Large Capacity Float Valve Team, Spring 2015

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Abstract

The goal of this team is to develop a large capacity float valve to regulate flow from a storage tank to the entrance tank. This system will be put in place for smaller plants, so that they may still be operated at design flow rate during droughts. This subteam aims to create a plant that is easier to operate, troubleshoot, and build.

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Task List

Task Details

Large Float Valve

Team: Kwabena Nimo

Challenges:

1. Understand the forces at work in a float valve

- Determine the main forces at work and which dimensionless constant are changing.
- Determine what variables need to be controlled

- Complete February 21st

2. Calculate float size necessary to overcome forces on the valve
- Float valve must be able to throttle 12 L/s of flow
- Float valve must be able to operate with up to 1.5 m of head
- If the design float valve is impractically sized, explore what other options are available.
- Complete by March 9th

3. Design a lever system and float system as needed to achieve the required force and design a simple valve closure system
- Complete by March 26th

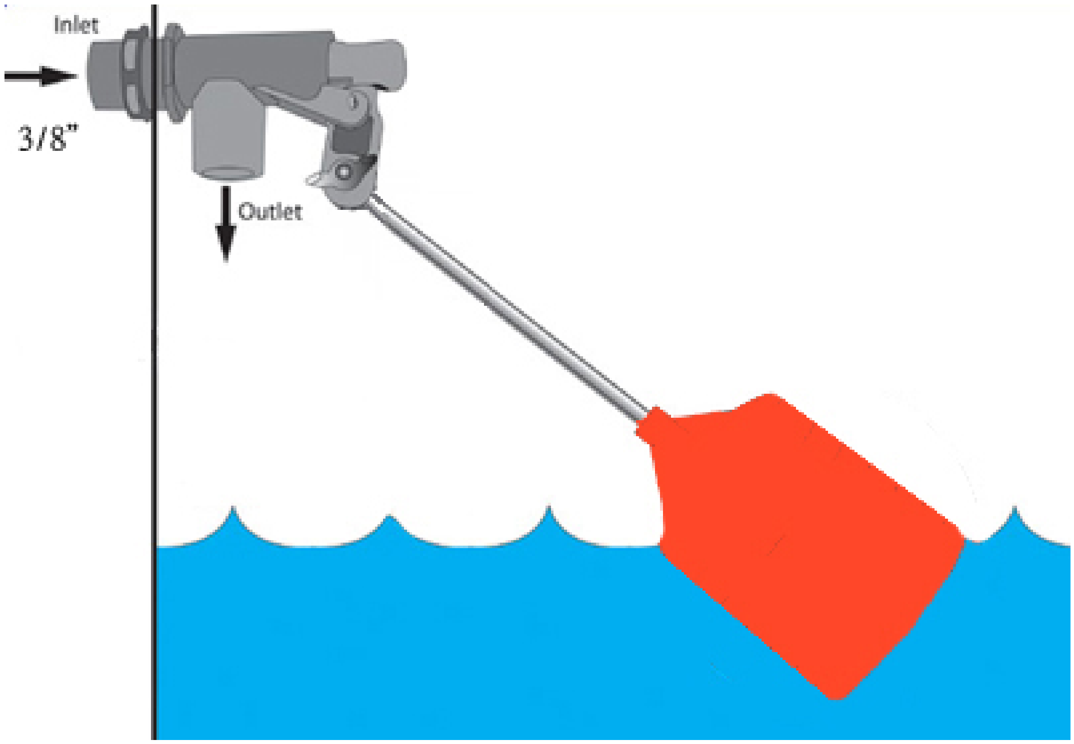
4. Fabricate a test model of the valve that can effectively handle the target 12 L/s of flow
- Construct a way to easily test the float valve model

  - Tasks in green have been completed; tasks in orange are partially completed; tasks in red still must be done

Introduction

The large-capacity float valve will be very helpful in backwashing plants with only one filter. Such smaller plants can run into problems during droughts, having too little raw water to backwash the filter. By connecting a storage tank upstream of the entrance tank, and having it feed into the entrance tank through the large float valve, we can maintain the necessary flow rate for backwash through the plant even during a drought. Thus, the large float valve will be instrumental in allowing smaller plants to backwash their filters more regularly. This is a new project in AguaClara, and will aim to optimize the current float valve technology for this particular situation, in which the valve must be able to manage high flow rates from a tank with a relatively small amount of head.

Literature Review



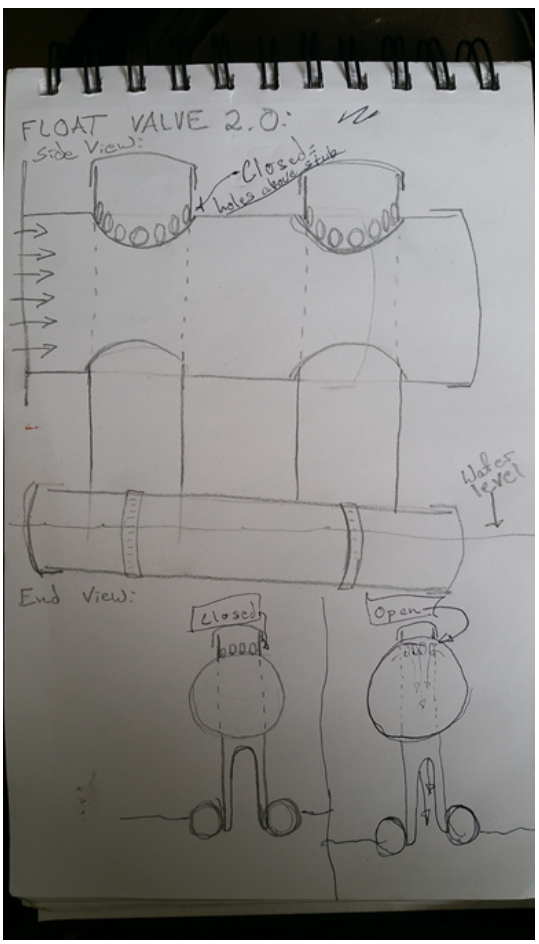
The float valve is a tool used to maintain a constant water level in a tank. As can be seen from the above diagram, the float valve works as the entrance into a tank. Its purpose is to throttle the flow into the tank as the water level rises. As the water level rises in the tank, the float rises, and it closes the outlet pipe, lowering the flow rate through the valve. When the float is completely down, the flow is unrestricted, and when the float is completely up, the outlet is sealed and the flow is zero. As such, a float valve can be used to maintain a relatively constant water level (ie constant head) in a tank.

For the situation at hand, a float valve (fed by an upstream storage tank) will be implemented to maintain constant head in the entrance tank, such that a plant with one filter may be properly backwashed. In order to achieve this, the float valve must be able to handle very high flow rates (up to 12 L/s) and 1.5 m of head. Commercial floats are typically designed to handle very high pressures and low flow rates. This, combined with their high cost, makes them an unattractive option. Thus, the Fabrication team intends to develop its own, low cost float valve that can handle the necessary flow rate and pressure.

Methods

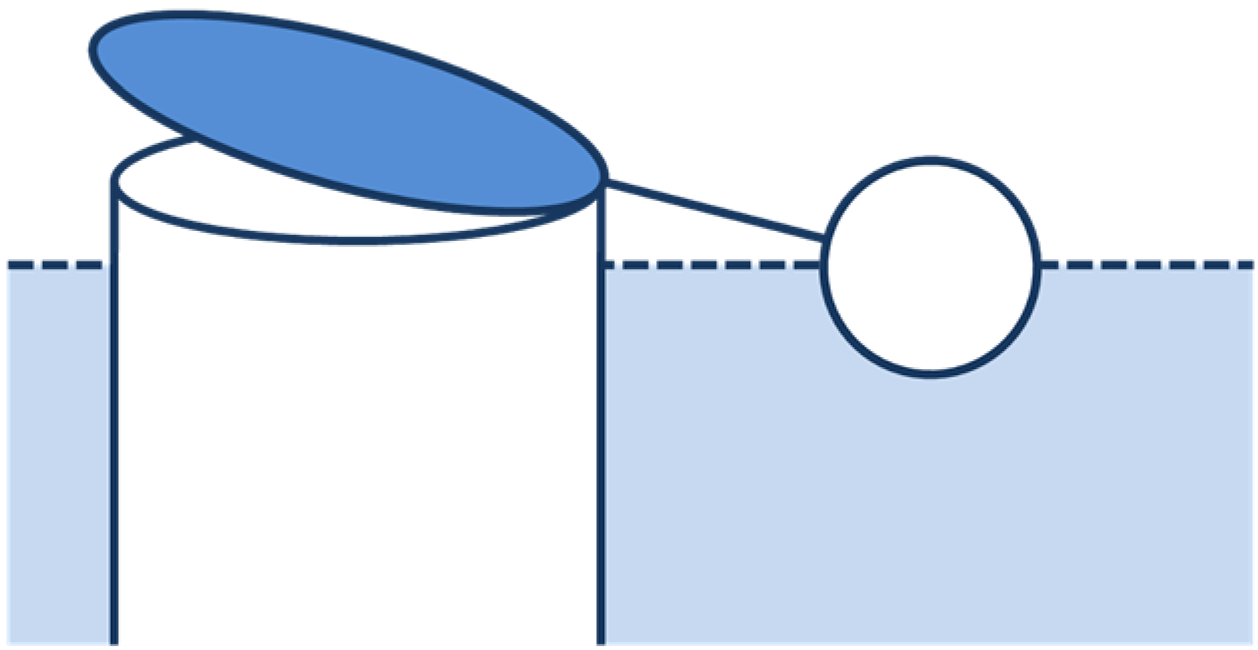
There are currently three main designs being considered for this new float valve. The first would be similar to a standard float valve (as seen in the picture in the literature review). The throttling capability of this type of float valve is directly proportional to the cross-sectional area of the float (i.e. a larger float is needed to throttle a larger flow rate). Considering the very high flow rate that is to be used, the required float size was expected to be very large (and likely impractical). As a result, alternative designs are being considered to keep the valve space and cost efficient. That said, the standard design was still considered, at the very least as a control so that the other potential designs could be judged against it.

The second design (developed by Ethan Keller of the AguaClara team) is a system of PVC pipes:



To explain the above drawing, the main horizontal pipe is the entrance pipe into the entrance tank (where the water from the storage tank flows in from). It is capped on the opposite end, and has two holes in it to make room for the two pipe system (which have a series of small holes around their top end in a circular shape) to be able to slide with relative ease between. Like in the picture, these two pipes are connected to 2 sealed PVC pipes at their other end, which act as the floats. In this design, when the water level is low, the 2-pipe system slides down, such that the holes are in the main entrance pipe channel, allowing the water from the channel to flow through them and then down into the entrance tank. As the water level rises, so do the holes in the 2 pipe system, which decreases the cross sectional area that the water from the storage tank can flow through. This effectively throttles the flow into the entrance tank.

The third design under consideration (developed by Jonathan Christensen, an AguaClara engineer working in Honduras, where this new float valve design is to be eventually implemented) is shown below:



For this design, the flow would go up through the PVC pipe and into the entrance tank. When the water level is low, the float will hang down, which opens the lid covering the top of the entrance channel, allowing the tank to fill with water. As the water level rises, so does the float, and the PVC pipe will slowly close, throttling the flow.

Analysis

Upon closer inspection, the force balance for the standard float valve and Jonathan's valve are essentially the same (dependent on the cross-sectional area of the float). So the analysis below applies to both:

ANALYSIS OF STANDARD/JONATHAN'S DESIGN

$Q_{Plant} := 12 \frac{L}{s}$ design flow rate that we need throughout the plant to ensure that backwash will work properly

$\Pi_{VC} := 0.62$ vena contracta constant

$\Delta h_{Low} := 0.3m$ smallest head that the float valve should be able to handle

$\Delta h_{High} := 1.5m$ highest head that the float valve should be able to handle

$\rho_{Water} := 1000 \frac{kg}{m^3}$ density of water

As the head increases, the diameter of the orifice decreases. So to accomodate all required conditions, the diameter of the valve opening will be designed with delta h = 0.3m, which will give the biggest diameter that is needed for all potential piezometric heads

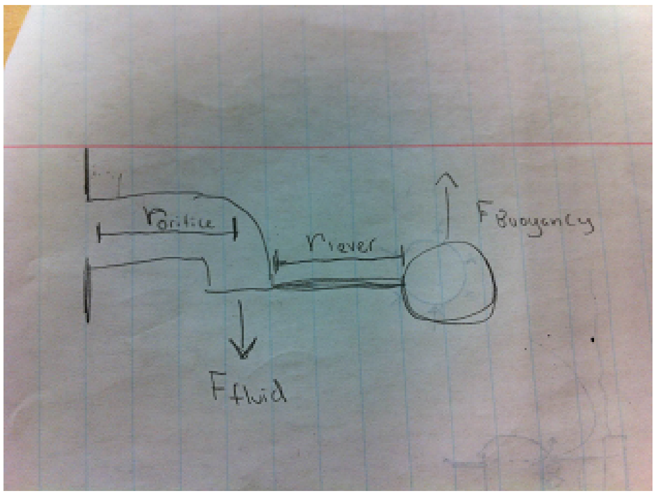
$$D_{Orifice} := \sqrt{4 \cdot \frac{Q_{Plant}}{\pi \cdot \Pi_{VC} \cdot \sqrt{2 \cdot g \cdot \Delta h_{Low}}}} = 3.968\,in$$

Diameter of valve opening needed to provide the design flow rate under the specified conditions

$$A_{Orifice} := \frac{\left(\pi \cdot D_{Orifice}^2\right)}{4} = 12.368\,in^2$$

Total orifice area needed for a 12L/s flow and 0.3m head

With the area of the orifice known, the next step is to find how large the float has to be:



As illustrated in the picture above, the moment created by the fluid entering thet tanks has to be equal to the moment created by the buoyancy force of the float for the float valve to successfully throttle the flow.

$$F_{Fluid} := \rho_{Water} \cdot g \cdot \Delta h_{High} \cdot A_{Orifice} = 117.372\,N$$

In this case, the max head is used in the equation, as it determines the how big the force of the fluid could be, and as such the max amount of force the float must be able to withstand

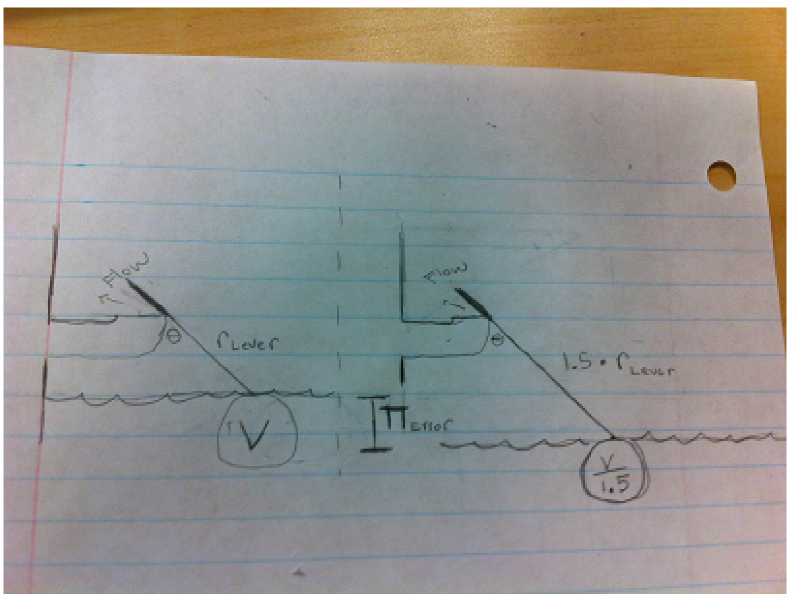
$$F_{Buoyancy} := F_{Fluid} = 117.372\,N$$

The Force of buoyancy is equal to density*gravity*Vol of the float, so...

$$V_{Float} := \frac{F_{Fluid}}{\rho_{Water} \cdot g} = 11.969\,L$$

what the above value shows is the theoretical case where R.orifice and R.lever are both 0 (if the float was somehow right next the orifice, and the orifice was right next the to side of the entrance tank), the float would have to be approximately 12L (imagine 6 2 liter soda bottles tied together) to resist the flow. If R.orifice was increased by a factor of 2, than the size of the float would be doubled. Similarly, if R.lever were increased by a factor of 2, then size of the float could be halved.

While a 12L float would be fairly ridiculous, one could argue that a viable strategy would be to simply increase R.lever so that the V.float can be made smaller. Unfortunately, this is also a poor strategy, as the error of the float valve system (Pi.error) increases as R.lever increases:



Look at the picture above (which is drawn approx. to scale): the flow rate coming from the storage tank is determined by how open the orifice is aka the angle theta. If the length of the lever arm is increased to decrease the size of the float, then the water level will have to be lower to get the same theta (and as such the same flow rate). That said, when the orifice is completely shut, the water level will have to be the same regardless of the lever arm length/ float size. In other words, as the lever arm length increases, so does the variability of the water level in the the entrance tank. The higher the variability, the more the float will have to adjust the orifice size, which means more variability in the flow rate to the plant.

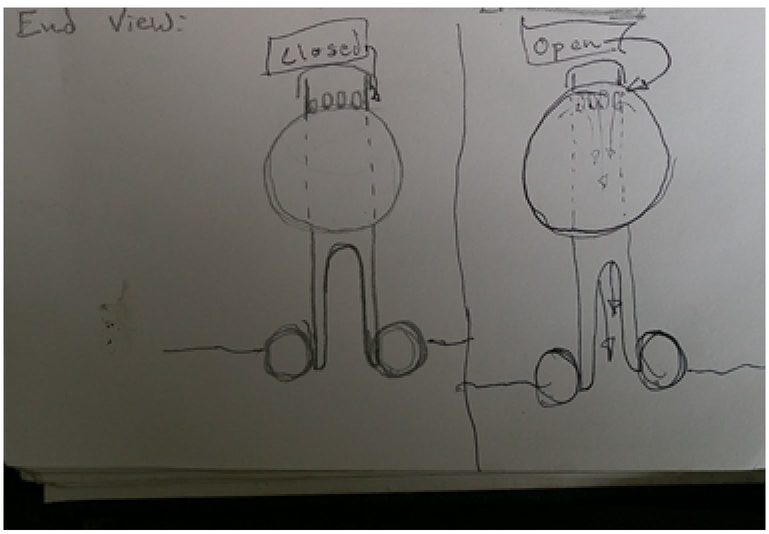
Thus the standard float valve design, and by extension Jonathan's design, are generally not very suitable for high flow rates. They are far too large, and the error in their design, while relatively minor for smaller floats, also becomes excessively large.

ANALYSIS OF ETHAN 1.0 DESIGN

By comparison, Ethan’s float valve design solves the two main problems of its competitors: size and error.

In Ethan’s design, the buoyancy force doesn’t have to directly oppose the force of the water trying to enter the tank. As such, the float can be made much smaller and still be effective. It can be constructed out of 3” to 4” PVC, so there should be no problem fitting it inside an entrance tank

The error/variability of the flow rate is also much smaller with Ethan’s design:



The difference in water height between the valve being completely open vs. completely closed is just the diameter of one of the openings i.e. about an inch or so, which is a large improvement over the design alternatives. With less fluctuations in water height, Ethan’s design should prove to be a much more accurate flow control system:

$$A_{1InchHole} := \frac{\pi \cdot (1in)^2}{4} = 0.785\,in^2$$

$$N_{1InchHolesReq} := \mathrm{ceil}\left(\frac{A_{Orifice}}{A_{1InchHole}}\right) = 16$$

Using 1 inch holes around the two entrance pipes, 16 holes will be needed between the two pipes (so 8 each) to be able to handle the design flow rate. Leaving 1/8th of an inch between holes:

$$N_{PerPipe} := \frac{N_{1InchHolesReq}}{2} = 8$$

$$PipeSizeReq := \mathrm{ceil}\left(N_{PerPipe} \cdot \frac{1.125}{\pi}\right) = 3$$

Thus, the two entrance pipes for Ethan's design will be designed with a pipe size of 3in

The only real potential problem with Ethan's design would be too much leaking along the outsides of the two vertical pipes pipes. But even this can be shown to be overall negligible:

$Gap := 1mm$ Assumption of size of gap between vertical pipe and hole in the entrance pipe (probably an overestimate, to be safe)

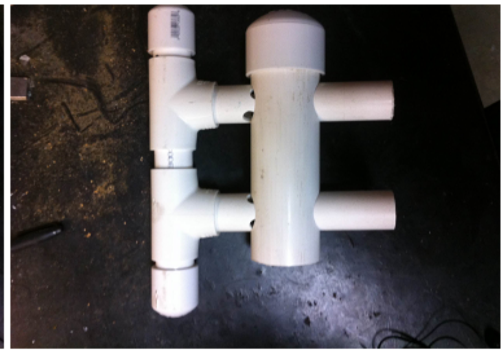
$$ODiam_{3IP} := 3.5in$$

$$A_{Gap} := \left[\pi \cdot \left(\frac{ODiam_{3IP}}{2} + 1mm\right)^2\right] - \left[\pi \cdot \left(\frac{ODiam_{3IP}}{2}\right)^2\right] = 0.438 \cdot in^2$$

$$Ratio := \frac{A_{Gap}}{A_{Orifice}} = 3.54\,\%$$

Im not completely sure how the the flow rate through the gap will compare to the flow rate through the orifice, but my guess is that it would be proportional to the areas. So at whatever flow rate the float is operating at, the amont leaking out of the gap will be about 3.5% (see above ratio calculation) of what is going through the orifice holes.

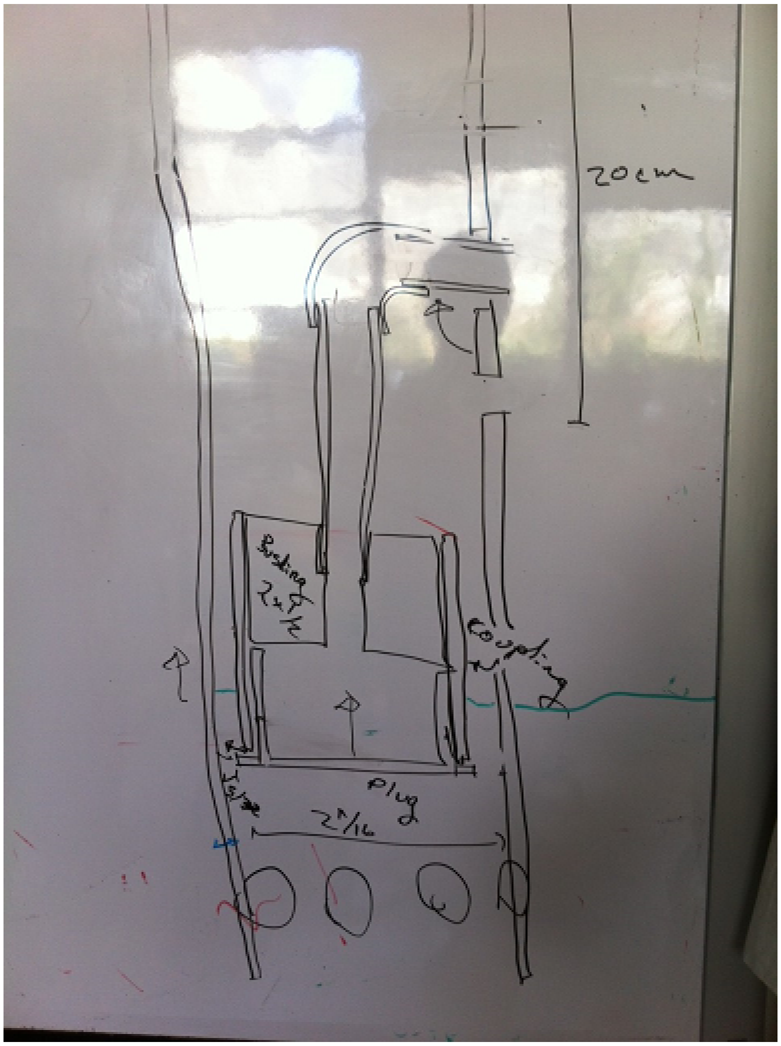
Ethan 1.0 Design: Prototype

Above is the first model of Ethan's design. The top left shows the valve fully closed, the top right partially closed, and the bottom left and right show the valve fully open. This prototype was made entirely out of PVC, and is as such very easy to construct and implement in any plant. When tested, the valve was able to cut the flow down to a minor trickle, at least a 90% reduction in flow. There is a slight misalignment of the two, 1-inch holes in the 2-inch entrance pipe. This makes the float not slide as easily in and out as it should, as well as not throttle the flow as well as it could. In addition, the effects of this minor misalignment on a scaled down model suggests that fabricating the full sized model could pose some problems.

Another issue that must be addressed is the task of refilling the storage tank once the backwashing is complete. In order to do this, we need to essentially run the system in reverse such that the pressure difference will cause the raw water to flow back up into the storage tank. We can only do that if we can set the flow rate on the float valve, as well as adjust for the varying water heights in the LFOM (about 20cm of head). In order to accommodate these new parameters, Ethan's design had to be updated:

Ethan 2.0 Design: Description



The above drawing is a look inside one of the vertical pipes of the new design. Using a system of bushings, couplings, and plugs, a pocket of air is created inside of the pipe, and acts as the float. This unit is attached to the pipe which will get “slotted” into one of several holes that extend for around 20cm. As the water level rises, the pocket of air inside of the pipe will cause the pipe to rise with the water and throttle the flow, same as Ethan’s old design. The main advantage of this design is that by changing which hole the float is slotted in, the water level in the entrance tank can be adjusted by 20cm, which solves the aforementioned complications with the last design.

Ethan 2.0 Design: Model


The above pictures show the preliminary model of the 2.0. The picture to the left would be zero flow, and the picture to the right is full flow. As stated earlier, this force balance of this design is identical to the 1.0. The real difference here is that the float is now inside of the vertical sliding pipe, and the position of the float can be adjusted to account for the LFOM. This model is to scale of what should actually be used in Honduras. For the actual float valve however, there would be two vertical pipes sliding in the horizontal entrance pipe. Each would operate independently of each other with their own float inside. This eliminates the potential alignment issues of having vertical pipes connected, while providing the operator with enough orifice area to achieve the desired 12 L/s flow rate


These pictures show the float, which is just a combination of a plug, coupling, and bushing, used to create a pocket of air.

The float is locked into a certain height setting by the elbow piece which slots into one of the ½ holes. As the water level rises, the float will cause the whole vertical pipe to rise with it, throttling the flow. The ½ inch holes span 20cm, giving the operator multiple setting options for the float valve.

Conclusions & Future Work

There are a couple things that must be done before this system should be applied in Honduras:

1. A pipe with an OD of ½ inches should be used to slot the float valve into the vertical pipe. The current model is not using the appropriate sized piece. A ¼ inch ID pipe should be just about right.
2. The horizontal entrance pipe shown has thinner walls than the standard PVC pipe, and should be replaced with a standard PVC 6 inch pipe (so that the cap will properly fit)
3. The next researcher should find an appropriate way to test the functionality of the float valve in the lab. This would require a large drum of some kind, and a constant water source (perhaps a water pump)

These tasks shouldn’t require too much time. Ideally, a summer AguaClara team could make the changes and run the tests at the beginning of the summer so that we can implement the design in Honduras ASAP.