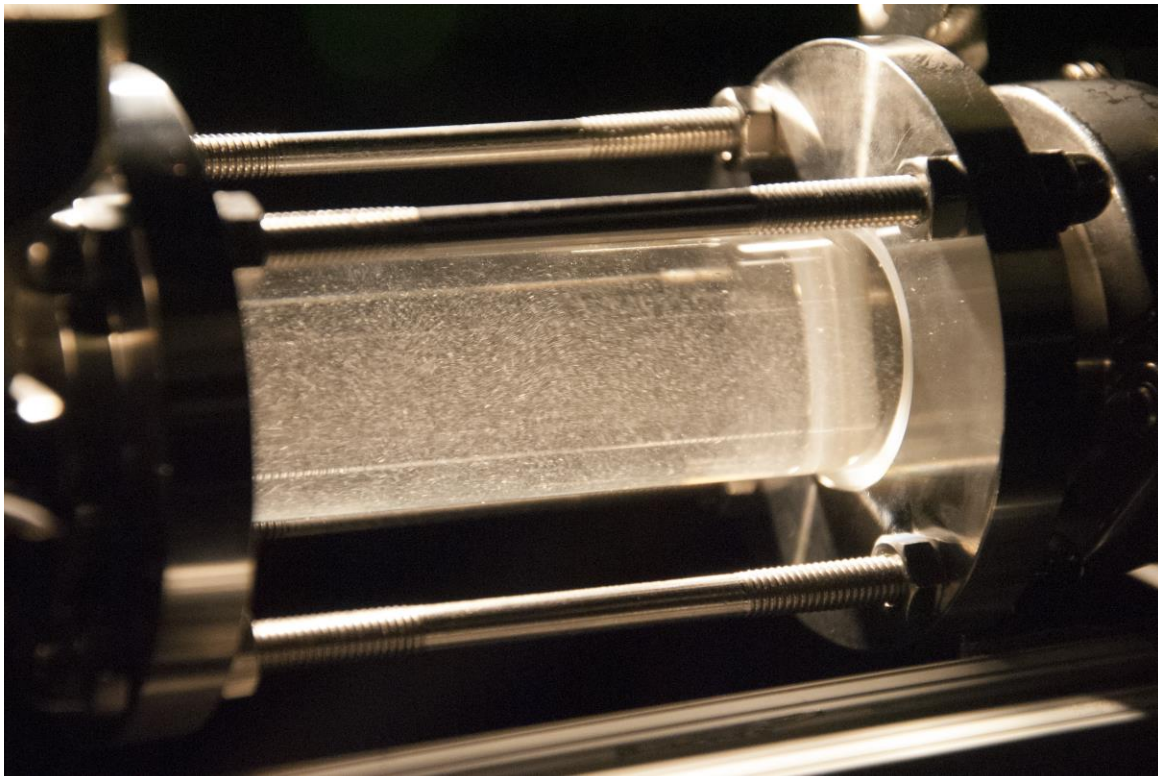

Figure 1. Original image

This image didn't require much post processing, the background was already very dark since the shutter speed was so high, and the lighting was good enough to show the subject very well. So, what I did was crop out a small portion of the sides and the foreground to limit distractions in the image. But, I thought that seeing the sight glass was valuable to the photo. Removing too much of it would take away from the overall perspective of the photo. So, with some minor cropping and slight adjustments to the brightness, this is the final image:

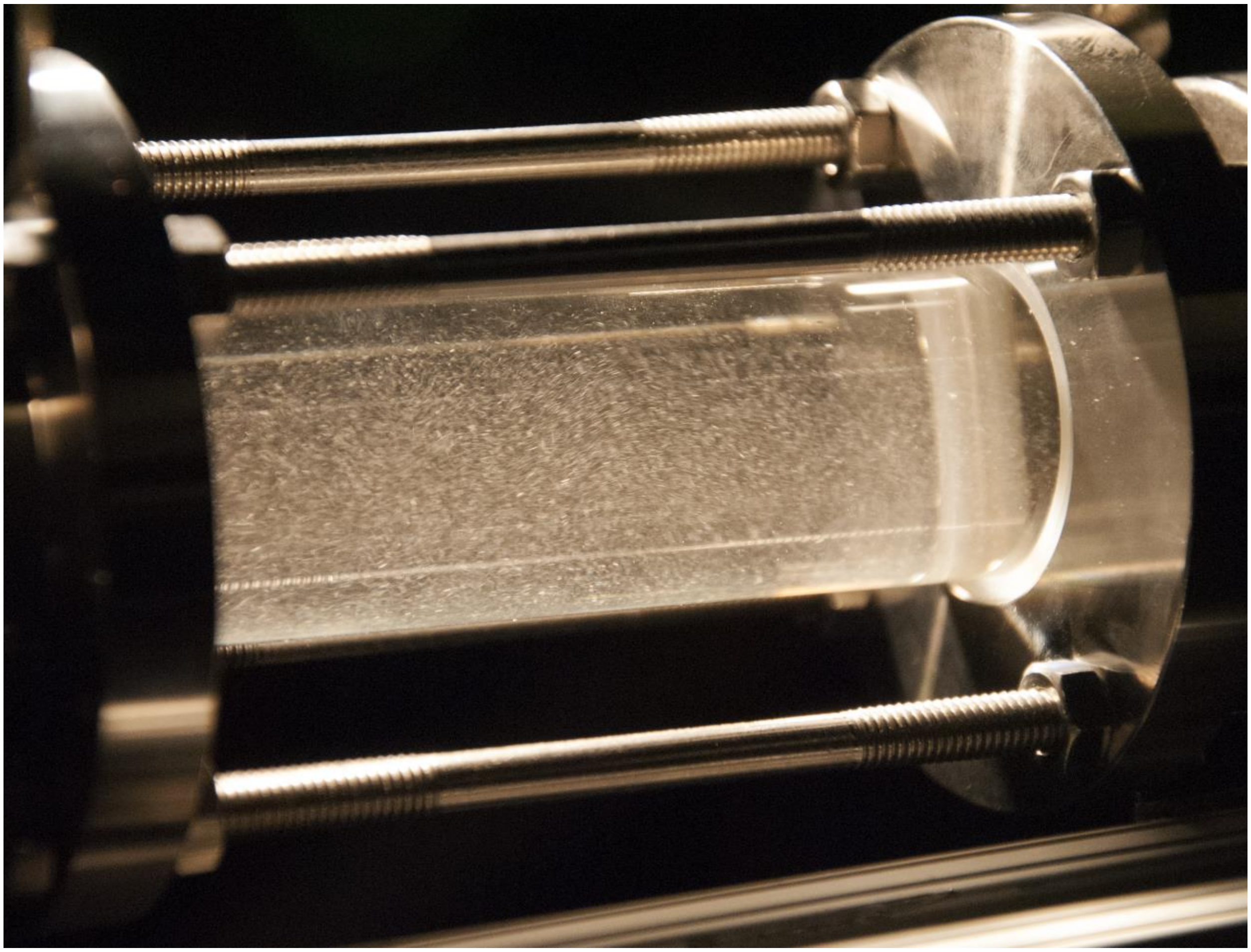

Figure 2. Edited photo.

This image doesn't seem to look much different than the first, but when switching between the two, I like that the section with the bubbles seems bigger and more important with the edits. I thought this image did a good job of highlighting the bubbles without losing too much of the context of the sight glass.

To fully explain the setup of the flow, I will need to explain the setup and the cameras. Then, I will explain the tested flowrates. Finally, the reason and methodology of using microbubbles to visualize flow. Below is a SolidWorks 3D model to show the components of the stand.

I. Test Stand

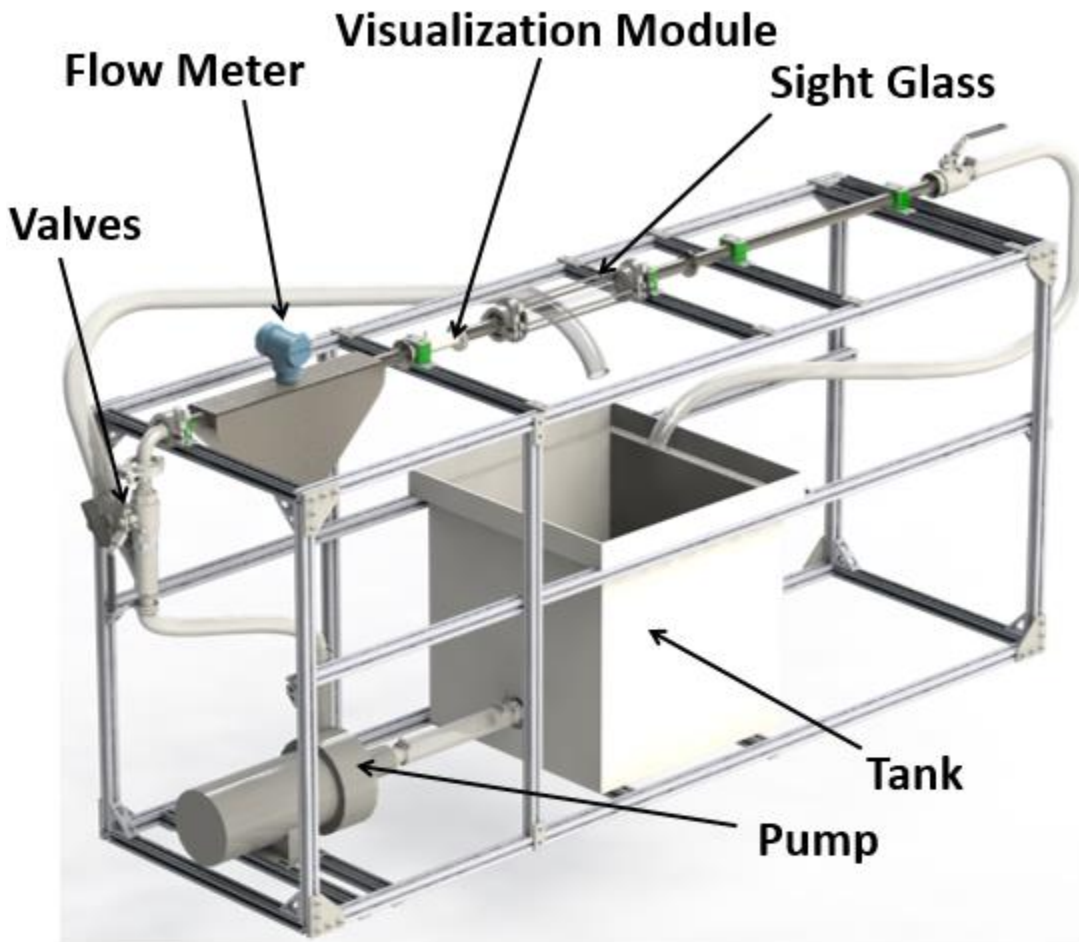

Figure 3. SolidWorks render of the test stand setup.

Below is the actual setup, it is important to note that the actual setup is slightly different than the SolidWorks model. The flow meter is at the start of the flow because this will guarantee that we get an accurate flow rate. If the flow meter sits after the cavitation tube, then it will not read the flow accurately since the cavitation tube causes the formation of bubbles. The bubbles affect the accuracy of the measurement from the flow meter. The size of our visualization section is 6 inches, which is the section that was filmed for the video. The stand itself has overall dimensions of 6’ x 2’ x 3’.

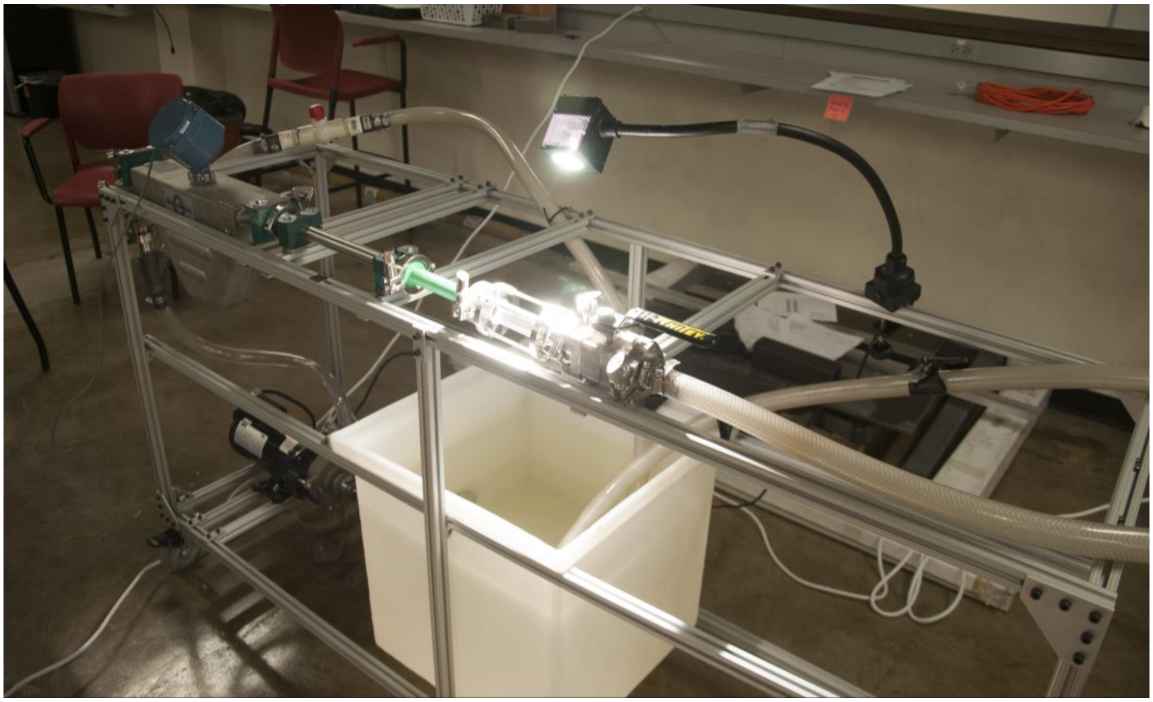

Figure 4. Test stand setup.

This setup uses a flow stand that my senior design team constructed to visualize flow for Micro Motion Incorporated. Water leaves the tank, gets pumped through to the valve section where the flow speed is controlled. After the valves, the water flows through the flow meter which records the speed of the flow. The water then moves into a cavitation tube where it is dropped below its vapor pressure to produce tiny bubbles. These bubbles trace the flow very well since they are so small, but more on that later.

II. Camera

The picture was taken using a Nikon D3000 at a shutter speed of 1/4000 with an aperture of f/5.6, this was so that the camera could get as much light as possible but also capture the image at the fastest speed possible. The bubbles were moving through the sight glass at a volumetric flow rate of 10 gallons per minute, I will elaborate more about the flow rates in the next section.

I took the photo with a 105 mm lens, as shown in **Figure 5** we can see how the field of view of the camera can be calculated using the focal length and the viewing angle. The focal length of the my specific 105 mm lens is 8.76 inches, and the viewing angle is 94 degrees. This gives a field of view of 10.44 inches at the minimum focal distance. I estimate that I was standing about 9 inches away from the subject so that I could get the best picture of the bubbles. This makes the field of this image around the calculated 10.44 inches that I calculated.

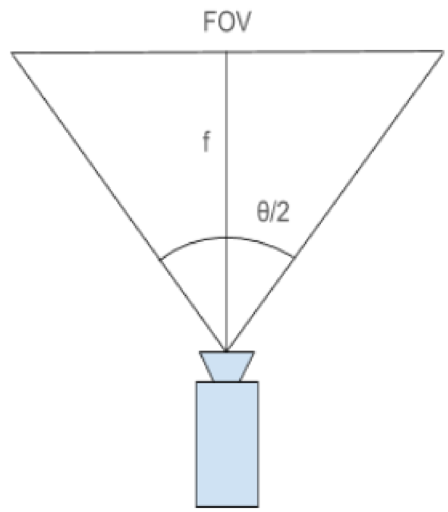

Figure 5. Field of view for a camera using its focal length (f) and viewing angle (θ).

III. Flowrates

The flowrates that I chose were based off of the Reynold's number for water. Reynold's number can be used to determine if a flow is laminar, transitional, or turbulent. Laminar flows are uniform and at Reynold's numbers lower than 2400. Turbulent flows are at Reynold's numbers above 4000 [2]. Anything in between can be considered transitional. Reynold's number can be calculated using:

$$Re = \frac{v * D}{\nu}$$

Where v is the one dimensional velocity of the flow, D is the diameter of the pipe, and ν (nu) is the kinematic viscosity of water. The pump outputs the water at 1 gallon per minute, a volumetric flowrate. So, I converted the flow to a linear velocity by dividing by the cross-sectional area of the pipe:

$$v = \frac{Q}{A}$$

Where A is cross-sectional area and Q is the volumetric flowrate:

$$A = \pi * (D/2)^2$$

Therefore:

$$v = \frac{Q}{\pi * (D/2)^2}$$

Plotting this relationship shows where the flow is laminar. I plotted Reynold's number on a logarithmic scale to make it easier to visualize with this graph:

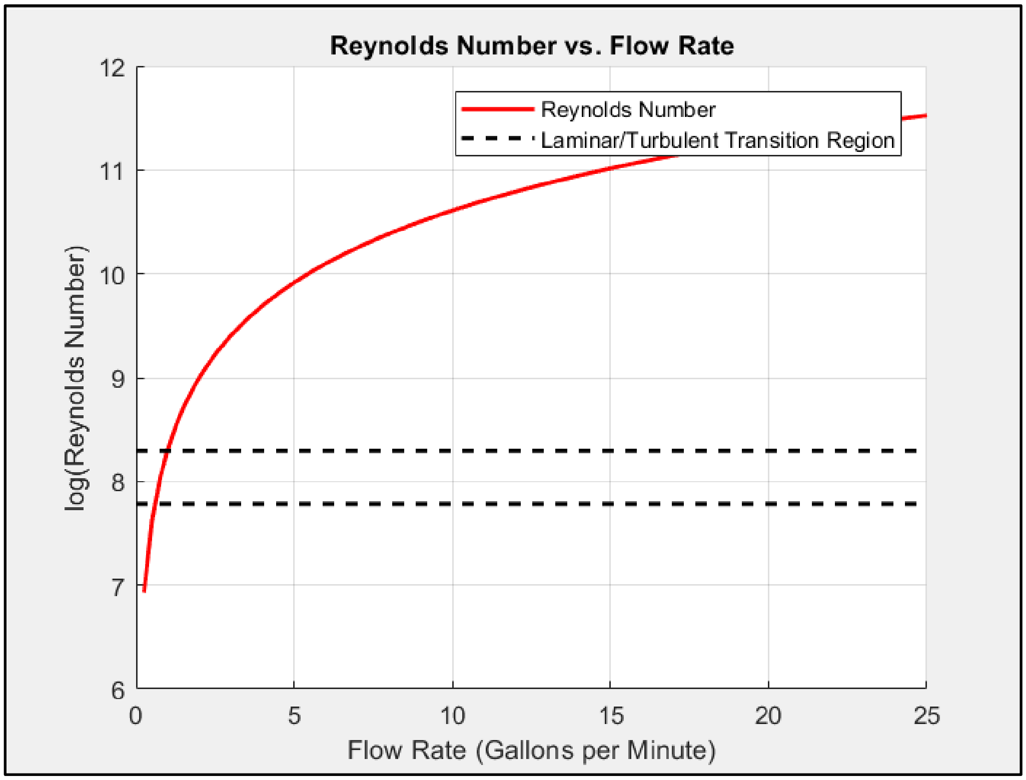

Figure 6. Graph of Reynold's number versus the volumetric flowrate on a logarithmic scale.

This picture was taken at a flow rate of 10 gallons per minute, which gives a Reynold's Number of 40,505. This number is well above the turbulent Reynold's number for water. This makes sense, as we can see in the photo there are lots of swirls in the water and there is no specific bullet profile that we would expect to see in laminar flow. The bullet profile is shown below, this is a velocity "bullet" that you expect to see when flow is stable. If we compare this to the image, we can see that the flow is not behaving laminar at all.

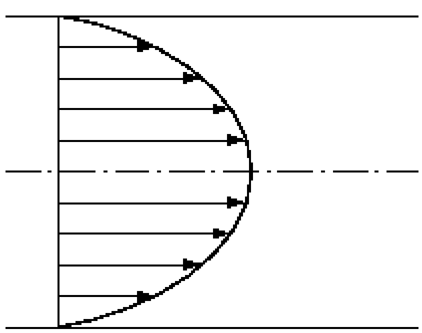

Figure 7. The laminar "bullet" profile. [1]

IV. Method of Visualization

Microbubbles were chosen to visualize this flow because they are small enough to negate the effects of buoyancy, meaning they won't rise to the top of the sight glass.

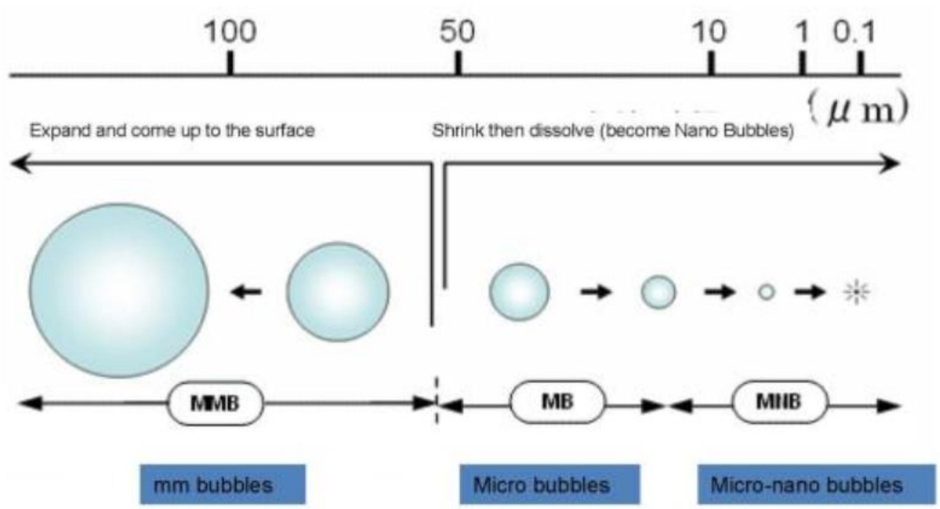

Figure 8. The effects of bubble size on buoyancy.

Venturi cavitation tubes work by flowing liquids through a constricted section which causes the velocity to increase that's calculated by setting the mass flow rates equal to each other:

$$V_1A_1 = V_2A_2$$

where point one is a reference point with the same mass flow and point two is the parameters in the constricted section of the tube. This increased velocity causes a pressure drop due to the Bernoulli's equation. We dropped this pressure to the vaporization pressure of water. The idea was to bring the water to the point of cavitation, this caused some vapor bubbles to form and drew out air bubbles from within the water. This pressure wasn't maintained, so the bubbles that you can see through the sight glass are actually air bubbles rather than the vapor bubbles caused by cavitation.

$$P_{cav} = P_{ref} + \frac{\rho}{2} * (V_{ref}^2 - V_{cav}^2)$$

By setting the reference pressure equal to zero, the pressure drop that occurs in the Venturi cavitation tube was calculated for various flow rates that the test stand will operate at, as shown below:

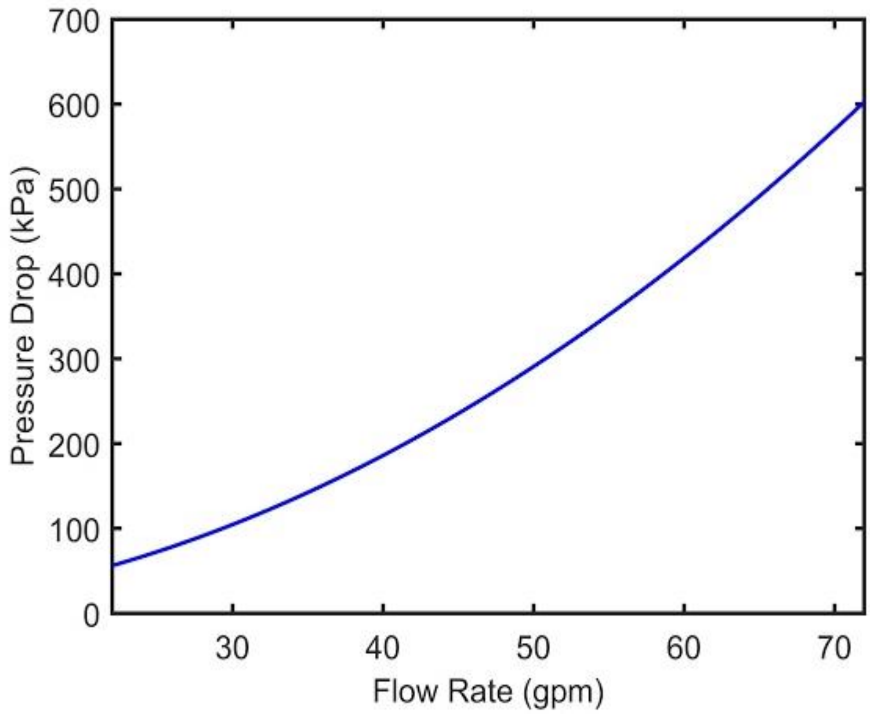

Figure 9. Pressure drop required to cause cavitation in the tube.

For 1 gallon per minute, the required pressure drop is 88 kPa. This required the design of a cavitation tube that would cause this amount of pressure drop. By changing the cross-sectional area of the tube, we were able to achieve this pressure drop. The radius of the tube was decreased from .87” to .375” which caused cavitation in the flow. By using images of the sight glass, we could determine that the bubbles sizes were around 200 microns which is small enough to avoid the effects of buoyancy. This is seen in the video, the bubbles follow the flow well which confirms that they aren’t affected heavily by buoyancy.

V. Conclusion

In conclusion, this image accurately shows a turbulent flow through a straight sight glass. This is known to be accurate because a lot of work went into making bubbles that are small enough to trace the flow of the water through the section. This was done by dropping the pressure of the water below is vaporization pressure, then bringing the pressure back up. This drew out air bubbles from inside the water which stayed in the flow. The bubbles were brought out since the water’s pressure went to its vaporization pressure. Even though this pressure wasn’t maintained, we can still see that the pressure drop brought out air bubbles that remained in the flow through the test section.

VI. References

[1]: Scalar Transport. Dr. S D Harris, University of Leeds School of Earth and Environment. https://homepages.see.leeds.ac.uk/~amt6xw/Distance%20Learning/CFD5050TURB/node7.html

[2]: Transition and Turbulence. *The Engine and the Atmosphere: An Introduction to Engineering* by Z. Warhaft, Cambridge University Press, 1997. https://www.princeton.edu/~asmits/Bicycle_web/transition.html

[3]: Michaud, L D. "Venturi Cavitation Tube." Mineral Processing & Metallurgy, 17 Mar. 2017, www.911metallurgist.com/blog/venturi-cavitation-tube.