Fall 2019 Research Report

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December 11th, 2019
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My research experience this semester was dedicated to building a single-phase low-Reynolds-number flow loop at the Richmond Field Station Physical Model Test Facility. The objective of creating the flow loop was to be able to assess the function of an ultrasonic velocity profiler (UVP) by generating consistent and repeatable laminar (smooth) flow, so that the UVP may be tested under simple conditions (i.e. without complications from turbulence). It was important that the flow rate could be adjusted precisely (i.e. in small increments of a few gallons per hour). A UVP functions by emitting ultrasonic waves at an angle and processing the return signal that is reflected off of the object or flow of interest. In the case of this project, the UVP would be used to determine the shape of the fully-developed (parabolically-shaped) flow being emitted from the free end of the output pipe in the flow loop. Based on the specifications for UVP resolution, the UVP can read up to ten points per 7.4 mm of distance, meaning it is reasonable to find the shape of the flow leaving a pipe with 1" diameter. Generally, "a flow loop is a laboratory instrument for investigating the characteristics of fluid flow in pipes...the fluids are circulated continuously in a loop...Fluid properties, holdups, and velocities can all be varied" [1].

Prior to building the final flow loop, several weeks were dedicated to preparation. To begin, a reference spreadsheet was created with theoretical values for various flow parameters, including the Reynold's number, pipe diameter, and kinematic viscosity (which is dependent on temperature). These independent parameters were varied and used to create several sub-spreadsheets of values for the dependent parameters: velocity, volumetric flow rate, and entrance length. These reference values were used later on when determining the appropriate pipe diameter, the length of pipe needed to accommodate the expected entrance length, and approximately what flow rate and velocity to expect.

A timeline and preliminary parts list were drafted to ensure all components of the project would be completed in time. After researching flow loops and broadly understanding the parts needed, a few preliminary schematic diagrams were created and used to begin building a test flow loop. A large wooden crate lined with a plastic sheet was used as the main reservoir and had one ~10 ft long length of PVC (for the entrance length) feeding into the crate. The submersible pump inside the crate connected to a pipe, which connected to a gate valve and an Emerson coriolis flowmeter. The valve constrained the flow and allowed manipulation of the flow rate, while the flowmeter gave a reading of the flow rate in lbs/min, among other outputs. The coriolis flow meter consists of a transmitter and mass flow meter. The flow meter uses the coriolis effect to measure flow rate, among other parameters. One or more measuring tubes are caused to artificially oscillate by an exciter. When the fluid begins flowing in the measuring tube, sensors detect the additional twisting due to the fluid's inertia as a "phase difference" which directly corresponds to mass flow [2]. Flow meters can be used for both liquids and gases, are highly accurate, and can be used independent of the fluid properties or flow profile.

After completion of the test flow loop, the final design was started. A few changes were made for the final assembly: there was a switch from 1" pipe to 0.5" tubing to allow for flexibility as well as a smaller entrance length. Additionally, rather than using a gate valve, a platform of adjustable height was used in order to change the flow rate more precisely. This necessitated two reservoirs (tanks 1 and 2) and two aquarium pumps, with one of the reservoirs placed on top of the platform. By Bernoulli's principle, the velocity and flow rate of the fluid entering the second reservoir is directly related to the height difference between the water levels in tank 1 and 2. Thus, by changing the height difference, the flow rate can be precisely adjusted.

The reservoirs are connected with flexible 0.5" ID tubing, which accommodates the height difference. This tubing connects to connectors, which attach to the flow meter and the original 10 ft entrance length pipe. This PVC is fed into a smooth pipe flange on the side of tank 2. Each reservoir has an overflow receptacle which keeps the water level constant. Each pump transfers water from the overflow receptacles to the main reservoir (tank 1). The 0.5" tubing is sealed to tank 1 using epoxy resin. The schematic drawings for the final design are attached in the appendix. Based on the initial parameters spreadsheet, for Re = 2100 the calculated entrance length needed is 1.524 m, maximum allowable flow rate Q is 15.95 GPH (~3.20 lbs/min), and maximum allowable velocity is 0.13 m/s. Correspondingly, the maximum allowable height difference is $v_2 = \sqrt{2gh}$ = 8.61 × 10^{-4} m, or 0.8614 mm (this is incredibly small). Bernoulli's equation is calculated using point 1 and point 2 as the surfaces of tanks 1 and 2, respectively. For this problem, $P_1 = P_2 = P_{atm}$, $v_1 = 0$, and $\rho_1 = \rho_2 = \rho_{air}$. Upon applying these simplifications the equation reduces to the following:

$$P_1 + \tfrac{1}{2}\rho v_1^2 + \rho g z_1 = P_2 + \tfrac{1}{2}\rho v_2^2 + \rho g z_2$$
$$\rho g(z_1 - z_2) = \tfrac{1}{2}\rho v_2^2$$
$$v_2 = \sqrt{2gh}$$

We completed a functional single-phase flow loop with adjustable flow rates at relatively low Reynolds numbers which can be used in the future to test the UVP. Through this project, I learned the importance of progressing quickly through the testing phase and creating multiple test designs prior to the final design. I also learned to ensure that I adhere to my timeline more strictly. More specifically, I learned about the function and setup of a flow loop, the coriolis flow meter, various types of tubing and piping and their applications, and several hands-on skills.

References

[1] Flow loop definition: https://www.glossary.oilfield.slb.com/Terms/f/flow_loop.aspx
[2] Coriolis flow meter:
https://www.us.endress.com/en/field-instruments-overview/flow-measurement-product-overview/Coriolis-mass-flowmeters?wt_mc=paid-search.google.flow-coriolis-how.othr.paid-search-google.sc-usa.admedia_64166817096_327929272970&gclid=EAIaIQobChMI0vf7tbO55gIVHR-tBh1_NQ-EEAAYAiAAEgKwb_D_BwE

Appendix

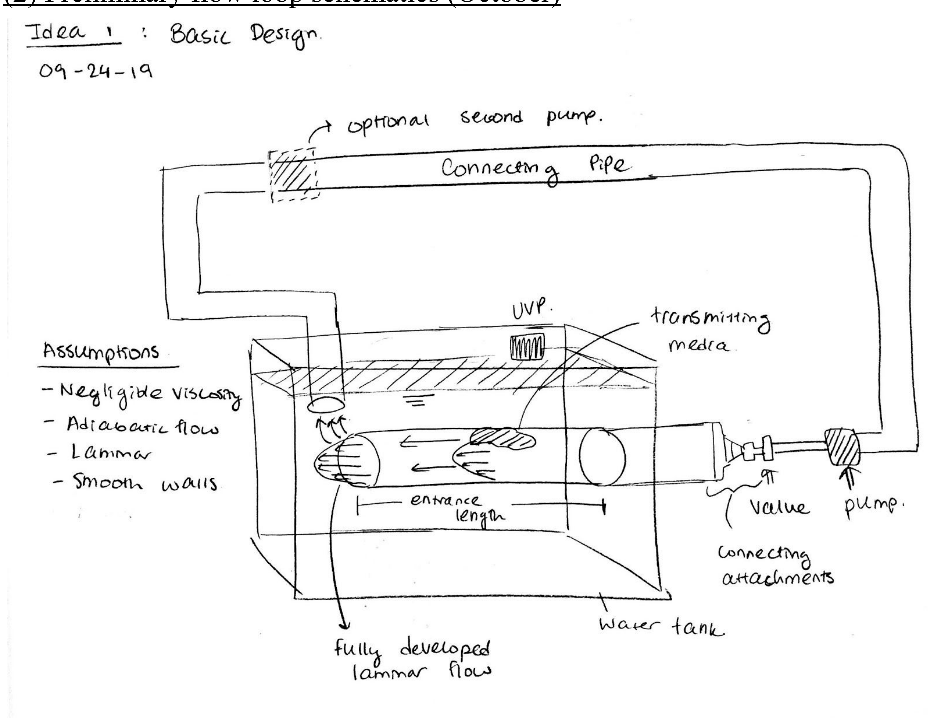
The appendix includes the following information, in the order listed:

1. Schedule/timeline overview
2. Preliminary flow loop schematics
3. Preliminary flow loop images
4. Final parts list draft (CAD not available)
5. Final design schematics & calculations
6. Final flow loop images
7. Reference parameter spreadsheet (for Re = 2100 only)

(1) Schedule/Timeline overview (September)

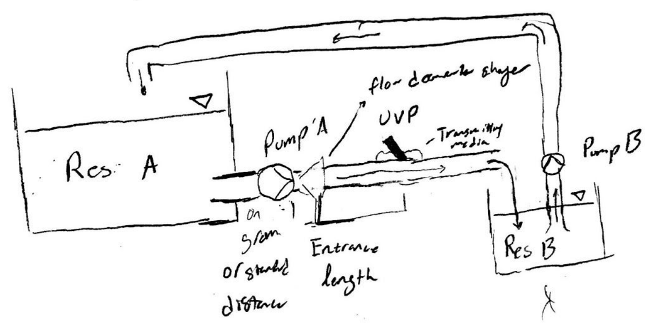
Overall Timeline	Due Date
Research, diagramming, planning for flow loop (draw schematic)	09/26
Build mock-up using parts already in workspace	10/03
Create a list of parts based on what is missing	10/10
Purchase parts - make flow loop attempt #1	10/24
Time for correction / modifications	11/07
[Opt.] Change parts/purchase other parts - make flow loop attempt #2	11/28

(2) Preliminary flow loop schematics (October)



Idea 2 : 2 Reservoirs

09-24-19



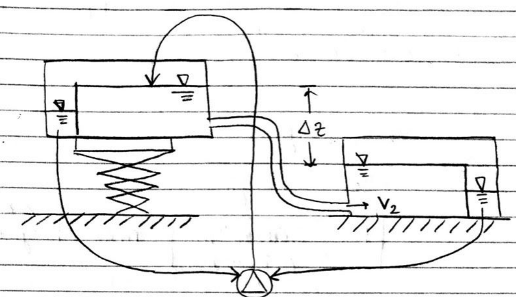
$\dot{m}_A = \dot{m}_B$

(3) Preliminary flow loop images (November)

(4) Final Parts List *Draft* (November)

1. (x1) **Zinc-Plated Steel Barbed Hose Fitting -** https://www.mcmaster.com/5350k79
2. (x1) **Standard-Wall PVC Pipe Fitting for Water (Adapter, 1/2 Socket Female x 1/2 Barbed Male) -** https://www.mcmaster.com/4880k413
3. (x1) **Standard-Wall PVC Pipe Fitting for Water (Reducer, 1 Socket-Connect Female x 1/2 Socket-Connect Female) -** https://www.mcmaster.com/4880k001
4. (x1) **Smooth-pipe Flange (with gaskets?) -** https://www.mcmaster.com/44685K222 (1" pipe diameter)
5. (x2) **Aquarium pump with 0.4" ID tubing extension -** *in workspace*
6. (x1) **Coriolis Flowmeter -** *in workspace*
7. (x2) **Plastic storage bins -** https://www.amazon.com/Homz-Plastic-Storage-Stackable-Latching/dp/B06ZZXZZ2V/ref=pd_cp_468_2/135-5614983-7790824?_encoding=UTF8&pd_rd_i=B06ZZXZZ2V&pd_rd_r=6306fb83-6712-4249-b983-fb2778847a79&pd_rd_w=ELFEl&pd_rd_wg=zNdPQ&pf_rd_p=0e5324e1-c848-4872-bbd5-5be6baedf80e&pf_rd_r=49XJ278M6V9H16CWGD82&psc=1&refRID=49XJ278M6V9H16CWGD82
8. (x3) **Acrylic plates (to insert in bins for overflow compartments & through-hole fitting) -** https://www.amazon.com/Acrylic-Plexiglass-SimbaLux-Transparent-Projects/dp/B07D5553SR/ref=sr_1_6?keywords=acrylic%20sheet%201%2F4&qid=1575500201&sr=8-6
9. (x1) **Acrylic glue -** if not already in workspace, https://www.amazon.com/Weldon-Applicator-Bottle-Pint-10308/dp/B00TCUJ7A8/ref=zg_bs_256226011_2?_encoding=UTF8&psc=1&refRID=SZZ3TEV7H01PWFD23S13
10. (x2) **Male-Male 1/2" OD Plastic on/off valves with barbed fittings (connecting 0.4" pump tubing to 1/2" general tubing) -** https://www.mcmaster.com/4796K75 (Red PPE plastic body would also work as opposed to black nylon, but black nylon didn't have a picture)

(5) Final design schematics & calculations



(Re=2100)

max entrance length needed: $\boxed{\sim 1.6\ m}$

typical entr. length: $\boxed{\sim 0.75\ m}$

max (Re = 2100) flow rate

$Q = 15.95\ GPH \approx \boxed{8.20\ \frac{lbs}{min}}$

$V = \boxed{0.13\ m/s}$

typical (Re = 1000) flow rate

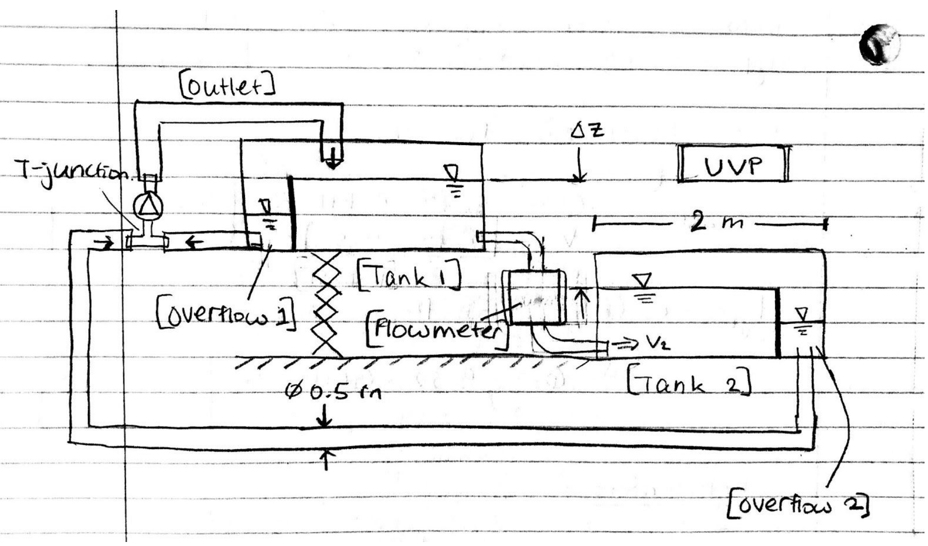
$Q = 9.52\ GPH \approx \boxed{1.32\ \frac{lbs}{min}}$

Constraints

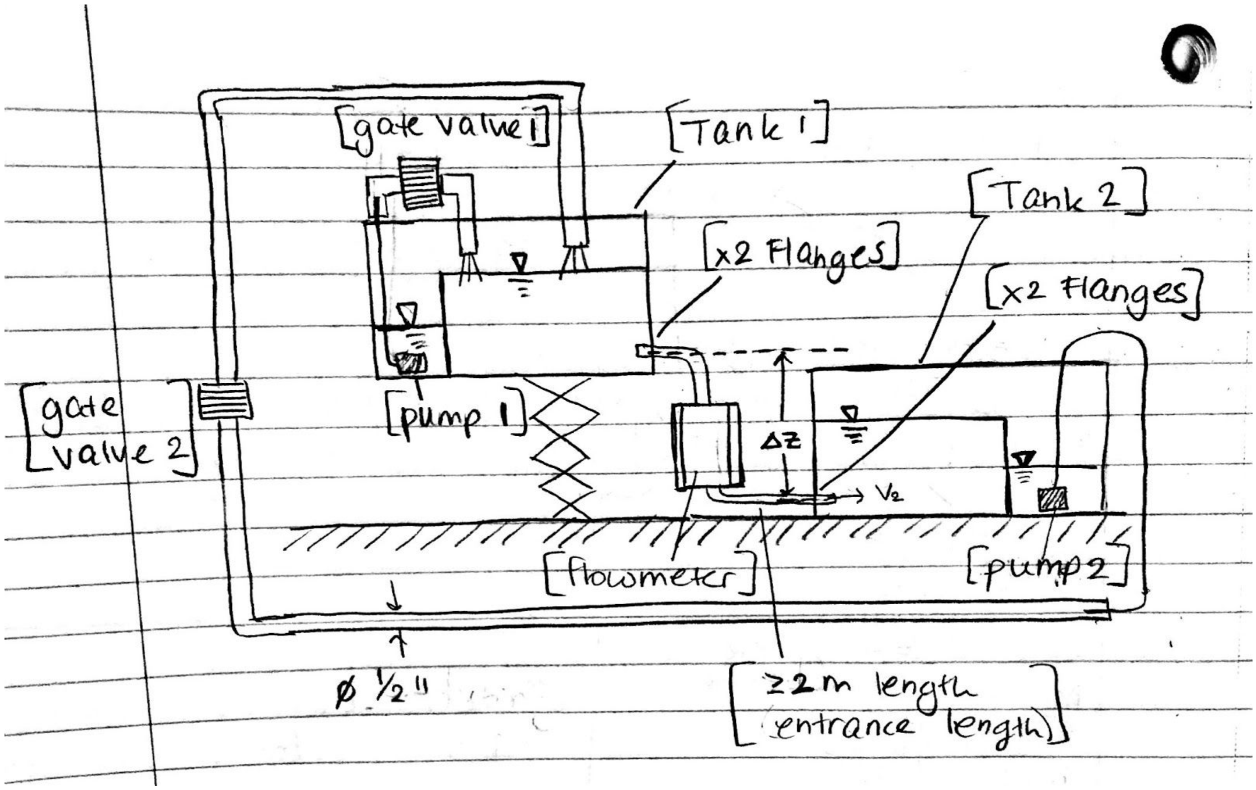
entrance length at least (1.6 m)

flow rate at most $\left(3.20\ \frac{lbs}{min}\right)$

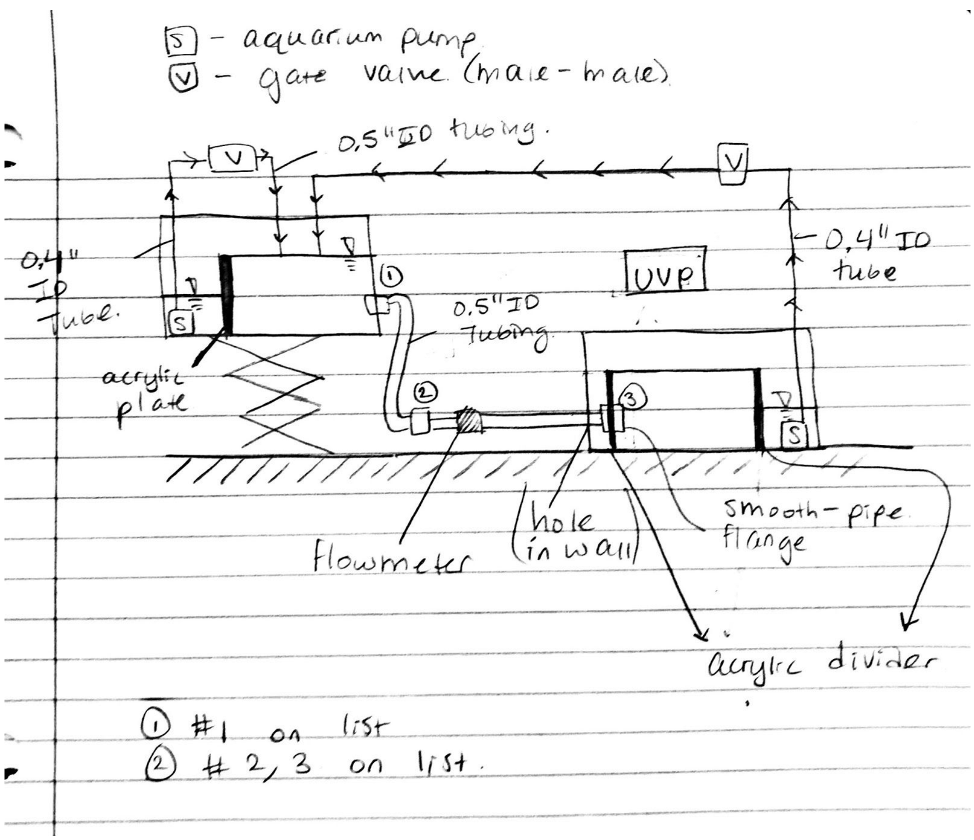
velocity at most (0.13 m/s)



Version 1



Version 2



Version 3

(6) Final flow loop image

(7) Reference parameters spreadsheet for Re = 2100 only (attached below)