Stacked Rapid Sand Filtration - Full Scale Progress Report

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Introduction

The purpose of this report is to effectively summarize the progress that has been made to fabrication methods for the stacked rapid sand filtration system over the course of the semester. The stacked rapid sand filtration system is a new technology developed by AguaClara. It has many advantages over traditional sand filtration systems. First, it uses less water to backwash, because the filter layers are stacked. The filtration system also uses the same water for to backwash all the filter layers, producing a concentrated waste stream and reducing backwash time. Furthermore, this technology is much easier to operate than conventional rapid sand filters. It fits all the criteria of AguaClara technology, as the normal filtration and backwash cycles are driven by gravity. Materials are relatively cheap and widely available in Honduras. Finally, this filtration system has been proven to lower the effluent turbidity sufficiently, producing treated water below the EPA standard of 0.3 NTU and often even less than 0.01 NTU.

The first field scale design of this filtration system was recently implemented at the AguaClara plant in Tamara. There have been several previously unforeseen issues that have arisen. In Tamara, in order to fit the slotted pipes into the trunk line and end lines, compression slots were cut into the slotted pipes. However, this allowed sand to leak into the inlet and outlet plumbing. Sand leakage is a serious issue because it increases head loss in the filter, reduces the length of the filter cycles, lowers the efficiency of the filter, and makes it harder to backwash. One of our main goals for this semester was to find a way to make a sand-tight connection between the slotted pipes and the trunk line and end lines. Another challenge we are facing is to find a new construction method so that the manifold can be built outside of the filter box. After the manifold is completely assembled, it will be lowered into the filter box as a unit. A key part to our progress this semester is the steady feedback from the team in Honduras at the Tamara site. Changes that we make this semester will aid in the maintenance of the Tamara filter and the design and implementation of the next stacked rapid sand filtration system in San Nicolas.

Part I
Connections Using Regular PVC Pipes

1 Goals

The goal was to create a sand-tight connection between the 1" diameter branch pipes and the side of a 2" end pipe and a 6" trunk line. The current connection requires creating compression slots at the ends of the 1" diameter pipes and then squeezing the ends together to fit inside the slightly smaller 1.25" hole in the trunk pipe. Because the slots extend beyond the inside of the trunk pipe, there are small crevices where the sand leaks, which is undesirable. We seek to find a solution to this that require minimal materials while still maintaining the integrity of the connections. Various methods of modifying the ends of the pipes were tested in order to find the one that was most effective as far as secure fit and ease of construction.

2 Experimentation and Results

2.1 Boiling Water - No Mold

2.1.1 Testing

Heating the pipe with boiling water has been an effective technique already used in Honduras in order to cause the pipe to be malleable. A large beaker filled with water and salt was placed on a hot plate and brought to a boil. A 1" diameter pipe was boiled in the solution for 30 minutes with the intention that this malleable piece of PVC could be squeezed directly into the holes.

2.1.2 Outcome

Although previous AguaClara experience suggested this method, it was quickly realized that it would not work sufficiently for our piping. Although the salt water was brought to a full boil, even submersing the pipe for upwards of 30 minutes did not soften it enough to make it malleable. This idea was quickly discarded and other options were explored. It was found that the most convenient and efficient method was a heat gun.

2.2 Heat gun - No Mold

2.2.1 Testing

A heat gun was used to heat the end of the pipe for approximately 1 minute. This malleable piece of PVC was then placed directly into the holes in the pipes.

We hypothesized that this would have the most secure fit, since the pipe would form directly to the outline of the hole, and would then harden when cooled.

2.2.2 Outcome

This method provided us with a very snug fit. After heating the pipe and using force, the 1" pipe was fitted to the hole. After it cooled, it hardened to the shape of the hole. The very end of the pipe expanded and secured the pipe in the hole. However, although this method works with one pipe, having to do the same process simultaneously with the entire manifold is impractical. Although inserting one side of the pipe into one of the end pipes would be feasible, it would be unlikely that the other ends could be heated and inserted to the other pipe at the same time. Thus, this idea was discarded as well.

2.3 Tapered Mold

2.3.1 Testing

We explored a molding process in which we made a mold by drilling a tapered hole into a solid piece of aluminum. The hole was comprised of a "guide" section (for straight insertion of the pipe) that has the same diameter as the outside diameter of the standard 1" PVC pipe (which is 1.316"). This section tapers into a smaller section which decreases the diameter of the end of the 1" pipe to 1.25" over a length of about 2 cm. The taper was intended to allow for a gradual easy fit into the holes in the sides of the 2" pipe.

2.3.2 Outcome

The tapered mold did not work as effectively as we had originally hoped. The taper that was created was too steep to be effective in securing the pipe connection. Although it reduced the outer diameter of the 1" pipe as planned, it was difficult to keep the pipe straight after it was inserted in the hole. The taper caused instability in the connection and the pipe would often tilt. Also, it was envisioned that the taper would allow the pipe to stop gradually and fit snugly, but after testing, this was found to be untrue. The material of the pipe did not allow the taper to work in the way that it was planned.

2.4 Straight Mold

2.4.1 Testing

A second option was tested in which a mold similar to the tapered mold was created. This mold maintained the same "guide" section, but included only a very slight taper to the 1.25" diameter section. This was hoped to create a tighter fit than a tapered version that would not allow the 1" pipe to tilt when inside the hole. The smaller section that will mold the pipe has a 1.245" diameter. The image below shows the straight mold that was used. See Figure 1.

Figure 1: A top view of the straight mold.

2.4.2 Outcome

Using the straight mold was relatively successful in securing the connections between the two pipes. The mold reduced the outer diameter of the pipe sufficiently and it fit better than wit the tapered mold. However, there was still instability in the connection and it would not likely be sand-tight when implemented. Although it happened to a lesser degree, the pipe still tilted because the of the significant curvature of the 2" end pipe that it was being inserted into.

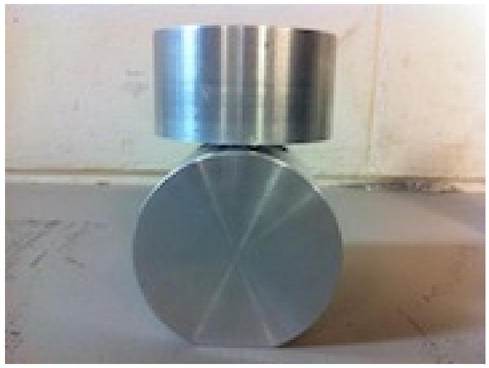
2.5 Straight Mold in Cylinder

2.5.1 Testing

Another method that was tested used a similar mold to the straight mold, but was instead cut out of the side of a 2" diameter cylinder of aluminum, instead of a flat surface. This also included a guide section, which fed into a 1.25" diameter hole cut into the side of the cylinder. Having the hole cut out of a rounded surface would model the geometry of the pipe's connection more exactly than a hole through a flat surface. This would theoretically also add the benefit of rotationally constraining the 1" pipe within the hole. Pictures of this mold are shown in Figures 2a and 2b.

Figure 2

(a) Side View of the Straight Mold in Cylinder



(b) Front View of the Straight Mold in Cylinder

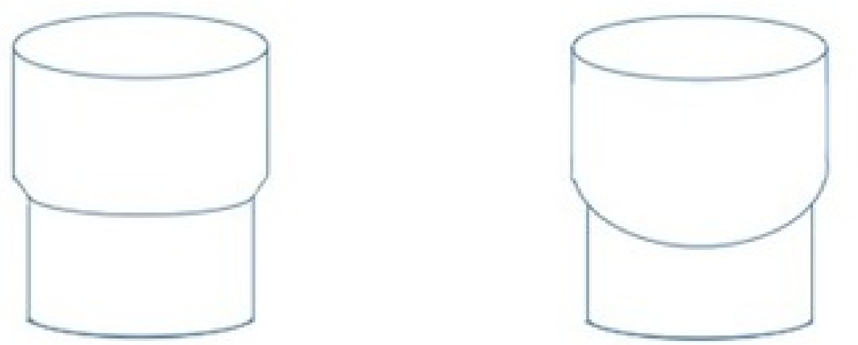
2.5.2 Outcome

Using the straight mold in the cylinder consistently gives us the best connections. While the heated pipe is in the mold, a line was traced of where the molded section begins in order to ensure alignment when the pipe is inserted. The cylinder section of the mold does conform to the end of the pipe in the way that was envisioned. The end of the 1" pipe fits into the hole drilled in the 2" pipe better than any of the previous methods and should be sand tight when it is combined with the steel cable in the full assembly. The results of this molding technique are shown in the diagrams in Figures 3a and 3b.

Figure 3: Effects of Various Molds

(a) Pipe End Molded with the Straight Mold

(b) Pipe End Molded with the Straight Mold in Cylinder



We have begun using the straight mold in the cylinder. This appears to give us the most secure fit as far as inserting the 1" pipe to the two inch pipe. There is no need to make a similar mold for the 6" pipe. The curvature of the 6" trunk line pipe is small enough to be negligible. This is ideal because it means that only one end has to have a direction-specific mold; we need to make sure that the slots are facing towards the left and right side in order to ensure lateral stability. This provides an easier construction process for when we construct the full scale version of the manifold. However, once we began constructing our full scale version of the manifold using the slotted pipes, some issues regarding the curved mold arose.

Part II
Connections using Slotted PVC Pipes

3 Goals

In regards to using the slotted pipes, we encountered one main problem. As we heat up the slotted pipe and push it into the mold, the lip is catching on the mold and folding upwards. This makes the pipe significantly harder to work with. We have also noticed that as the slotted portion of the pipe heats up, the slots can become deformed. If the slotted portion is too warm, when the pipe is inserted into the mold, the slots will close up. Also, if the slotted portion is too warm when it is in the mold, the slots will catch onto the guide section of the mold as the pipe is removed. The slots in the pipe can then open up, which creates space for sand to enter the pipes. This issue needs to be fixed. Our goal is to find out how to make this molding process easier and more consistent. These problems are likely because of the slotted nature of these pipes. We believe that by heating the pipe more accurately, the slots will not become malleable and this will thus eliminate this whole issue.

4 Experimentation and Results

4.1 Oil - Cylinder Mold

A photo of our setup can been seen below in Figure 4.

Figure 4: Oil Molding Setup

4.1.1 Testing

We decided to not use a heat gun because it might not be entirely feasible in Honduras. Although it provides us with a simple and efficient way to construct our prototype, electricity is expensive and not available on every job site in Honduras. Because of this, it is likely not the best option. Due to our previously failed experimentation with boiling water, we decided to look into liquids with higher boiling points. The option that we chose was Crisco Pure Canola Oil. Pure canola oil has a smoke point of around 400ºF based on an online catalogue of cooking oil smoke points. Because the smoke point of pure canola oil is roughly 400ºF, we wanted to ensure safety by not reaching levels above 340ºF. As can be seen in the figure above, the oil was placed inside a beaker on top of a hot plate. The oil level is about 1" (2.54 cm) above the bottom of the beaker. The reason this amount of oil was chosen was so that it would not reach the bottom of the slots, which begin 3 cm from the end of the pipe. We hope that this will allow the pipe to be molded with minimum effect of the slots. We performed testing at various temperatures between 240ºF and 340ºF. We chose the lower limit because it is slightly above the boiling temperature of water, which we previously found was too low of a temperature to successfully mold the pipes. The ideal temperature to mold pipes is between 240ºF and 270ºF. An infrared thermometer was used to measure the temperature of the oil and the hot plate was adjusted accordingly so it would stay within the accurate range.

4.1.2 Outcome

We realized that regardless of the temperature and time the pipe was submerged in the oil, it would still have the problems of having the lip catch and fold upwards. We noticed that this problem occurred in the section where there is an empty space between the guide and the cylinder part of the mold. The pipe was folding out into the space and this made it hard to insert into the mold or to take out of the mold. We also believe that due to the coating of oil on the pipe, the pipe cools down a lot faster when it is inserted into the mold. The mold is relatively cool in comparison to the pipe and the heating oil coating, and the oil increases the thermal conductivity and the rate of heat loss from the pipe. Once the mold comes in contact with the oil, the pipe will cool down to the point where it is not malleable enough to be molded. A solution we found for this problem was to quickly wipe away oil of the outside of the pipe with a paper towel before inserting it into the mold. However, the problem remains that our current cylinder mold faces significant difficulties in molding the pipe. Because of this, we have developed a new mold that should reduce these issues.

4.2 Oil - Curved Guide Cylinder Mold

4.2.1 Testing

As a solution to the problems experienced with the mold and slotted pipes, a curved guide section was fabricated. This was intended to eliminate the flaring out of the ends of the pipe when they are inserted into the mold, by constraining the pipe to a smaller area. Options were considered to determine the best way to fabricate the mold. First the idea of a rectangular block of aluminum was considered. A hole would be drilled out of the center, with the same diameter as the original mold. Then a perpendicular hole would be drilled out of it with the diameter of the pipe, to serve as the guide section. The original mold would slide right into the hole and line up with the guide, to give a direct feed from one section into the other. However, the price of an aluminum block that would have been large enough to house the mold was over $100.

This first option was determined to be unfeasible, so an alternative was selected. We were able to use the remains of the aluminum rod that was used for the original mold to construct a guide section. This mounted directly onto the original curved mold, but did not leave any open spaces (which cause the "flaring" of the pipe ends) as with the flat guide section. The shapes fit perfectly on top of each other, allowing for a seamless transition between the two diameters. See Figure 5 below for the mold with curved guide.

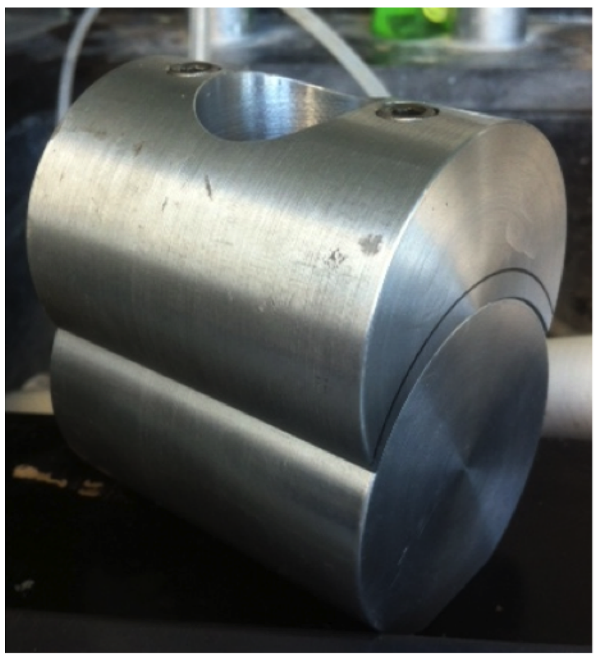


Figure 5: Modified Curved Guide Mold

4.2.2 Outcome

After conducting testing and slightly modifying the dimensions of the mold, we found that the modified curved guide mold was both successful and consistent in molding the 1" slotted pipes. We eliminated the problems of the pipe catching on the mold and flaring outwards. In addition, it is best for the oil to stay within our previously stated range of 240ºF and 270ºF. We submerged the end of the pipe in the oil for approximately 1 minute. It is important to not submerge the pipe for too long as this causes the end to flare out. At the same time, if the pipe is submerged for too short of a time, it is not malleable enough to mold. After removing the pipe from the oil, we quickly used paper towels to wipe the oil off the outside of the pipe before inserting it into our mold. It takes a decent amount of effort to ensure that the pipe reaches the bottom of the mold. After leaving the pipe in the mold for about 1 minute, we then remove the pipe and place the end into cold water. The water helps the pipe to cool down and maintain its newly molded shape. If multiple pipes are molded, each successive pipe becomes easier to mold. We believe this is because some of the heat transfers from the pipes to the mold. Once this happens, it is especially important to submerge the pipe in cold water after it is removed from the mold. If the pipe stays heated after removal from the mold, it is possible that the pipe will regain its original shape. We have also found out that a few slots near the end of the pipe were being compressed together during molding, but this problem appears to be unavoidable. It is also important to note that there is a directional aspect that we need to take note of when we mold the pipes. We want the slots to be facing the straight ends of the mold. When we assemble the manifold, we want it to have vertical stability.

5 Conclusion

We can conclude that the modified curved guide cylinder mold is the most effective and consistent way to mold the end slotted pipes that will fit into the 2" end line. For the end of the slotted pipe that connects to the 6" trunk line, our straight mold remains the best option.

Part III
Spacing

6 Goals

One of the main issues with designing the manifold is the spacing of branch pipes. In order for the manifold to fit in the pre-sized concrete filter box, we need to stick to the strict dimension requirements. While fabricating the design, three main components needed to be modified: the end caps, the trunk connection, and the saddle tees, in order to design the most effective manifold.

7 Experimentation and Results

7.1 End Caps

7.1.1 Goals

The previous design included PVC end caps, which created a large 'dead space' - that is, the manifold was not utilizing the maximum available area for the slotted pipes. Our goal was to change the construction of the end caps, thus allowing us to use more of the filter box.

7.1.2 Testing

By designing multiple alternatives, we used the distance between branches as our limiting factor. We designed models that put each branch 10, 9.5, 9, 8.5, and 8 cm apart. Designing these models then gave us a visual representation, as well as a numerical value, to the allowances that remained for the other core pieces.

7.1.3 Outcome

After designing manifolds using different distances between branches, we encountered good and bad outcomes. A major issue we realized was that for ease of construction, we would want to limit the amount of drilled holes that would need to be pass through caps. To do this, we set the branch distances to 8 cm apart. This worked out well, as it would only require us to drill through one main cap, but it created other issues. By decreasing the distance between the branches, the branches became more concentrated towards the center of the box, thus creating more 'dead zones' in the sand bed. After drawing more designs of other options with different spacing, we concluded that in order to maximize use of the box space, we would need to modify the end caps. The PVC end caps had too much of a base that extended over the pipes, as well as having a large convex head.

After researching end caps, we found that a Fernco end cap minimized the cap base and did not have a bulky head. These rubber end caps are fastened by metal straps, which allow for easy removal as well. By minimizing the unnecessary material from the caps, we can now extend the branches farther along the trunk, increasing usable area within the box. We have decided to maintain our original plan of equal 10 cm spacing between each branch. This reduces dead space within the filter box and will allow for more even flow of water, as shown in Figure 6.

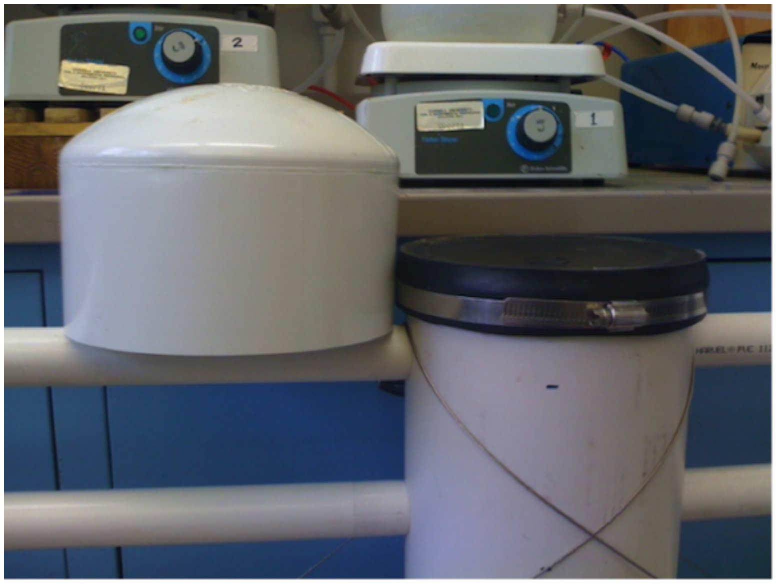


Figure 6: PVC Modified Fernco Comparison

7.2 Trunk Line

7.2.1 Goals

Originally the plan to attach the trunk was to allow a 10 cm space so the extended trunk from the manifold could slide into a coupling cemented through the filter box wall. The problem this created was again causing some area in the box to be 'dead space.' In order to create the best fit, we would try to minimize the space needed to make the connection between trunk ends.

7.2.2 Testing

In order for the maximum space to be utilized, we would attempt to eliminate 'dead space' from the trunk connection. This was made possible by another Fernco piece. By using a Fernco coupling, we could slide the coupling over the base of the trunk on the manifold; the manifold could then be lowered into the box. As the two trunk lines meet within the box, the coupling would then be slipped over the trunk connector coming from the wall. The coupling would then be fastened to the trunks lines with metal hose clamps.

7.2.3 Outcome

The design allows for minimal allowances on the trunk, but with modifications it is feasible. To make a tight fit between the trunk pieces, we capitalized on the distance between the first branch of the manifold and the box wall. To maximize the amount of coverage for the Fernco coupling, we decreased the length of the manifold trunk line, and increased the box trunk length by the difference.

By cutting the coupling to 4 cm wide, we are still able to slide the entire coupling over the trunk, slide the trunk in the box, then slide the coupling onto both ends of the trunk, with enough space for the metal clamps to successfully fasten the trunk ends together. This method will be tested to make sure the allowances give enough room for any sort of distortion of coupling or PVC. An immediate issue was the vertical allowance between manifolds for the bottom layer and the second to bottom.

7.3 Saddle Tees

7.3.1 Goals

Due to the modifications using Fernco couplings, we are now presented with a tolerance issue. In the San Nicolas design, the lower 8" PVC trunk will overlap the 6" PVC trunk directly above it when the Fernco couplings and caps are installed. We need a big enough space so there is no contact between couplings or caps, but also leave room for the saddle tees to be placed between the manifolds.

7.3.2 Testing

A simple solution for this problem is to change the dimensions of trunk spacing. By making the space between the two trunks 22 cm instead of 20 cm, this allows for caps, couplings, and saddle tees to be installed unimpeded. Whether this is a viable option or not depends on how it will affect the hydraulics and solids-removal performance of the stacked rapid sand filter.

7.3.3 Outcome

The calculations have been made, but no testing has been carried out. Based on the calculations, there should be no reason why it should not fit. There will also be no testing due to the fact that we will only be creating a single manifold and not actually installing an 8" trunk and 6" trunk.

8 Conclusion

These three main issues allow maximum use of box space for the filter pipes. Although the calculations tell us that everything would fit perfectly, we will still give 2 cm of space for any sort of error or deformation of pipes and fittings. The progress on the spacing between pipes and overall manifold layout has essentially been completed. The end caps have been selected, and the connections to the trunk line and 2" pipe are being perfected by making the mold slightly larger. The upcoming tasks are perfecting the assembly method in each manifold with the use of steel cable, as well as testing the methods for stacking the manifold. Once the method is completed, the manifold assembly process should be suitable for the conditions in Honduras and will be a key part of the movement towards using more professional-looking and safe equipment. A diagram of our current plans has been included in Figure 7

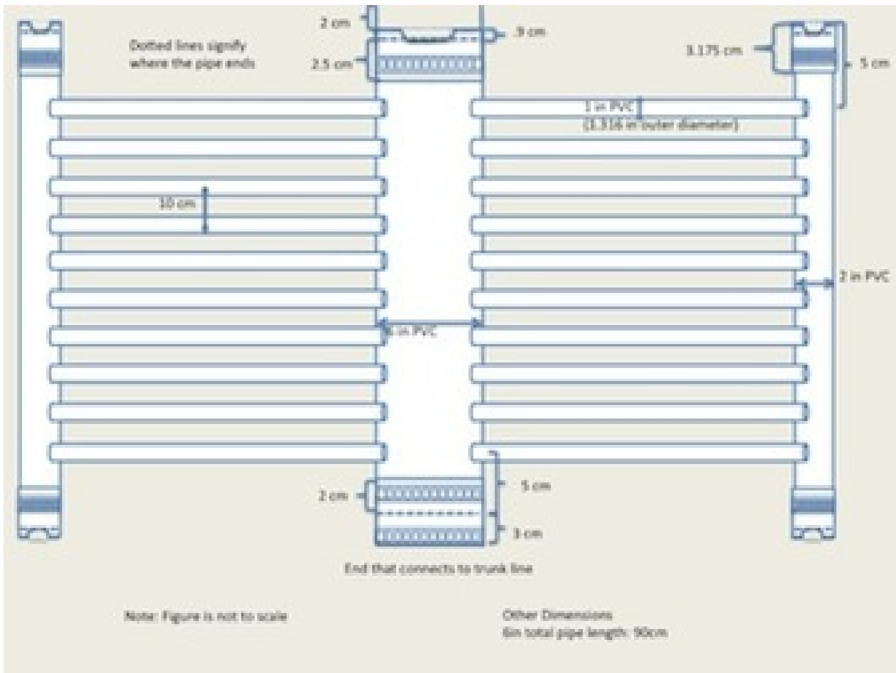


Figure 7: Current Manifold Dimensions

Part IV
Manifold Assembly

9 Experimentation and Fabrication

Over the past few weeks we began carrying out our design by building a full-scale mockup of the manifold. We have encountered some problems but also found better, quicker, and cheaper solutions to create the manifold. By building a to-scale model, we reinforced the concept that all the dimensions must be met exactly as planned. This refers to such shortcuts as using PVC cap ends instead of Fernco caps. Shortcuts cannot be made when relying on predetermined measurements such as the dimensions of the caps. Even though the Fernco caps cost a significant amount more than the PVC caps, the design requires a smaller cap, namely the Fernco cap.

9.1 Pipe Connections

We have discovered that our previous idea of using a straight mold, instead of a curved custom mold, for the trunk side of the branches is sufficient. The connection between the branch and the large trunk pipe seem to have minimal space when using the ordinary reducing mold. Also, the custom curved mold allows for a decent fit along the 2" PVC pipe, but we are seeking alternative solutions that produce a tighter fit. We noticed that when the holes were drilled into the 2" pipe, the quality of the holes makes a big difference. One side of the manifold had sufficiently better holes than the other side, and it makes a noticeable difference. We are attempting to modify our mold by increasing the size of the hole cut in the aluminum mold, which in turn reduces the branch ends less than previously. This will be tested to make sure there is still enough room to easily insert the branches into the trunk and 2" side pipes. In order to ensure that the connections were sufficiently tight, we measured the gap with a 0.009" (0.2 mm) feeler gauge and found that sand would not leak through. A photograph of these connections is shown in Figure 8.

Figure 8: Molded Pipe Connection

9.2 Securing the Pipes

In order to ensure that the pipes stay together both during installation and during operation, we explored various methods of holding the pipes connections in place. Both the material and the orientation of this system were considered in the design.

9.2.1 Stainless Steel Cable

1/16" diameter steel cable was purchased and tied around the ends of the manifold in order to apply the necessary force to keep the pipes in the holes. In order to allow the cable to attach to securing devices, loops were made at the ends of the sections by placing a compression sleeve around the cable. The main issue with these sleeves is tightening them. Ideally, a large tool would be used to clamp them down on the cable. This is expensive and not feasible. Instead, we simply hit a narrow piece of steel with a hammer onto the sleeve, which pinched the sleeve closed. This is technique seems primitive and was very time-consuming, but it is simple. The steel cable did not allow for flexibility in the length of cable. If the cable were cut just a little bit too short, or a different style of attaching the ends was desired, one had to cut a new piece of cable and reapply the compression sleeves as well. Again, this is a very time consuming process and certainly not ideal.

9.2.2 Kevlar Cable

An alternative to the steel cable was sought out due the inconvenience of using the material. A string of Kevlar-based material was purchased with the intent that the loop-tying would be far more convenient than with the steel cable. The approximately 1/8" diameter string is strong (rated at 300 lb.) and rigid, so it will not stretch with time. The flexibility of a string made it very easy to work with and to adjust, and also allowed the ends to be looped with a simple knot instead of a sleeve. However, there was hesitation towards using Kevlar because of our relative inexperience with this material. The integrity of Kevlar submerged in water is unknown, but a requirement is that the material should be able to withstand fifteen or more years of being submersed in the water and sand bed. This is difficult to know, and the material might also be difficult to obtain in Honduras. Because of these factors, additional options were considered.

9.2.3 Steel Wire

Steel wire was suggested because it represents a compromise between the reliability of the steel cable with the ease of assembly of the Kevlar string. The 0.380" diameter steel wire offers more flexibility than the cable and also does not require sleeves to create loops. The wire could be looped at the ends by wrapping the wire around itself in a twist-tie fashion. This was found to be extremely convenient. However, the wire is not as strong as the other materials. It provides sufficient force in tension, but is weak in shear, which must be considered when determining which method of attachment to use. However, when wrapped in parallel loops using the turnbuckle method (to be discussed), the wire did provide sufficient tension to keep the pipes together.

9.3 Fastening the Support

Several methods were used for attaching the ends of the cable, string, and wire to each other and providing tension to ensure the stability of the manifold. Turnbuckles were a primary option. They were used to connect the end loops of the wire and were then tightened. Nuts were placed at the ends of the screws in the turnbuckle to ensure a permanent set. The turnbuckles were extremely secure and looked very professional, but they did cost almost $5 each. See Figure 9a below for the turnbuckle attachment. When used with the steel cable, the 2.5" of tightening leeway that the turnbuckle offered was not sufficient. This issue could be solved by choosing a material that is easier to adjust (in terms of length), which would allow for a tighter initial fit.

Zip ties were considered instead of turnbuckles in order to increase the possible tightening distance. These zip-ties were reusable, very inexpensive, and rated for 300 lb., offering both ease of use and strength. The ties were tightened with pliers and were able to achieve sufficient tension. However, the zip ties do not look professional, which is a concern when trying impress visitors to the filter, as for instance to obtain government approval. The corrosion resistance is also unknown, so a more reliable alternative was sought.

In the case of a steel wire, a twisting tool was used to twist the wire ends together, without a loop. However, the stress from being twisted was too high and the wire broke. A tourniquet method was also used and sufficiently tightened the wire, but the nature of the method requires fastening the tourniquet lever to something to prevent reversal. This is a minor inconvenience, but enough to open the door for exploring other options. Both the tourniquet and the turnbuckle methods, however, are still considered as possible options. The turnbuckle can be seen below in Figure 9a and the connection between the turnbuckle hook and steel wire can be seen in Figure 9b

(a) Turnbuckle

(b) Turnbuckle Hook Steel Wire

Figure 9

9.3.1 Cable Installation Pattern

The pattern in which to wrap the string, wire, or cable around the manifold were all tested by the steel cable. The cable was tried in an x-pattern initially to provide maximum stability. The test manifold proved to be extremely stable when assembled this way, but when the same technique was used for the slotted pipe manifold, the pipes bowed and the manifold deformed. Thus, tension in the cables should not exceed the bending limit for the pipes in compression. The cable was then tested with 2 loops in parallel with the pipes. Each loop was attached with one of the aforementioned methods and tightened. This pattern did not cause any bending in the pipes. It did not, however, provide much additional structural support. This is not a primary concern because the mold connections are tight enough without the extra cable to not bend excessively during transport. A single loop was also tested and proved to be almost as successful as the double loop method. Other orientations of cable were tested, which included wrapping a single long strand around the entire manifold. However, due to the length of cable, it was difficult to achieve enough tension with the single connection to make the large amount of cable worthwhile. Therefore, if a reinforcement is desired, the recommendation is having a single loop wrap around the manifold in parallel with the pipes.

9.3.2 Gluing Requirement

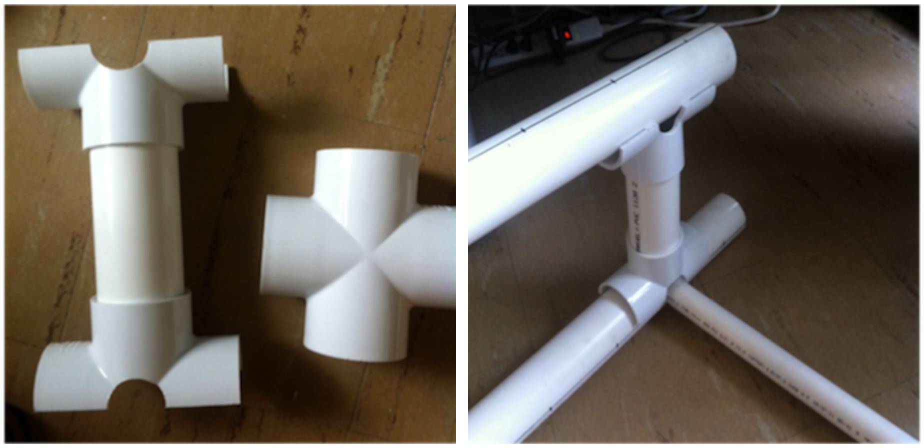
As we have been trying to figure out the most efficient way to support the wings of the manifold, we have exhausted two options; using steel cables or glue. The problems we have with steel cable are the ability to tighten the structure without deforming the wings. Once the turnbuckles have reached a moderate tightness, the slotted pipes begin to deform. As the force increases on these pipes, the flexing along the slots becomes a severe issue. The alternative idea was glue. Initially we planned to not use glue because of single pipe replacements. Once a slotted pipe is glued, it cannot be replaced if broken; the entire manifold will have to be reconstructed. Understanding this concept led us to work out the issues with steel cables. After closer inspection of the steel cables we have concluded that the steel cables are a reliable source of support as long as a certain maximum of force is not applied by the turnbuckle. This maximum can be found by continuously tightening the turnbuckle until the first slotted pipe begins to flex. Once this occurs, loosen the turnbuckle slightly until the pipes have returned to their original shape. This amount of support should be sufficient enough to keep all the pipes together without deforming the wings of the manifold.

9.4 Stacking Layers - 2" Pipe

In order to create the full, layered manifold assembly, we are required to develop a method for stacking the manifolds on top of each other. A method was tested in which a cross-fitting for 2" pipe was cut into two pieces. There is the possibility that cross fittings will not be available in Honduras. However, if this is the case, we can just utilize regular tees to fabricate the same parts. There should not be a problem with this, as tees are readily available and relatively inexpensive. A 1.5" diameter hole was cut into the center of the fitting prior to the center cut being made in order to avoid interference with the slotted pipes. Once cut, a piece of 2" pipe was then inserted into the fitting and the assembly was used as a "saddle" attaching to the 2" pipe. These connections are to be used at the four corners of the assembly. The cross fittings for the 2" trunk lines are shown in Figures 10a and 10b, while Figure 11 shows the location of all required spacing connections. Notice that there is an extra area marked on the 6" pipe. This connection will be discussed in the following section.

Figure 10: Stacking Layers

(a) Using Cross-Fittings (b) Stacked Layers



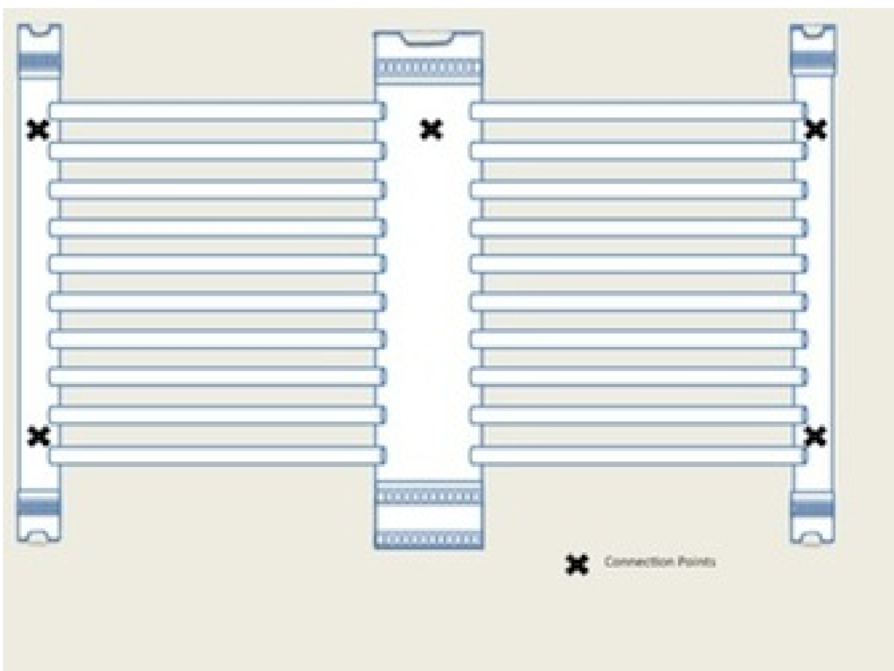


Figure 11: Stacking Positions

The saddle portion was originally secured with two zip ties to keep the stacking post from sliding. However, upon further testing, we replaced the zip ties with hose clamps. Not only were the hose clamps more aesthetically pleasing, they were also much easier to tighten and provided a more secure grip. Although hose clamps are not as cheap as zip ties, we believe that they are more durable and will be more cost efficient in the long run. It is not likely that the hose clamps will need to be replaced. The use of these hose clamps can be seen below in Figure 12

Figure 12: Hose Clamps

This attachment method will be tested by assembling 2 layers of the manifold and applying forces in various directions to simulate the loading to the manifold during the backwash and filtration cycles.

For the complete filter assembly, each stacking piece will be secured with a hose clamp to the manifold layer below it. Each layer with an attached stacking piece will be lowered into the filter box and settle on top of the layer below it. Because there will be nothing securing this connection, we will smooth down the inside of the cross tee so that the 2" pipe will rest more securely. In addition, we are considering the idea of using glue instead of hose clamps. Although hose clamps are very secure, it takes a significant amount of time to put them in place. However, as it stands, we still believe that hose clamps are the best option for securing the stacking pieces.

9.5 Stacking Layers - 6" Pipe

The stacking connection for the trunk line requires a slightly different procedure since the 6" cross-fittings are extremely rare and if found, are extremely expensive. In addition, they are so big that there is no space for them between the trunk lines, given the 20 cm spacing we want between the 6" pipes. Therefore, some alternative was needed.

9.5.1 PVC Pipe Stacking Testing

A method was tested which used a 2" pipe, stacked perpendicularly to the trunk line. The ends of the pipe were cut (with a band saw) to match the curvature of the 6" trunk line. A small hole will be drilled near the curve so that a zip tie could be threaded through the hole and around the trunk line to secure the stacking

9.5.2 Outcome

This method was unsuccessful because of the diculty in matching the ends of the pipe to the exact curvature of the 6" diameter pipe. We also feel that this method would be extremely impractical in the eld. Because of this, we began looking into dierent options for stacking the 6" pipes.

9.5.3 Rubber/1" PVC Pipe Testing

As a solution, the remnants of the 6" Fernco cap were used. Since there was a 5 cm section of Fernco material (in the shape of a sleeve) unused, we drilled 1.25" diameter holes on opposite sides of the sleeve. This sleeve then wrapped around the 6" pipe and be placed in the desired location. A short section of 1" PVC pipe (whose actual outer diameter of 1.316" is slightly larger than the hole) was cut to achieve the 20" spacing, and was inserted into the hole. The ttings are suciently tight so that movement should not be a problem. However, if desired, a hose clamp can be placed around the tting to secure it further.

9.5.4 Outcome

This method was eective for stable stacking, but it proved dicult to assemble. The t between the pipe and the hole in the Fernco cap was so tight that it proved hard to insert the pipe into the hole. Additionally, the weight of the second manifold and the orientation made it dicult to align. The connection is shown below in Figure 13.

Figure 13: 6” Pipe Stacking

The alternative is to drill a larger hole in the Fernco sleeves in order to facilitate the pipe section placement. However, this does not alleviate the diculty of aligning the pipes upon placement. We required a simpler solution that allowed for easy placement and attachment of the manifold layers.

9.5.5 1” Horizontal Spacers

In order to alleviate the problems with ease of installation, a solution was developed that placed two one-inch sections of pipe parallel to each other. Holes were drilled (0.265” diameter) into the pipes and they were connected with threaded rod which ran through the holes. Two jam-nuts were used at the ends of each segment to allow for adjustment of spacing. See Table 1 for the full list of materials.

Materials	Quantity
4” piece of 1” diameter PVC pipe	2
5” piece of ij-20” threaded rod	2
ij-20” nuts	8

Table 1: Materials for 1” Horizontal Spacing

The manufacture was simple and only required a hand drill and a 0.265” drill bit, in addition to the raw materials. Figure 14 shows the assembled spacing piece.

Figure 14: 1” Horizontal Spacer

9.5.6 Outcome

The piece was placed into the manifold to test the support and stability. It proved to be very effective. It was also extremely easy to align the upper manifold onto the piece. If the piece were glued outside the manifold, then no attachments or fastenings would be required once the upper manifold was placed onto the lower. This solution is very versatile because it is adjustable. In order to increase or decrease the spacing, the nuts must only be moved. Once the desired spacing is achieved, the jam nuts are tightened to each other for a permanent hold. See Figure 15below for the stacked assembly.

Figure 15: 6" Pipe with 1" Horizontal Spacer

A full picture of the stacked layers can be seen below in Figure 16.

Figure 16: Final Stacked Layers

Part V
Conclusion

We have compiled a summary of the most effective way to fabricate the Stacked Rapid Sand Filter based on our work this semester. The summary has been divided into three separate sections. These sections are molding pipes, manifold assembly, and stacking layers. Each section has a list of materials and tools needed for construction as well as a short procedure.

9.6 Molding Pipes

Table 2 details the materials needed and Table 3 details the required tools for molding the slotted pipes.

Materials	Quantity	Specifications
1" Slotted PVC pipe	18	87 cm length

Table 2: Molding Materials

Tools	Purpose
Heat Source (hot plate)	To heat the pipe
Oil (pure canola oil)	To heat the pipe
Curved guide cylinder mold	To mold the pipe for the 2" end line connection
Straight Mold	To mold the pipe 6" trunk line connection
Infrared thermometer	To measure the temperature of the oil
Paper towel or cloth	To wipe down pipe before insertion
Cool water	To cool down the pipe after molding

Table 3: Molding Tools

First, heat the oil with a heat source. The oil should reach about 1" (2.54 cm) above the bottom of the beaker. For our purposes, we used a hot plate. Use a thermometer to ensure that the temperature stays within 240ºF and 270ºF. Leave the end of the pipe submerged for approximately 1 minute.

After removing the pipe from the oil, wipe the oil off the outside of the pipe and insert it into the mold. Make sure the pipe is inserted completely into the mold and that it reaches the bottom. In addition, ensure that the slots on the pipe are facing the straight ends of the mold. Leave the pipe in the mold for about 1 minute, then remove the pipe and place the end into cold water.

9.7 Manifold Assembly

9.7.1 Drilling

Table 4 details the materials needed and Table 5 details the required tools for drilling holes in the trunk line and end lines.

Materials	Quantity	Specifications
6" PVC pipe	1	90 cm length
2" PVC pipe	2	90 cm length

Table 4: Drilling Materials

Tools	Purpose
Drill Press	To accurately drill holes
Milwaukee 1 1/4" Steel Hawg Hole Saw	To accurately drill holes
Tape Measure	To measure

Table 5: Drilling Tools

The most important part in building the manifold is the preciseness of drilling the holes. The accuracy of the drilling process and the exact lengths where the holes are drilled will decide how tight the connections between the pipes are. To begin, mark off the holes on the 2" pipes. The holes are symmetrical to each end of the pipe, having centers 5 cm from the end of the pipe. Each additional hole should be 10 cm from the center of the previous. There are 9 holes in total. The same concept should be done to the 6" trunk. On the trunk, more accuracy is required because two sets of 9 holes will be drilled exactly opposite to one another. The same measurements apply to the trunk as they did to the 2" pipe. Using a drill press and the Milwaukee 1 1/4" Hole Saw, drill out the holes slowly. The faster the drill press is used, the less accurate the holes will be.

9.7.2 Assembly

Table 6 details the materials needed and Table 7 details the required tools for drilling holes in the trunk line and end lines.

Materials	Quantity	Specifications
6" PVC trunk with holes	1	90 cm length
2" PVC sides with holes	2	90 cm length
2" Fernco end caps	4	
6" Fernco coupling	1	
6" Fernco end caps	1	
6" hose clamp	2	
2" hose clamp	4	
Stainless steel turnbuckle	1	6.875" closed length
Stainless steel cable	approximately 110 cm	1/16"
Stainless steel compression sleeves	2	1/16"

Table 6: Assembly Materials

Tools	Purpose
Razor blade	To cut the Fernco connectors
Screwdriver	To tighten the hose clamps
Anvil	To tighten sleeves
Hammer	To tighten sleeves

Table 7: Assembly Tools

Once the pipes are molded and the holes are drilled, we can then insert the pipes into the end lines and trunk line. First, insert the pipes into the 2" end line individually. Notice that the molds on the slotted pipes are now directional and should be oriented correctly into the 2" pipe. The next process is tricky because an entire side of the manifold must be inserted at the same time once the pipes are inserted into the 2". Align the holes of one side of the manifold with the remaining pipe ends from the 2" pipe. Push the pipes in until each pipe has gone into the 6" trunk slightly. While maintaining pressure on the 2" pipe towards the 6" pipe, force each slotted pipe into the trunk. How well the pipes were molded and how accurate the holes were drilled will determine the tightness of this connection. Moderate force should be required to fully insert the pipes into the corresponding holes. Repeat this to the opposite side and then apply the Fernco caps and couplings, which need to be modified first.

We need to cut the 6" Fernco cap and coupling to a size that will not interfere with the holes. Using a razor, trim the cap to 3.5 cm. Do this to the coupling as well. Trim the coupling to 5cm. Hose clamps secure all of the Fernco connections. Tighten the clamps with a screw river but make sure to not over-tighten because it will break the clamps. Once the four 2" Fernco caps, the 6" Fernco cap, and 6" Fernco coupling are all applied, the steel cable can then be applied. To make the cable, use the approximately 110 cm of stainless steel cable and slide a sleeve over one end, roughly 4" from the end. Fold the cable end into a loop and into the sleeve. Using some sort of anvil and hammer, smash the sleeve closed onto the cable, creating a loop.

Depending on the type of turnbuckle used, it might be necessary to insert one of the ends of the turnbuckles into the loop before closing. This is necessary if "closed-loop" turnbuckles are used instead of "open-loop" turnbuckles. Use this method to make the loop on the other side as well. Once the loops are made in the cables, wrap the cable around the manifold horizontally. Put the turnbuckle together, and begin to slowly tighten the turnbuckle. Depending how the amount of slack allowed, the cable should begin to tighten. Be careful while tightening because too much tightening will cause the slotted pipes to flex and deform. If this starts to happen, loosen the turnbuckle slightly. The turnbuckle is strong enough to keep all the pipes together without deforming the slotted pipes.

9.8 Stacking Layers

Table 8 details the materials needed and Table 9 details the required tools for stacking the manifold layers.

Materials	Quantity	Specifications
Stainless steel hose clamp (2”)	8	For 2” pipe diameter
2” pipe	4	13.5” length segments
2” pipe cross fittings	2	
1” pipe	2	4” length segments
Threaded rod ij-20” thread	2	6” length segments
Jam nuts (1/4-20” thread)	8	
PVC Glue		

Table 8: Stacking Materials (Per Manifold)

Tools	Purpose
1.5” hole saw (with hand drill)	To drill center hole in cross fitting
Saw	To cut PVC
Screwdriver	To fasten hose clamps
“G” drill bit (0.261”)	To drill holes in 1” pipe for 6” stacking pieces

Table 9: Stacking Tools

The manifold layers will stack on top of each other at 5 connection points in addition to the connection to the trunk line coming through the wall. Refer to Figure 11 for the connection points.

9.8.1 2” Connection Points

The four corner connections will connect to the 2” pipe end lines using the “2” stacking pieces.” These stacking pieces can be seen in Figure 10a. To construct these pieces, cut four segments of the 2” pipe. Then, drill holes using the 1.5” hole saw into the center of the cross fittings, all the way through the piece. Next, cut the cross fittings in half so that the cut goes through the center of the hole. Assemble the stacking pieces as shown in section 9.4 and use the hose clamps to fasten the stacking piece to the 2” end line in the manifold. Four of these stacking pieces will be secured at the four corners, with the “clearance hole” fitting over the second slotted pipe from each end.

9.8.2 6” Connection Points

The remaining connection point will be located between the second and third pipes from the end on the 6” trunk line. (On the side opposite that which goes into the wall) To construct this, cut two 4” long segments of 1” pipe. Then, drill two holes into each pipe segment, each 1" from the end. See Figure 14. Arrange the nuts as shown in the diagram and insert the threaded rod through the holes. Adjust to desired spacing (3") and glue the spacer to the manifold that it will be placed onto.

10 Future Work

10.1 Modifications for the Bottom Manifold

The bottom layer of the manifold also requires assembly, but it has differently-sized trunk lines and 2" branch pipes. A new curved mold will have to be made so that the slotted pipes fit a different dimension of pipe. All stacking dimensions and connections have to be modified slightly to fit the difference in the pipes. All of the techniques used for the other manifolds should suffice, if slightly modified.

10.2 Filter Box Anchoring

In order to properly anchor the manifolds into the filter box, we have come up with a possible idea. The anchoring concept requires attaching two I-bolts to the filter floor, preferably by cementing them in. These I-bolts will be directly off-center from the 2" pipes, and off-center from the middle slotted pipe. This orientation will allow a threaded rod to be inserted the entire depth of the filter box. By bending the end of the threaded rod into a hook, we will be able to insert the rod into the I-bolts on the bottom after the manifolds have been installed. These rods will then extend past the manifolds and above the top layer. At the top, a piece of stainless steel will extend over one side of the slotted pipes, parallel to one of the 2" pipes. This piece of steel will have a hole in it allowing it to be inserted onto the threaded pipe. By tightening lock nuts on top of the piece of steel, we will be able to tighten all the manifolds at once. In order to secure the trunks, we will use another piece of steel. This rectangular piece of steel, preferably 2" wide, ij" thick, and a desired length to span from rod to rod over the trunk, will then be tightened down with lock-nuts as well. As each side tightens the upper lock nuts, it will apply a center force on the trunk, thus allowing for each component of the manifold to be secured to the filter box. These ideas are theoretical only and have not been tested.