VORTEXING OFF A COMMON SUCTION HEADER

FINAL DESIGN REVIEW

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Statement of Disclaimer

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LIST OF NOMENCLATURE

Off-take angle - The angle between an axis parallel to the main line and axis parallel to the branch line at the tee junction.

Main line - The pipe that has an inlet at the reservoir and bends 180° to have an outlet at the reservoir.

Branch line - The pipe that is in-between the two tee junctions

Critical submergence depth - Depth of water in the pipe before a vortex occurs

Nondimensional equation - Equation describing physical quantities that scales to various parameters with the full removal of units.

ABSTRACT

This project is the first iteration of a testing rig to determine the critical submergence of a vortex off a main suction header. The rig was designed with supplies purchased and provided by PG&E, including 4-6” schedule 40 PVC pipe and fittings, a large water tank, a pump, and a flowmeter. PG&E at Diablo Canyon Power Plant presented their problem to the Cal Poly Mechanical Engineering Senior Project class, and three mechanical engineers took up the project.

The following report details the ideation, design, build, and test processes used during the 2016-17 academic year to create the vortex testing rig. We determined through testing that the location of hydraulic jump can be influenced by how open or closed the branch line valve was, which in turn influenced when gas ingestion to the pump occurred.

1 INTRODUCTION

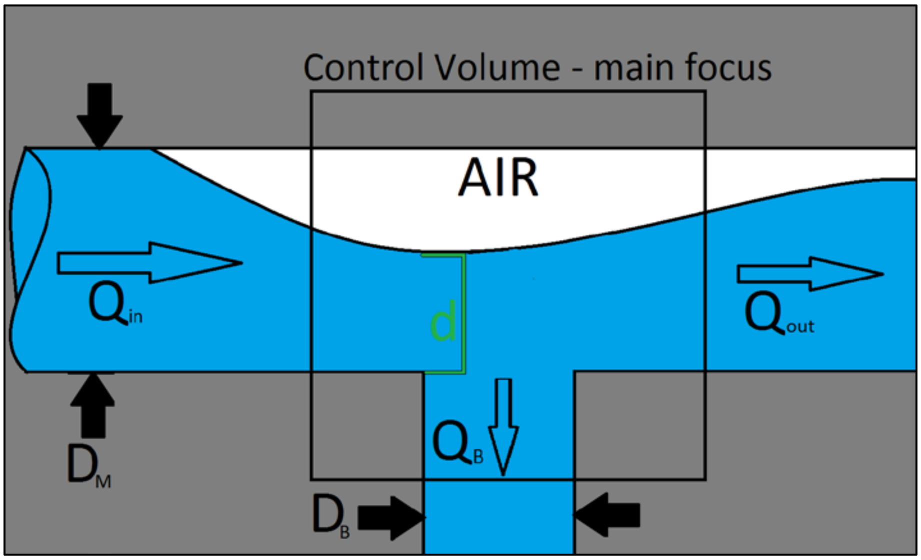
1.1 ABOUT THE PROJECT

This study of exploring vortexing off a common header is a senior project for the 2016-17 California Polytechnic State University of San Luis Obispo’s (Cal Poly SLO) Mechanical Engineering department. This senior project is sponsored by PG&E, one of the largest electric utility companies in California serving 5.2 million households. The project will be overseen by our adviser, Professor Eileen Rossman, and our sponsor, Anderson Lin, who is a Principal Engineer at Diablo Canyon Power Plant located in Avila Beach, California.

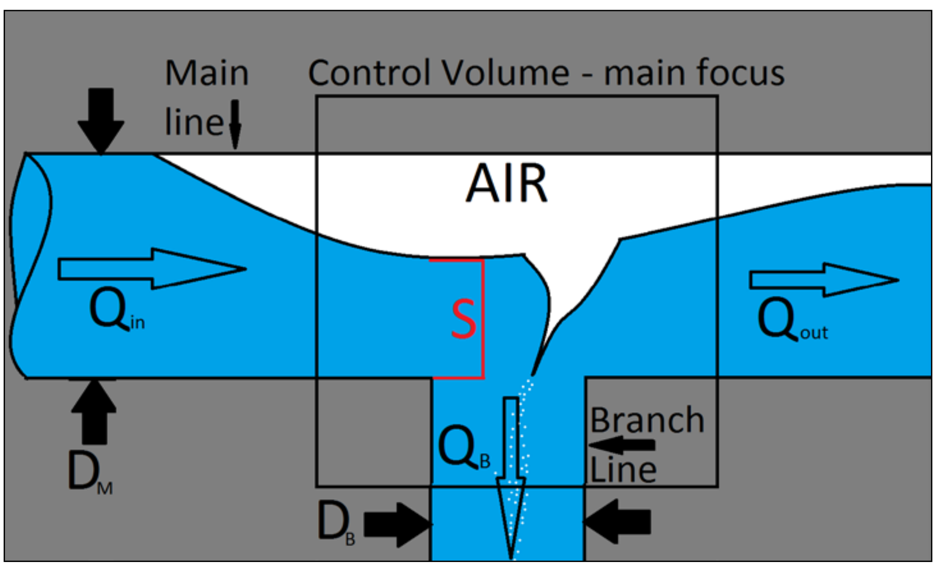
We will be working closely with Mr. Lin and a team of other employees at PG&E to design a testing apparatus that will simulate the systems that are currently operating in the plant. This occurrence does not happen in any particular part of the power plant system, but rather vortexing is an event PG&E would like to accurately measure in order to report the safety or vulnerability of the plant to the Nuclear Regulatory Commission (NRC). Currently, the NRC has a zero tolerance policy regarding the intrusion of bubbles into any system throughout a power plant. But if there is any form of maintenance in a system where the removal of components is necessary, then a small volume of air is bound to linger within the system piping.

PG&E is sponsoring us to design a test rig and develop a nondimensional equation to predict the depth of fluid at which a vortex begins to form to ingest air from a common suction line into a branch line, also known as the critical submergence depth, S. This test rig will allow us to visually observe the critical depth at which a vortex forms that will ingest air bubbles through the branch lines, or offtake lines, leading to a pump. This gas ingestion could be damaging to the pump or the overall system and can eventually compromise plant operation. A graphic shown in Figure 1 illustrates that the air bubble is formed in the main suction line downstream of a fluid tank, while the vortex will form downwards into the branch suction nozzle. Our main focus when we conduct experiments is in the black box labeled ‘Control Volume’, but we will be designing

the entire system. Note that in Figure 1 the vortex occurs when the flowrate through the branch line increases. Even though the submergence depth does not change, the system still becomes critical. Thus the submergence depth is tied to some aspect of the flowrate. We will also like to observe the effects of the vortex when the branch line coming off the main suction line is in either the vertical, horizontal, or 45° position, always perpendicular to the main line.



(a)



(b)

Figure 1. Sample drawing of project where d is the submergence depth, S is the Critical Submergence Depth, DM is the diameter of the main suction header, and DB is the diameter of the branch suction nozzle.

(a) Noncritical case (b) Critical case

2 BACKGROUND

2.1 MOTIVATION

Several of the piping systems in a nuclear plant have a large number of locations where gas can be introduced to, or generated within, the lines. This gas could challenge plant operations if a large enough bubble makes its way into a pump; the pump will lose suction and will not operate as designed. Loss of a pump can degrade plant safety and cause a safe, but economically costly, shutdown.

In 1988, Diablo Canyon Power Plant experienced loss of a pump during a routine refueling of one of the reactors. Normal procedure for refueling a reactor requires that the level of water in the reactor be reduced to mid-loop to drain the steam generators. To be reduced to mid-loop means to decrease the maximum fluid level to only one half the diameter of the pipe. In order to keep the core cool, a branch line is opened and cooling water is diverted from the reactor system into a branch suction line to a heat exchanger. In the case of this incident, the branch line ingested enough gas due to vortexing and lost the siphon in the pump suction high point to break the flow of water to the pump, causing it to gas bind and fail. This resulted in the loss of core cooling, which led to the emergency flooding of the nuclear vessel to cool the core. A configuration that may closely represent this problematic area is shown in Figure 2. This event highlighted the importance of studying how vortices form at junctions in piping systems. Because there are many different locations where this phenomenon is important to model, we are interested in developing a nondimensional equation that can be applied to a large range of flows and geometries.

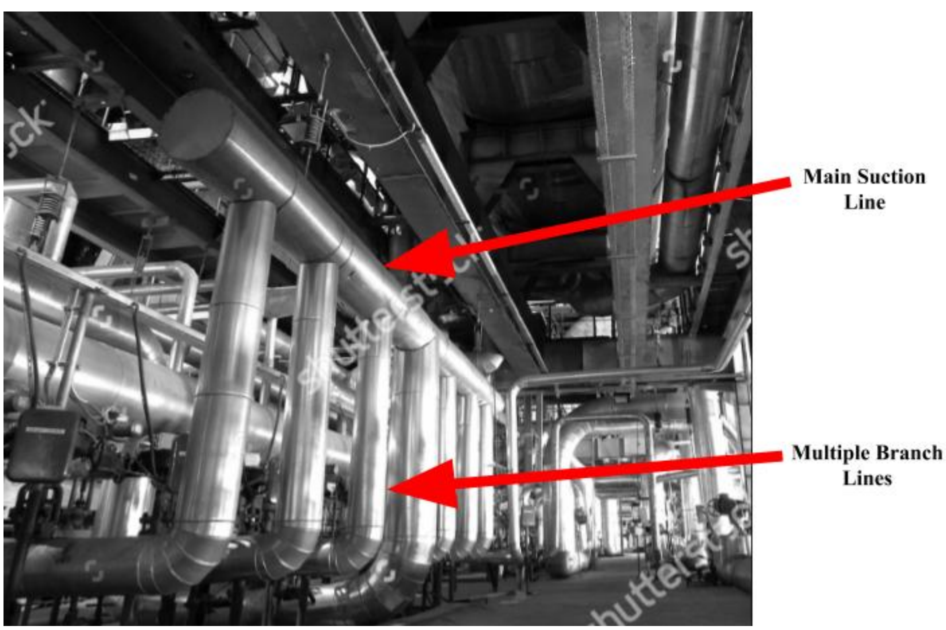


Figure 2. General nuclear power plant piping system illustrating main line with multiple branch lines[1].

2.2 BACKGROUND RESEARCH

Due to the difficulty of the governing equations for fluid dynamics, a majority of problems cannot be solved with a direct analytical approach and instead rely on correlations developed from experimental data. In order for the results of our experiment to be applicable to a wide range of systems, we need to employ the concept of similitude. Our experimental rig will be able to scale kinematic, geometric, and dynamic factors where possible in order to scale to larger systems.

The first step in nondimensional analysis is to determine which variables are of interest and to represent these variables as a set of nondimensional numbers. A powerful method of determining these nondimensional groups is called the Buckingham Pi theorem. The terms are determined by first reducing each of the relevant variables into its basic dimensions of mass, length, and time. The variables are then split into the dependent variable that is of interest (in our case it is the critical submergence depth), repeating variables, and non-repeating variables. For the first pi term, the dependent variable is kept in the denominator and three repeating variables are each raised to a coefficient such that the basic dimensions cancel out. This process is repeated for each remaining non-repeating variable. The process yields a set of fewer nondimensional groups than the original number of variables of interest [2].

Once we calculate our nondimensional groups we can begin testing and collecting data. In collecting data, we need to record data for all of our variables so we can explore a variety of relationships between our nondimensional groups. We will form an equation from our collected data by regression analysis. This is a statistical method to estimate the relationship between two variables resulting in an equation. There are a number of different methods to use with the most common being the ordinary least squares method.

Several studies have been done to determine a nondimensional relationship to predict the critical submergence depth for a vortex that will form in a stagnant tank of water. The critical submergence depth, S, is nondimensionalized by dividing it by the pipe's diameter, D, both illustrated in Figure 1. Many of experimental studies have found S/D to be a function of the Froude number [3]. The Froude number characterizes the ratio of the inertial forces to the gravitational forces in the fluid and is defined as

$$Fr = \frac{V}{\sqrt{gD}} \tag{1}$$

In Equation 1, V represents the characteristic flow velocity, g represents Earth's gravitational constant, and D represents the diameter of the pipe [2]. The Froude number is often used when studying flow with a free surface.

2.3 History and Definition of Vortices

There has been much research done to determine the characteristics of vortices. Starting in 1858, Hermann von Helmholtz published a mathematical study of vortices, perhaps being the first to investigate vortex motion and its properties. He was followed by William Thomson, better known as Lord Kelvin, in 1869, who developed a theory of the material atom as a vortex ring [4].

Vortices usually describe the motion in a frictionless fluid. If there was no friction in fluids, there would be no way to create or stop the motion of a vortex, although that is not the case in reality because frictionless fluids do not exist. In order to overcome friction and continue the vortex motion, one needs to apply a constant power supply to the fluid.

The vorticity of a vortex is the measure of the strength of rotation, which is defined as the curl [5] of the velocity vector of the fluid. The individual vectors are connected with what is called a vortex line. As one begins to group up the vortex lines, you are left with a vortex tube, which is what many people are familiar with when they see whirlpools or tornadoes.

The formation of a vortex is a simple concept. As a water molecule is pulled towards the bottom of the tee it accelerates in a straight line, however, as the other molecules around it also try to accelerate directly at the bottom of the tee, they interfere with one another and generate an overall rotation in the flow. This effect compounds until the downdraft of the flow is enough to drag air along with it, and a vortex is formed.

2.4 Previous Experiments

The experiment we will conduct is unique because the cross flow in the main suction line will not be stagnant. Some differences between our experiment and experiments found online include transient flow in the main suction line and the fact that the main suction line will not be exposed to the atmosphere. The following cases are different to our scenario, but have some research that will allow us to improve our study as will be described below.

2.4.1 Case 1

In 2014, a paper by Carlos Julián Gavilán Moreno [3] was published that studied the accuracy of predicting critical submergence depth based on the Weber and Reynolds number. Although this study showed that common calculations in determining critical submergence used the Froude number, this study did not use it. We will be using Froude's number in determining our nondimensional equation, but this study provides an interesting alternative.

One way this paper quantified the depth for a vortex formation was based on certain types of vortices. Both the paper and our sponsor recommended obtaining data for a Type 6 vortex, as shown in Figure 3.

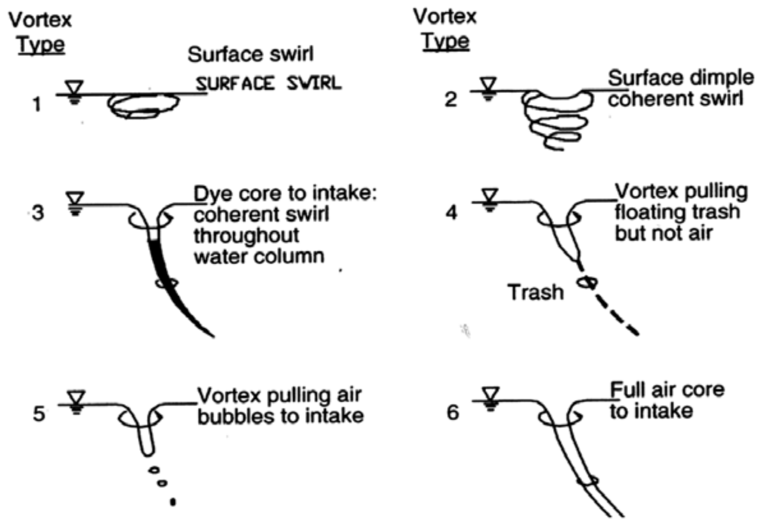


Figure 3. Types of vortices to determine critical submergence depth [3].

In Case 1, flow from a reservoir leading to a pipe with a nozzle is observed. First, he calculated Fr for a range of values using Equation 2.

$$Fr = We\sqrt{\frac{\rho}{\sigma g}} = \frac{Re \cdot \vartheta}{L^2\sqrt{gL}} \tag{2}$$

Then, he numerically modeled critical submergence using Finite Element Analysis. To ensure his model was accurate, he compared the simulated submergence with experimentally determined submergence, and for various flowrates he observed a total simulation error of less than 5%. He plotted these two sets of data and used the non-linear least squared method in order to obtain the coefficients for a corrected critical submergence; Equation 3 is the result,

$$S_c = a + b\left(\frac{Re}{10^6}\right) + c \cdot We + d\left(\frac{Re}{10^6}\right) \cdot We + e\left(\frac{Re}{10^6}\right)^2 + f \cdot We^2 \tag{3}$$

with a, b, c, d, e, and f are the coefficients obtained from the non-linear least squared method.

The take away from Case 1 is the use of obtained experimental data and plotting the data in order to refine the anticipation of a particular phenomenon. In our case, this phenomenon is critical submergence.

2.4.2 Case 2

Next, we examined a paper published by Yaser Sheikhi and Babak Lashkar-Ara, a student and professor in Iran. By using four different models, a nondimensional equation was found using nonlinear regression (as opposed to linear regression analysis) [6]. One way they found this equation was by using a critical spherical sink surface (CSSS). The CSSS has the same center and discharge as where the fluid enters from the reservoir into the pipe and the radius of the CSSS is equal to the critical submergence for an intake. In order to determine the radius of the CSSS, the

total area minus the area that is blocked is accounted for. For a detailed account of the math, please refer to the reference section [6]. This imaginary surface is then used as a way to determine critical submergence and is employed as a means with experimental data to create a nondimensional equation.

The most relevant knowledge this paper provided was about the Kolf number. The Kolf number is a nondimensional parameter that depends on the geometry of the intake and whether or not there is end circulation in the pipe. End circulation, Γ, is “the strength of the vortex tube” and is defined by “the product of the vorticity normal to the surface enclosed by the curve C” [7], shown in Figure 4; the equation to calculate end circulation is defined in Equation 4.

$$\Gamma = \int \omega \bullet n \, dA \quad (4)$$

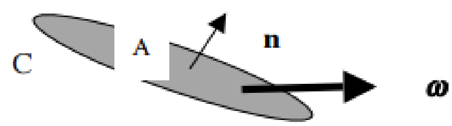


Figure 4. Vectors showing end circulation components.

Inevitably, the authors of this paper disregarded the Kolf number since there was no imposed end circulation. However, the Kolf number is considered here because it might affect our data depending on how the test rig is designed. Although our testing rig down the line may share similarities to their schematic shown in Figure 5, they fail to attempt this experiment with cross flow in the main suction header and only use one branch line, whereas we will experiment with cross flow and apply three different angled branch lines.

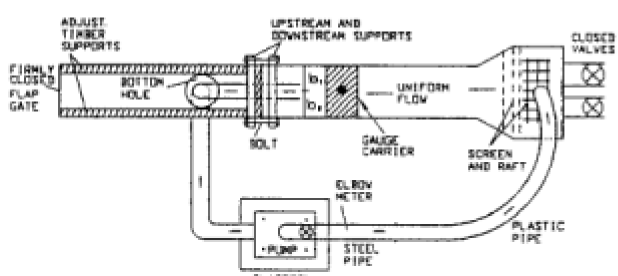


Figure 5. Schematic of experiment for horizontal flow.

3 OBJECTIVES

3.1 STATEMENT

We will investigate the phenomenon that creates a vortex and attempt to relate specific conditions of the piping system (pipe diameters, flowrates, etc.) to a correlation of the critical submergence depth to the formation of a vortex. Once we build a test rig to conduct observations and use various instruments to capture flow and fluid depth data, we will deliver our results to the team at PG&E. Our intention is that they will be able to use our results to accurately predict when a pump will fail due to the gas-binding of oxygen.

3.2 SPECIFICATIONS

In order to create a test rig, we utilized a process called Quality Function Deployment House of Quality (QFD), shown in Appendix A, in order to obtain realistic targets for our design. The QFD is a tool that considers the following: customer requirements and needs, technical research, and benchmarking. The main objective is to focus on what is needed for a project rather than how to achieve it. We took the requirements presented to us by PG&E to find what needs were most important to the design of the test rig. We then attempted to benchmark their needs to similar test apparatus found online. Based on these inputs, the QFD helped us find a list of engineering specifications and their associated targets. Since one specification can be dependent on another, the top of the QFD shows the positive or negative relationship they have on one another. By determining the relative importance of a specification to a requirement, we were able to determine the relative weight of each customer requirement. From utilizing the QFD process, we obtained the specifications found in Table 1. We assigned a High (H), Medium (M) or Low (L) risk to each specification. Then we listed how we will verify each specification with different methods: Analysis (A), Test (T), Similarity to Existing Designs (S), or Inspection (I).

Table 1. Specification Table derived from QFD.

Spec. #	Parameter Description	Requirement or Target (units)	Tolerance	Risk	Compliance
1	Overall Dimensions	20 ft x 8.5 ft x 6 ft	Max.	L	I
2	Number of Offtake Angles	0°, 45°, 90°	N/A	M	T
3	Accuracy	3 test runs are predicted in a row	± 5%	H	T
4	Color of Pipe	Clear	N/A	H	I
5	Modular for 4-6" Diameter Pipe	Split into multiple parts for pipe swaping	N/A	H	I
6	Fully Developed Flow	Turbulent flow for accurate flowrate measurements	N/A	M	A
7	Fluid Flowrate	100-500 gpm	N/A	M	A, T
8	Range of Froude Numbers	0-3	N/A	M	A, T

For our first specification, we chose to focus on the overall size of our test rig. Because we are given a shipping container at Pismo Yard for transportation of the project, we decided to provide a maximum size relative to the dimensions of the shipping container. We do not expect our project to reach that upper limit, but do not know at this time.

Also, we were asked to investigate how the critical submergence depth changes as the angle of the branch coming off the main suction pipe changes. This is why we would like to conduct the experiment using various branch suction nozzles positioned at angles of 0°, 45°, and 90°. These multiple angles are shown in Figure 6 that are positioned radially from and perpendicular to the main suction line.

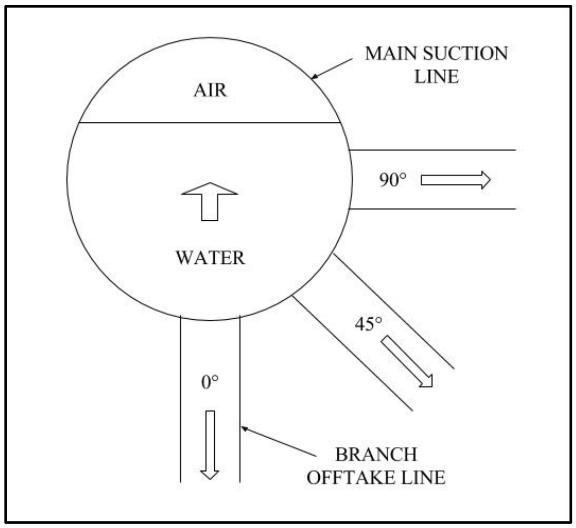


Figure 6. Section view of multiple offtake branch angles at 0, 45, and 90°.

Accuracy is a high risk parameter because it would be desirable to obtain test results that are repeatable as well as accurate in order to predict when a vortex would occur. PG&E would like to use our rig and procedure to train employees in the future, so this requirement is a necessity.

In order to determine when a vortex will occur, we decided to choose a transparent pipe to visually see the effect of changing water height and fluid flowrate. Thus the color of the pipe is an important requirement in the determination of a vortex.

PG&E asked us to investigate the formation of vortices using multiple pipe dimensions such as 4” to 6” diameter pipe for the main suction and branch offtake lines as to get data based on varying parameters. Therefore, we chose to make our design modular in order to swap out sections rather than to build a new piping system for each diameter we would want to test. Applying this specification to the rest of the rig will also aid transportation from location to location and assist in easy repairs if the need arises.

For certain flowmeters, it is necessary to develop fully developed flow throughout the piping system. This is because we need to know what the flow profile looks like. Therefore, we

need to create fully developed turbulent flow. We will perhaps do this by installing flow guide vanes in the 90° elbows or honeycomb plates for the straight run lines.

In the power plant, the main suction header and branch offtake lines experience different flowrates in the system. But since our project is a scaled down version of the power plant system, in theory and in conjunction with data obtained using dimensionless numbers, we have determined we will be working with a range of flowrates from 500 – 1500 gpm. More analysis will be made to determine a more exact range of flowrates our pump will provide during operation.

Our last specification is the range of Froude numbers we expect to be working with. From research online, we determined to be working with Fr numbers in the range of 0-3. This will provide us with a good starting point on what we should be expecting to see during the testing phase.

Something else to consider is the budget for the overall test rig. We were not given an estimate on the budget for the project, so we projected a rough cost of $10,000. We do not expect to reach this number, but thought it was appropriate for a worst case scenario amount. By doing an initial budget calculation of the parts needed for the rig, we expect to spend roughly $1,500, without factoring in the cost of renting a pump since we do not know how long we would need to rent it for.

The system within the power plant uses a boric acid-water solution, specifically 2500 parts per million boric acid. This concentration is very small; therefore, we will be conducting the experiment with water. Other vortex tests in the industry also use water rather than boric acid for the simulation, so therefore we would be able to adequately compare our results later on to others experiments. To ensure that this substitution is valid, EES calculations are produced in Appendix B, showing that the density of the two fluids have a negligible percent difference and behave quite similarly. If we have time in our design process, we would like to determine the similarities of other fluid properties, such as viscosity and surface tension, since these are parameters that govern the behavior of the air bubble.

4 DESIGN DEVELOPMENT

Once presented with this project, we began by defining the problem faced by PG&E. In order to do that, we spoke with the PG&E team overseeing this project and asked questions about what already exists and what is lacking in those systems. There have been no other tests done to simulate the conditions provided by our sponsor. We proceeded to research similar papers and experiments that involved inspecting the effects of a vortex in a similar system to ours, all of which was covered in Section 2, Background.

4.1 CONCEPT GENERATION

We created a Quality Function Deployment House of Quality, shown in Appendix A, by using the requirements from PG&E and the engineering specifications, which are shown in Table 1, we came up with for our test rig design, along with benchmarking previous tests from other research groups. This allowed us to evaluate the parameters we used to come up with possible designs of our test rig.

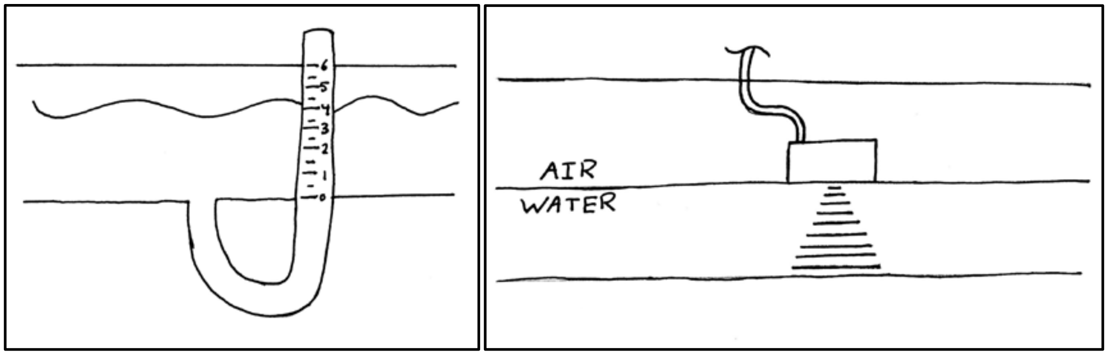
Next, we brainstormed different ways we could meet all the parameters described above in section 3.2, focusing on one specific function at a time. Some individual functions we identified were the following: measuring the water depth in the main line, changing the offtake angle, and measuring the flowrate in the main and branch lines. To help us generate methods of achieving these functions, we went to the local hardware store and explored the parts available for building small piping systems. We looked at ways to join pipes, regulate flow, make removable connections, change pipe diameter, and connect hose to pipe. We then held a brain writing session to generate the following methods of performing the aforementioned functions.

4.1.1 Measuring Water Depth

The first method developed to achieve the measurement of water depth function was to etch markings along the side of the tube that correspond to the depth of water at the center of the tube, essentially creating a ruler directly measuring the depth in inches. We decided to use this method as our datum to compare all our further ideas with so we could rank the methods against one another. The rest of our ideas for this function include:

- Marked U-Tube
- Water Level Marked on a Weighted String
- Floating Transducer Inside Pipe
- Camera Setup w/ Height Marks on Backboard

Figure 7 shows a few of these solutions. In Figure 7 (a), we illustrate the U-Tube device marked with incremental measurements on the side to determine the water depth. Since this system is under pressure, we cannot have the U-Tube open to atmosphere. Therefore, the design would require a connection at the top of the tube back to the main suction line, where the air pressure would be the same. In Figure 7 (b), we show a transducer floating on the surface of the water inside the pipe, sending out a signal to determine the depth of the water.



(a) (b)

Figure 7. Solutions to measure water depth in main suction line.

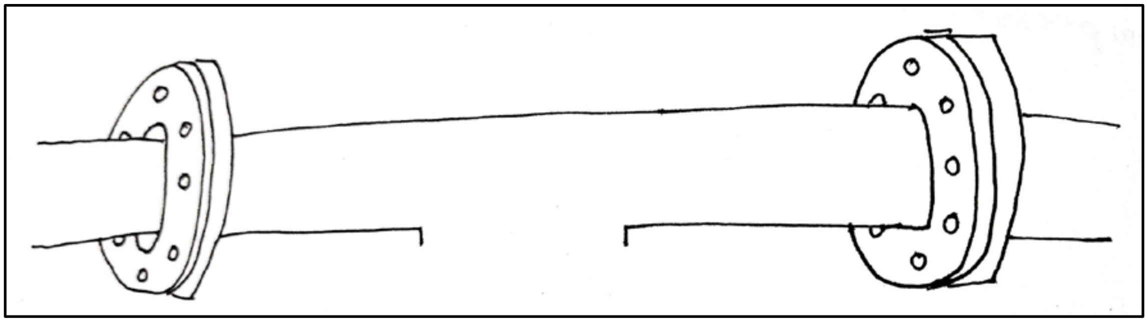
(a) Marked U-tube (b) Floating Transducer

4.1.2 Changing the Offtake Angle

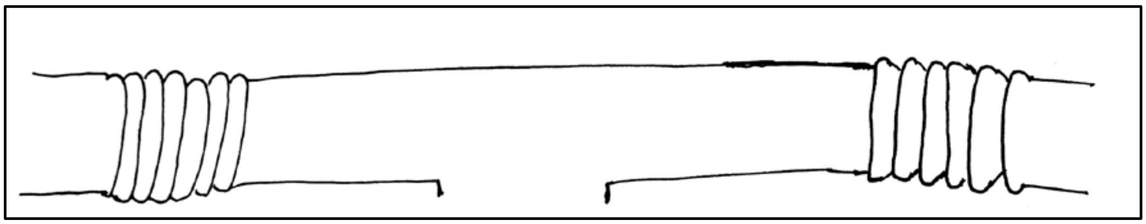
Our sponsor suggested to us to use flanged connections in order to change the offtake angle during one of our preliminary meetings. This gave us the idea to put eight bolt flanges, shown in Figure 8 (a), on either side of the main and branch line intersection to rotate the offtake angle of the branch line. The flange needs to have eight bolts because it ensures angle between each bolt is 45°. We used this idea as our baseline datum, while the other ideas we formulated for this function include:

- Threaded Union
- Rubber Tube w/ Hose Clamps
- Flexible Tubing

Figure 8 (b) shows the use of flexible piping on either side of the intersection. This would make it possible to rotate the pipe without having to drain the system, but would require a significant force to hold in place at the three desired angles.



(a)



(b)

Figure 8. Solutions to rotate the branch offtake angle.

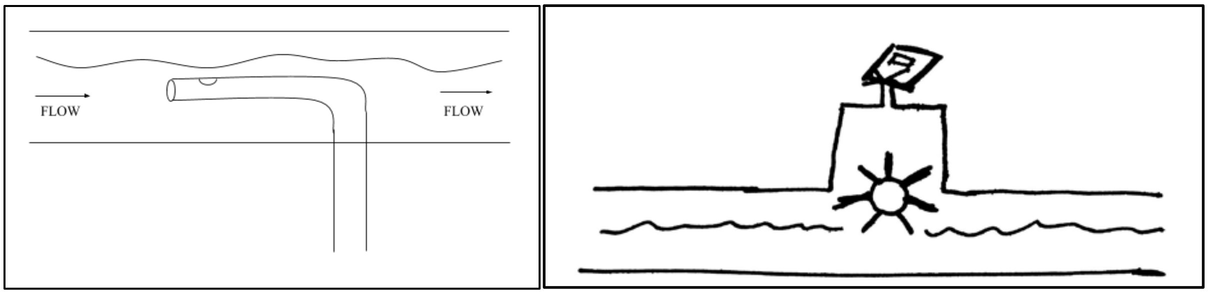
(a) Eight Bolt Flange (b) Flexible Tubing

4.1.3 Measuring the Flowrate in the Main and Branch Lines

Another function we looked at was determining how to measure the flowrate in a pipe line. The most common idea that we have had experience with in college is the pitot-static tube. We used this as our datum but came up with a few other alternatives to solve this particular function:

- Rotameter Attachment
- Ultrasonic Flowmeter
- Turbine Flowmeter
- Nutating Disk Flowmeter

Figure 9 (a) illustrates the use of a pitot-static tube inserted into the main suction line to determine the flowrate using the velocity of the fluid. A pitot-static tube determines the flow velocity by measuring the difference between the flow's static and dynamic pressure. The flow velocity is generally measured at the center of the pipe where the flow is moving fastest. Furthermore, determining the flowrate in a tube from its centerline velocity requires knowing the velocity profile in the pipe. This velocity profile can vary wildly such that accurate analysis can only be performed after the flow has had time to settle into a constant shape. Figure 9 (b) shows a paddlewheel meter attached to the pipe as a pipe fitting. Paddlewheel flow meters work by using a small rotating wheel to measure the velocity of the flow near the edge of the pipe.



(a) (b)

Figure 9. Solutions to measure flowrate throughout system.

(a) Pitot-Static Tube (b) Turbine Flowmeter

4.1.4 Creating Flow Through Piping System

Next, we wanted to look into how we were going to create the fluid flow throughout the piping system. To us, there was an obvious solution to this function, the pump. But we decided to figure out if there were any other ways we could complete the same task differently. The solutions to this function are as follows:

- Pump
- Gravity
- Siphon

There are pros and cons to each of these options, all of which we will discuss in the next section, Idea Selection.

4.1.5 Creating a Bubble Inside Main Line

The last function that we needed to brainstorm was a definitive way to create and insert an air bubble within the main line of the system. We needed to insert either a stagnant slug of air within the pipe and be able to gradually increase its' size, or insert a constant flow of air, then increase that flowrate to increase the bubble size. The solutions are as follows:

- Air Compressor
- Bike Pump
- Open Channel to Atmosphere
- Air Blower

4.2 Idea Selection

To select the best ideas, our team set up Pugh matrices, shown in Appendix C. A Pugh matrix is a scoring tool we used for concept selection where different options are scored relative to a criterion, or datum. The selection is made based on the consolidated scores. For each of these functions above, we used this tool to compare and evaluate a number of valid ideas based on the specifications we created earlier. Some of these criteria include accuracy, ease of installation, availability, overall dimensions, and cost. We felt that these and a few other criteria were essential

to look into. Once we assigned scores to each option based on the specifications and weighed the individual specifications according to what we thought to be most important to the project, we came up with the best option.

4.2.1 Evaluating Water Depth Measuring Devices

4.2.1.1 Directly Marking the Tube - Datum

Etching markings for water depth directly on the tube would be very low cost, but would lose some accuracy when we mark the tube ourselves, rather than using a calibrated piece of equipment. The device is incredibly non-complex and easy to install because it only requires something to mark the tube. The markings on the tube would require almost no maintenance. The only upkeep is refreshing the markings if they ever begin to fade.

4.2.1.2 U-Tube Measuring

Using the U-Tube would be easier since the measurements are read off a vertical tube with equally spaced markings, rather than having to make readings off the curved surface of the pipe. It would also be more accurate because we can purchase a calibrated graduated cylinder for our readings, rather than using lines we marked ourselves. However, the installation would be more difficult than directly marking the tube.

4.2.1.3 Floating Transducer

We believe this may not work because the bulk of the device may disrupt the flow and it may be difficult to keep the device centered in the pipe to determine the maximum water depth. The cost, complexity, installation, and maintenance requirement would all be much greater than the datum. This analysis led us away from using the transducer.

4.2.2 Evaluating Means of Changing the Offtake Angle

4.2.2.1 8 Bolt Flange - Datum

Eight bolt flanges are widely available in a variety of pipe sizes for relatively cheap and when used with a gasket they are watertight. They are able to provide great accuracy in our angle of rotation because their bolt pattern ensures that we turn the intersection exactly 45° for each trial. However, performing this rotation requires us to drain this part of the system, unbolt the flanges, rotate them by 45°, and then re-bolt them. This may prove to be a time consuming process that will slow our testing.

4.2.2.2 Threaded Union

When compared to the 8 bolt flange, the threaded union is more expensive, and harder to find for pipe sizes greater than 4 inches. As a positive, it is easier to adjust than the flange because there is only one large thread to loosen, as opposed to 8 smaller bolts. We also believe that the union is more leak-proof than the flange because of its integrated O-ring.

4.2.2.3 Flexible Tube

The flexible tubing is harder to adjust and less accurate than the 8 bolt flange. Furthermore, this solution would require the use of a protractor to accurately measure the rotation of the branch

line. Lastly, we have not been able to find a product we could purchase that would fit our use without heavy modification.

4.2.3 Evaluating Flowrate Measurement Solutions

4.2.3.1 Pitot-static tube – Datum

The pitot-static tube is a cheap and simple solution, but the tube must be pointed directly in line with the flow to get accurate results. Unfortunately, this alignment is difficult and time consuming. The pressure drop caused by the pitot-static tube is almost negligible and its interruption to the flow is minimal.

4.2.3.2 Turbine Flowmeter

The turbine flowmeter costs more than the pitot-static tube. It produces a similar pressure drop and is about as easy to use. This would give us an accurate reading but we found it challenging to find a 6-inch pipe variant without a long backorder time. Although, we could use a 4-inch variant of the flowmeter that is available.

4.2.3.3 Ultrasonic Flowmeter

The ultrasonic flowmeter has the advantage of being more accurate, easier to use, and more available then the pitot static tube. However, these benefits come at a steep cost that may outweigh the benefit more than the Pugh matrix shows.

4.2.4 Evaluating Means of Creating Flow

4.2.4.1 Pump – Datum

A pump is the most common and simplest way to create a constantly moving flow. It does this through a pressure difference in the piping. There will be a sizable jump in price for this solution, but it will be reliable and repeatable.

4.2.4.2 Gravity

Another way we could move flow is by using gravity to transport the water. We could create a vertical piping system, but this may be very tall and take up a lot of space. A downside to this solution is that we would have to keep adding or pumping water back up to the initial height, which may complicate the design.

4.2.4.3 Siphon

We could also use a siphon to cause the water to flow from one elevation to another. However, since the amount of water needed would decrease in a tank, the flowrate of the system would change with time. Although it may be an easy option, we could only run the system for a certain amount of time before the water runs out. It would require a pump to get water back up to the starting point.

4.2.5 Evaluating Bubble Formation Solutions

4.2.5.1 Air Compressor – Datum

Although the air compressor may be an expensive alternative, we believe that it can supply a constant flow of air. The rate at which it can inject air is much faster than the other options. The pressure to overcome that of water and volumetric flow to push air down to half the diameter (assuming critical submergence happens at or before this depth) is about 6 psi and 19 cfm as shown in Appendix N. This calculation assumes a pump outputting 450 gpm, but since the pump we chose will have about 420 gpm, the flow needed to introduce an air bubble will be less than 19 cfm. With the aid of an air booster, we will be able to reach upwards of 50 cfm.

4.2.5.2 Bike Air Pump

The bike pump is a cheap option when it comes to inserting air into the system. Unfortunately, this method does not allow us to provide a constant flow of air since the pump would need to be recharged after one pump. In addition, knowing how much pressure is already going to be within the system, it will be very hard to inject air if we cannot meet and exceed that value.

4.2.5.3 Open Channel to Atmosphere

Rather than injecting air into the system, we thought we could leave the water at a constant level within the main line. Air from the atmosphere that enters by the tank would fill in the rest of the main line. If we change the flowrate, then the height of water, or critical submergence depth, would change. The downside to this solution is that it can only work with low fluid flowrates; once past this range, the pipe would fill up the whole cross section, pushing out the open channel of air needed to find the critical submergence depth.

4.2.5.4 Air Blower

Another option besides using an air compressor is an air blower. Air blowers can output high amounts of volumetric flow, but operate at low pressures. Unfortunately, since the pressure at the location where we are going to inject air will be around 6 psi, using air blowers might not be the best option to produce an air bubble.

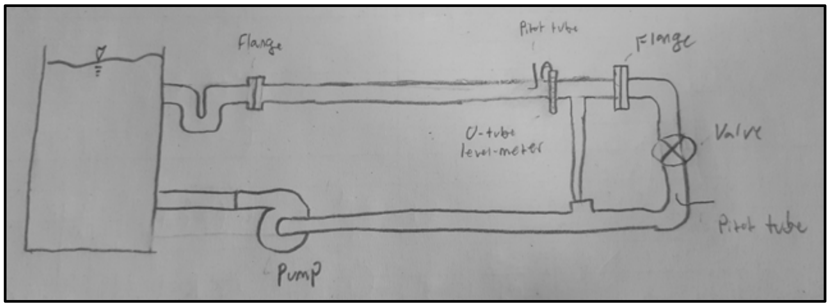
4.2.6 Forming Concepts

To narrow down the number of combinations of concepts, we discussed some components that would work well compared to their respective options. Two of the functions we narrowed down were the means of which to create flow through the pipe and an air bubble in the main line. Evaluating our options, we found that the best and most efficient way to create flow throughout the system would be to use a pump that produces a pressure head and causes flow. This allows us to get repeatable quick data, rather than resetting the system after each run (which is needed if we chose the gravity or syphon concepts). Next, we figured that the best way to induce a bubble within the main line of the system would be to make use of an air compressor. Again, this component choice gives us the ability to get continuous and accurate data without having to reset the system or rely on human labor to inject air, such as with the bike air pump. For the other functions, we decided to determine which components worked best with each other as a whole. For the functions

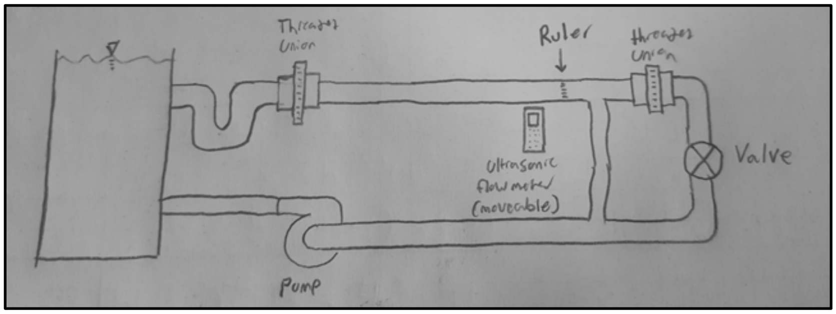
from sections 4.2.1, 4.2.2, and 4.2.3, we used the top three ideas from each of our Pugh matrices and inserted them into a morphological chart, which can be found in Appendix D. A morphological chart is a tool that allows us to present all possible combinations of solutions so a team can quickly visualize the options and select the top contenders.

The X-, Y-, and Z- axes of this three dimensional chart corresponds to a particular function, and each space on these axes corresponds to a method of performing the function. Each space on a particular axis will intersect every combination of the spaces on the other two axes. By examining these combinations, we can see all the options for our concepts. When evaluating combinations, Ryan chose the concept in Figure 10 (a) with 8-bolt flanges, the marked U-Tube, and pitot-static tubes for pressure measurements resulting in a fluid flowrate. Brian chose the concept in Figure 10 (b) with threaded unions, a ruler projected directly on the pipe, and an ultrasonic flow meter. Lastly, Brett chose the concept in Figure 10 (c) with threaded unions, the marked U-Tube, and a paddlewheel flowmeter. After we each chose a unique concept that may satisfy the needs of the customer the best, we used a final decision matrix, in Appendix E, to compare the concepts to each other. This decision matrix acts much like the Pugh matrix mentioned in the start of section 4.2. We used it to evaluate and prioritize all three concepts we came up with by establishing a list of weighted criteria and proceeded to evaluate how well those options met those criteria. Those criteria are very similar to the criteria used in the Pugh matrices, including cost, ease of use, availability of parts, and accuracy. Once we added up the weighted scores, we produced our final design.

The basis behind selecting certain scores for one concept evolved from the theory of approaching the construction of the test rig in a cautious manner. We chose to go with flanges instead of unions because flanges are more readily available for larger sizes. For measuring the height of flow, we selected a U-Tube instead of a marked ruler on the pipe for accuracy purposes. Lastly, for measuring flowrate, we chose to use a pitot-static tube, instead of either an ultrasonic flowmeter or paddlewheel meter, mainly to keep the cost down.



(a)



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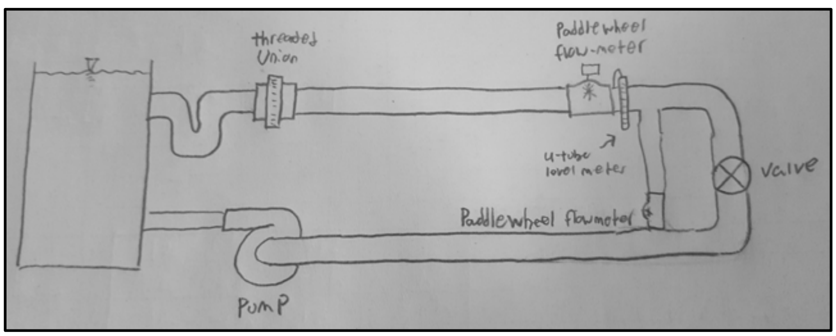

(c)

Figure 10. Each member's initial concept. (a) Ryan's concept selection, (b) Brian's concept selection, and (c) Brett's concept selection.

4.2.7 Initial Concept

Our initial top design, shown in Figure 11, ended up using 8-bolt flanges, the U-Tube level meter, and pitot-static tubes. We included offset 6" to 4" reducers to allow for our main line to be either 4" or 6" if we had time to run additional tests at a larger main line diameter. Both our main line and the tee to the branch line would have been made using clear PVC. This would have allowed us to see the bubble size in the main line during the formation of a vortex at the intersection. Due to the high cost of large clear pipe and clear fittings, these areas were the only ones constructed with clear PVC. Common Schedule 40 PVC pipe would have made up the rest of the system.

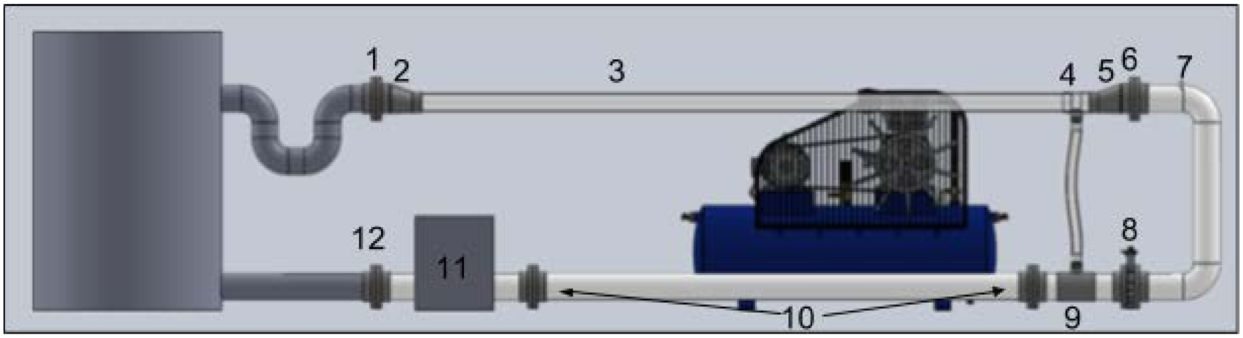

Figure 11. A basic Solidworks model of the proposed piping system. Clockwise from the top of the tank on the far left we have: an 8 bolt flange (1), a 6”-4” reducer (2), a clear main line (3), a clear tee (4), a 6”-4” reducer placed backwards (5), another flange (6), the air inlet (7), a butterfly valve attached with flanges (8), our bottom tee (9), two more flanges (10), the pump (11), and finally flanges connecting back to the tank (12). Note the flexible hose forming the branch line between the two tees.

The hose connecting the top tee to the bottom tee would have been made using flexible EVA plastic to allow the main line to rotate from 0° to 45 and 90° without having to replace the branch line pipe. All unthreaded connections would have been glued together with primer and PVC cement, and all threaded connections would have been tightened down with Teflon tape over the threads to prevent leaks. The flanged connections would have a gasket in between the two halves for leak prevention. The main line would have had an uninterrupted straight entrance length of 14 feet between the tank and the control volume, shown in Figure 1, to allow the flow to become fully developed. This allowed us to use a simple Pitot static tube to calculate the flow rate of the water based off the measured centerline velocity. The pipe exiting the tank would have had a 6-inch diameter pipe to allow us to run tests with a 4-inch main line, and a 6-inch main line if we had time to run the tests. The U-shaped bubble trap shown at the tank outlet would trap air in the main line as the system is initially filled with water and would be as compact as possible to minimize head loss.

Figure 12 shows a close-up view of the clear tee where we planned to expect to see our vortex, the 6” to 4” offset reducer, and the air compressor inlet. The offset reducer, by the 90-degree elbow downstream of the control volume, along with the U-shaped bubble trap next to the tank, created a higher elevation area where an air bubble would become trapped while initially filling the system with water. This allowed us to have an initial bubble in the system that we could later expand. We expected this initial bubble to amass in the upper elbow where the flow turns from horizontal to flowing downwards and along the length of the pipe due to the U-shaped bubble trap. This is because the friction between the bubble and water would try to pull the air along the path of the water’s flow, but once the flow turns downward, the buoyancy of the air would have forced the bubble upward until the force due to friction and the buoyancy force cancel out. Our intuition tells us that the friction due to the water flowing past would not have been enough to force our large bubble down the vertical pipe and away from the air inlet. The air inlet is positioned

near the elbow in order to take advantage of this and add air to our already formed bubble. This would reduce the time it takes to set our system up by ensuring all the air we add to the system is immediately part of our large bubble, rather than spray into the water and forming a multitude of small bubbles that will require time to rise and meld together. However, since the initial size of this air bubble might be too big, a bleed valve might have been necessary to release some air from the main line into the atmosphere, thereby increasing the water depth and avoiding critical submergence too early in the process.

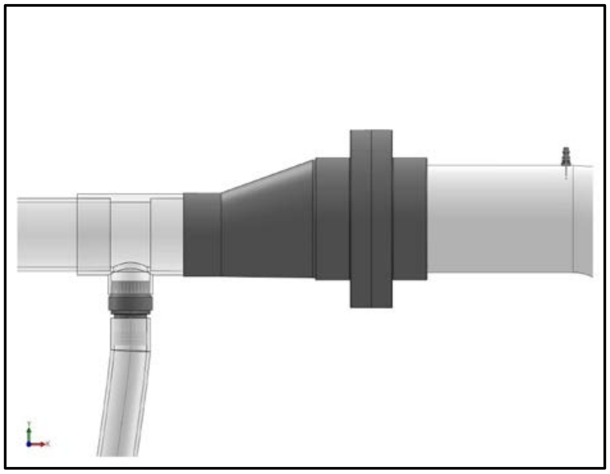

Figure 12. A larger view of the Solidworks model focusing on the clear tee, backwards 6”- 4” offset reducer, and air inlet.

Dimensions of components in the testing rig were determined based on the conditions for smooth flow. The vertical height of the tube was estimated at 4 feet. We would have continued to research previous projects and studies in order to estimate the total height required to contain the bubble if we proceeded with this design. We researched flow-conditioning devices, such as tube bundles and honeycomb straighteners, to obtain fully developed flow with less pipe, and positive displacement meters for liquids that were large enough to fit on our pipe without requiring a reducer. With this design in mind, we gave a presentation on our PDR to our sponsor and his team at Diablo Canyon Power Plant.

4.3 ORIGINAL DESIGN CHANGES

With their feedback, we made some critical changes to our design. For the purposes of describing what sections were areas of concern, Figure 13 shows the original design.

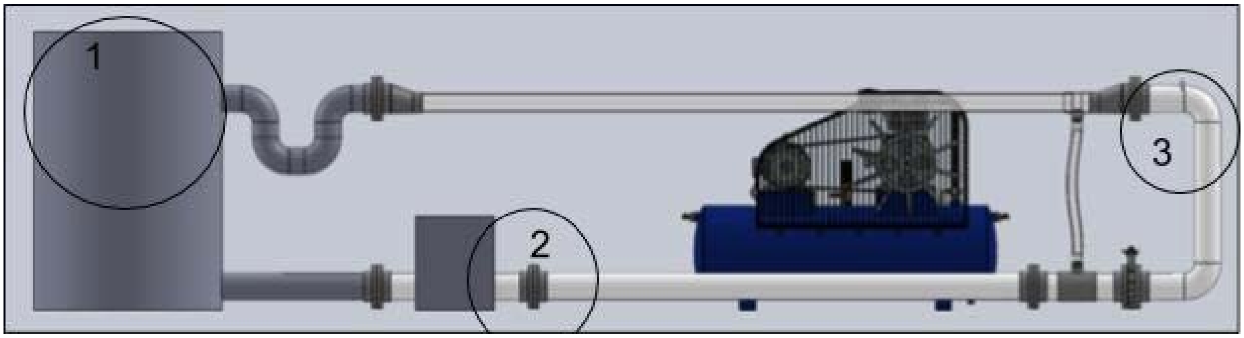

Figure 13. Initial design with areas of interest circled.

The first issue our sponsors mentioned is that based on this design, the pump would not increase flow in the main line. This is because although altering the performance of the pump will increase the flowrate of water into the tank, the only thing driving the flow from the tank into the U-trap is the pressure of water above the inlet, and so altering the pump performance will not increase flow into the main line.

The second issue we had was the possibility of cavitation at the inlet of the pump. Due to major losses and lack of pressure, the head will be below the required net positive section head (NPSHR) before the flow reaches the pump. Therefore, to avoid cavitation, the pump should have been placed somewhere at the top on the main line.

One last concern was the influence of falling water on the air bubble. Because the water will be turbulent, the air bubble may be dragged down at the downward elbow after the intersection. We assumed a constant air bubble condition, but this disruption might affect our bubble size upstream and could lead to inconclusive results.

The team at Diablo Canyon also suggested to use alternate components to the ones we selected using our Pugh Matrices. They advocated for the use of unions to rotate the main line because we would not have to drain the system of water and it would save a lot of time during the testing phase of the project. The team also suggested to move away from the U-Tube water measurement concept because there will be too much pressure within the pipes to use a rubber tube. To make it easier, they referred us back to our datum idea of simply writing the water height on the side of the main line to determine critical submergence. Since we have a large budget to work with, they recommended substituting the Pitot-static flowrate measurement device with a turbine flowmeter. This will allow us with more accurate flow data the ability to easily attach anywhere within our system.

5 FINAL DESIGN

Based on the feedback from our sponsor, we made alterations to avoid for improper pump placement, potential cavitation, and turbulent disturbances. Our new design is shown in Figure 14.

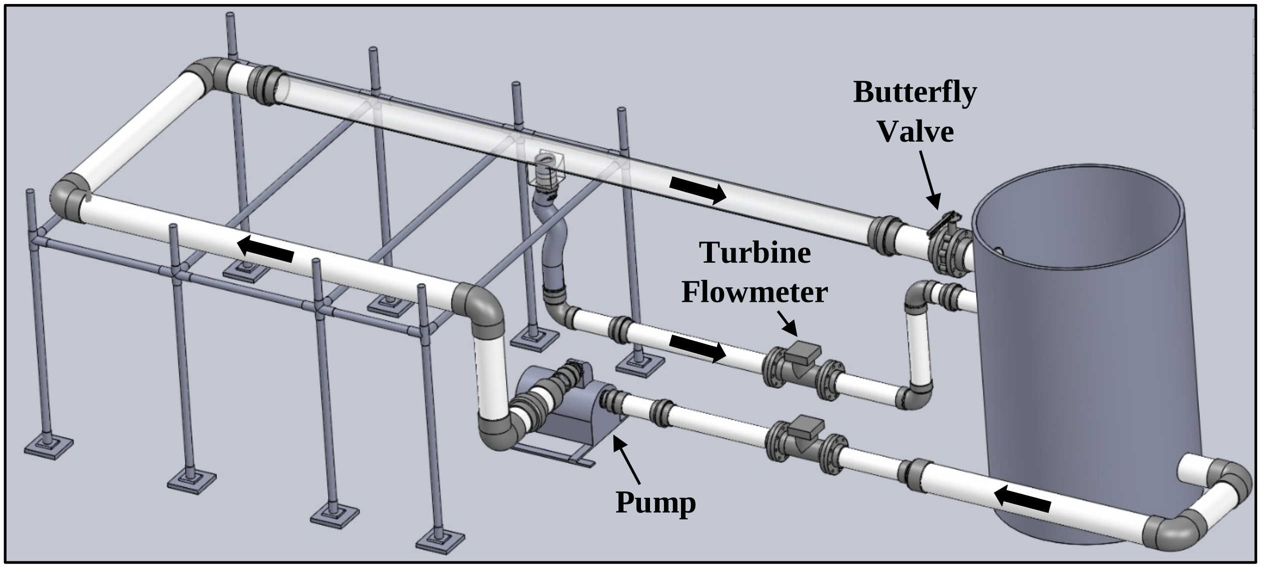

Figure 14. Assembly of the updated design (air compressor not shown).

In the new design, the pump acts to add pressure to the system that increases the flow of water, and has a discharge connecting pipe to pipe (not pipe to tank). By positioning the pump after the tank in the system, we found that we would avoid pump cavitation. The last major revision we made is the pipe layout in relation to where air is injected into the main pipe. Before, due to the pipe layout, after air was injected into the main line, it would proceed to travel vertically downwards. This was adverse for several reasons. One reason is because it might have disrupted the air bubble upstream of this vertically downward portion and would tamper with data on when critical submergence would occur. Another reason is because the pump was located downstream of the air bubble, with no way to the vent the bubble, so that there was a good chance air bubbles would reach and harm the pump.

The tank in the new system will be open to atmosphere to allow the release of bubbles from the system upstream of the pump. Instead of using flanges, we changed to unions as the component to change the main-branch offtake angles, due to maximum pressure that the component can withstand while serving the same purpose of pipe rotation. We also fixed the two diameters of the main and branch line since having several diameters of the branch line proved too difficult to design for. This is because we would have to drain the top half of the testing rig in order to swap out different sized piping, which would take up a lot of time and water. Having the modularity of various branch diameters can be a consideration to include in a second version of this system. Due to the valve location near the inlet, there is a possibility that the valve might disrupt the steady state growth of the air bubble. To account for this, we decided to use a length equivalent to 15

times the diameter of the pipe. This will be covered more in depth in Section 5 of Engineering Validation & Analysis.

5.1 MATERIAL SELECTION

Much of the testing rig will comprise of opaque Schedule 40 PVC pipe, with the exception of the main line pipe and intersecting tee junction. The main reason for this is to decrease spending since the only area of interest is where the vortex will occur. As noted before the main line and intersection will be made of a clear PVC material. The water tank in the system is made of a plastic material that is readily available.

After drawing a system curve and comparing it to a pump curve, the Multiquip QP4TH was chosen because it can handle a flowrate up to 550 GPM. This pump is also ideal because it was provided to us for free by Quinn Cat Rentals (Appendix M). The pump inlet and outlet are equipped with National Pipe Threads (NPT) so we will therefore be able to connect the pump directly to PVC pipe using a flange and female adapter. Since the inlet and outlet diameters for the pump is 4", a reducer will also need to be used since the PVC pipe joining to the pump will be 6" in diameter.

Next, we will also need something to support the piping of the testing rig. To handle this task, we are using metal scaffolding readily available at Pismo Yard, pictured in Figure 15. This scaffolding is left over from a past senior project sponsored by PG&E.

Figure 15. Scaffolding at Pismo Yard to support test rig piping.

5.2 SAFETY CONSIDERATIONS

We must be cautious when manufacturing and constructing the rig itself. We will be working with a few large, heavy pipes and machinery and must handle them with care. When transferring or attaching pipes to the assembly, we will make sure to use both hands and have it supported by at least two people at a time. Our team requires that no one person is working on the project alone in case of serious injury and in need of immediate assistance.

In obtaining data for this experiment, the engineers operating the system should be cautious and alert in order to avoid any injuries. Since this system contains long lengths of pipe, extra attention will be paid to our surroundings for safety precautions as to not hit one's head on an elevated object or lean up against an unsteady part. Several failure effects considered in the FMEA in Appendix I include an unstable structure harming individual or water spilling on electronics due to pipe burst. Other safety considerations consist of electrical hazards from the generator or if air somehow manages to reach the pump and damage it.

While the entire system is up and running, safety glasses and hearing protection will be worn at all times for the pump and air compressor running the system. Close-toed shoes are a requirement when working with or near the assembly due to the use of large objects. We will ask our sponsor to provide us with hard hats as well for head protection. We also ask that our sponsor, or a member of the PG&E team, attends the assembly and testing phases to provide us with guidance and supervision at the testing site located at Pismo Yard.

5.3 MAINTENANCE & REPAIR CONSIDERATIONS

During the manufacturing of the acrylic block intersection part or the clear PVC main line, a crack may form within the part. If this did occur, we ordered a backup part to ensure the least amount of setback in our schedule. Once the testing rig was manufactured and built to completion, there were inevitable maintenance issues that had to be faced to ensure the rig was working correctly. If a water leak was found anywhere in the system, we shut down the process and repaired the seal between the parts in question with either PVC glue or caulking. This mainly occurred at the joint between the tank and the PVC fitting. All we could do was replace the silicon sealant to mitigate any leakages. Another place where we experienced leaks was at most of the unions used in the system. We found that it was very difficult to tighten these by hand, and there were no tools large enough for this job at local hardware shops. Most likely long after our testing is over, the waterproof seals, located at the inlet and outlet of the tank, will eventually degrade and need to be replaced. We don't believe that the degradation of the seals will cause a problem in the few months that we are testing the rig.

The pipes throughout the system are supported by a scaffolding structure. Special care was taken to ensure that over time, the scaffolding does not deflect to a significant degree under its own weight. Based on the analysis shown in Appendix K, we are confident the piping will be sufficiently supported, but this analysis is covered more in depth next in Section 5.4. If for some reason during testing this was not the case and there was a clear sag in the pipe, we would have halted testing and added another support at that location. This is relatively easy because the

scaffolding can be easily removed and transferred to another location using portable rod clamps provided by PG&E.

Corrosion was not an issue because the main material we are using, PVC, has excellent corrosive resistance. Although, if the metal scaffolding showed signs of rust from prolonged exposure to rain, we would have used steel wool or other corrosion removal methods to clear the metal from rust.

5.4 ENGINEERING VALIDATION & ANALYSIS

5.4.1 Simulating a Boric Acid Solution

We found that the addition of boric acid to water at 2500 parts per million causes a negligible change in density when compared to pure water. We calculated this by specifying a ratio of 2500 moles of boric acid to 1 million moles of water. The densities of the separate substances were used to determine the volume of the previously mentioned molar amounts and the molar masses of both water and boric acid were used to determine the mass of each. The volumes and masses of both were added and divided out to find the total density. From this calculation, the difference in the density was so small it fell outside the range of the significant figures we chose to use. Therefore, we are using water for this experiment. The Engineering Equation Solver file used to do this calculation is included in Appendix B.

5.4.2 Determining Flowrate Ratio

When water is flowing through a system with parallel branches, the water will take the path of least resistance until the flowrate through that path is large enough to equalize its resistance with the other paths. Major losses in pipes refers to the losses due to friction with the material and diameter pipe walls. Pipes with smaller diameters have greater major losses than larger pipes at the same flow rate. Because we are interested in testing the effects of branch lines with smaller diameters than the main line, more water will flow along the main line than the branch line. To determine the different ratios of flow rates achievable with our system, we explored the ratio in flowrates between the branch line and the main line at our maximum flow rate of 1000 gallons per minute. We used the circuit analogy to simplify the piping system as shown in Figure 16.

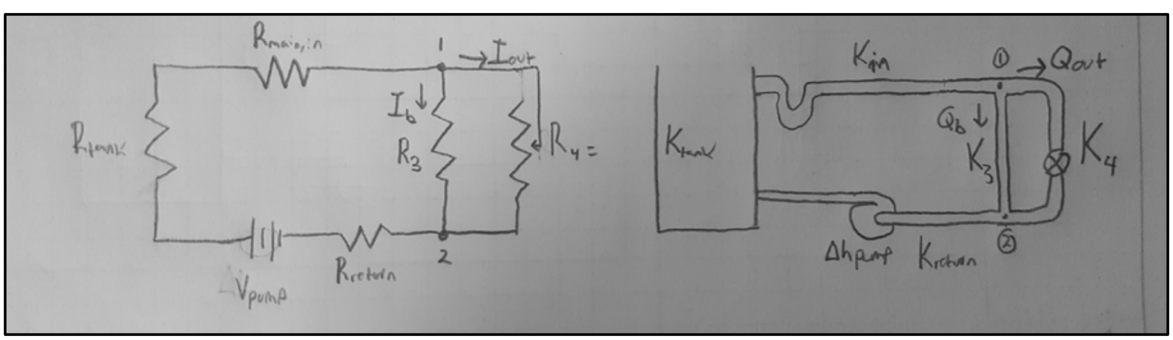

Figure 16. Circuit analogy for the piping system.

Here, flow rate Q is analogous to current, pressure head h to voltage, and loss coefficient K_L to resistance. Note that in fluid systems at a given loss head loss is proportional to the square of the flow rate whereas in electrical systems the voltage drop is directly proportional to the current [2]. This gives us Equation 5.

$$h = K_{Losses}Q^2 \tag{5}$$

The major losses in a pipe on a flow rate basis are given by Equation 6,

$$K_{maj} = f\,\frac{l}{2Dg}\left(\frac{4}{\pi D^2}\right)^2 \tag{6}$$

where f is the Darcy Friction Factor, l is the length of the pipe, D is the diameter of the pipe, and g is the gravitational constant. The Darcy friction factor is a nondimensional function of the flow's Reynolds number and the equivalent roughness, ε/D [2]. For smooth plastic pipe, ε is assumed to be zero [2]. The Moody chart, Figure 8.20 in Reference 1, gives us $f = 0.014$ for our flow in 4 inch pipe at an assumed 750 gpm[*]. The controllable source of losses in our system is the variable minor loss coefficient for the butterfly valve, $K_{L,valve}$. Minor losses occur at obstructions to the regular flow of the water such as valves, bends, and tees. Each device has its own minor loss coefficient, K_L, as shown in Table 2.

The minor loss in a pipe per unit flow rate is given by Equation 7.

$$K_{min} = K_L\,\frac{1}{2g}\left(\frac{4}{\pi D^2}\right)^2 \tag{7}$$

The branch and the main line outlet both start from the upper tee, Point 1 in Figure 16, and meet up again at the bottom tee, Point 2 in Figure 16. Each of these points have the same change in pressure head, h_{12}. This allows us to equate the ratio between the main line outlet flowrate and the branch line flowrate as a ratio of the square roots of their loss factors. This yields Equation 8.

$$\frac{Q_b}{Q_{out}} = \frac{\sqrt{K_4}}{\sqrt{K_3}} \tag{8}$$

By varying the minor loss coefficient of the valve, we are able to vary the ratio of flow rates from 0.25 when the valve is entirely open, all the way to infinity, when the valve is closed all the way. A list of these valve losses are found in Table 2. These varying flow rates will give us a wide enough range of Fr_{out}/Fr_b to get a useful relationship, where Fr_{out} is the Froude number for the main line outlet and Fr_b is the Froude number in the branch line. The EES file showing these calculations is in Appendix F.

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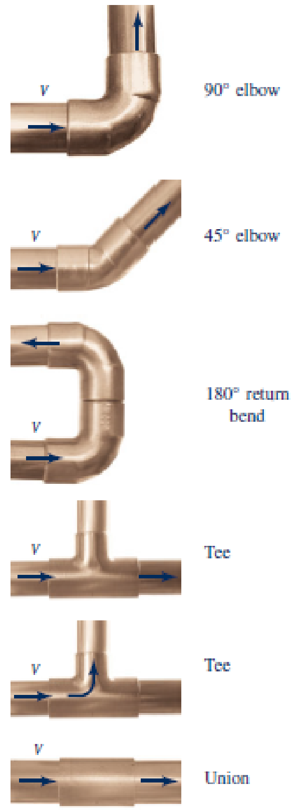
[*] Note that the Reynolds number, and thus the friction factor, changes with flow rate, so the friction factor should be recalculated each time the flow rate changes. However, this calculation is being used as an estimation and the difference between a friction factor of 0.014 and 0.0125 does not significantly change the results.

Table 2. Minor loss coefficients for common geometries [2].

Loss Coefficients for Pipe Components $\left(h_L = K_L \frac{V^2}{2g}\right)$ **(Data from Refs. 5, 10, 27)**

Component	K_L
a. Elbows	
Regular 90°, flanged	0.3
Regular 90°, threaded	1.5
Long radius 90°, flanged	0.2
Long radius 90°, threaded	0.7
Long radius 45°, flanged	0.2
Regular 45°, threaded	0.4
b. 180° return bends	
180° return bend, flanged	0.2
180° return bend, threaded	1.5
c. Tees	
Line flow, flanged	0.2
Line flow, threaded	0.9
Branch flow, flanged	1.0
Branch flow, threaded	2.0
d. Union, threaded	0.08
***e. Valves**	
Globe, fully open	10
Angle, fully open	2
Gate, fully open	0.15
Gate, $\frac{1}{4}$ closed	0.26
Gate, $\frac{1}{2}$ closed	2.1
Gate, $\frac{3}{4}$ closed	17
Swing check, forward flow	2
Swing check, backward flow	∞
Ball valve, fully open	0.05
Ball valve, $\frac{1}{3}$ closed	5.5
Ball valve, $\frac{2}{3}$ closed	210



*See Fig. 8.32 for typical valve geometry.

5.4.3 Determining Bubble Stability

Since the bubble in the system will extend along the length of the main line, the bubble can break up by either the velocity gradient of the flow throughout the pipe, or due to turbulent flow when the path of the fully developed flow is disturbed. Although there exist equations to determine whether a bubble will be stable or unstable, these equations still are not reliable, and bubble instability might happen earlier than expected or vary with constant parameters for multiple test runs. However, the equations that exist will be a starting point [8]. We will likely determine bubble stability empirically.

5.4.3.1 Breakup Due to Velocity Gradient

The velocity gradient along the fully developed flow may be enough to drag the bubble throughout the rest of the system. Equation 9 is used to estimate the initial bubble radius when the bubble starts to become unstable,

$$N = \frac{a_o G \mu}{\sigma} \tag{9}$$

where N is a nondimensional velocity gradient, a_o is in the initial size of bubble, G is the shear rate, μ is viscosity of the water, and σ is surface tension. Equation 10 can then be used to determine N_{crit} in order to find the initial bubble size at the transition from stable to unstable.

$$N_{crit} = \frac{1}{2}\left(\frac{1+\kappa}{1+19\kappa/16}\right) \tag{10}$$

κ is experimentally determined, where when k>3 no breakup occurs and becomes elongated along the flow direction [8].

5.4.3.2 Breakup Due to Turbulent Flow

Another way to characterize bubble stability is by examining how it behaves in turbulent flow. Equation 11[8] is used to determine the diameter of an equivalent volume sphere is,

$$\tau > \left(\sigma + \mu_p \sqrt{\tau/\rho_p}\right)/d_e \tag{11}$$

where τ is the local shear stress, μ_p is viscosity of bubble, ρ_p is density of air, and d_e is the diameter of an equivalent volume sphere.

5.4.4 Entrance Length Analysis

To ensure that we are taking water height measurements at the intersection correctly and without error, we need to make sure the fluid is fully developed in the turbulent phase. To confirm this condition, we performed calculations on the entrance length needed prior to the vortex location at the intersection. From this analysis shown in Appendix L, we found that there must be approximately 14 ft of pipe upstream of the tee-junction. Although, once this entrance length exceeds the equivalent of 10 diameters of the pipe, one can use this distance. Therefore, since our pipe is 6 inches in diameter, we must have an entrance length of at least 5 ft. To account for any error in that approximation, we provided an extra 1’8” to our entrance length, resulting in a total of 6’8” long, or equivalent to about 13 diameters of pipe.

5.4.5 Pump Selection Analysis

In the same manner that the flowrate ratio was found, an Engineering Equation Solver (Appendix M) program was created using the circuit analogy for pipe flow. The program simultaneously solved for the pressure at each point indicated in Figure 17, the flow rate of each pipe section, the Reynolds and Froude numbers for each pipe section, and the required pump head for a given return line flow rate and a flow coefficient for the butterfly valve, C_v. The program populated a table that found these values at return line flowrates from 0.1 ft^3/s (44.9 gpm) to 2 ft^3/s

(897.6 gpm) and flow coefficients corresponding to a 6-inch butterfly valve at 10° intervals from 90° (fully open) to 10° (almost all the way closed).

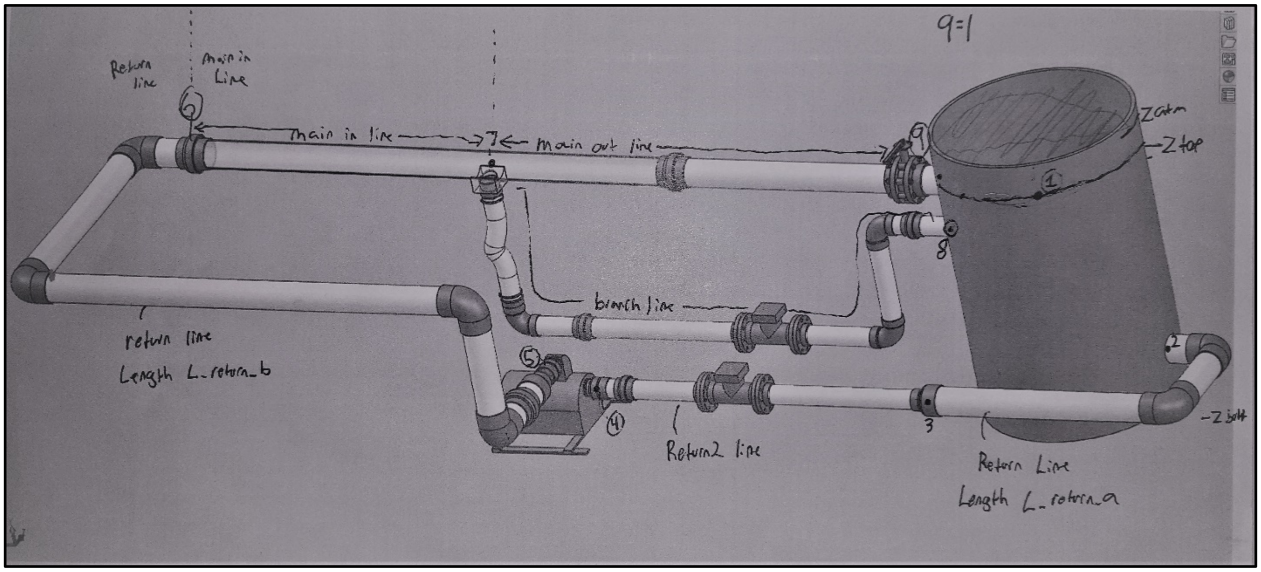


Figure 17. Labeled view of the piping system showing what each of the variables in the EES system curve code corresponds to.

We were interested in how closing the butterfly valve would affect the ratio between the Froude number of the main line flow and the Froude number of the branch line flow. We plotted this ratio versus the flowrate for each of the valve positions in Figure 18. From this graph, one can see that valve actuation has less and less of an effect on the Froude ratio as the flowrate increases. We decided that reaching flowrates farther above 1 ft^3/s did not give us enough variation in the Froude ratio to justify the cost of the large pump the flowrates would require.

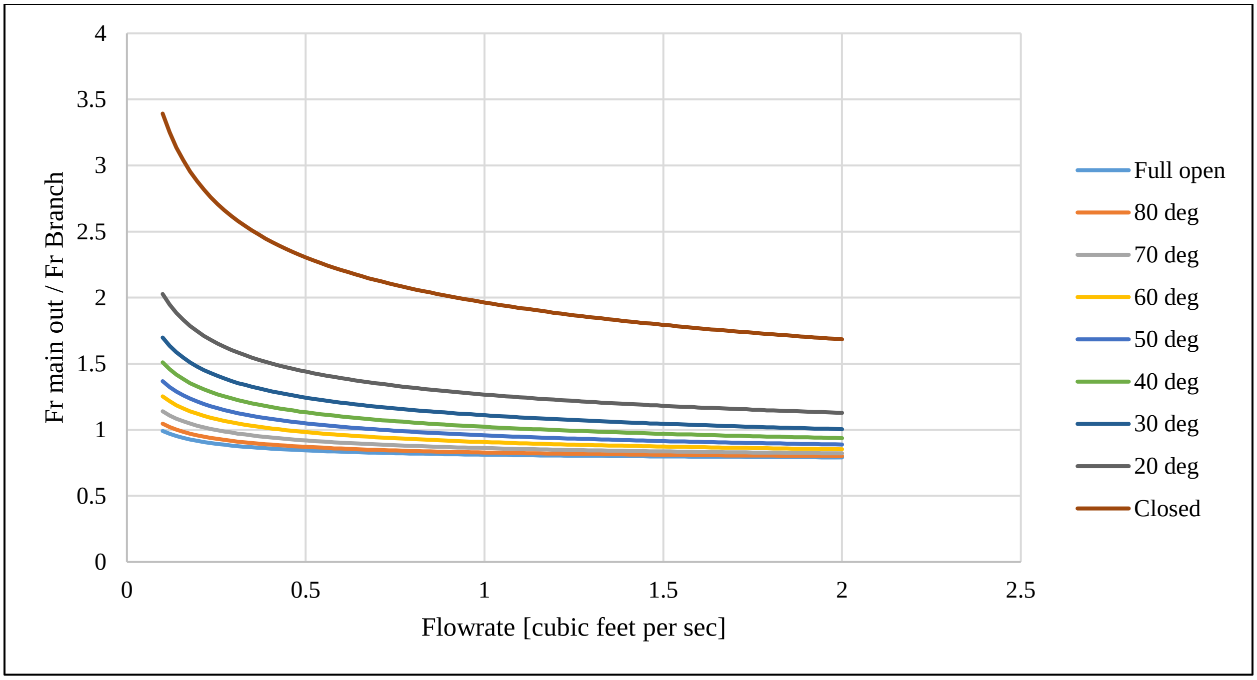


Figure 18. The results of the EES system curve code showing how the ratio of Froude numbers changes with flowrate and butterfly valve angle.

The system's resistance will increase when the butterfly valve closes, and thus require a larger pump head. We then plotted the flowrate versus the required pump head curve, show in Figure 19 when the butterfly valve is open only 10° in order to find the required pump head pressure at our desired flowrate of around 1 ft^3/s, or 448.8 GPM.

From the graph shown in Figure 19, we can see that required pump head at a flowrate of 448.8 GPM is only 20 feet or about 8.7 psi. Because we are looking at a high flowrate at a relatively low pressure, we decided to look for pumps that were designed for use in such conditions. Additionally, the site where testing will occur is on the edge of the grid and cannot supply enough current to power a large pump. This led us to explore agricultural irrigation pumps, trash pumps, and other gasoline or diesel powered pumps that were designed to be non-permanent and pump a large amount of water over a small vertical distance.

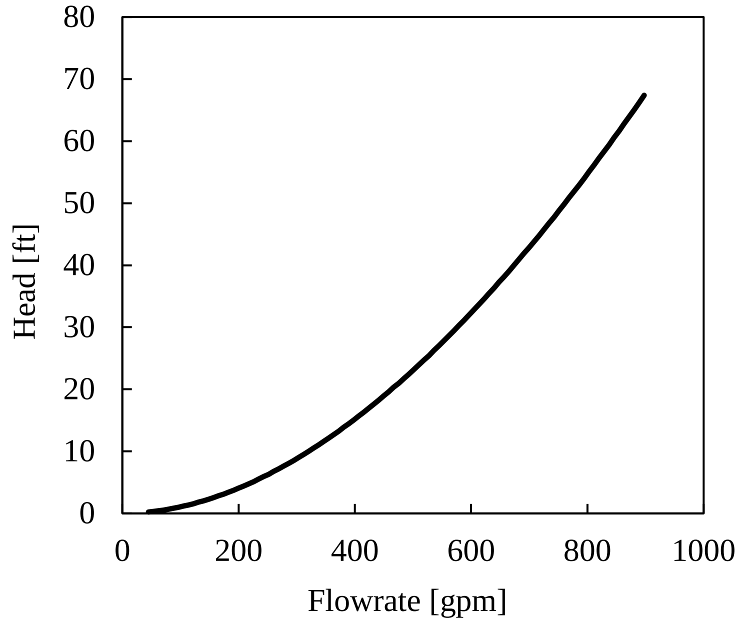


Figure 19. System curve showing the required pump head to obtain a desired flowrate with a main line diameter of 6 inches and a 4-inch diameter branch line with the butterfly valve 10° open.

We selected the DuroMax XP904WP gas powered trash pump. We opted for this model because it provides a higher maximum flowrate and a lower maximum pressure than similarly priced competitors. It has a maximum flowrate of only 427 GPM (0.95 ft^3/s) but any pump capable of a higher flowrate would cost over $1000 more than the DuroMax. However, we cannot find a published pump curve for it. The pump is not often used in a closed system like we have, but rather in trash clearing applications where it is not essential to accurately predict pump performance.

Our initial design had the pump placed in a location that would cause the pump inlet to experience less than atmospheric pressure. This puts the pump in danger of experiencing such a low water pressure in the wake of the impeller blades that the water begins to cavitate and the pump stalls. In order to ensure that this will not happen with this design we decided to look at the pressure at the pump inlet (point 4 in Figure 17). We found that at our worst-case scenario, when the pump is at its maximum flowrate of 427 GPM, the pressure at the inlet is 1.8 feet of head above atmospheric pressure. Because the pump is experiencing greater than atmospheric pressure at the inlet we are confident that there is no danger of pump cavitation.

5.4.6 Scaffolding Analysis

Another aspect of design to consider is the scaffolding. Due to the lengths and diameters of pipe used, struts will be needed so that no sag appears. ASME has standards available to determine strut locations for the span of a pipe section, but the standards assume a low bending stress of 15.9 MPa [9]. In order to determine a safe enough length based on a more conservative method, Equations 12[9] and 13[9] are used:

$$S_b = \frac{(0.0624wL^2 + 0.1248w_cL)D}{I} \tag{12}$$

$$y = \frac{5wL^4 + 8w_cL^3}{384EI} \tag{13}$$

where
S_b = Maximum bending stress (N/m^2)
w = uniformly distributed weight of pipeline (N/m)
L = Span length (m)
w_c = Concentrated weight on pipe line, e.g., flanges, valves, other significant point loads (N)
D = Outsider diameter of pipe (m)
I = Moment of Inertia of pipe (m^4)
y = Maximum deflection (m)
E = Young's modulus (N/m^2)

To start the analysis, the longest length of pipe was considered since it would set a standard for the lengths of the other sections of pipe. Therefore, the length of pipe considered is the horizontal distance of the main traveling from the inlet of the tank to the end where the pipe connects to an elbow. An initial calculation was done to determine the span length of sag using an assumed factor of safety of 10. The result gave a span length of 3.2 m. For a pipe filled with water, ASME standard B31.3 results in a less conservative span length of 5.2 m, but this considers only the deadweight of the pipe and not any concentrated loads (such as flanges or valves); which means that we will be designing our scaffolding such that our design should not overload the support in a way that is more cautious than accepted engineering standards. Further analysis was done to determine the maximum deflection at a length of 3.2 m and was found to be 8 mm. Since this relatively is a high deflection for the purpose of constructing a 25' pipe section, a table was created at smaller lengths of 3.2 m, as shown in Table 3.

Table 3. Range of struts to determine prevention of a system collapse.

Length Between Struts (m)	Maximum Deflection (mm)
3.0	6.26
2.8	4.89
2.6	3.75
2.4	2.82
2.2	2.08
2.0	1.49
1.8	1.03
1.6	0.69
1.4	0.43
1.2	0.26
1.0	0.14
0.8	0.07
0.6	0.03
0.4	0.01

We decided to pick a length between struts of 1.0 m because we wanted to be conservative in anticipating the loading of the pipes and components on the scaffolding. This would mean that for a length of 25 ft (7.6 m), there would be approximately eight struts for support. PG&E has scaffolding available at their yard in Pismo Beach, so we will be able to save money on purchasing scaffolding materials. Comparing the amount of pipe support for a past experiment that PG&E accomplished, we feel comfortable that the scaffolding will support the weight of our piping system.

5.4.7 Air Compressor Analysis

In determining the power needs of a desirable air compressor to produce a slug of air, we created a rudimentary calculation in EES; the purpose of this calculation was to determine the cubic feet per minute (CFM) necessary in order to match the flowrate of water when the pipe is initially full. A flow of 18.19 CFM was determined to be necessary for the above assumption as shown in Appendix N. To compare this flow with the flows provided by air compressors at a pressure, a calculation was done to convert 18.19 cfm to standard cubic feet per minute (SCFM) using Equation 14. Using a P_{actual} value of (6 psi +14.7 psi) and an assumed T_{actual} value of 70°F or 529.67°R Equation 14 gave 25.53 SCFM.

$$SCFM = CFM * \left(\frac{P_{actual}}{14.7\ psi}\right) * \left(\frac{528\ °\mathrm{R}}{T_{actual}}\right) \tag{14}$$

Looking at air compressors, we decided to select the Makita 10 Gal. Twin Stack Air Compressor. This air compressor operates at 84 dBA, provides 14.0 SCFM @ 40 PSI, and is powered by gas. Since any noise level above 85 dBA can result in permanent hearing damage, ear

protection may potentially be necessary, but because we will not be exposed to this sound intensity for several hours continuously, we won't make noise protection equipment mandatory.

Finding an air compressor that could provide the required amount of flow of 25.53 SCFM seemed not feasible. The Makita Air Compressor we selected does not provide this amount; therefore, before we officially purchase the Makita, we plan on testing out a length of pipe—with water passing through—using a cheaper and smaller air compressor in order to see if our calculations are guiding us in the right direction.

6 PRODUCT REALIZATION

Manufacturing of the test rig consists mainly of assembling purchased parts. However, some parts need to be manufactured and the large size of the pieces means that the manufacturing requires special consideration. Furthermore, to make the project as safe as possible, we will be doing all manufacturing and gluing at the Cal Poly machine shops under supervision of the shop technicians.

6.1 PURCHASING & ORDERING PARTS

Our group started off by submitting our bill of materials (BOM) to our sponsor. From there, PG&E made the initial purchases based on what we specified for the project. Because there was a little shortsightedness within our group, we found that there were parts missing from our original bill of materials that we required. There was also a large delay in the time we submitted our BOM to the time we received the shipments, ranging from a few weeks to two months until parts arrived. We purchased the rest of the parts ourselves from the local hardware store and agricultural supply store. Our sponsor reimbursed these orders once we provided him with the complete receipts. These purchases can be found in the cost analysis in Appendix Q: Cost Analysis w/ List of Vendors & Pricing (Incl. Tax & Shipping).

6.2 SCAFFOLDING ASSEMBLY

We got the scaffolding from PG&E's property in Pismo Beach where it had been used for a previous project that had been completed. We replicated this configuration when assembling the scaffolding at Cal Poly for our project. Before disassembling, we took pictures to have something to match the assembly on the Cal Poly campus. Once the metal rods and joints were transported via trucks, we used wrenches to attach the rods together using the joints. Once the scaffolding assembly was finished, we could begin building the testing rig on top of and around the scaffolding.

6.3 MANUFACTURING VARIOUS LENGTH PIPES (DRAWING NOS. PIPE6IN-XX AND PIPE4IN-XX)

The project required many lengths of PVC pipe to be cut. These cuts did not need to be very precise because there is a fair amount of room in the fittings to accommodate differences from the specified length. These cuts were made with a large hand saw, as shown in Figure 20, which

was regularly used for the 4" and 6" sized pipes. These drawings are included within Appendix P: Detail Part Drawing.

Figure 20. Brett using a hand saw to cut a PVC pipe section.

6.4 Manufacturing Test Section Assembly (Drawing NO. A2)

The piece that attaches to the test section and creates the tee-junction for our branch line to attach (Drawing NO. TS-2 in Appendix P: Detail Part Drawing) is machined from a 6" by 6" by 4" block of acrylic. Acrylic is a difficult material to machine, and the large size of the part means that it is more prone to cracking. Therefore, we elected to have the part machined with a CNC mill by a Cal Poly machine shop technician, Tobias Shirts. This part is shown in Figure 21. Because the blocks were not exactly the 6" by 6" by 4" blocks we thought they'd be, the first time a block was machined, the counterbore was off centered. We elected to redo the machining with the second block we ordered after changing the datum from an outside corner to the center of the part. This change allowed us to machine a perfectly centered counterbore with high tolerances.

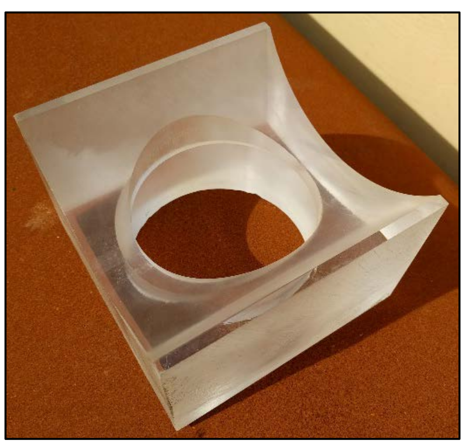


Figure 21. Manufactured acrylic block.

The clear length of the main line that makes up the majority of our test section (Drawing NO. TS-1 in Appendix P: Detail Part Drawing) is size 6 schedule 40 clear PVC pipe. We used a hand drill tool and a combination of a center drill and a hole saw to create the 4.03" diameter hole in the side of the pipe. We opted for a slow cutting speed to avoid cracking the pipe. This manufacutring process is shown in Figure 22.

We attempted to join the two parts with Weld-On® 4SC™ which was order by accident instead of the correct Weld-On® 40™. Weld-On® 40™ is an adhesive designed to join acrylic to polyester, butyrate, polycarbonate, PVC and other materials whereas Weld-On® 4SC™ is only designed to join acrylic to acrylic. The Technical and Material Safety Data Sheet for this product appear in Appendix R. After letting the Weld-On® 4SC™ dry, we found that the glue did not adhere the two pieces and realized the error in ordering. We then opted to use clear PVC primer and cement, which worked well and bonded the acrylic block to the clear PVC pipe. To add extra leak security of the two parts, we applied a bead of silicon sealant around the joint.

Figure 22. Brett drilling a center hole while Brian holds the pipe steady.

6.5 MANUFACTURING MODIFIED TANK (DRAWING NO. M1-TANK)

We were given a tank 4 feet in diameter by PG&E that had been used for a previous project. However, this tank did not have the holes that our project required to connect the pipes. We modified the tank by measuring the locations of the holes' centers with a tape measure. We ensured that the 6" hole on the bottom of the tank was directly opposite the other two holes by measuring the tank's circumference and dividing it by two. After we located the holes, we measured out the real outer diameter of the pipe, 6.625" for size 6 pipe, or 4.500" for size 4 pipe, and drew the required hole size onto the tank with a sharpie. A 4" hole saw with a center drill removed the majority of the material within each of the marked circles. We used a reciprocating saw to carefully remove additional material until the thickness of the line was the sole remainder of material that needed to be removed. This last bit of material was ground off with a curved file by hand until each of the pipes fit in their respective holes.

6.6 MANUFACTURING ORIFICE PLATE

Initially, we wanted to have a flowmeter in the branch line to be able to measure the flow rate. After proposing this idea to engineers at PG&E, we decided to opt for an orifice plate instead, saving them money and exposing us to alternate methods of measuring flow.

To determine the flowrate through the 4” offtake branch, we needed to create and install an orifice plate. This orifice consisted of 1x1 foot 16-gauge steel plate. During manufacturing, we drilled eight 3/4” clearance holes for 5/8” bolts in a circular orientation to pair with 4” flanges on either side. This process of the manufacturing is displayed in Figure 23.

The 3” center hole was drilled out with a hole saw of appropriate size as shown in Figure 24. The hole saw was cooled and lubricated with cutting oil. We then cut and ground down the edges to create a more circular plate.

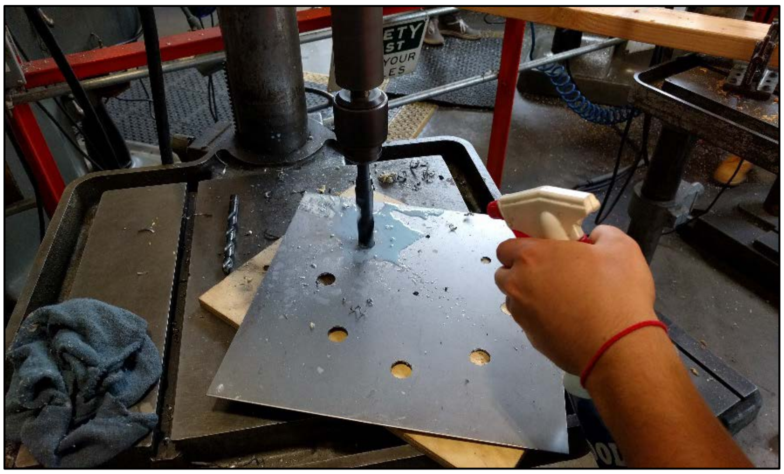


Figure 23. Brian drilling holes into a steel plate to form the orifice plate.

Figure 24. A hole saw was used to drill the main section of the orifice.

6.7 Assembling the Compressed Air Hose Line

After our Critical Design Review with our sponsors at Diablo Canyon, we decided to completely assemble on Cal Poly's campus. This opened up the possibility to use the machine shop's compressed air to insert air into our test rig piping. After scrapping the air compressor idea, we considered how we were going to design and manufacture the air hose line. The compressed air line was mostly assembled of purchased pieces that were threaded together with Teflon tape.

One part that we needed to include in the hose assembly was a control valve. However, because the flow control valve had a push-to-connect fitting for 3/8" OD tube, we needed to cut down a piece of ¼" copper tubing, which has a 3/8" OD, and solder it into a copper ¼" tube to ¼" NPT adapter.

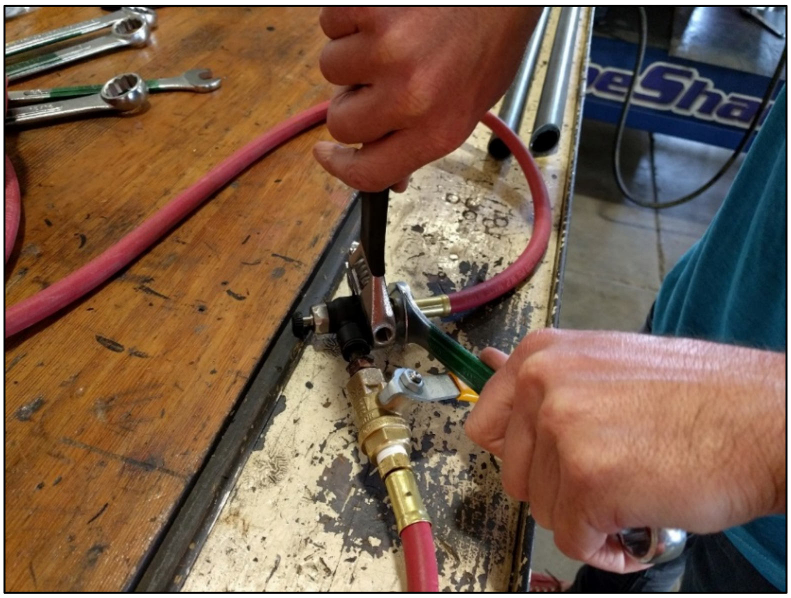


Figure 25. Brett installing the air flow control valve on the air line with wrenches to compress the Teflon tape.

6.8 Creating Water Level Measurement Device

In order to measure the water level depth at the intersection of the main line, we created a transparent ruler to be taped onto the pipe. We used the Matlab software to create increments of 1/8" starting from the bottom center of the main line to the top center of the main line to create a ruler that would represent the vertical height when taped onto a curved surface. For more information, refer to Appendix T: Ruler Matlab Code.

Next, a SolidWorks drawing was created for the ruler. The lines of the ruler were dimensioned per the vertical equivalent of a curved height, then renamed so that the distance of the line on the ruler was spaced accurately. But the number given to each increment corresponded only to the vertical height of any point on a curved surface. This is because we are only interested in this height when recording when a vortex occurs. Because we are not interested with measurements regarding the outer diameter of the main pipe, we accounted for the thickness of the

main line and started the ruler at the bottom part of the inner diameter and ended the ruler at the top part of the inner diameter.

After the ruler was created and labeled with proper inch increments, we used the printing service from the Cal Poly Print & Copy shop to print the ruler on an 8.5” by 11" transparent page. This assembly is shown in Figure 26.

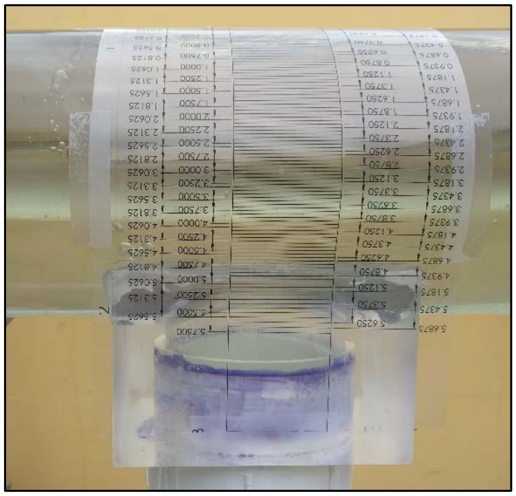


Figure 26. Transparent ruler taped to the main line.

6.9 ASSEMBLING WIRING

Wiring made up a large part of the electronics that had to be connected for the project to work. First, the Omega FTB740 turbine flowmeter (Appendix U: Omega FTB740 Turbine Flowmeter Spec Sheet) was connected to an Omega DPF701 display (Appendix V: Omega DPF701 Display Meter), the same way it was given to us by PG&E. We also needed to connect a pressure transducer for the orifice plate to the same display to read a voltage corresponding to a differential pressure. To feed both connections into the same display, we had to wire in a double pole double throw (DPDT) on/on switch onto the back of the display meter. Now once both devices were connected properly to the display, we had to power them. The flowmeter already came with a power cord, but the transducer did not. To power it, we installed a power converter to supply 24V DC power to the transducer.

However, the Omega display could only be used for totalizing rate inputs and would not display the transducer reading as it was a steady voltage and not the oscillating frequency that the display looks for and analyzes in signals. Instead we used a 250-ohm resistor across the signal output of the transducer and the negative of the power supply. This created a 1V to 5V voltage from the transducer’s output that we read with a Fluke Multimeter. The wiring diagram for the pressure transducer is shown below in Figure 27.

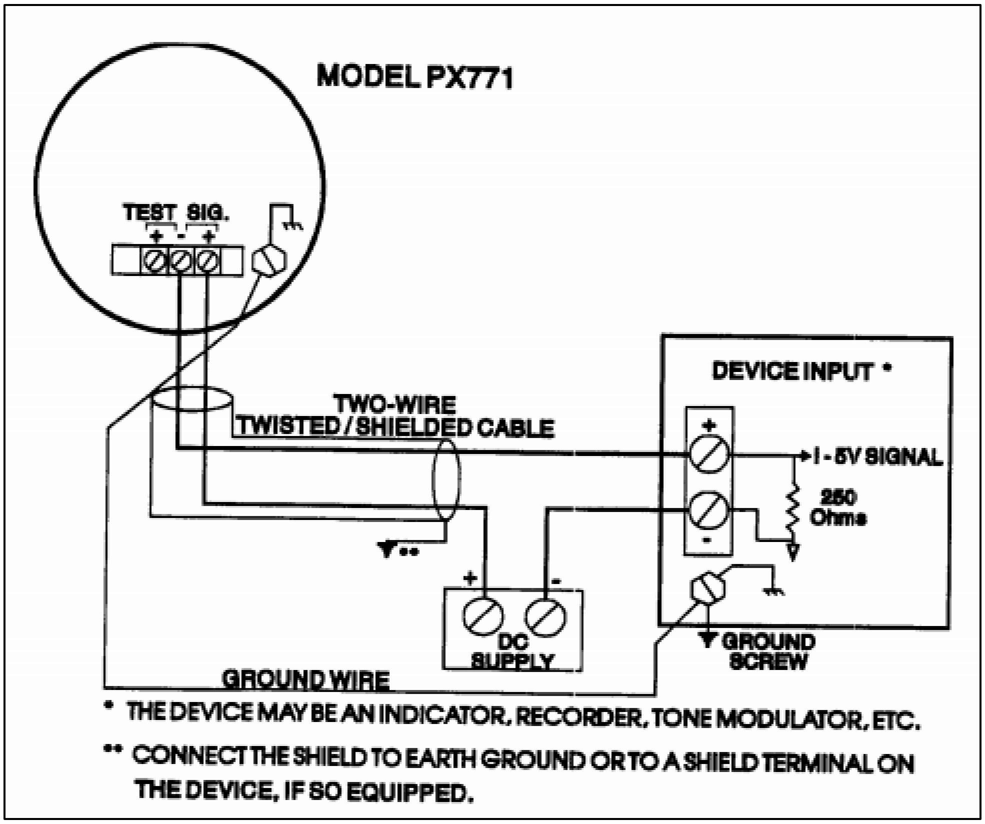


Figure 27. The wiring diagram for the pressure transducer connected to the DC power supply and a multimeter as the device input.

6.10 TOTAL ASSEMBLY (DRAWING NO. A1)

The final assembly of the test rig was assembled at Mustang ’60 machine shop once the individual parts were manufactured. This assembly was built as per the drawing found in Appendix O. Each of the socket connections will be joined together using PVC primer and PVC solvent glue, also known as PVC cement, shown in Figure 27. All socket connections will be cleaned, sanded, and primed before gluing takes place. The solvent glue that will be used is Harvey P-12 heavy bodied PVC cement, which is designed to solvent weld schedule 40 and schedule 80 PVC items up to 12" in diameter. We will also use Harvey Purple Solvent to properly prepare the pipes and fittings for the cement. The Material Safety Data Sheets for both the cement and primer are found in Appendix S. Flanged joints will be bolted together with the appropriate sized bolts. For the 6” flanges on either side of the butterfly valve, we used 3/4” threaded rods and 3/4” washers and nuts to secure the fitting. For the 4” flanges on either side of the butterfly valve and the orifice plate, we used 5/8” threaded rods and 5/8” washers and nuts to secure the fittings. Because bolts with half threads on the shaft would not work with our valves, we needed to cut our own steel rods to approximately 7” in length. Figure 28 shows how the threaded rods were cut to length with an abrasive shop saw. The ends of the threaded rods were then beveled on the belt sander.

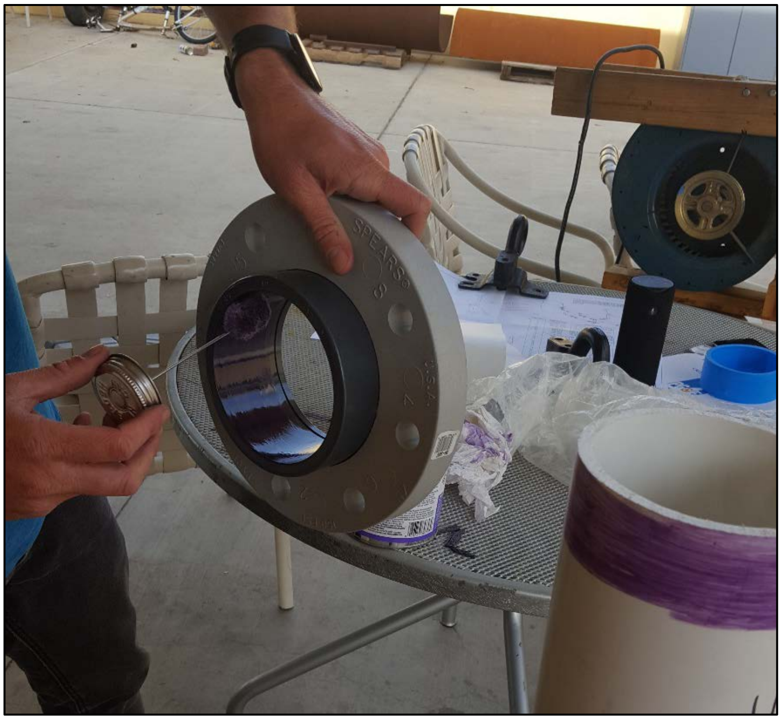


Figure 28. Brett applying primer to a flange fitting and PVC pipe.

Figure 29. Brian using an abrasive cut-off saw to cut steel rods.

6.11 OVERALL PROTOTYPE

The overall prototype came together largely following our original design along with new changes to the testing rig. One major change was the way in which we inserted compressed air into the piping. Rather than using an air compressor, we used the machine shop's compressed air. Another change was the specific pump that we used. Our calculations led us to select the DuroMax XP904WP gas powered trash pump which we thought we would need to purchase or rent. To conserve our budget, our sponsor put us in contact with Quinn CAT Rental Services who provided us with a Multiquip QP4TH pump to rent for free. This added a small change to our designed system, changing the maximum calculated flowrate we could achieve from the previous 427 gpm to the new 550 gpm. We also added a second butterfly valve in line with the 4" branch line to allow for additional flowrate adjustments throughout the system. The orifice plate replaced the second turbine flowmeter that we had designed for initially, where we then had to design and manufacture the plate and wiring to the differential pressure transducer. All of these changes can be seen in the final design CAD rendering in Figure 30 and compared to the actual final prototype in Figure 31 and 32. Figure 33 shows a close up of the butterfly valves that act to regulate the two inlets to the water tank.

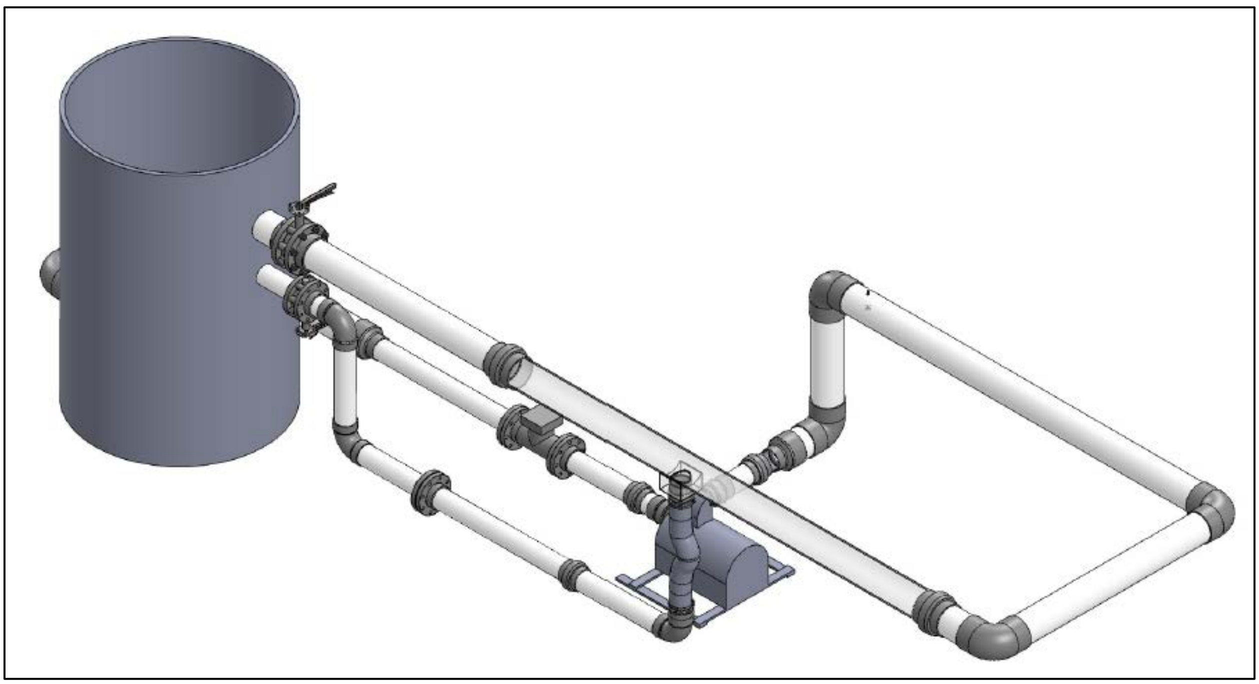


Figure 30. Solidworks CAD drawing of the final design of the testing rig.

Figure 31. Frontal view of the complete prototype of our vortexing test rig.

Figure 32. Additional isometric view of the testing rig.

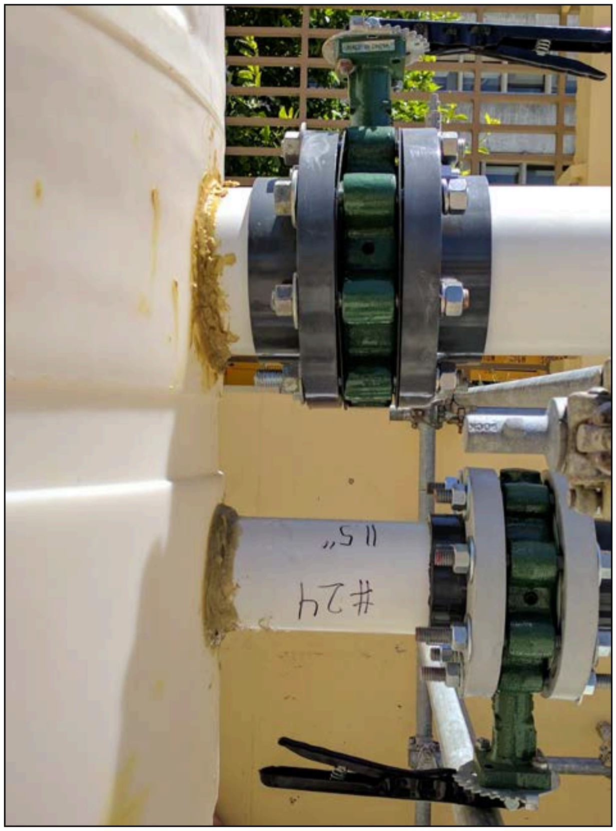


Figure 33. Both butterfly valves for the 6” & 4" pipes.

7 DESIGN VERIFICATION & TESTING

After the manufacturing was completed, we were finally able to test the rig. Rather than the usual product testing such as stress analysis and function assessments, our tests consisted of determining when a vortex forms, along with other parameters we chose to test for in our Design Verification Plan. When testing, we had one person operating and closing the valves, while another group member read the water height in the main line. The third member tabulated the data called out on a laptop computer. A computer was the only additional tool necessary to complete the testing phase of the project. Our original objective was to change flowrates in the main and branch lines and rotate the main line to observe multiple critical submergence depths at which the vortex forms. To get as many data points as possible, we configured a testing plan. We looked to set up three trials for each case for the three different offtake angles of the main line, along with closing the butterfly valve from 0 to 90° in 10° increments to see when a vortex would form. This will provide us with a total of 90 trials. Unfortunately, this testing did not come to fruition for a few reasons.

7.1 ORIFICE PLATE CALIBRATION

Before we could begin testing and collecting any data that we could, we first had to calibrate the orifice plate. There is no flowrate display associated with the orifice, so we had to

conduct a procedure using the turbine flowmeter. In order to use the orifice plate to measure flow, we cut off all of the flow going through the main line, so that all of the flow would be redirected to the branch line. We then would record the pressure drop using a pressure transducer connected to the display after setting a flowrate on the pump and reading it from the turbine flowmeter.

7.2 Design Alterations

Our group had to alter our testing because we found it hard, if not impossible, to rotate the main line without the flexible hose buckling and kinking. This would just add large pressure losses and restrict flow through the branch line, defeating the purpose of this machine. Therefore, we settled with just testing one offtake angle, 90° downward; however, if more time was available, it would have been possible to test for the three different angles with three separate hoses.

7.3 Testing Complications

As we began to test for the orifice plate calibration, we noticed that there was only one readout from the display. Prior, we discussed how we installed a DPDT on/on/on switch on the back of the display. One of the connections to this switch appeared to be faulty and did not show a value. To determine which one was defective, we removed the connection to the pressure transducer and just used a multimeter to read the voltage coming from the device. That left only the flowmeter, and we found that it was not outputting values to the display. In an attempt to figure out if there was a loose wire within the flowmeter that would cause it to not transmit a value, we removed the housing. Because we did not know how the flowmeter was constructed, this removal allowed water to pour out. During this operation, water landed on the display circuitry and shorted it out, giving us no way to read a flowrate. At this point, we concluded that we could not get any numerical, quantitative results from this experiment with the time left in the project schedule, with only a week left. What followed was an attempt at getting qualitative results to inform the reader at what point vortexes form.

7.4 Testing Results

To conduct qualitative testing with the equipment we had left, we followed a procedure mapped out to us by our sponsor. First, we filled the tank to its maximum height, approximately 6 feet, which allowed us to completely fill the 6” main line, while keeping the branch line closed. From this point while running the system, we slowly opened the branch line valve to lower the main line water level, until the air reached about 5, 10, and 15% area at the top of the pipe. These area percentages correspond to a distance of 0.59, 0.95, and 1.26 inches respectively from the top of the pipe. At each of these levels, we opened the branch line valve to allow air and water to travel downward creating the vortex.

When the main line valve is fully open, the majority of the flow passes by the tee and the stratified flow is not greatly influenced by the branch line. When we close the valve, the water is slowed down and experiences a hydraulic jump which forces the air out of the way and the water fills the full bore of the pipe. This traps any air present within the pipe and, as the zone of slow moving water grows, pushes the hydraulic jump phenomena upstream towards the tee. The

location of the hydraulic jump is the cause of gas ingestion because flow disturbance causes bubbles to break away from the stratified flow, which then get ingested into the branch line. However, this behavior only occurred when gas accounted for more than around 40% of the cross-sectional area.

Another way we tried to get quantitative data was to find the point at which a vortex formed at full pump speed. Since the flowmeter was inoperable, there was no way to verify the speed at which the fluid was running at, making it impossible to calculate Froude numbers. However, we had the pump curve for full operating speed and we knew the maximum speed, so in essence we could run the system and obtain data for one point. Unfortunately, when attempting to obtain data at this speed, the hose located at the tee junction almost burst when the main line valve was slowly closed. When running the system at the same maximum pump speed, but tinkering with components at a slower pace, we still could not obtain a vortex.

8 CONCLUSION & RECOMMENDATIONS

8.1 UNIONS VS FLANGES

One large obstacle of this project was the leakages through unions installed throughout the testing rig. As stated above in Maintenance & Repair Considerations, we had difficulty completely tightening the unions to a point where water was not able to escape the system. We first could only tighten them by hand, which was not enough torque applied to create a perfect seal. After searching for a strap wrench large enough to fit a 6” or 8” wide union at our local hardware stores, we devised our own tool consisting of a waist belt and a ratchet strap. This worked well enough to create a constant seal and stopped the leaks. But this device was far from ideal. We found that the flanges in our system work well and provide no leaks whatsoever. We would wholly advise the use of flanges rather than unions in any future development because they are easier to rotate and seal back up once the main line is at its desired offtake angle.

8.2 USE BULKHEAD FITTINGS ON TANK

We had many issues with water getting past the silicon sealant at the intersecting fitting of the tank outlet hole and the PVC pipe. We attempted to lather the sealant generously to fill gaps and make it watertight. Unfortunately, the water often found a way to get past the silicon seal. Another problem we faced was that as we filled the tank with more volume of water, the pressure and outward force on the elbow at the tank outlet overpowered the seal and pushed the fitting away from the tank. Therefore, we recommend purchasing a 6” bulkhead fitting to install at the bottom outlet to the tank. This would provide a sure way to completely seal this intersection and save days if not weeks of attempting to re-glue the seal. The only downside is that one of these bulkhead fittings cost upwards of $300. However, to save money, we used a piece of rectangular wood to provide compressive support at the pipe outlet to counteract the force of the water flowing out of the tank and maintain the seal.

8.3 Flexible Tubing Alternatives

As stated above in Section 7, we were forced to cut the flexible tube for only one offtake angle measurement due to excessive buckling at the slightest bend. If time permitted or our sponsor wanted to continue testing with a secondary team, we would recommend looking into other types of flexible hose that could hold firm their circular shape as one bent the tube.

9 Management Plan

9.1 Team Responsibilities

Our group agreed on individual responsibilities regarding this project. Brett was the communication officer who was the main point of contact with our sponsor and the project team at PG&E. Brett was also in charge of setting up and coordinating any meetings over the span of the project, along with relaying topics addressed in meetings to other members, or the sponsor, if they are absent. Brian acted as the team treasurer, maintaining the team's travel and materials budget throughout the project. Ryan was the recorder of meetings and kept track of the team's progress of the yearlong project and oversaw the deadlines of deliverables. Regarding team meeting leads, we decided to share the role when meeting our advisor, sponsor, and as a team. Also, we ensured that the meeting rules are followed as per our team contract provided to Anderson Lin on October 6, 2016.

9.2 Schedule

For a clear view of our schedule throughout the year long project, please refer to Appendix H for a Gantt chart. This chart allowed us to keep on schedule and determine if we were off track. This provided us with a tool to visually map out every step of the project, from idea generation to manufacturing dates.

Appendices

A. QFD – House of Quality
B. 2500 ppm Boric Acid Engineering Equation Solver File
C. Pugh Matrices
D. Morphological Chart
E. Final Decision Matrix
F. Flowrate Ratio Verification EES File
G. Design Safety Hazard Identification Checklist
H. Gantt Chart
I. Failure Modes and Effects Analysis
J. Design Verification Plans
K. Scaffolding Analysis
L. Entrance Length Analysis

M. Pump Selection Analysis
N. Air Compressor Analysis
O. Design Assembly with Bill of Materials (Drawing No. A1)
P. Detail Part Drawing
Q. Cost Analysis w/ List of Vendors & Pricing (Incl. Tax & Shipping)
R. Weld-On Literature & MSDS
S. Harvey P-12 Cement & Primer MSDS
T. Ruler Matlab Code
U. Omega FTB740 Turbine Flowmeter Spec Sheet
V. Omega DPF701 Display Meter Spec Sheet

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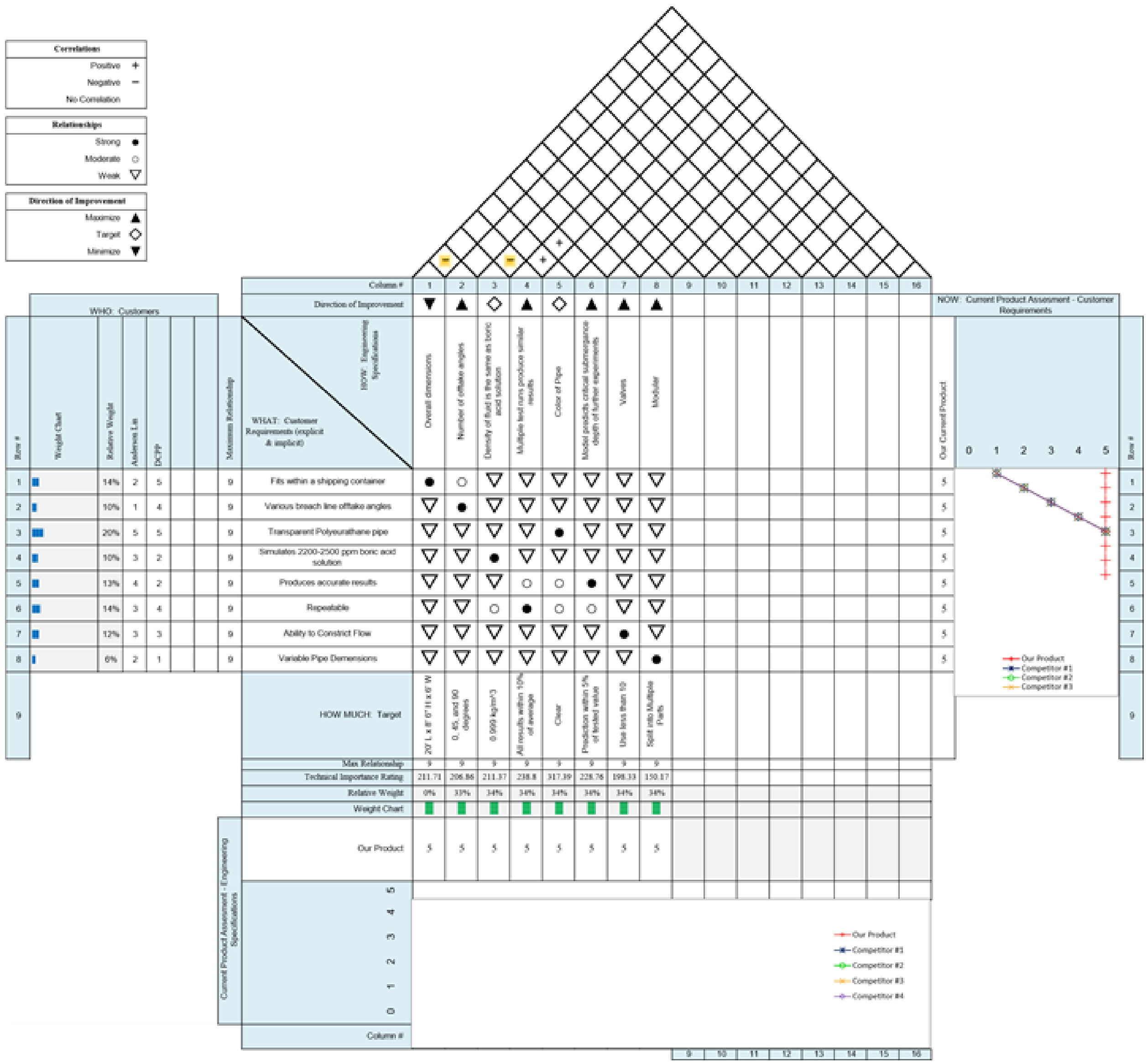
APPENDIX A: QFD - HOUSE OF QUALITY



APPENDIX B: 2500 PPM BORIC ACID EES FILE

File:E:\Sr Project\ba density.EES 2/10/2017 4:12:13 PM Page 1

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$\rho_{h2o} = 0.999$

$\rho_{BA} = 1.435$

$molar_{mass,BA} = 61.83$

$molar_{mass,h2o} = 18.0153$

$moles_{BA} = 2500$

$moles_{h2o} = 1000000$

$mass_{h2o} = molar_{mass,h2o} \cdot moles_{h2o}$

$mass_{BA} = molar_{mass,BA} \cdot moles_{BA}$

$$vol_{h2o} = \frac{mass_{h2o}}{\rho_{h2o}}$$

$$vol_{BA} = \frac{mass_{BA}}{\rho_{h2o}}$$

$$density_{mix} = \frac{mass_{h2o} + mass_{BA}}{vol_{h2o} + vol_{BA}}$$

SOLUTION

Unit Settings: SI C kPa kJ mass deg

$density_{mix} = 0.999$ [g/cm³]
$mass_{BA} = 154575$ [g]
$mass_{h2o} = 1.802E+07$ [g]
$molar_{mass,BA} = 61.83$ [g/mol]
$molar_{mass,h2o} = 18.02$ [g/mol]
$moles_{BA} = 2500$ [mol]
$moles_{h2o} = 1000000$ [mol]
$\rho_{BA} = 1.435$ [g/cm³]
$\rho_{h2o} = 0.999$ [g/cm³]
$vol_{BA} = 154730$ [cm³]
$vol_{h2o} = 1.803E+07$ [cm³]

No unit problems were detected.

APPENDIX C: PUGH MATRICES

Pugh Matrix: Measure Water Depth Level						
		Baseline	Alternative Solution			
Criteria	Weight (%)	Ruler Written on Pipe	Marked U-Tube	Water Level Marked on Weighted String	Floating Transducer	Camera Records Height Marks on Backboard
Overall Dimensions	10	D	-	0	0	-
Accuracy	30	A	+	+	+	0
Ease of Installation	20	T	-	-	-	0
Complexity	10	U	-	-	-	0
Cost	10	M	0	0	-	-
Power Consumption	10		0	0	-	-
Ease of Maintenance	10		0	-	-	0
Sum of all +			1	1	1	0
Sum of all -			3	3	5	3
Sum of all 0			3	3	1	4
Total			**-2**	**-2**	**-4**	**-3**
Total Weighted +			0.3	0.3	0.3	0
Total Weighted -			0.4	0.4	0.6	0.3
Total Weighted			**-0.1**	**-0.1**	**-0.3**	**-0.3**

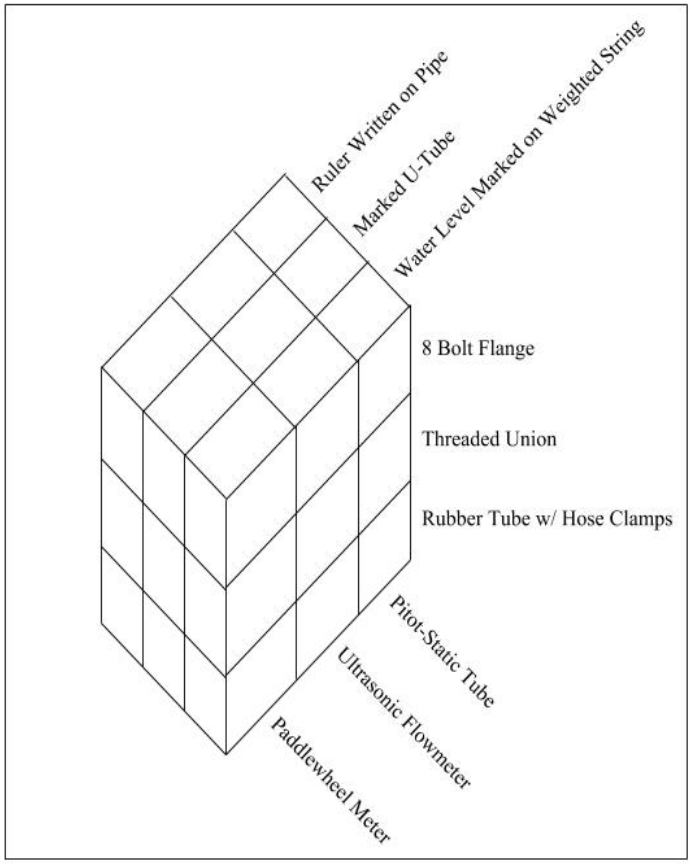
Pugh Matrix: Offtake Angle Rotation					
		Baseline	Alternative Solution		
Criteria	Weight (%)	8 Bolt Flange	Threaded Union	Rubber Tube w/ Hose Clamps	Flexible Tube
Easy to Adjust	25	D	+	+	-
Cost	10	A	-	+	-
Availability	15	T	0	0	-
Pressure Rating	25	U	0	-	0
Leak Proof	25	M	+	-	0
Sum of all Positives, +			2	2	0
Sum of all Negatives, -			1	2	3
Sum of all Neutrals, 0			2	1	2
Total			**1**	**0**	**-3**
Total Weighted +			0.5	0.35	0
Total Weighted -			0.1	0.5	0.5
Total Weighted Score			**0.4**	**-0.15**	**-0.5**

Pugh Matrix: Measure Fluid Flowrate							
		Baseline	**Alternative Solution**				
Criteria	**Weight (%)**	**Pitot-Static Tube**	**Rotameter**	**Ultrasonic Flowmeter**	**Turbine Flowmeter**	**Nutating Disk Flowmeter**
Accuracy	25	D	-	+	+	+
Pressure Drop	15	A	-	0	0	-
Cost	20	T	0	-	-	-
Ease of Installation	15	U	-	+	+	0
Availability	15	M	0	+	+	-
Ease of Use	10		-	0	0	0
Sum of all Positives, +			0	3	3	1
Sum of all Negatives, -			4	1	1	3
Sum of all Neutrals, 0			2	2	2	2
Total			**-4**	**2**	**2**	**-2**
Total Weighted +			0	0.55	0.55	0.25
Total Weighted -			0.65	0.2	0.2	0.5
Total Weighted Score			**-0.65**	**0.35**	**0.35**	**-0.25**

Pugh Matrix: Flow Creation				
		Baseline	**Alternative Solution**	
Criteria	**Weight (%)**	**Pump**	**Gravity**	**Siphon**
Time Efficient	25	D	-	-
Overall Dimensions	20	A	-	-
Cost	15	T	+	+
Repeatable	25	U	-	-
Ease of Use	15	M	0	-
Sum of all Positives, +			1	1
Sum of all Negatives, -			3	4
Sum of all Neutrals, 0			1	0
Total			**-2**	**-3**
Total Weighted +			0.15	0.15
Total Weighted -			0.7	0.85
Total Weighted Score			**-0.55**	**-0.7**

Pugh Matrix: Bubble Formation					
		Baseline	**Alternative Solution**		
Criteria	**Weight (%)**	**Air Compressor**	**Air Blower**	**Bike Air Pump**	**Open Channel to Atmosphere**
Time Efficient	45	D	0	-	0
Overall Dimensions	10	A	0	0	+
Cost	10	T	0	+	+
Repeatable	25	U	0	-	-
Ease of Use	10	M	0	-	-
Sum of all Positives, +			0	1	2
Sum of all Negatives, -			0	3	2
Sum of all Neutrals, 0			5	1	1
Total			**0**	**-2**	**0**
Total Weighted +			0	0.1	0.2
Total Weighted -			0	0.8	0.35
Total Weighted Score			**0**	**-0.7**	**-0.15**

APPENDIX D: MORPHOLOGICAL CHART



APPENDIX E: FINAL DECISION MATRIX

Weighted Matrix for Test Rig						
		Cost	**Ease of Use**	**Availability of Parts**	**Accuracy**	**Total**
	Weight (%)	25	35	20	20	100
Concept 1 (8 Bolt Flange, Marked U-Tube, & Pitot-Static Tube)	**Rating**	8	3	7	7	
	Wgt Rtg	2	1.05	1.4	1.4	5.85
Concept 2 (Threaded Union, Marked U-Tube, & Turbine Flowmeter)	**Rating**	2	8	4	3	
	Wgt Rtg	0.5	2.8	1	0.6	4.9
Concept 3 (Threaded Union, Ruler on Pipe, & Turbine Meter)	**Rating**	4	7	6	8	
	Wgt Rtg	1	2.45	1.2	1.6	6.25

APPENDIX F: FLOWRATE RATIO VERIFICATION EES FILE

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Flow Ratio Calculations

$$FR = \frac{K_4^{0.5}}{K_3^{0.5}}$$ *FR is Qbranch / Qmain*

$$g = 32.2$$

$$K_3 = 2 \cdot \frac{K_{L,branchtee}}{2 \cdot g} \cdot \left[\frac{4}{\pi \cdot D_b^2}\right]^2 + f_b \cdot \frac{l_b}{D_b} \cdot \frac{\left[\frac{4}{\pi \cdot D_b^2}\right]^2}{2 \cdot g}$$

$$K_{L,branchtee} = 2$$

$$D_b = \frac{2}{12}$$

$$f_b = 0.02$$

$$l_b = 4$$

$$K_4 = \left[\frac{2 \cdot K_{L,maintee} + 2 \cdot K_{L,elbow} + K_{L,valve}}{2 \cdot g}\right] \cdot \left[\frac{4}{\pi \cdot D_m^2}\right]^2 + f_m \cdot \frac{l_m}{D_m} \cdot \frac{\left[\frac{4}{\pi \cdot D_m^2}\right]^2}{2 \cdot g}$$

$$K_{L,maintee} = 0.9$$

$$K_{L,elbow} = 1.5$$

$K_{L,valve} = 210$ *This value changes depending on the % closed the valve is. 0% closed = 0.03, 33% closed = 10, 66% closed = 210.*

$$D_m = \frac{4}{12}$$

$$l_m = 4$$

$$f_m = 0.04$$

SOLUTION

Unit Settings: SI C kPa kJ mass deg

$D_b = 0.1667$	$D_m = 0.3333$
$FR = 1.733$	$f_b = 0.02$
$f_m = 0.04$	$g = 32.2$
$K_3 = 146.2$	$K_4 = 439$
$K_{L,branchtee} = 2$	$K_{L,elbow} = 1.5$
$K_{L,maintee} = 0.9$	$K_{L,valve} = 210$
$l_b = 4$	$l_m = 4$

No unit problems were detected.

APPENDIX G: DESIGN SAFETY HAZARD IDENTIFICATION CHECKLIST

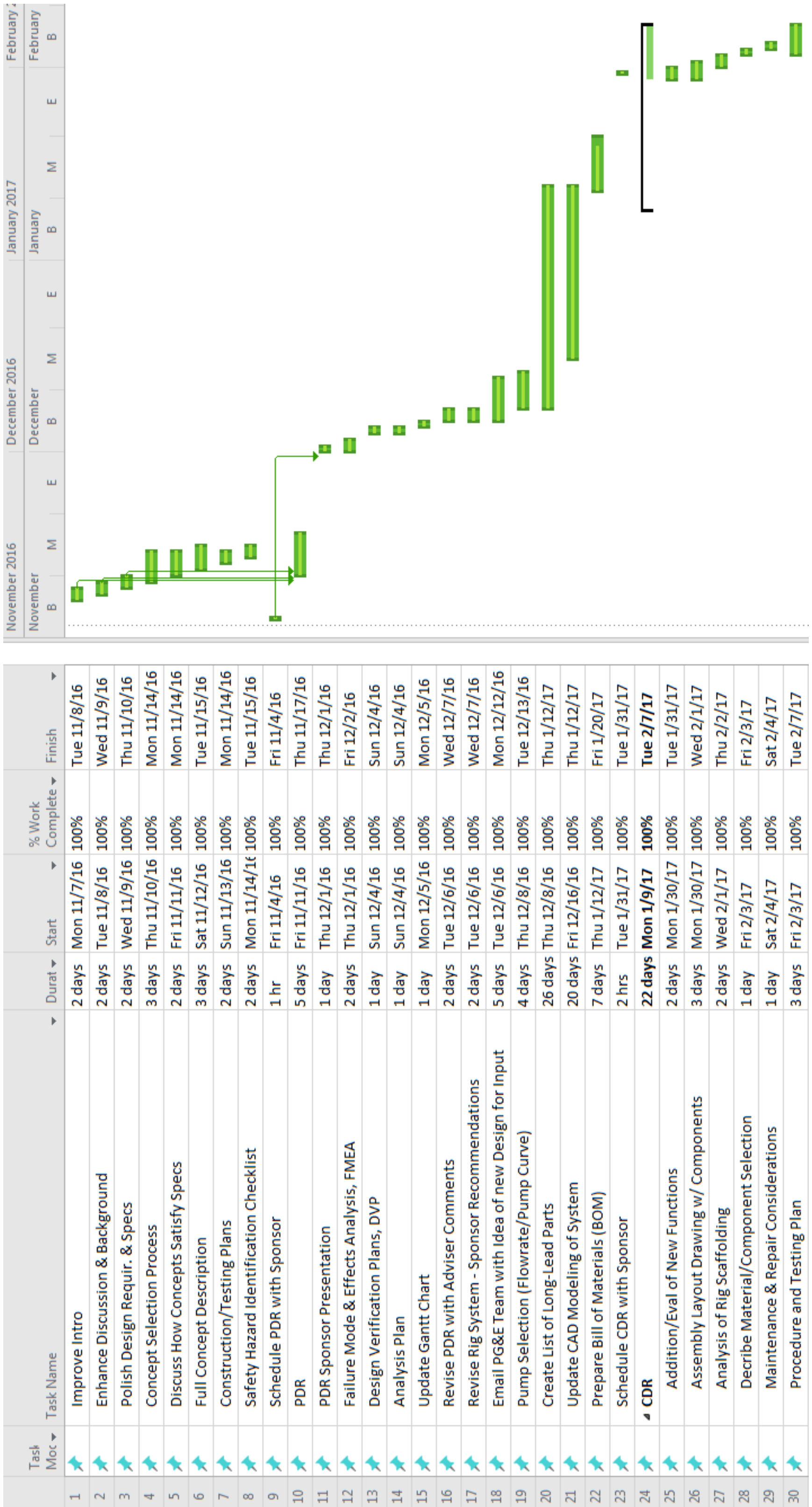
DESIGN HAZARD CHECKLIST

Team: Vortexing Off a Common Suction Header Advisor: Rossman

Y	N	
☐	☒	1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?
☐	☒	2. Can any part of the design undergo high accelerations/decelerations?
☐	☒	3. Will the system have any large moving masses or large forces?
☐	☒	4. Will the system produce a projectile?
☐	☒	5. Would it be possible for the system to fall under gravity creating injury?
☐	☐	6. Will a user be exposed to overhanging weights as part of the design?
☐	☒	7. Will the system have any sharp edges?
☐	☒	8. Will any part of the electrical systems not be grounded?
☐	☒	9. Will there be any large batteries or electrical voltage in the system above 40 V?
☐	☒	10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
☒	☐	11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
☐	☒	12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
☐	☒	13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
☒	☐	14. Can the system generate high levels of noise?
☒	☐	15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?
☐	☒	16. Is it possible for the system to be used in an unsafe manner?
☐	☒	17. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

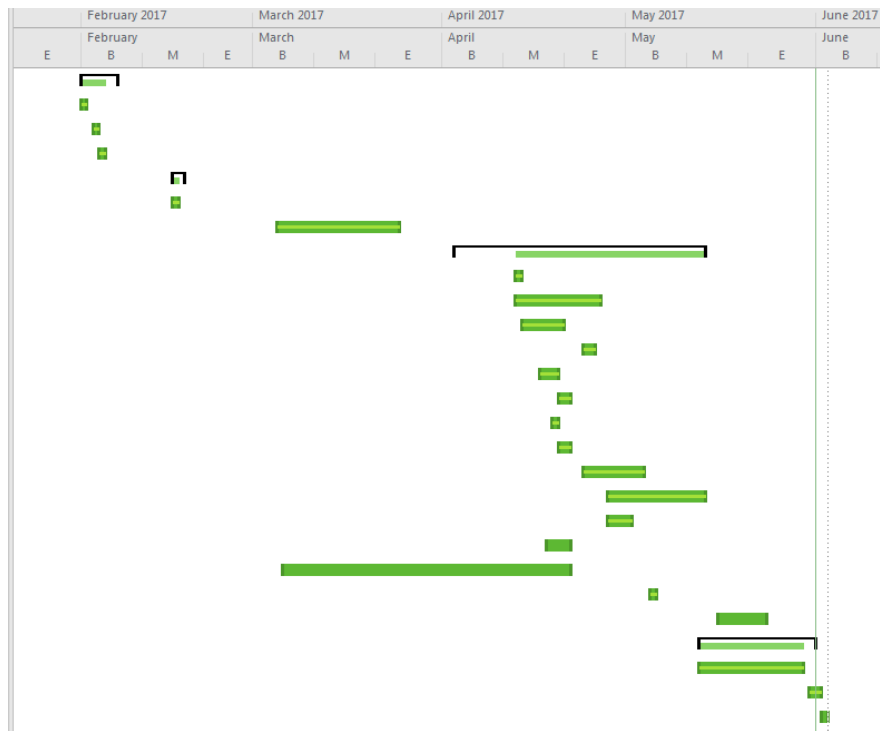
For any "Y" responses, add (1) a complete description, (2) a list of corrective actions to be taken, and (3) date to be completed on the reverse side.

APPENDIX H: GANTT CHART



	Task Mode	Task Name	Duration	Start	% Work Complete	Finish
1		Improve Intro	2 days	Mon 11/7/16	100%	Tue 11/8/16
2		Enhance Discussion & Background	2 days	Tue 11/8/16	100%	Wed 11/9/16
3		Polish Design Requir. & Specs	2 days	Wed 11/9/16	100%	Thu 11/10/16
4		Concept Selection Process	3 days	Thu 11/10/16	100%	Mon 11/14/16
5		Discuss How Concepts Satisfy Specs	2 days	Fri 11/11/16	100%	Mon 11/14/16
6		Full Concept Description	3 days	Sat 11/12/16	100%	Tue 11/15/16
7		Construction/Testing Plans	2 days	Sun 11/13/16	100%	Mon 11/14/16
8		Safety Hazard Identification Checklist	2 days	Mon 11/14/1(	100%	Tue 11/15/16
9		Schedule PDR with Sponsor	1 hr	Fri 11/4/16	100%	Fri 11/4/16
10		PDR	5 days	Fri 11/11/16	100%	Thu 11/17/16
11		PDR Sponsor Presentation	1 day	Thu 12/1/16	100%	Thu 12/1/16
12		Failure Mode & Effects Analysis, FMEA	2 days	Thu 12/1/16	100%	Fri 12/2/16
13		Design Verification Plans, DVP	1 day	Sun 12/4/16	100%	Sun 12/4/16
14		Analysis Plan	1 day	Sun 12/4/16	100%	Sun 12/4/16
15		Update Gantt Chart	1 day	Mon 12/5/16	100%	Mon 12/5/16
16		Revise PDR with Adviser Comments	2 days	Tue 12/6/16	100%	Wed 12/7/16
17		Revise Rig System - Sponsor Recommendations	2 days	Tue 12/6/16	100%	Wed 12/7/16
18		Email PG&E Team with Idea of new Design for Input	5 days	Tue 12/6/16	100%	Mon 12/12/16
19		Pump Selection (Flowrate/Pump Curve)	4 days	Thu 12/8/16	100%	Tue 12/13/16
20		Create List of Long-Lead Parts	26 days	Thu 12/8/16	100%	Thu 1/12/17
21		Update CAD Modeling of System	20 days	Fri 12/16/16	100%	Thu 1/12/17
22		Prepare Bill of Materials (BOM)	7 days	Thu 1/12/17	100%	Fri 1/20/17
23		Schedule CDR with Sponsor	2 hrs	Tue 1/31/17	100%	Tue 1/31/17
24		**CDR**	**22 days**	**Mon 1/9/17**	**100%**	**Tue 2/7/17**
25		Addition/Eval of New Functions	2 days	Mon 1/30/17	100%	Tue 1/31/17
26		Assembly Layout Drawing w/ Components	3 days	Mon 1/30/17	100%	Wed 2/1/17
27		Analysis of Rig Scaffolding	2 days	Wed 2/1/17	100%	Thu 2/2/17
28		Decribe Material/Component Selection	1 day	Fri 2/3/17	100%	Fri 2/3/17
29		Maintenance & Repair Considerations	1 day	Sat 2/4/17	100%	Sat 2/4/17
30		Procedure and Testing Plan	3 days	Fri 2/3/17	100%	Tue 2/7/17

	Task Mode	Task Name	Duration	Start	% Work Complete	Finish
31		**Manufacturing Plan**	**4 days**	**Wed 2/1/17**	**100%**	**Mon 2/6/17**
32		List of Manufactured Parts	1 day	Wed 2/1/17	100%	Wed 2/1/17
33		Decribe CNC Process	1 day	Fri 2/3/17	100%	Fri 2/3/17
34		Hire Professional - Contact Toby Shirts	1 day	Sat 2/4/17	100%	Sat 2/4/17
35		**CDR Sponsor Presentation with PG&E**	**2 days**	**Thu 2/16/17**	**100%**	**Fri 2/17/17**
36		Present BOM for Approval of Parts	1 day	Thu 2/16/17	100%	Thu 2/16/17
37		Purchase Online Parts/ Allow Time For Shipping	16 days	Sun 3/5/17	100%	Fri 3/24/17
38		**Prototype Construction**	**31 days**	**Mon 4/3/17**	**100%**	**Sat 5/13/17**
39		Pump Delivery	1 day	Thu 4/13/17	100%	Thu 4/13/17
40		Manufacture CNC Acrylic Block	10 days	Thu 4/13/17	100%	Wed 4/26/17
41		Cut PVC Pipes	5 days	Fri 4/14/17	100%	Thu 4/20/17
42		Glue PVC Pipes	2 days	Mon 4/24/17	100%	Tue 4/25/17
43		Pick up scaffolding & water tank	3 days	Mon 4/17/17	100%	Wed 4/19/17
44		Assemble Scaffolding	2 days	Thu 4/20/17	100%	Fri 4/21/17
45		Drill Tank Holes	1 day	Wed 4/19/17	100%	Wed 4/19/17
46		Assemble Air Line Hose	2 days	Thu 4/20/17	100%	Fri 4/21/17
47		Manufacture Orifice Plate	8 days	Mon 4/24/17	100%	Wed 5/3/17
48		Assemble Display Wiring	12 days	Fri 4/28/17	100%	Sat 5/13/17
49		Heat/Chemically Treat Acrylic Block	2 days	Fri 4/28/17	100%	Mon 5/1/17
50		Purchase Local Parts IF NECESSARY	4 days	Tue 4/18/17	100%	Fri 4/21/17
51		Write Operator's Manual	35 days	Mon 3/6/17	100%	Fri 4/21/17
52		Project Hardware / Safety Demo	1 day	Fri 5/5/17	100%	Fri 5/5/17
53		Fix Leaks at Unions & Connections	6 days	Tue 5/16/17	100%	Tue 5/23/17
54		**Testing**	**14 days**	**Sat 5/13/17**	**100%**	**Wed 5/31/17**
55		Obtain Qualitative Data	12 days	Sat 5/13/17	100%	Mon 5/29/17
56		Expo Board Printout	2 days	Wed 5/31/17	100%	Thu 6/1/17
57		FDR Project Expo	1 day	Fri 6/2/17	100%	Fri 6/2/17



APPENDIX I: FAILURE MODE AND EFFECT ANALYSIS

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s) / Mechanism(s) of Failure	Occurence	Criticality	Recommended Action(s)	Responsibility & Target Completion Date	Action Results: Actions Taken	Action Results: Severity	Action Results: Occurence	Action Results: Criticality
Form vortex	Bubble Instability	No Data	3	Flowrate too High	6	18	Indicate maximum setting for pump	5/3/2017	550 gpm			
				No Branch Line Suction	6	18	Fully open branch line valve	5/3/2017	Fully open valve			
		Gas Bind Pump	7	Bubble too Large	4	28	Reduce power to air compressor	5/3/2017	Install control valve			
				Flowrate too High	6	42	Design air release vent	5/3/2017	Quick disconnects			
	Insufficient Branch Line Flowrate	No Data	3	Valve not closed enough	2	6	Close Valve	5/3/2017	Close valve			
				Pump not Strong Enough	5	15	Get appropriately sized pump	5/3/2017	Pump performs above specified flowrate			
Assembly	Structure Becomes Unstable and Brakes	Injury to User	9	Earthquake	1	9	Install dampers/springs	5/3/2017	No dampers installed			
				Manufacturing Error	5	45	Double-Check All Bolt Connections	5/3/2017	Triple checked			
				Corrosion	2	18	Use Galvanized Steel	5/3/2017	1/2 galvanized			
				High Winds	1	9	Install Wind Shields	5/3/2017	Assembled next to wall			
		Time Needed to Rebuild Rig	2	Earthquake	1	2	Install dampers/springs	5/3/2017	No dampers installed			
				Manufacturing Error	5	10	Use Galvanized Steel	5/3/2017	1/2 galvanized			
				Corrosion	2	4	Install Wind Shields	5/3/2017	Assembled next to wall			
				High Winds	1	2	Install dampers/springs	5/3/2017	No dampers installed			
Equipment to Measure Water Height	Body explodes Due to Pressure	Get Wet	1	Bubble too Large	4	4	Reduce power to air compressor	5/3/2017	Install control valve			
				Flowrate too High	6	6	Indicate maximum setting for pump	5/3/2017	550 gpm			
		Time Lost to repair U-Tube	2	Bubble too Large	4	8	Reduce power to air compressor	5/3/2017	Install control valve			
				Flowrate too High	6	12	Indicate maximum setting for pump	5/3/2017	550 gpm			
	Connection Between U-Tube and Main Line Bursts	Get Wet	1	Bubble too Large	4	4	Reduce power to air compressor	5/3/2017	Install control valve			
				Flowrate too High	6	6	Indicate maximum setting for pump	5/3/2017	550 gpm			
		Time Lost to repair U-Tube	2	Bubble too Large	4	8	Reduce power to air compressor	5/3/2017	Install control valve			
				Flowrate too High	6	12	Indicate maximum setting for pump	5/3/2017	550 gpm			
Circulates Water	Leak	Error in data	2	Improper Connections	5	10	Tighten connections on bolts before test	5/3/2017	Triple checked			
				Excess pressure	2	4	Indicate maximum setting for pump	5/3/2017	550 gpm			
	Gas Bind Pump	Time Lost to repair pump	2	Vortex in reservoir	4	8	Install a float activated alarm to warn user of low tank water height	5/3/2017	Using semi-transparency to visually indicate water level			
		Cost to replace pump	5	Vortex in reservoir	4	20	Install a float activated alarm to warn user of low tank water height	5/3/2017	Using semi-transparency to visually indicate water level			
		Efficiency Loss	2	Vortex in reservoir	4	8	Install a float activated alarm to warn user of low tank water height	5/3/2017	Using semi-transparency to visually indicate water level			
		Excess noise	2	Vortex in reservoir	4	8	Install a float activated alarm to warn user of low tank water height	5/3/2017	Using semi-transparency to visually indicate water level			
	Pipe Bursts	Time lost to repair	2	Excess pressure	2	4	Indicate maximum setting for pump	5/3/2017	550 gpm			
				Flaw in pipe	1	2	Inspect pipe	5/3/2017	Inspected all piping			
		Get Wet	1	Excess pressure	2	2	Indicate maximum setting for pump	5/3/2017	550 gpm			
				Flaw in pipe	1	1	Inspect pipe	5/3/2017	Inspected all piping			
Measure Flowrate	Connection Between Pitot-Static Tube and Line Bursts	Time lost to repair	2	Excess pressure	2	4	Indicate maximum setting for pump	5/3/2017	550 gpm			
				Manufacturing Error	5	10	Inspect pipe	5/3/2017	Inspected all piping			
		Get Wet	1	Excess pressure	2	2	Indicate maximum setting for pump	5/3/2017	550 gpm			
				Manufacturing Error	5	5	Inspect pipe	5/3/2017	Inspected all piping			
	Inaccurate Readings	Error in data	2	Flawed logic	10	20	Use positive displacement flowmeters/paddlewheel meters/ultrasonic meter	5/3/2017	Using turbine flowmeter with display accurate to +/- 0.05 A			
				Crossflow due to turbulence	7	14	Insert flow conditioners	5/3/2017	None inserted			
Changing offtake angle	Rotated to Incorrect Angle	Error in data	2	Measurement mistake	1	2	Have 2 team members measure	5/27/2017				

APPENDIX J: DESIGN VERIFICATION PLANS

ME428 DVP&R Format

Report Date 6/2/17			Sponsor	Andeson Lin					Component/Assembly			REPORTING ENGINEER:	
TEST PLAN										**TEST REPORT**			
						SAMPLES		TIMING		TEST RESULTS			
Item No	Specification or Clause Reference	Test Description	Acceptance Criteria	Test Responsibility	Test Stage	Quantity	Type	Start date	Finish date	Test Result	Quantity Pass	Quantity Fail	NOTES
1	Size	Measure with tape measure	Smaller than seatrain	Brian	DV	1	B	4/20/2017	4/30/2017	20x7'	100%	0%	
2	Color	Visually inspect pipe transparency	Water level visible from outside	Brett	DV	1	B	12/25/2017	1/31/2017	Clear Pipe	100%	0%	
3	Modular	dissasemble and measure pieces	Ability to lift by 2 members, 100lbs, 20 ft long max	Ryan	DV	1	B	12/25/2017	1/31/2017	Unions are used	100%	0%	
4	Accuracy	Make multiple runs at a given bubble height and flowrates	Each test is within the error bars of the others	All Members	PV	5	C	5/4/2017	5/20/2017	Couldn't take data	0%	100%	
5	Number of offtake angles	Count the number of experiments run	3	Ryan	PV	1	C	5/4/2017	5/20/2017	Cut flexible tube for only 1 angle	33%	67%	
6	Equation works	Use our developed equation to predict critical submergance at an untested flow rate ratio and compare it to a value found by experiment.	Less than 5% error	All Members	PV	3	C	5/4/2017	5/20/2017	Couldn't take data	0%	100%	
7	No leaks	Visually inspect for no water leakage	1 water droplet	Ryan	PV	1	C	5/4/2017	5/20/2017	Only a few drips	90%	10%	

APPENDIX K: SCAFFOLDING ANALYSIS

File:C:\Users\melab2\Downloads\max length and max deflection.EES 2/9/2017 2:07:25 PM Page 1
EES Ver. 10.096: #0552: for use only by students and faculty, Mechanical Engineering, Dept. Cal Poly State University

```
"Scaffolding Analysis"

"Finding max deflection in longest length of main"
S_yield=0.0552 [GPa]*convert(GPa,N/m^2) "yield strength"
rho_water=995.7 [kg/m^3] "density of water"
diameter_main_OD=6.625 [in]*convert(in,m)
diameter_main_ID=6.065 [in]*convert(in,m)

"Get allowable stress based on assumed factor of safety"
S_allowable=S_yield/10 "Assume factor of safety of 10"

"Max bending stress is 30% of allowable stress"
S_maxbending=.3*S_allowable

weight_water=(pi/4)*diameter_main_ID^2*rho_water*9.81 "Weight of water in N/m"
weight_pipe=3.53[lbf/ft]*convert(lbf/ft,N/m) "Weight of pipe in N/m"
total_weight=weight_water+weight_pipe

"concentrated weights"
weight_flange=20 [lbf]*convert(lbf,N)
weight_valve=20 [lbf]*convert(lbf,N)
weight_elbow=7.5 [lbf]*convert(lbf,N)
weight_concentrated=(2*weight_flange)+weight_valve+weight_elbow

"moment of inertia of pipe"
I_main=(pi*diameter_main_ID^4)/64

"solving for length of main portion"
S_maxbending=(((0.0624*total_weight*length_main^2)+(0.1248*weight_concentrated*length_main))*diameter_main_OD)/
I_main

"young's modulus"
E_pvc=2.4 [GPa]*convert(GPa,N/m^2)

" finding max deflection at worst length possible"
max_deflection=(((5*total_weight*length_main^4)+ (8*weight_concentrated*length_main^3))/(384*E_pvc*I_main))*1000
```

SOLUTION

Unit Settings: SI C kPa kJ mass deg

$diameter_{main,ID}$ = 0.1541 [m]
$diameter_{main,OD}$ = 0.1683 [m]
E_{pvc} = 2.400E+09 [N/m^2]
I_{main} = 0.00002765
$length_{main}$ = 3.222 [m]
$max_{deflection}$ = 8.095 [mm]
ρ_{water} = 995.7 [kg/m^3]
$S_{allowable}$ = 5.520E+06
$S_{maxbending}$ = 1.656E+06
S_{yield} = 5.520E+07 [N/m^2]
$total_{weight}$ = 233.6
$weight_{concentrated}$ = 300.3
$weight_{elbow}$ = 33.36 [N]
$weight_{flange}$ = 88.96 [N]
$weight_{pipe}$ = 51.52 [N/m]
$weight_{valve}$ = 88.96 [N]
$weight_{water}$ = 182.1

7 potential unit problems were detected.

Parametric Table: Table 1

	$length_{main}$ [m]	$max_{deflection}$ [mm]
Run 1	3	6.258
Run 2	2.8	4.887
Run 3	2.6	3.752
Run 4	2.4	2.824
Run 5	2.2	2.078
Run 6	2	1.488
Run 7	1.8	1.031
Run 8	1.6	0.6866
Run 9	1.4	0.4348
Run 10	1.2	0.258
Run 11	1	0.1401
Run 12	0.8	0.06705
Run 13	0.6	0.0263
Run 14	0.4	0.007207
Run 15	0.2	0.0008276

APPENDIX L: ENTRANCE LENGTH ANALYSIS

File:C:\Users\melab2\Downloads\Entrance Length Analysis.EES 2/6/2017 7:49:12 PM Page 1
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```
"Entrance Length Analysis"

Q = 427*convert(gpm,ft^3/min)              "Maximum flowrate produced by pump"
d = 0.5                                    "diameter of pipe"
A = pi/4 * (d)^2
nu = 1.924*10^(-5)                         "kinetic viscosity of water"
V = Q/A*convert(ft/min,ft/s)
Re = V*D/nu                                "Reynolds number"

"From Wikipedia"
EntranceLength_1 = 1.359*D*(Re)^0.25       "for turbulent flow"

"From Fluid Mechanics - Munson"
EntranceLength_2 = 4.4*D*(Re)^(1/6)        "for turbulent flow"
```

SOLUTION

Unit Settings: SI C kPa kJ mass deg

A = 0.1963 [ft^2]

d = 0.5 [ft]

$EntranceLength_1$ = 12.8 [ft]

$EntranceLength_2$ = 15.58 [ft]

ν = 0.00001924 [ft^2/s]

Q = 57.08 [ft^3/min]

Re = 125916

V = 4.845 [ft/s]

No unit problems were detected.

APPENDIX M: PUMP SELECTION ANALYSIS

File:E:\Sr Project\System_curve_v2.EES 2/10/2017 2:30:54 PM Page 1
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EES for determining the System Curve

$g = 32.2$ *Earth's gravitational constant [ft/s^2]*

$kinvisc = 0.0000121$ *kinematic viscocity of water at room temp [ft^2/s]*

$z_{atm} = z_{topline} + 0.5$ *height of free surface at top of tank [ft]*

$z_{topline} = \frac{54}{12}$ *height of main line [ft]*

$z_{bottomline} = \frac{12}{12}$ *height of return line and bottom of branch line [ft]*

$z_{branchexit} = \frac{42}{12}$ *height at which the branch line enters the tank [ft]*

$Q_{return} = Q_{mainout} + Q_{branch}$

$D_{return} = \frac{6}{12}$ *Diameter of return line. Always 6 inch [ft]*

$L_{return,a} = \frac{85.27}{12}$ *Length of the 6 return line before the pump [ft]*

$L_{return,b} = \frac{220.49}{12}$ *Length of the 6 return line after the pump [ft]*

$V_{return} = \frac{Q_{return}}{\frac{\pi}{4} \cdot D_{return}^{2}}$ *flow velocity of the return line assuming uniform flow profile [ft/s]*

$f_{return} = 0.316 \cdot Re_{return}^{\left[\frac{-1}{4}\right]}$ *Darcy Friction Factor for the return line*

$Fr_{return} = \frac{V_{return}}{\left[g \cdot D_{return}\right]^{0.5}}$ *Froude number of the return line*

$Re_{return} = V_{return} \cdot \frac{D_{return}}{kinvisc}$ *Reynolds number of the return line*

$D_{return2} = \frac{4}{12}$ *Diameter of return2 line. 4 inch for the flowmeter and pump [ft]*

$L_{return2} = \frac{66}{12}$ *Length of 4 return line before the pump [ft]*

$V_{return2} = \frac{Q_{return}}{\frac{\pi}{4} \cdot D_{return2}^{2}}$

flow velocity of the return2 line assuming uniform flow profile. Flowrate is the same as rest of return line [ft/s]

$f_{return2} = 0.316 \cdot Re_{return2}^{\left[\frac{-1}{4}\right]}$ *Darcy Friction Factor for the return line*

$Fr_{return2} = \frac{V_{return2}}{\left[g \cdot D_{return2}\right]^{0.5}}$ *Froude number of the return2 line*

$Re_{return2} = V_{return2} \cdot \frac{D_{return2}}{kinvisc}$ *Reynolds number of the return line*

$D_{mainin} = \frac{6}{12}$ *Diameter of main line. Always equal to* $D_{mainout,ft}$

$L_{mainin} = \frac{70}{12}$ *Length of main line before the tee [ft]*

$V_{mainin} = \frac{Q_{return}}{\frac{\pi}{4} \cdot D_{mainin}^{2}}$ *flow velocity of the main line before tee assuming uniform flow profile [ft/s]*

$f_{mainin} = 0.316 \cdot Re_{mainin}^{\left[\frac{-1}{4}\right]}$ *Darcy Friction Factor for the mainin line*

$Fr_{mainin} = \frac{V_{mainin}}{\left[g \cdot D_{mainin}\right]^{0.5}}$ *Froude number of the mainin line*

$Re_{mainin} = V_{mainin} \cdot \frac{D_{mainin}}{kinvisc}$ *Reynolds number of the mainin line*

$D_{mainout} = D_{mainin}$ D_{mainin} *%Diameter of main line. Always equal to* D_{mainin} *[ft]*

$L_{mainout} = \frac{115.5}{12}$ *Length of main line after the tee [ft]*

$V_{mainout} = \frac{Q_{mainout}}{\frac{\pi}{4} \cdot D_{mainout}^{2}}$ *flow velocity of the main line after tee assuming uniform flow profile [ft/s]*

$f_{mainout} = 0.316 \cdot Re_{mainout}^{\left[\frac{-1}{4}\right]}$ *Darcy Friction Factor for the mainout line []*

$Fr_{mainout} = \frac{V_{mainout}}{\left[g \cdot D_{mainout}\right]^{0.5}}$ *Froude number of the mainout line*

$Re_{mainout} = V_{mainout} \cdot \frac{D_{mainout}}{kinvisc}$ *Reynolds number of the mainout line*

$D_{branch} = \frac{4}{12}$ *Diameter of branch line. [ft]*

$L_{branch} = \frac{96.5}{12}$ *total length of branch line from tee until reservoir [ft]*

$V_{branch} = \dfrac{Q_{branch}}{\dfrac{\pi}{4} \cdot D_{branch}^{\ 2}}$ *flow velocity of the branch line assuming uniform flow profile [ft/s]*

$f_{branch} = 0.316 \cdot Re_{branch}^{\left[\frac{-1}{4}\right]}$ *Darcy Friction Factor for the branch line []*

$Fr_{branch} = \dfrac{V_{branch}}{\left[g \cdot D_{branch}\right]^{0.5}}$ *Froude number of the branch line*

$Re_{branch} = V_{branch} \cdot \dfrac{D_{branch}}{kinvisc}$ *Reynolds number of the branch line*

$C_{union} = 0.08$

$C_{elbow} = 1.5$ *flow coefficient for a 6 inch 90 degree elbow 439*

$C_{reducer,6to4} = 0.305$ *flow coefficient for a 6 in to 4 in reducer P436*

$C_{reducer,4to6} = 0.135555$ *flow coefficient for a 4 in to 6 in expander P436*

$C_{exit} = 1$ *flow coefficient for a sharp edged exit P436*

$C_{entrance} = 0.5$ *flow coefficient for a sharp edged entrance P434*

$C_{teemain} = 0.9$ *flow coefficient for the main through flow in a tee P439*

$C_{teebranch} = 2$ *flow coefficient for the branch line flow through a tee P439*

$C_{butterfly}$ = 2786 flow coefficient for a 6 in butterfly valve. Changes depending on % closed [GPM/PSI]

http://www.valvias.com/flow-coefficient-butterfly-valve.php

$h_1 = h_{atm} + z_{atm} - z_{topline}$ *pressure head at top of tank*

$h_2 = h_1 + z_{topline} - z_{bottomline}$

$h_3 = h_2 - h_{loss23}$

$h_4 = h_3 - h_{loss34}$

$h_5 = h_4 + pumphead$

$h_6 = h_5 - h_{loss56} - \left[z_{topline} - z_{bottomline}\right]$

$h_7 = h_6 - h_{loss67}$

$h_8 = h_7 - h_{loss78} + z_{topline} - z_{branchexit}$

$h_8 = h_{atm} + z_{atm} - z_{branchexit}$

$h_1 = h_7 - h_{loss71}$

$h_{atm} = 0$ *feet head*

$$h_{loss23} = f_{return} \cdot \frac{L_{return,a}}{D_{return}} \cdot \frac{V_{return}^2}{2 \cdot g} + \left[3 \cdot C_{elbow} + C_{reducer,6to4} + C_{entrance} \right] \cdot \frac{V_{return}^2}{2 \cdot g}$$

$$h_{loss34} = f_{return2} \cdot \frac{L_{return2}}{D_{return2}} \cdot \frac{V_{return}^2}{2 \cdot g} + 4 \cdot C_{union} \cdot \frac{V_{return}^2}{2 \cdot g}$$

$$h_{loss56} = f_{return} \cdot \frac{L_{return,b}}{D_{return}} \cdot \frac{V_{return}^2}{2 \cdot g} + \left[4 \cdot C_{elbow} + C_{reducer,4to6} + 2 \cdot C_{union} \right] \cdot \frac{V_{return}^2}{2 \cdot g}$$

$$h_{loss67} = f_{mainin} \cdot \frac{L_{mainin}}{D_{mainin}} \cdot \frac{V_{mainin}^2}{2 \cdot g} + C_{union} \cdot \frac{V_{mainin}^2}{2 \cdot g}$$

$$h_{loss71} = f_{mainout} \cdot \frac{L_{mainout}}{D_{mainout}} \cdot \frac{V_{mainout}^2}{2 \cdot g} + \left[C_{union} + C_{exit} + C_{teemain} \right] \cdot \frac{V_{mainout}^2}{2 \cdot g} + \frac{Q_{mainout}}{C_{butterfly} \cdot 0.0009659}$$

$$h_{loss78} = f_{branch} \cdot \frac{L_{branch}}{D_{branch}} \cdot \frac{V_{branch}^2}{2 \cdot g} + \left[3 \cdot C_{elbow} + C_{exit} + 3 \cdot C_{union} + C_{teebranch} \right] \cdot \frac{V_{branch}^2}{2 \cdot g}$$

OPERATION AND PARTS MANUAL

MULTIQUIP®

MODEL QP4TH
TRASH PUMP
(HONDA GX340K1QA2/GX340U1QA2/GX340UT2QA2 GASOLINE ENGINE)

Revision #3 (01/29/14)

To find the latest revision of this publication, visit our website at: www.multiquip.com

THIS MANUAL MUST ACCOMPANY THE EQUIPMENT AT ALL TIMES.

PROPOSITION 65 WARNING

⚠ WARNING ⚠

CALIFORNIA — Proposition 65 Warning

Gasoline engine exhaust and some of its constituents are known to the State of California to cause cancer, birth defects and other reproductive harm.

NOTES

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QP4TH Centrifugal Pump

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NOTICE

Specifications and part numbers are subject to change without notice.

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Note: Discounts Are Subject To Change

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- ❒ **Quantity, Part Number and Description of Each Part**
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MQ MULTIQUIP

SAFETY INFORMATION

Do not operate or service the equipment before reading the entire manual. Safety precautions should be followed at all times when operating this equipment. Failure to read and understand the safety messages and operating instructions could result in injury to yourself and others.

SAFETY MESSAGES

The four safety messages shown below will inform you about potential hazards that could injure you or others. The safety messages specifically address the level of exposure to the operator and are preceded by one of four words: **DANGER, WARNING, CAUTION** or **NOTICE.**

SAFETY SYMBOLS

DANGER

Indicates a hazardous situation which, if not avoided, **WILL** result in **DEATH** or **SERIOUS INJURY.**

WARNING

Indicates a hazardous situation which, if not avoided, **COULD** result in **DEATH** or **SERIOUS INJURY.**

CAUTION

Indicates a hazardous situation which, if not avoided, **COULD** result in **MINOR** or **MODERATE INJURY.**

NOTICE

Addresses practices not related to personal injury.

Potential hazards associated with the operation of this equipment will be referenced with hazard symbols which may appear throughout this manual in conjunction with safety messages.

Symbol	Safety Hazard
	Lethal exhaust gas hazards
	Explosion hazards
	Burn hazards
	Pressurized fluid hazards
	Battery acid hazards
	Eye safety hazards

GENERAL SAFETY

CAUTION

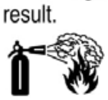
- **NEVER** operate this equipment without proper protective clothing, shatterproof glasses, respiratory protection, hearing protection, steel-toed boots and other protective devices required by the job or city and state regulations.

- **NEVER** operate this equipment when not feeling well due to fatigue, illness or when under medication.

- **NEVER** operate this equipment under the influence of drugs or alcohol.

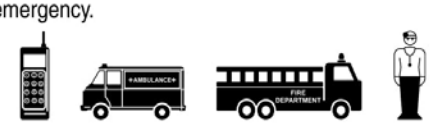
NOTICE

- This equipment should only be operated by trained and qualified personnel 18 years of age and older.
- Whenever necessary, replace nameplate, operation and safety decals when they become difficult read.
- Manufacturer does not assume responsibility for any accident due to equipment modifications. Unauthorized equipment modification will void all warranties.
- **NEVER** use accessories or attachments that are not recommended by Multiquip for this equipment. Damage to the equipment and/or injury to user may result.
- **ALWAYS** know the location of the nearest **fire extinguisher.**



- **ALWAYS** know the location of the nearest **first aid kit.**

- **ALWAYS** know the location of the nearest phone or **keep a phone on the job site.** Also, know the phone numbers of the nearest **ambulance, doctor** and **fire department.** This information will be invaluable in the case of an emergency.



PUMP SAFETY

DANGER

- **NEVER** pump volatile, explosive, flammable or low flash point fluids. These fluids could ignite or explode.
- The engine fuel exhaust gases contain poisonous carbon monoxide. This gas is colorless and odorless, and can cause death if inhaled.
- The engine of this equipment requires an adequate free flow of cooling air. **NEVER** operate this equipment in any enclosed or narrow area where free flow of the air is restricted. If the air flow is restricted it will cause injury to people and property and serious damage to the equipment or engine.

- **NEVER** operate the equipment in an explosive atmosphere or near combustible materials. An explosion or fire could result causing severe **bodily harm or even death.**

WARNING

- **NEVER** pump corrosive chemicals or water containing toxic substances. These fluids could create serious health and environmental hazards. Contact local authorities for assistance.
- **NEVER** open the priming plug when pump is hot. Hot water inside could be pressurized much like the radiator of an automobile. Allow pump to cool to the touch before loosening plug. The possibility exists of scalding, resulting in severe bodily harm.

- **NEVER** disconnect any **emergency or safety devices.** These devices are intended for operator safety. Disconnection of these devices can cause severe injury, bodily harm or even death. Disconnection of any of these devices will void all warranties.

CAUTION

- **NEVER** lubricate components or attempt service on a running machine.
- **NEVER** block or restrict flow from discharge hose. Remove kinks from discharge line before starting pump. Operation with a blocked discharge line can cause water inside pump to overheat.

NOTICE

- **ALWAYS** fill the pump casing with water before starting the engine. Failure to maintain water inside the pump housing will cause severe damage to the pump and mechanical seal.
- In winter drain water from pump housing to prevent freezing.
- **NEVER** start the pump with the clean-out cover removed. The rotating impeller inside the pump can cut or sever objects caught in it. Before starting the pump, check that the clean-out cover is securely fastened.
- **ALWAYS** keep the machine in proper running condition.
- **ALWAYS** ensure pump is on level ground before use.
- Fix damage to machine and replace any broken parts immediately.
- **ALWAYS** store equipment properly when it is not being used. Equipment should be stored in a clean, dry location out of the reach of children and unauthorized personnel.

ENGINE SAFETY

WARNING

- **NEVER** operate the engine with heat shields or guards removed.
- **DO NOT** remove the engine oil drain plug while the engine is hot. Hot oil will gush out of the oil tank and severely scald any persons in the general area of the pump.

CAUTION

- **NEVER** touch the hot exhaust manifold, muffler or cylinder. Allow these parts to cool before servicing equipment.

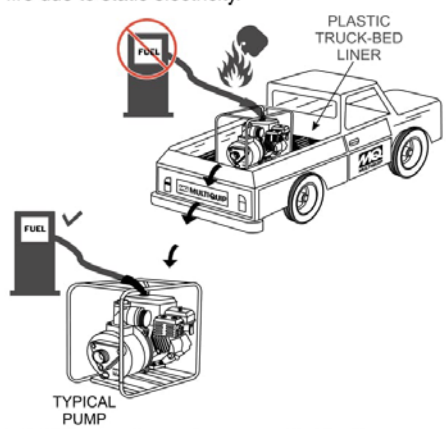
NOTICE

- **NEVER** run engine without an air filter or with a dirty air filter. Severe engine damage may occur. Service air filter frequently to prevent engine malfunction.
- **NEVER** tamper with the factory settings of the engine or engine governor. Damage to the engine or equipment can result if operating in speed ranges above the maximum allowable.

FUEL SAFETY

DANGER

- **DO NOT** add fuel to equipment if it is placed inside truck bed with plastic liner. Possibility exists of explosion or fire due to static electricity.



- **DO NOT** start the engine near spilled fuel or combustible fluids. Fuel is extremely flammable and its vapors can cause an explosion if ignited.
- **ALWAYS** refuel in a well-ventilated area, away from sparks and open flames.
- **ALWAYS** use extreme caution when working with **flammable** liquids.
- **DO NOT** fill the fuel tank while the engine is running or hot.
- **DO NOT** overfill tank, since spilled fuel could ignite if it comes into contact with hot engine parts or sparks from the ignition system.

- Store fuel in appropriate containers, in well-ventilated areas and away from sparks and flames.
- **NEVER** use fuel as a cleaning agent.
- **DO NOT** smoke around or near the equipment. Fire or explosion could result from fuel vapors or if fuel is spilled on a hot engine.

BATTERY SAFETY (ELECTRIC START ONLY)

DANGER

- **DO NOT** drop the battery. There is a possibility that the battery will explode.
- **DO NOT** expose the battery to open flames, sparks, cigarettes, etc. The battery contains combustible gases and liquids. If these gases and liquids come into contact with a flame or spark, an explosion could occur.

WARNING

- **ALWAYS** wear safety glasses when handling the battery to avoid eye irritation. The battery contains acids that can cause injury to the eyes and skin.

- Use well-insulated gloves when picking up the battery.
- **ALWAYS** keep the battery charged. If the battery is not charged, combustible gas will build up.
- **DO NOT** charge battery if frozen. Battery can explode. When frozen, warm the battery to at least 61°F (16°C).
- **ALWAYS** recharge the battery in a well-ventilated environment to avoid the risk of a dangerous concentration of combustible gases.
- If the battery liquid (dilute sulfuric acid) comes into contact with **clothing or skin**, rinse skin or clothing immediately with plenty of water.

- If the battery liquid (dilute sulfuric acid) comes into contact with **eyes**, rinse eyes immediately with plenty of water and contact the nearest doctor or hospital to seek medical attention.

CAUTION

- **ALWAYS** disconnect the **NEGATIVE battery terminal** before performing service on the equipment.
- **ALWAYS** keep battery cables in good working condition. Repair or replace all worn cables.

TRANSPORTING SAFETY

CAUTION

- **NEVER** allow any person or animal to stand underneath the equipment while lifting.

NOTICE

- Before lifting, make sure that the equipment parts (hook and vibration insulator) are not damaged and screws are not loose or missing.
- Always make sure crane or lifting device has been properly secured to the lifting bail (hook) of the equipment.
- **ALWAYS** shutdown engine before transporting.
- **NEVER** lift the equipment while the engine is running.
- Tighten fuel tank cap securely and close fuel cock to prevent fuel from spilling.
- Use adequate lifting cable (wire or rope) of sufficient strength.
- Use one point suspension hook and lift straight upwards.

- **DO NOT** lift machine to unnecessary heights.
- **ALWAYS** tie down equipment during transport by securing the equipment with rope.

ENVIRONMENTAL SAFETY/DECOMMISSIONING

NOTICE

Decommissioning is a controlled process used to safely retire a piece of equipment that is no longer serviceable. If the equipment poses an unacceptable and unrepairable safety risk due to wear or damage or is no longer cost effective to maintain (beyond life-cycle reliability) and is to be decommissioned (demolition and dismantlement),be sure to follow rules below.

- **DO NOT** pour waste or oil directly onto the ground, down a drain or into any water source.
- Contact your country's Department of Public Works or recycling agency in your area and arrange for proper disposal of any electrical components, waste or oil associated with this equipment.
- When the life cycle of this equipment is over, remove battery and bring to appropriate facility for lead reclamation. Use safety precautions when handling batteries that contain sulfuric acid.
- When the life cycle of this equipment is over, it is recommended that the trowel frame and all other metal parts be sent to a recycling center.

  Metal recycling involves the collection of metal from discarded products and its transformation into raw materials to use in manufacturing a new product.

  Recyclers and manufacturers alike promote the process of recycling metal. Using a metal recycling center promotes energy cost savings.

EMISSIONS INFORMATION

NOTICE

The gasoline engine used in this equipment has been designed to reduce harmful levels of carbon monoxide (CO), hydrocarbons (HC) and nitrogen oxides (NOx) contained in gasoline exhaust emissions.

This engine has been certified to meet US EPA Evaporative emissions requirements in the installed configuration.

Attempting to modify or make adjustments to the engine emmission system by unauthorized personnel without proper training could damage the equipment or create an unsafe condition.

Additionally, modifying the fuel system may adversely affect evaporative emissions, resulting in fines or other penalties.

Emission Control Label

The emission control label is an integral part of the emission system and is strictly controlled by regulation(s).

The label must remain with the engine for its entire life.

If a replacement emission label is needed, please contact your authorized engine distributor.

SPECIFICATIONS (PUMP)

Table 1. Specifications (Pump)		
Pump	Model	QP4TH
	Type	Trash Pump
	Suction	4.0 in. (100 mm.)
	Discharge Size	4.0 in. (100 mm.)
	Maximum Pumping Capacity	555 gallons/minute (2,100 liters/minute)
	Max. Solids Diameter	1.57 in. (40 mm)
	Max. Lift	25 ft. (7.62 meters)
	Max. Head	92 ft. (28.0 m)
	Max. Pressure	40 psi (275 kPa)
Dry Net Weight		222 lbs. (100.5 Kg.)

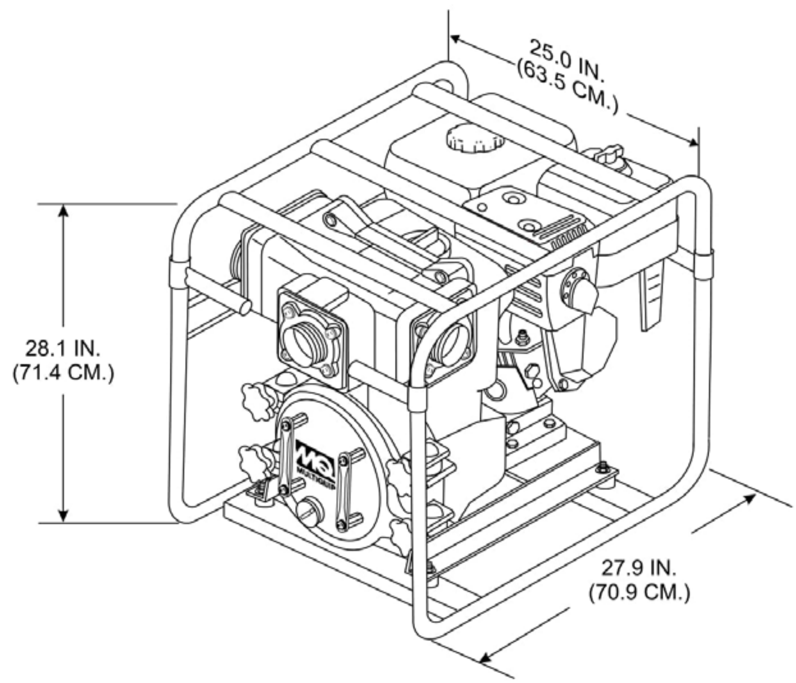


Figure 1. QP4TH Dimensions

SPECIFICATIONS (ENGINE)

Table 2. Specifications (Engines)		
Engine	Model	HONDA GX340K1QA2/ GX340U1QA2/GX340UT2QA2
	Type	Air-cooled 4 stroke, Single Cylinder, OHV, Horizontal Shaft Gasoline Engine
	Bore x Stroke	3.46 in. x 2.28 in. (88 mm x 64 mm)
	Displacement	20.53 cu-in (337 cc)
	Max Output	10.7 H.P.*/3,600 R.P.M.
	Fuel Tank Capacity	Approx.1.62 U.S. Gallons (6.1 Liters)
	Fuel	Unleaded Automobile Gasoline
	Lube Oil Capacity	1.16 quarts (1.10 liters)
	Speed Control Method	Centrifugal Fly-weight Type
	Starting Method	Recoil Start
Dimension (L x W x H)		15.0 x 17.7 x 17.4 in. (380 x 450 x 443 mm)
Dry Net Weight		69.4 lbs (31.5 Kg.)

* Engine power ratings are calculated by the individual engine manufacturer and the rating method may vary among engine manufacturers. Multiquip Inc. and its subsidiary companies makes no claim, representation or warranty as to the power rating of the engine on this equipment and disclaims any responsibility or liability of any kind whatsoever with respect to the accuracy of the engine power rating. Users are advised to consult the engine manufacturer's owners manual and its website for specific information regarding the engine power rating.

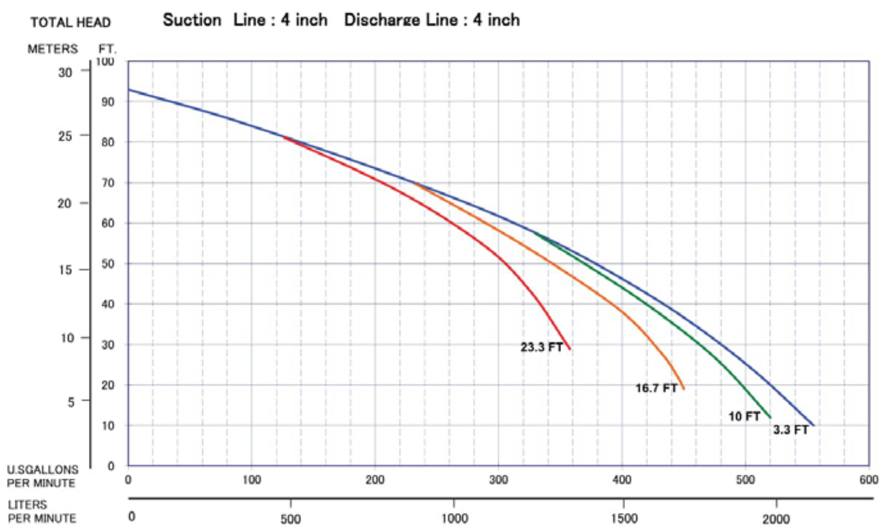


Figure 2. QP4TH Performance Curve

APPLICATION

The Multiquip QP4TH Trash Pump is designed to be used for dewatering applications. Both the suction and discharge ports on the QP4TH trash pump use a 4-inch diameter opening,which allows the pump to pump at a rate of approximately 555 gallons/minute (gpm) or 2,100 liters/minute (lpm).

TRASH PUMP

Trash pumps derive their name from their ability to handle a greater amount of debris and solids than standard centrifugal pumps. These pumps generally handle solids up to 1/2 the size of the discharge opening making them less likely to clog. Also trash pumps are capable of handling water with 25% solids by weight.

The advantage of using a trash pump is that it can be quickly and easily disassembled in the field "without tools" and easily cleaned when clogged.

POWER PLANT

This trash pump is powered by a 10.7 horsepower air cooled 4-stroke, single cylinder HONDA GX340 gasoline engine that incorporates a low "Oil Alert Feature."

OIL ALERT FEATURE

In the event of low oil or no oil, the HONDA GX340 engine has a built-in oil alarm engine shut-down feature. In the event the oil level is low the engine will automatically shutdown.

SUCTION LIFT

This pump is intended to be used for dewatering applications and is capable of suction lifts up to 25 feet at sea level. For optimal suction lift performance keep the suction hose or line as short as possible. In general always place the pump as close to the water as possible.

PUMP SUPPORT

The pump should always be placed on solid stationary ground in a level position.

NEVER place the pump on ***soft soil.*** The suction hose or pipe connection should always be checked for tightness and leaks. A small suction leak in the hose or fittings could prevent the pump from priming.

Elevation

Higher elevations will effect the performance of the pump. Due to less atmospheric pressure at higher altitudes, pumps **DO NOT** have the priming ability that they have at sea level. This is due to the "thinner air" or lack of oxygen at higher altitudes.

A general rule of thumb is that for every 1,000 feet of elevation above sea level a pump will lose one foot of priming ability.

For example, in Flagstaff, Arizona where the elevation is approximately 7,000 feet, the pump would have a suction lift of only 18 feet rather than the 25 feet at sea level. Table 3 shows suction lift at various elevations.

Table 3. Suction Lift at Various Elevations

Altitude Feet (Meters)	Suction Lift in Feet (Meters)			
Sea Level	10.0 (3.048)	15.0 (4.572)	20.0 (6.096)	25.0 (7.620)
2,000 (610)	8.80 (2.680)	13.2 (4.023)	17.6 (5.364)	22.0 (6.705)
4,000 (1,219)	7.80 (2.377)	11.7 (3.566)	15.6 (4.754)	19.5 (5.943)
6,000 (1,829)	6.90 (2.103)	10.4 (3.169)	13.8 (4.206)	17.3 (5.273)
8,000 (2,438)	6.20 (1.889)	9.30 (2.834)	12.4 (3.779)	15.5 (4.724)
10,000 (3,048)	5.70 (1.737)	8.60 (2.621)	11.4 (3.474)	14.3 (4.358)

Table 4 shows percentage drops in performance as elevation increases.

Table 4. Performance Loss at Various Elevations

Altitude Feet (Meters)	Discharge Flow	Discharge Head
Sea Level	100%	100%
2,000 (610)	97%	95%
4,000 (1,219)	95%	91%
6,000 (1,829)	93%	87%
8,000 (2,438)	91%	83%
10,000 (3,048)	88%	78%

PUMP COMPONENTS

Figure 3 shows a typical application using the QP4TH centrifugal pump. Please note that this pump is intended for the removal of clean water.

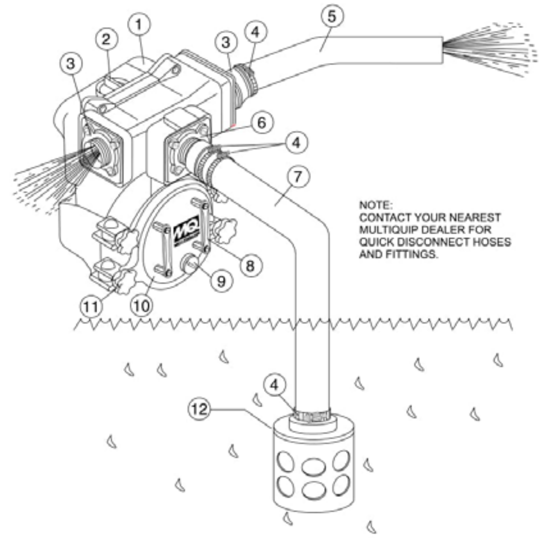


Figure 3. QP4TH Pump Application

1. **Pump** — The model QP4TH is a 4-inch trash pump aused in general dewatering applications.Typical dewatering applications consist of manholes, septic tanks, fast and slow seepage ditch water, silt water, mud water and muck water.
2. **Fill Cap** — Prior to operation, the pump casing should be filled with water. Remove this cap to add water to the pump. After the initial prime, a sufficient amount of water will be retained in the casing so that the operator will not need to re-prime later.
3. **Discharge Port** — Connect a 4-inch discharge hose to this port.
4. **Worm Clamp —** Used to secure the hose to the inlet and outlet ports on the pump. Use two clamps to secure the hose on the inlet side of the pump.
5. **Discharge Hose** — Connect a flexible rubber hose to the discharge port on the pump. Make sure that the hose lays flat and is not kinked. Use only recommended type discharge hose. Contact Multiquip Parts Department for ordering information.
6. **Suction Port —** Connect a 3-inch inlet hose to this port Use two worm clamps to secure the hose.
7. **Suction Hose** — Connect this flexible rubber hose to the suction port on the pump. Make sure that the hose lays flat and is not kinked. Use only recommended type suction hose. Contact Multiquip parts department for ordering information.
8. **Clean-out Cover Handles** — To gain access to the pump's clean-out area, grip both handles, then pull to remove cover. Make sure both locking knobs have been released before attempting to remove clean-out cover.
9. **Drain Plug** — Remove this plug to drain water from the pump.
10. **Clean-out Cover** — Remove cover to gain access to the clean-out area.
11. **Locking Knobs** — Turn both knobs clockwise to secure clean-out cover, turn counter-clockwise to release cover.
12. **Strainer** — Always attach a strainer to bottom side of the suction hose to prevent large objects and debris from entering the pump. Strainer should be positioned so that it will remain completely under water. Running the pump with the strainer above water for long periods can damage pump.

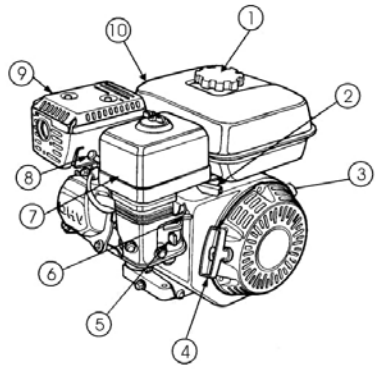


Figure 4. Engine Controls and Components

INITIAL SERVICING

The engine (See Figure 4) must be checked for proper lubrication and filled with fuel prior to operation. Refer to the manufacturers engine manual for instructions and details of operation and servicing. The engine shown above is a HONDA engine, operation for other types of engines may vary somewhat.

1. **Fuel Filler Cap —** Remove this cap to add unleaded gasoline to the fuel tank. Make sure cap is tightened securely. **DO NOT** over fill.

DANGER

Adding fuel to the tank should be done only when the engine is stopped and has had an opportunity to cool down. In the event of a fuel spill, **DO NOT** attempt to start the engine until the fuel residue has been completely wiped up, and the area surrounding the engine is dry.

2. **Throttle Lever** — Used to adjust engine RPM speed (lever advanced forward ***SLOW***, lever back toward operator ***FAST***).

3. **Engine ON/OFF Switch —** ON position permits engine starting, OFF position stops engine operations.

4. **Recoil Starter (pull rope) —** Manual-starting method. Pull the starter grip until resistance is felt, then pull briskly and smoothly.

5. **Fuel Valve Lever — OPEN** to let fuel flow, **CLOSE** to stop the flow of fuel.

6. **Choke Lever —** Used in the starting of a cold engine, or in cold weather conditions. The choke enriches the fuel mixture.

7. **Air Cleaner** — Prevents dirt and other debris from entering the fuel system. Remove wing-nut on top of air filter cannister to gain access to filter element.

NOTICE

Operating the engine without an air filter, with a damaged air filter, or a filter in need of replacement will allow dirt to enter the engine, causing rapid engine wear.

WARNING

Engine components can generate extreme heat. To prevent burns, **DO NOT** touch these areas while the engine is running or immediately after operating. **NEVER** operate the engine with the muffler removed.

8. **Spark Plug** — Provides spark to the ignition system. Set spark plug gap to 0.6 - 0.7 mm (0.028 - 0.031 inch). Clean spark plug once a week.

9. **Muffler —** Used to reduce noise and emissions.

10. **Fuel Tank** — Holds unleaded gasoline. For additional information refer to engine owner's manual.

INSPECTION (ENGINE)

⚠ CAUTION

DO NOT attempt to operate the pump untilthe Safety Information, General Information and Inspection sections of this manual have been read and thoroughly understood.

BEFORE STARTING

1. Read safety instructions at the beginning of manual.
2. Clean the pump, removing dirt and dust, particularly the engine cooling air inlet, carburetor and air cleaner.
3. Check the air filter for dirt and dust. If air filter is dirty, replace air filter with a new one as required.
4. Check carburetor for external dirt and dust. Clean with dry compressed air.
5. Check fastening nuts and bolts for tightness.

Engine Oil Check

1. To check the engine oil level, place the pump on secure level ground with the engine stopped.
2. Remove the filler dipstick from the engine oil filler hole (See Figure 5) and wipe clean.

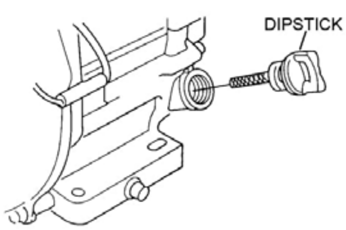


Figure 5. Engine Oil Dipstick (Removal

3. Insert and remove the dipstick without screwing it into the filler neck. Check the oil level shown on the dipstick.
4. If the oil level is low (See Figure 6), fill to the edge of the oil filler hole with the recommended oil type (Table 5). Maximum oil capacity is 1.16 quarts (1.1 liters).

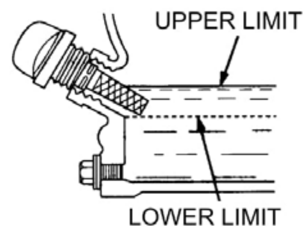


Figure 6. Engine Oil DipStick (Oil Level

Table 5. Oil Type		
Season	**Temperature**	**Oil Type**
Summer	25°C or Higher	SAE 10W-30
Spring/Fall	25°C~10°C	SAE 10W-30/20
Winter	0°C or Lower	SAE 10W-10

⚠ DANGER

Motor fuels are highly flammable and can be dangerous if mishandled. **DO NOT** smoke while refueling. **DO NOT** attempt to refuel the pump if the engine is ***hot! or running.***

Fuel Check

1. Remove the gasoline cap located on top of fuel tank.
2. Visually inspect to see if the fuel level is low. If fuel is low, replenish with unleaded fuel.
3. When refueling, be sure to use a strainer for filtration. **DO NOT** top-off fuel. Wipe up any spilled fuel ***immediately!***

1. Place pump as near to water as possible, on a firm flat, level surface.
2. To prime pump, remove fill cap (See Figure 3) and fill pump casing with water. If the pump casing is not filled with water before starting, it will not begin pumping.
3. Attach suction and discharge hoses to the pump. Check that all hoses are ***securely*** attached to the pump. Make certain suction hose (See Figure 3) does not have any air leakage. Tighten hose clamps and couplings as required.
4. It is recommended that 2 clamps be used when securing the suction hose to the inlet side (suction) of the pump.
5. Remember suction hoses must be ***rigid*** enough not to collapse when the pump is in operation.
6. Check that the ***discharge*** hose (See Figure 3) is not restricted. Place hose so that it lays as straight as it is possible on the ground. Remove any twists or sharp bends from hose which may block the flow of water.

NOTICE

Suction and discharge hoses are available from Multiquip. Contact your nearest dealer for more information.

7. The discharge hose is usually a ***collapsible*** (thin-walled) hose, however if a thin-walled discharge hose is not available, a rigid suction hose can be substituted in its place.
8. Make sure the ***suction strainer*** (See Figure 3) is clean and securely attached to the water end of the suction hose. The strainer is designed to protect the pump by preventing large objects from being pulled in to the pump.

⚠ CAUTION

The strainer should be positioned so it will remain completely ***under water***. Running the pump with the strainer above water for long periods can damage the pump.

> **⚠ CAUTION**
>
> **DO NOT** attempt to start the engine unless the pump has previously been primed with water. Severe pump damage will occur if pump has not been primed.

STARTING THE ENGINE

1. Place the engine fuel valve lever (See Figure 7) to the **ON** position.

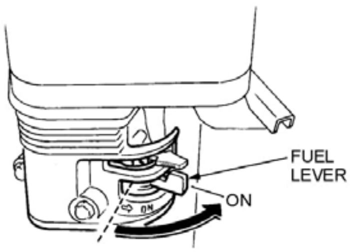


Figure 7. Engine Fuel Valve Lever (ON Position)

2. Move the throttle lever (See Figure 8) away from the slow position, about 1/3 of the way toward the fast position.

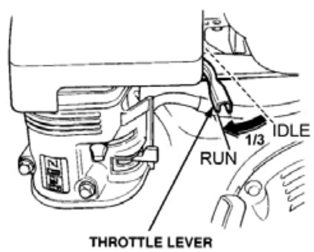


Figure 8. Throttle Lever (1/3 Start Position

3. Place the choke lever (See Figure 9) in the **CLOSED** position if starting a cold engine.

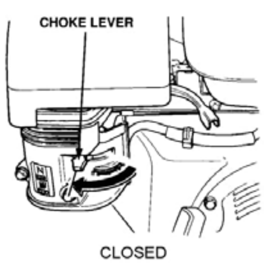


Figure 9. Engine Choke Lever (Closed)

4. Place the choke lever (See Figure 10) in the **OPEN** position if starting a warm engine or the temperature is warm.

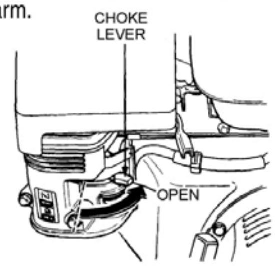


Figure 10. Engine Choke Lever (Open)

5. Place the engine **ON/OFF** switch (See Figure 11) in the **ON** position.

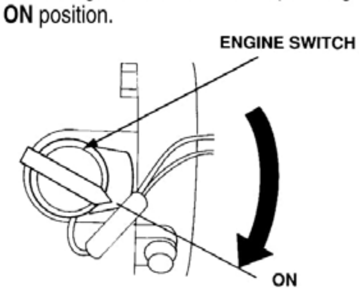


Figure 11. Engine ON/OFF Switch (ON Position)

6. Grasp the starter grip (See Figure 12) and slowly pull it out. The resistance becomes the hardest at a certain position, corresponding to the compression point. Pull the starter grip briskly and smoothly for starting.

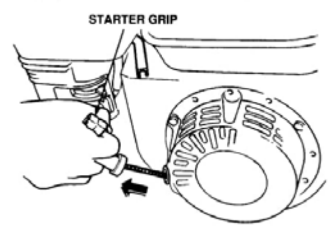


Figure 12. Starter Grip

7. If the engine has started and the choke lever was moved to the **CLOSED** position to start the engine, gradually move the choke lever to the **OPEN** position (Figure 13) as the engine warms up. If the engine has not started repeat steps 1 through 6.

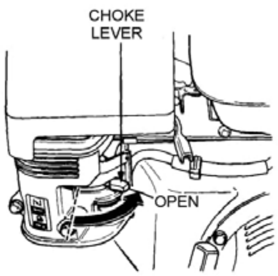


Figure 13. Choke Lever (Open)

8. Before the pump is placed in to operation, run the engine for several minutes. Check for fuel leaks, and noises that would associate with a lose component.

9. To begin pumping, place the throttle lever (See Figure 13) in the **RUN** position. If water is not flowing out of the discharge port, turn off the engine and check for and clear any obstructions within the suction hose.

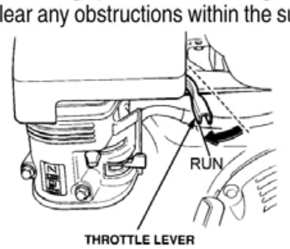


Figure 14. Throttle Lever (Run)

WARNING

Water must always be flowing through the pump casing while the engine is running. Loss of flow may be the result of a loss of prime, restricted water flow or a dead-head situation. Please note that in such a condition, water in the pump can reach temperatures of 150-200°F in 15 to 20 minutes. This can cause serious burns if this hot water comes into contact with unprotected skin.

Before touching or opening the fill plug or drain plug, first turn off the engine and allow the pump casing to cool to the touch, and then open the pump carefully. Be cautious of any built up water pressure.

CAUTION

ALWAYS run engine at ***full speed*** while pumping.

STOPPING THE ENGINE

Normal Shutdown

1. Move the throttle lever to the **IDLE** position (See Figure 14) and run the engine for three minutes at low speed.

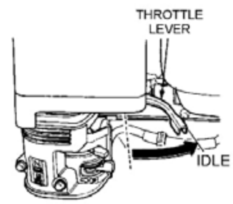


Figure 15. Throttle Lever (Idle)

2. After the engine cools, turn the engine **ON/OFF** switch to the **OFF** position (See Figure 15).

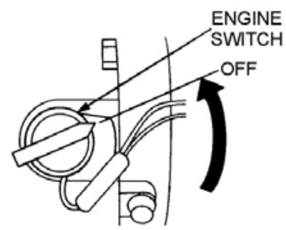


Figure 16. Engine ON/OFF Switch (OFF)

3. Place the fuel shut-off lever (See Figure 16) in the **OFF** position

Figure 17. Fuel Valve Lever (OFF)

Emergency Shutdown

1. Move the throttle lever quickly to the **IDLE** position, and place the engine **ON/OFF** switch in the **OFF** position.

PUMP VACUUM TEST

CAUTION

DO NOT attempt to start the engine unless the pump has previously been ***primed*** with water. Severe pump damage will occur if pump has not been primed.

To perform the pump vacuum test do the following:

1. Remove the pump fill cap (See Figure 3), and fill the pump with water.
2. Start the engine as outlined in the initial start-up section, and wait for the pump to begin pumping.
3. As shown in Figure 18, place a water hose inside the discharge opening of the pump, and turn on the water. This flow of water into the discharge opening will ***prevent*** the pump from running dry.
4. Place the Pump Vacuum Tester (P/N 7000030) over the pump suction (inlet) opening (See Figure 18) with the vacuum gauge facing upwards. It may be necessary to apply a small amount of water around the rubber seal of the vacuum tester to make a good suction fit.
5. Check and make sure that there are no air leaks between the vacuum tester and the inlet port on the pump. If air leaks are present reseat vacuum tester.
6. Run the pump for a few minutes while monitoring the vacuum gauge. If the gauge indicates a reading between -25 and -20 in. Hg. (inches of mercury) then it can be assumed that the pump is working correctly.

NOTICE

25 in. Hg (inches of mercury) translates into 25 feet of lift at ***sea level.***

7. If the vacuum tester gauge indicates a reading below -20 in. Hg, it can then be assumed that the pump is not functioning correctly, and corrective action needs to be taken.
8. To test the flapper valve, shutdown the engine. The vacuum tester should remain attached to the pump suction inlet port by vacuum. This indicates the pump's flapper valve is seating properly to hold water in the suction hose when the engine is stopped. This prevents backflow and allows for faster priming when the engine is restarted.

ADJUSTING IMPELLER CLEARANCE

1. If it is necessary to replace impeller or volute, be sure clearance between impeller and volute is adjusted
2. The impeller should be as close to the volute as possible without rubbing against it. Clearance is adjusted by adding or removing shims from behind the impeller.
3. Check clearance between impeller and insert by slowly pulling starter rope to turn impeller.

NOTICE

It is important not to remove too many shims or the clearance between the impeller and volute will become ***too wide*** and pump performance will be reduced. Remember as the impeller wear down, additional shims may be required to maintain the clearance between the impeller and insert.

4. Check the impeller every six months for wear, and for clearance between the impeller face and the volute. Also check the shaft seal for wear, as well as the shaft sleeve.

PUMP CLEANING

After pumping water containing large amounts of dirt and debris, perform the following:

1. Remove the drain plug from the pump housing (Figure 3) and drain any water left in the pump.
2. Loosen the two locking hand knobs (turn counterclockwise) and remove clean-out cover.
3. Clean and remove dirt, debris from pump casing. Inspect impeller and volute for wear. Replace any damaged or worn parts.

CAUTION

The impeller may develop sharp edges. Use extreme care when cleaning around the impeller to prevent being cut..

CAUTION

DO NOT RUN PUMP WITHOUT WATER.

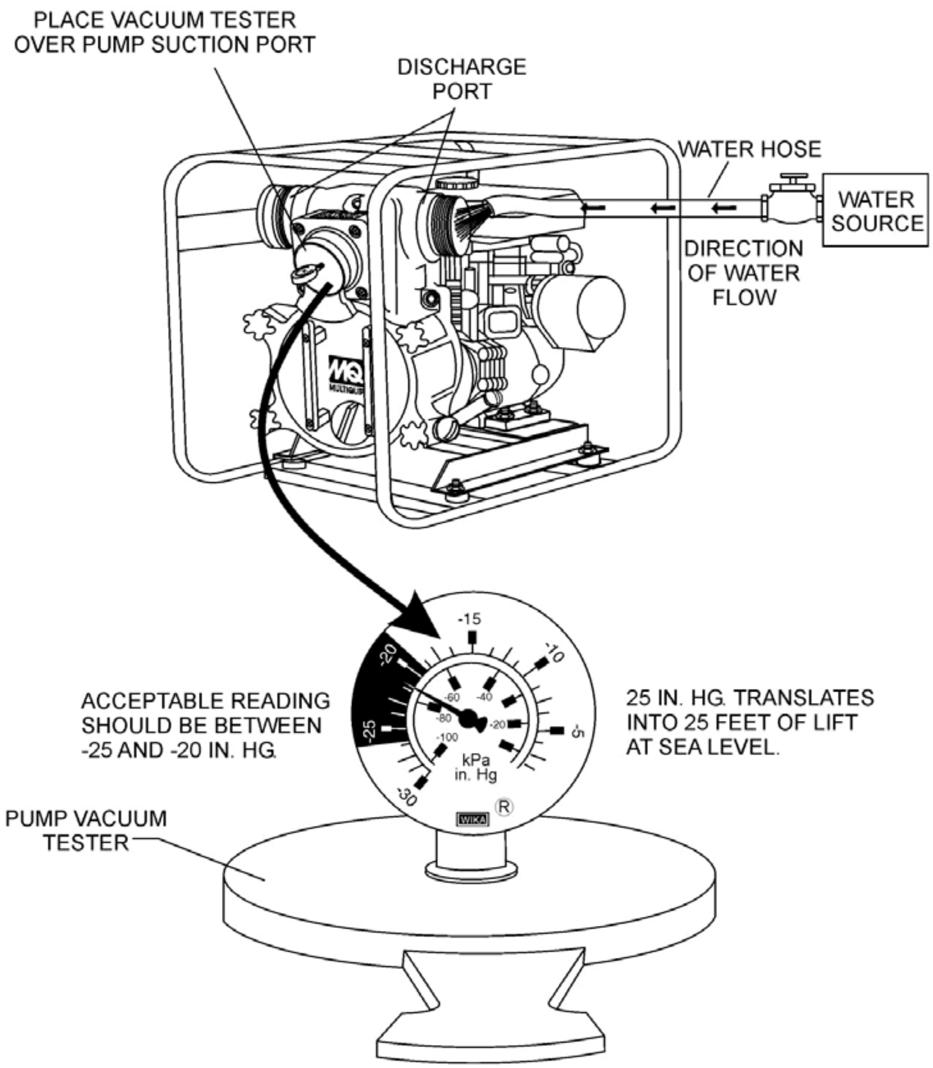


Figure 18. Pump Vacuum Tester

ENGINE MAINTENANCE

Perform engine maintenance procedures as referenced by Table 6 below:

Table 6. Engine Maintenance Schedule

Description (3)	Operation	Before	First Month or 10 hrs	Every 3 Months or 25 hrs	Every 6 Months or 50 hrs	Every Year or 100 hrs	Every 2 Years or 200 hrs
Engine Oil	CHECK	X					
	CHANGE		X				
Air Cleaner	CHECK	X					
	CHANGE			X (1)			
All Nuts and Bolts	Re-tighten If Necessary	X					
Spark Plug	CHECK-CLEAN				X		
	REPLACE						X
Cooling Fins	CHECK				X		
Spark Arrester	CLEAN					X	
Fuel Tank	CLEAN					X	
Fuel Filter	CHECK					X	
Idle Speed	CHECK-ADJUST					X (2)	
Valve Clearance	CHECK-ADJUST						X (2)
Fuel lines	CHECK	Every 2 years (replace if necessary) (2)					

1. Service more frequently when used in **DUSTY** areas.
2. These items should be serviced by your service dealer, unless you have the proper tools and are mechanically proficient. Refer to the HONDA shop Manual for service procedures.
3. For commercial use, log hours of operation to determine proper maintenance intervals.

NOTICE

Refer to manufacturer engine manual for specific servicing instructions.

DAILY

1. Thoroughly remove dirt and oil from the engine and control area. Clean or replace the air cleaner elements as necessary. Check and retighten all fasteners as necessary. Check the spring box and bellows for oil leaks. Repair or replace as needed.

WEEKLY

1. Remove the fuel filter cap and clean the inside of the fuel tank.
2. Remove or clean the filter at the bottom of the tank.
3. Remove and clean the spark plug (See Figure 19), then adjust the spark gap to 0.028~0.031 inch (0.6~0.7 mm). This unit has electronic ignition, which requires no adjustments.

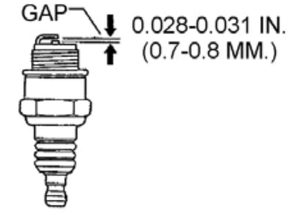


Figure 19. Spark Plug Gap

ENGINE OIL

1. Drain the engine oil when the oil is ***warm*** as shown in Figure 20.
2. Remove the oil drain bolt and sealing washer and allow the oil to drain into a suitable container.
3. Replace engine oil with recommended type oil as listed in Table 5. Engine oil capacity is 1.16 quarts (1.1 liters). **DO NOT** over fill.
4. Install drain bolt with sealing washer and tighten securely.

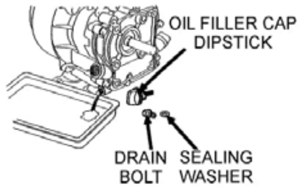


Figure 20. Engine Oil (Draining)

⚠ DANGER

DO NOT use gasoline as a cleaning solvent, because that would create a risk of fire or explosion.

ENGINE AIR CLEANER

1. Remove the air cleaner cover and foam filter element as shown in Figure 21.
2. Tap the paper filter element (See Figure 21) several times on a hard surface to remove dirt, or blow compressed air [not exceeding 30 psi (207 kPa, 2.1 kgf/cm^2)] through the filter element from the air cleaner case side. ***NEVER*** brush off dirt. Brushing will force dirt into the fibers. Replace the paper filter element if it is excessively dirty.
3. Clean foam element in warm, soapy water or non-flammable solvent. Rinse and dry thoroughly. Dip the element in clean engine oil and completely squeeze out the excess oil from the element before installing.

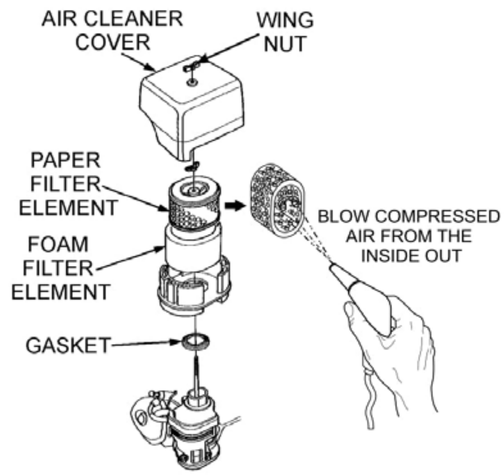


Figure 21. Engine Air Cleaner

SPARK ARRESTER CLEANING

Clean the spark arrester every 6 months or 100 hours.

1. Remove the 4 mm screw (3) from the exhaust deflector, then remove the deflector. See Figure 22.
2. Remove the 5 mm screw (4) from the muffler protector, then remove the muffler protector.
3. Remove the 4 mm screw from the spark arrester, then remove the spark arrester.

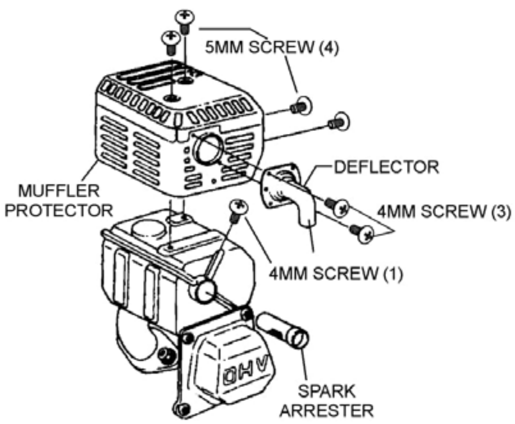


Figure 22. Spark Arrester Removal

4. Carefully remove carbon deposits from the spark arrester screen (Figure 23) with a wire brush.

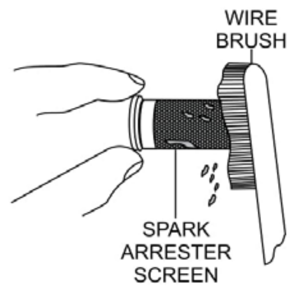


Figure 23. Cleaning The Spark Arrester

5. If the spark arrester is damaged and has breaks or holes, replace with a new one.
6. Reinstall the spark arrester and muffler protector in reverse order of disassembly.

PUMP STORAGE

For storage of the pump for over 30 days, the following is required:

- Drain the fuel tank completely.
- Run the engine until the fuel is completely consumed.
- Completely drain used oil from the engine crankcase and fill with fresh clean oil, then follow the procedures described in the engine manual for engine storage.
- Remove the drain plug from the pump and drain out any water from left in the housing.
- Remove the pump cover and clean inside of pump housing. Coat inside of pump housing with a light film of oil to reduce corrosion. A spray can of oil works well for this application.
- Cover suction and discharge ports with duct tape to prevent any foreign matter from falling into pump.
- Cover pump and engine with plastic covering or equivalent and store in a clean, dry place.
- To protect the water cooled-seals, place one-half pint of lubricating oil (new or used) through the discharge opening on the pump and crank the engine several times. This will prevent excessive corrosion and also keep the mechanical seal lubricated.

TROUBLESHOOTING (ENGINE)

Table 7. Engine Troubleshooting		
Symptom	**Possible Problem**	**Solution**
Difficult to start		
Fuel is available but spark plug will not ignite. (Power available at high tension cable).	Ignition plug being bridge?	Check ignition system.
	Carbon deposit at ignition?	Clean or replace ignition.
	Short circuit due to defective insulators?	Replace insulators.
	Improper spark gap?	Set spark plug gap to the correct gap.
Fuel is available but spark plug will not ignite. (Power **NOT** available at high tension cable).	Short circuit at stop switch?	Check stop switch circuit. Replace stop switch if defective.
	Ignition coil defective?	Replace ignition coil.
Fuel is available and spark plug ignites (compression **normal**).	Muffler clogged with carbon deposits?	Clean or replace muffler.
	Mixed fuel quality is inadequate?	Check fuel to oil mixture.
	Fuel in use inadequate (water, dust)?	Flush fuel system and replace with fresh fuel.
	Air Cleaner clogged?	Clean or replace air cleaner.
Fuel is available and spark plug ignites (compression **low**).	Defective cylinder head gasket?	Tighten cylinder head bolts or replace head gasket.
	Cylinder worn?	Replace cylinder.
	Spark plug loose?	Tighten spark plug.
Operation not satisfactory		
Not enough power available (compression normal, no miss-firing).	Air cleaner clogged?	Clean or replace air cleaner.
	Air in fuel line?	Bleed (remove air) from fuel line.
	Fuel level in carburetor float chamber improper?	Adjust carburetor float.
	Carbon deposits in cylinder?	Clean or replace cylinder.
Not enough power available (compression normal, miss-firing).	Ignition coil defective?	Flush fuel system and replace with fresh fuel.
	Ignition plug often shorts?	Replace ignition wires, clean ignition.
	Fuel in use inadequate (water, dust)?	Flush fuel system and replace with fresh fuel.
Engine overheats.	Excessive carbon deposition in combustion chamber?	Clean or replace crankcase.
	Exhaust or muffler clogged with carbon.	Clean or replace muffler.
	Spark plug heat value incorrect?	Replace spark plug with correct type spark plug.

TROUBLESHOOTING (ENGINE/PUMP)

Table 7. Engine Troubleshooting

Symptom	Possible Problem	Solution
Operation not satisfactory		
Rotational speed fluctuates.	Governor adjustment improper?	Adjust governor to correct lever.
	Governor spring defective?	Clean or replace ignition.
	Fuel flow erratic?	Check fuel line.
	Air taken in through suction line?	Check suction line.
Recoil starter not working properly.	Dust in rotating part?	Clean recoil starter assembly.
	Spring failure?	Replace spiral spring.

Table 8. Pump Troubleshooting

Symptom	Possible Problem	Solution
Pump does not take on water.	Not enough priming water in the housing?	Add water.
	Engine speed too low?	Increase throttle.
	Strainer plugged?	Clean strainer.
	Suction hose damaged?	Replace or repair hose, and clamps.
	Air leak at suction port?	Check that fittings are tight and properly sealed.
	Pump is located too high above water line?	Move pump closer to water.
	Debris collecting in pump housing?	Clean pump housing.
	Too much distance between impeller and volute.	Adjust clearance by adding shims or replace impeller. Min. .006" - Max. .020".
	Water leaking out weep hole between pump and engine?	Check condition of mechanical seal and gaskets, between pump end and engine housing.
Pump takes in water, little or no discharge.	Engine speed too low?	Increase throttle speed.
	Suction strainer partially plugged?	Clean strainer.
	Impeller/Volute worn?	Adjust clearance by adding shims or replace impeller/volute.
Suction hose leaks at inlet.	Fittings/clamps are not sealed properly?	Tighten, replace or add clamp. (Keep extra seals on pump).
	Hose diameter is too large?	Use smaller diameter hose or replace hose.
Discharge does not stay on coupling.	Pressure too high?	Check pressure, add additional clamp.
	Hose kinked or end blocked?	Check hose.
Impeller does not turn: pump is hard to start.	Impeller jammed or blocked?	Open pump cover and clean dirt and debris from inside housing.
	Impeller and volute binding?	Adjust clearance by removing shim from behind impeller.
	Defective engine?	See Engine Owner's Manual.

EXPLANATION OF CODE IN REMARKS COLUMN

The following section explains the different symbols and remarks used in the Parts section of this manual. Use the help numbers found on the back page of the manual if there are any questions.

> **NOTICE**
>
> The contents and part numbers listed in the parts section are subject to change **without notice**. Multiquip does not guarantee the availability of the parts listed.

SAMPLE PARTS LIST

NO.	PART NO.	PART NAME	QTY.	REMARKS
1	12345	BOLT	1	INCLUDES ITEMS W/%
2%		WASHER, 1/4 IN.		NOT SOLD SEPARATELY
2%	12347	WASHER, 3/8 IN.	1	MQ-45T ONLY
3	12348	HOSE	A/R	MAKE LOCALLY
4	12349	BEARING	1	S/N 2345B AND ABOVE

NO. Column

Unique Symbols — All items with same unique symbol (@, #, +, %, or >) in the number column belong to the same assembly or kit, which is indicated by a note in the "Remarks" column.

Duplicate Item Numbers — Duplicate numbers indicate multiple part numbers, which are in effect for the same general item, such as different size saw blade guards in use or a part that has been updated on newer versions of the same machine.

> **NOTICE**
>
> When ordering a part that has more than one item number listed, check the remarks column for help in determining the proper part to order.

PART NO. Column

Numbers Used — Part numbers can be indicated by a number, a blank entry, or TBD.

TBD (To Be Determined) is generally used to show a part that has not been assigned a formal part number at the time of publication.

A blank entry generally indicates that the item is not sold separately or is not sold by Multiquip. Other entries will be clarified in the "Remarks" Column.

QTY. Column

Numbers Used — Item quantity can be indicated by a number, a blank entry, or A/R.

A/R (As Required) is generally used for hoses or other parts that are sold in bulk and cut to length.

A blank entry generally indicates that the item is not sold separately. Other entries will be clarified in the "Remarks" Column.

REMARKS Column

Some of the most common notes found in the "Remarks" Column are listed below. Other additional notes needed to describe the item can also be shown.

Assembly/Kit — All items on the parts list with the same unique symbol will be included when this item is purchased.

Indicated by:

"INCLUDES ITEMS W/(unique symbol)"

Serial Number Break — Used to list an effective serial number range where a particular part is used.

Indicated by:

"S/N XXXXX AND BELOW"
"S/N XXXX AND ABOVE"
"S/N XXXX TO S/N XXX"

Specific Model Number Use — Indicates that the part is used only with the specific model number or model number variant listed. It can also be used to show a part is NOT used on a specific model or model number variant.

Indicated by:

"XXXXX ONLY"
"NOT USED ON XXXX"

"Make/Obtain Locally" — Indicates that the part can be purchased at any hardware shop or made out of available items. Examples include battery cables, shims, and certain washers and nuts.

"Not Sold Separately" — Indicates that an item cannot be purchased as a separate item and is either part of an assembly/kit that can be purchased, or is not available for sale through Multiquip.

QP4TH TRASH PUMP WITH HONDA GX340K1QA2/GX340U1QA2/GX240UT2QA2 ENGINES

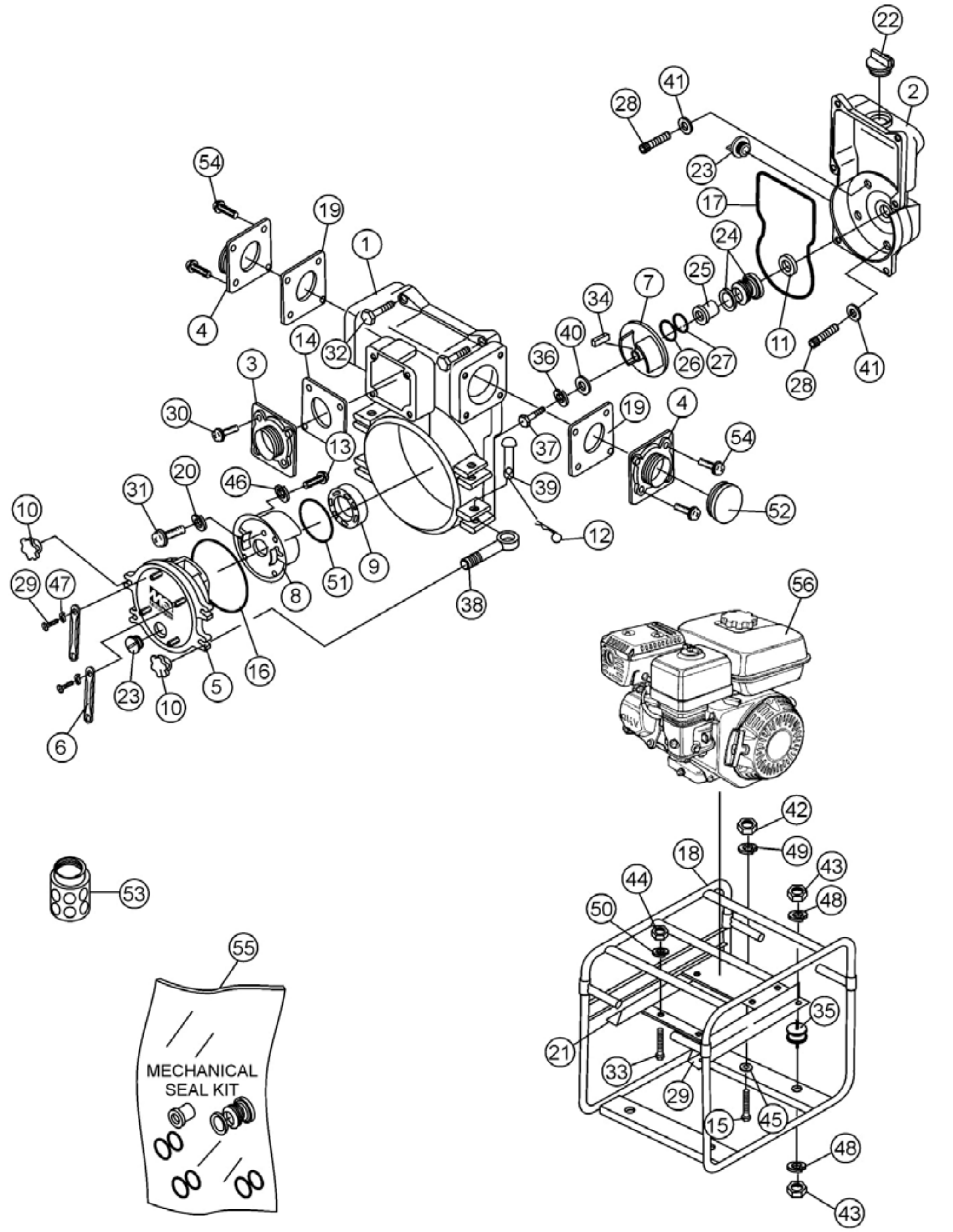
1 to 3 units

Qty.	P/N	Description
1	1466040030	IMPELLER
1	0811885433	MECHANICAL SEAL SLEEVE
2	0803442930	MECHANICAL SEAL
1	1401350350	CHECK VALVE
4	0631211159	DRAIN CAP
4	4660002200002	DRAIN COVER KNOB
1	0742214100	STEEL STRAINER
5	17210ZE3505	ELEMENT, AIR CLEANER, GX340K1QA2
5	17210ZE3010	ELEMENT, AIR CLEANER, GX340U1QA2/GX240UT2QA2
5	9807956846	SPARK PLUG, GX340K1QA2
5	9807955846	SPARK PLUG, GX340U1QA2/GX240UT2QA2
1	17620ZH7023	CAP, FUEL TANK, GX340K1QA2
1	17620Z4H020	CAP, FUEL TANK , GX340U1QA2/GX240UT2QA2
2	17672ZE2W01	FILTER, FUEL,GX340K1QA2
2	17672Z4H020	FILTER, FUEL, GX340U1QA2/GX240UT2QA2
1	28462ZE3W01	ROPE, RECOIL STARTER

NOTICE

Part numbers on this Suggested Spare Parts list may supersede/replace the part numbers shown in the following parts lists.

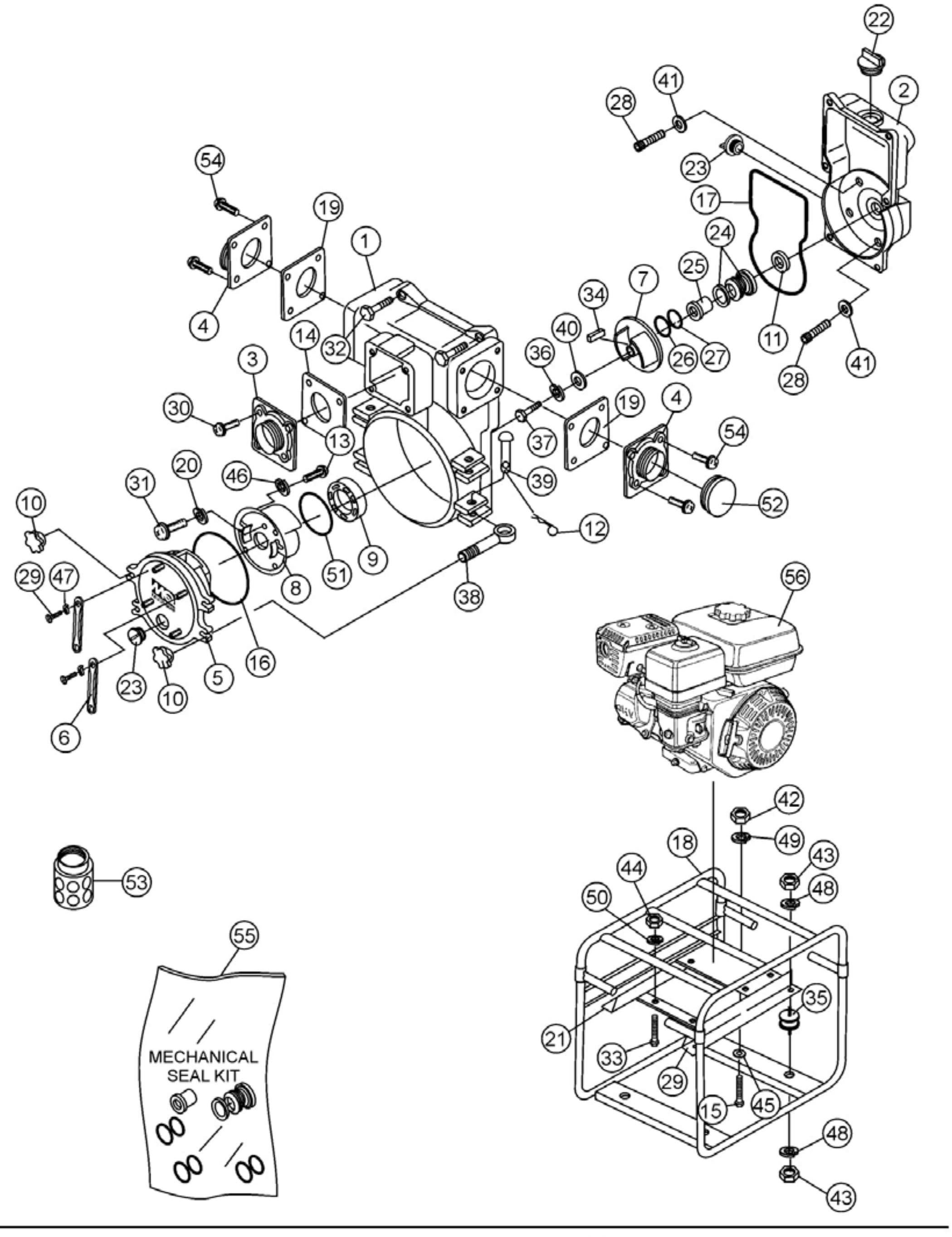
PUMP ASSEMBLY



PUMP ASSEMBLY

NO.	PART NO.	PART NAME	QTY.	REMARKS
1	14660600100002	CASING	1	
2	14660600200002	CASING COVER	1	OCTOBER 2007 AND BELOW
2	14660600210002	CASING COVER	1	NOVEMBER 2007 AND ABOVE
3	14660000900002	SUCTION COVER, NPT 4"	1	
4	14660000900002	DELIVERY COVER, NPT 4"	2	
5	14660601700002	DRAIN COVER	1	
6	12471002500002	DRAIN COVER SET HANDLE	2	
7	1466040031ASSY	IMPELLER ASSEMBLY	1	
8	1466000130	VOLUTE CASING	1	
9	1466040700	WEAR PLATE	1	
10	14660002200002	DRAIN SET HANDLE	4	
11*	0482200240	O-RING (MECHANICAL SEAL SLEEVE)	2	
12	0641400430	SPLIT PIN	4	
13	0131190820	CAP SCREW, M8X20 (VOLUTE CASING)	3	
14	1401350350	CHECK VALVE	1	
15	0105051045	BOLT, M10X45 (ENGINE)	4	
16*	0483602750	O-RING (DRAIN COVER)	1	
17	1466330460	O-RING (CASING)	1	
18	1466214010P002	BASE	1	
19	1401330360	DELIVERY COVER PACKING	2	
20	0451290080	WASHER, LOCK M8 (WEAR PLATE)	3	
21	14662140210014	ENGINE BASE	1	REPLACES 14662140200014
22	0631211159	FLOODING CAP, PF1 1/2"	1	
23	0631211159	DRAIN CAP, PF1 1/2"	2	
24*	0803442930	MECHANICAL SEAL	1	
25*	0811885433	MECHANICAL SEAL SLEEVE	1	
26*	0852834525	ADJUST LINER, F45XF25.4 T0.3	1	
27*	0852854525	ADJUST LINER, F45XF25.4 T0.5	1	
28	0131290665	CAP SCREW, 3/8-16UNC×65 (CASING CVR SET BOLT)	4	
29	0141050825	SCREW, M8×25 (DRAIN CUVER SET HANDLE)	4	
30	0131151225	CAP SCREW, M12×25 (SUCTION COVER	4	
31	0131190820	CAP SCREW, M8×20 (WEAR PLATE)	3	
32	0131151230	CAP SCREW, M12×30 (CASING)	6	
33	0105051040	BOLT, M10×40 (PUMP)	2	
34	0520040440	KEY, 6.3×40	1	
35	0723302546	CUSHION RUBBER	4	
36	0458220071	WASHER, SEAL (IMPELLER)	1	
37	0107090650	BOLT, 3/8-24UNFX50 (IMPELLER)	1	
38	1466200270	HINGE BOLT, M10×65	4	
39	1466220280	HINGE PIN	4	

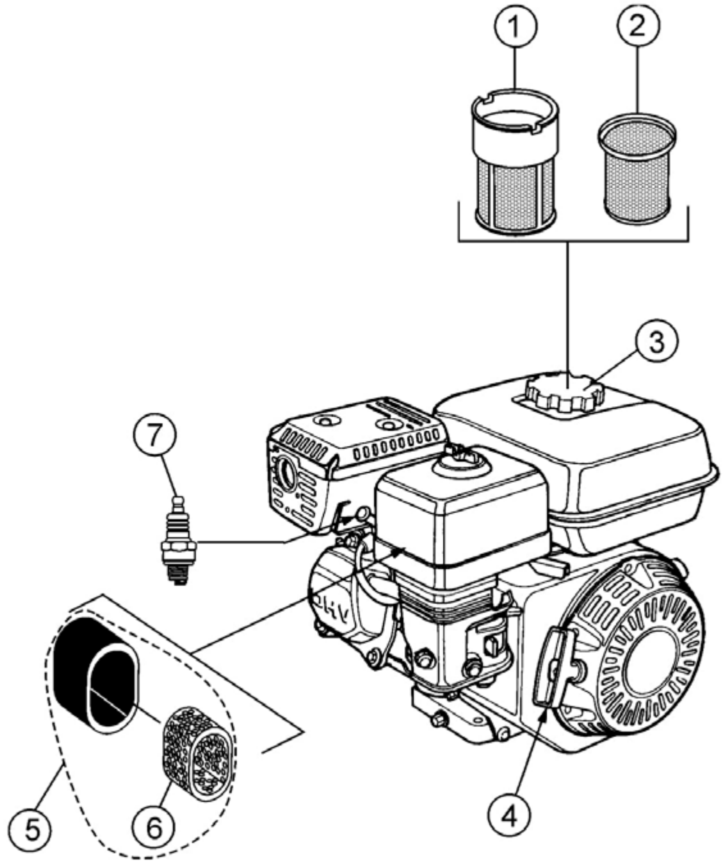
PUMP ASSEMBLY



PUMP ASSEMBLY

NO.	PART NO.	PART NAME	QTY.	REMARKS
40	1466251241	IMPELLER WASHER, 42 X 9.8 X T6.0	1	REPLACES 43342012400011
41	0458220071	SEAL WASHER, 3/8" (CASING COVER)	4	
42	0205450100	NUT, M10 (ENGINE)	4	
43	0205450100	NUT, M10 (CUSHION RUBBER)	8	
44	0205450100	NUT, M10 (PUMP)	4	
45	0401450100	WASHER, M10 (ENGINE)	4	
46	0451290080	WASHER, SPRING M8 (VOLUTE CASING)	3	
47	0451250080	WASHER, SPRING M8 (DRAIN COVER SET HANDLE)	4	
48	0451250100	WASHER, SPRING M10 (CUSHION RUBBER)	8	
49	0451250100	WASHER, SPRING M10 (ENGINE)	4	
50	0451250100	WASHER, SPRING M10 (PUMP)	2	
51*	0481572500	O-RING (VOLUTE CASING)	1	
52	1466108050	CAP	1	
53	0742214100	STRAINER	1	
54	0131151220	CAP SCREW, M12×20 (DELIVERY COVER)	8	
55	KIT4TH	KIT, MECHANICAL SEAL, SLEEVE, O-RINGS	1	INCLUDES ITEMS W/ *
56	GX340K1QA2	ENGINE, HONDA 10.7 HP	1	S/N 4TH-0249 AND BELOW
56	GX340U1QA2	ENGINE, HONDA 10.7 HP	1	S/N 4TH-0250 TO 4TH-3304
56	GX340UT2QA2	ENGINE, HONDA 10.7 HP	1	S/N 4TH-3305 AND ABOVE

ENGINE SERVICE PARTS



ENGINE SERVICE PARTS

NO.	PART NO.	PART NAME	QTY.	REMARKS
1	17672ZE2W01	FILTER, FUEL	1	GX340K1QA2
2	17672Z4H020	FILTER, FUEL	1	GX340U1QA2/GX240UT2QA2
3	17620ZH7023	CAP, FUEL TANK	1	GX340K1QA2
3	17620Z4H020	CAP, FUEL TANK	1	GX340U1QA2/GX240UT2QA2
4	28462ZE3W01	ROPE, RECOIL STARTER	1	
5	17210ZE3505	ELEMENT, AIR CLEANER	1	GX340K1QA2 INCLUDES ITEM W/ #
5	17210ZE3010	ELEMENT, AIR CLEANER	1	GX340U1QA2/GX240UT2QA2 INCLUDES ITEM W/ #
6#	17218ZE1507	FILTER, OUTER	1	
7	9807956846	SPARK PLUG	1	GX340K1QA2
7	9807955846	SPARK PLUG	1	GX340U1QA2/GX240UT2QA2

TERMS AND CONDITIONS OF SALE — PARTS

PAYMENT TERMS

Terms of payment for parts are net 30 days.

FREIGHT POLICY

All parts orders will be shipped collect or prepaid with the charges added to the invoice. All shipments are F.O.B. point of origin. Multiquip's responsibility ceases when a signed manifest has been obtained from the carrier, and any claim for shortage or damage must be settled between the consignee and the carrier.

MINIMUM ORDER

The minimum charge for orders from Multiquip is $15.00 net. Customers will be asked for instructions regarding handling of orders not meeting this requirement.

RETURNED GOODS POLICY

Return shipments will be accepted and credit will be allowed, subject to the following provisions:

1. A Returned Material Authorization must be approved by Multiquip prior to shipment.
2. To obtain a Return Material Authorization, a list must be provided to Multiquip Parts Sales that defines item numbers, quantities, and descriptions of the items to be returned.
   a. The parts numbers and descriptions must match the current parts price list.
   b. The list must be typed or computer generated.
   c. The list must state the reason(s) for the return.
   d. The list must reference the sales order(s) or invoice(s) under which the items were originally purchased.
   e. The list must include the name and phone number of the person requesting the RMA.
3. A copy of the Return Material Authorization must accompany the return shipment.
4. Freight is at the sender's expense. All parts must be returned freight prepaid to Multiquip's designated receiving point.
5. Parts must be in new and resalable condition, in the original Multiquip package (if any), and with Multiquip part numbers clearly marked.
6. The following items are not returnable:
   a. Obsolete parts. (If an item is in the price book and shows as being replaced by another item, it is obsolete.)
   b. Any parts with a limited shelf life (such as gaskets, seals, "O" rings, and other rubber parts) that were purchased more than six months prior to the return date.
   c. Any line item with an extended dealer net price of less than $5.00.
   d. Special order items.
   e. Electrical components.
   f. Paint, chemicals, and lubricants.
   g. Decals and paper products.
   h. Items purchased in kits.
7. The sender will be notified of any material received that is not acceptable.
8. Such material will be held for five working days from notification, pending instructions. If a reply is not received within five days, the material will be returned to the sender at his expense.
9. Credit on returned parts will be issued at dealer net price at time of the original purchase, less a 15% restocking charge.
10. In cases where an item is accepted, for which the original purchase document can not be determined, the price will be based on the list price that was effective twelve months prior to the RMA date.
11. Credit issued will be applied to future purchases only.

PRICING AND REBATES

Prices are subject to change without prior notice. Price changes are effective on a specific date and all orders received on or after that date will be billed at the revised price. Rebates for price declines and added charges for price increases will not be made for stock on hand at the time of any price change.

Multiquip reserves the right to quote and sell direct to Government agencies, and to Original Equipment Manufacturer accounts who use our products as integral parts of their own products.

SPECIAL EXPEDITING SERVICE

A $35.00 surcharge will be added to the invoice for special handling including bus shipments, insured parcel post or in cases where Multiquip must personally deliver the parts to the carrier.

LIMITATIONS OF SELLER'S LIABILITY

Multiquip shall not be liable hereunder for damages in excess of the purchase price of the item with respect to which damages are claimed, and in no event shall Multiquip be liable for loss of profit or good will or for any other special, consequential or incidental damages.

LIMITATION OF WARRANTIES

No warranties, express or implied, are made in connection with the sale of parts or trade accessories nor as to any engine not manufactured by Multiquip. Such warranties made in connection with the sale of new, complete units are made exclusively by a statement of warranty packaged with such units, and Multiquip neither assumes nor authorizes any person to assume for it any other obligation or liability whatever in connection with the sale of its products. Apart from such written statement of warranty, there are no warranties, express, implied or statutory, which extend beyond the description of the products on the face hereof.

Effective: February 22, 2006

NOTES

OPERATION AND PARTS MANUAL

HERE'S HOW TO GET HELP

PLEASE HAVE THE MODEL AND SERIAL NUMBER ON-HAND WHEN CALLING

UNITED STATES

Multiquip Corporate Office

18910 Wilmington Ave.
Carson, CA 90746
Contact: mq@multiquip.com
Tel. (800) 421-1244
Fax (310) 537-3927

MQ Parts Department

800-427-1244
310-537-3700
Fax: 800-672-7877
Fax: 310-637-3284

Service Department

800-421-1244
310-537-3700
Fax: 310-537-4259

Warranty Department

800-421-1244
310-537-3700
Fax: 310-943-2249

Technical Assistance

800-478-1244
Fax: 310-943-2238

CANADA

Multiquip

4110 Industriel Boul.
Laval, Quebec, Canada H7L 6V3
Contact: jmartin@multiquip.com
Tel: (450) 625-2244
Tel: (877) 963-4411
Fax: (450) 625-8664

UNITED KINGDOM

Multiquip (UK) Limited Head Office

Unit 2, Northpoint Industrial Estate,
Globe Lane,
Dukinfield, Cheshire SK16 4UJ
Contact: sales@multiquip.co.uk
Tel: 0161 339 2223
Fax: 0161 339 3226

This manual MUST accompany the equipment at all times. This manual is considered a permanent part of the equipment and should remain with the unit if resold.

The information and specifications included in this publication were in effect at the time of approval for printing. Illustrations, descriptions, references and technical data contained in this manual are for guidance only and may not be considered as binding. Multiquip Inc. reserves the right to discontinue or change specifications, design or the information published in this publication at any time without notice and without incurring any obligations.

Your Local Dealer is:

MULTIQUIP

APPENDIX N: AIR COMPRESSOR ANALYSIS

File:C:\Users\melab2\Downloads\AirCompressorCalc.EES 2/9/2017 2:20:02 PM Page 1
EES Ver. 10.096: #0552: for use only by students and faculty, Mechanical Engineering, Dept. Cal Poly State University

```
"Air Compressor Analysis"

D=6 [in]*convert(in,ft)                         "Diameter of Main"
A=((pi/4)*D^2)/2                                "Cross-sectional Area of Main"
V=5 [ft/s]*60                                   "Velocity of air is same as velocity of fluid initially; multiply by 60 to
get per minute"
Q=A*V                                           "Flowrate of air initially"

"We need a compressor that can deliver at least this flowrate in order to not empty this tank if running constantly"

Volume_Tank=5 [gal]*convert(gal,ft^3)           "Assume 5 gallon tank"

rho_AirCompressor=density(Air,T=70,P=130)       "Assume compressor conditions"
rho_AirOut=density(Air,T=68,P=80)               "Assume conditions less than at the compressor"

"Mass flow rate balance"

"Finding the volumetric flow at the compressor"
rho_AirCompressor * VolumetricFlow_compressor = rho_AirOut * Q

"Finding time until tank has 0 psi of air if below operating point of SCFM"
VolumetricFlow_compressor = Volume_Tank / Time_FullTank*convert(min,s)
```

SOLUTION

Unit Settings: Eng F psia mass deg

$A = 0.09817$ [ft^2]

$D = 0.5$ [ft]

$Q = 29.45$ [ft^3/min]

$\rho_{AirCompressor} = 0.6625$ [lbm/ft^3]

$\rho_{AirOut} = 0.4092$ [lbm/ft^3]

$Time_{FullTank} = 2.204$ [sec]

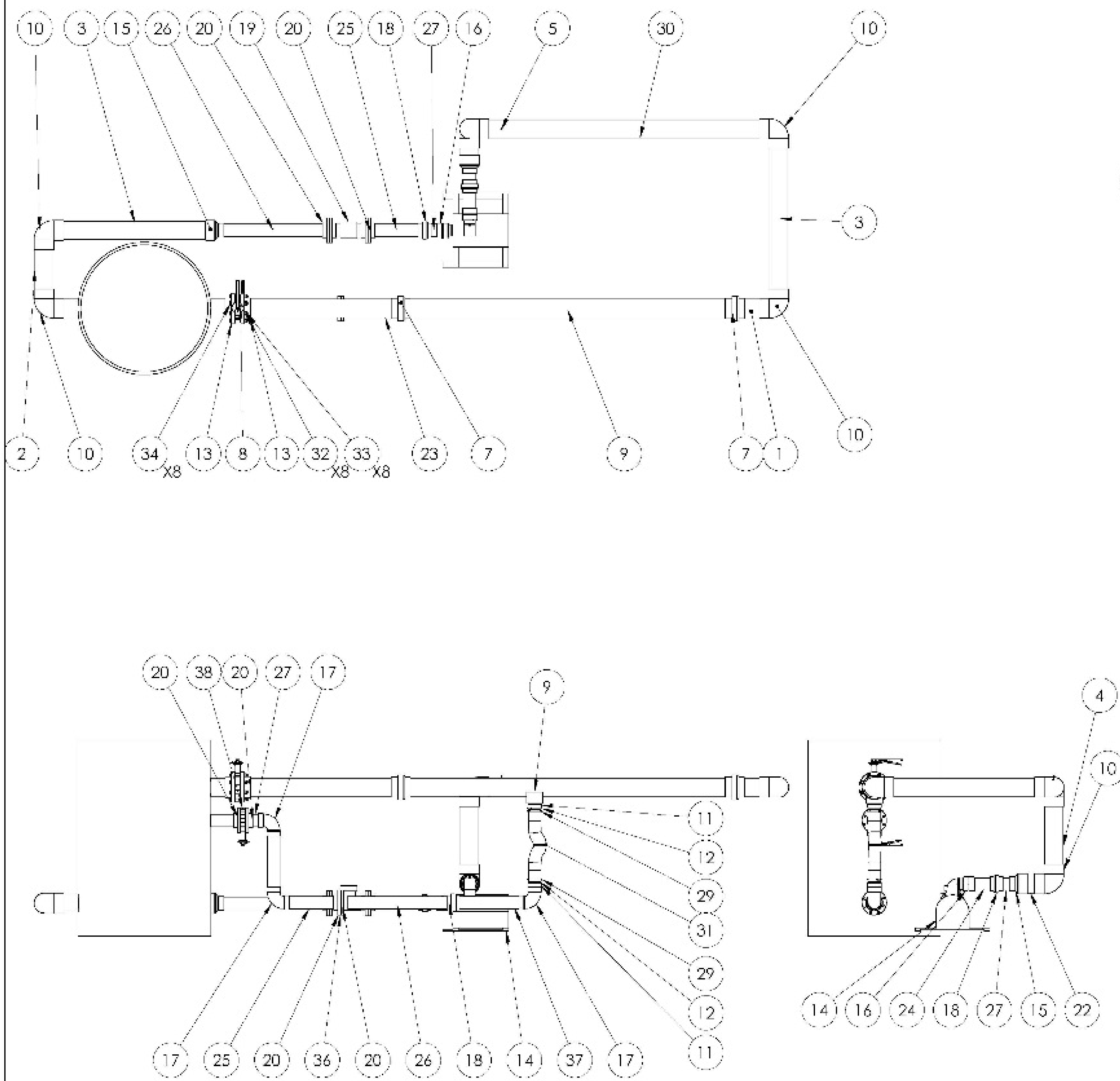
$V = 300$ [ft/min]

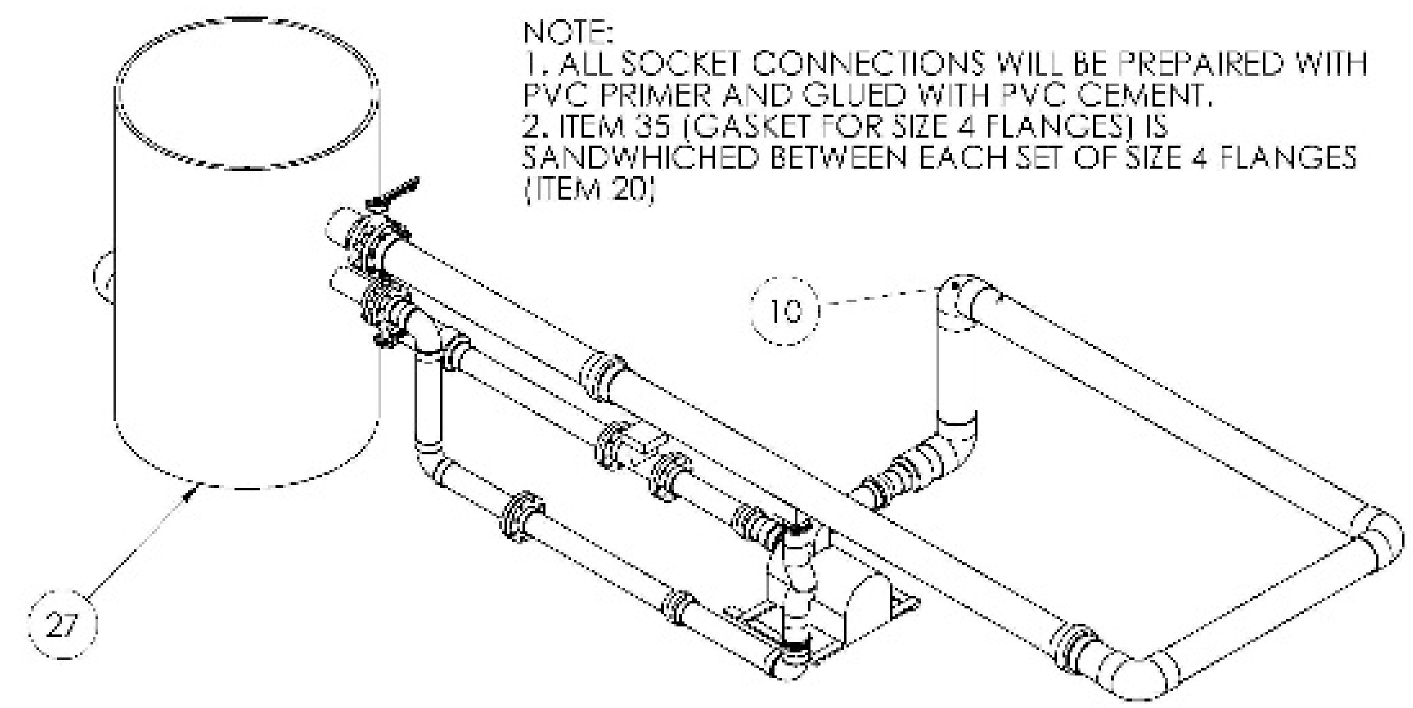
$VolumetricFlow_{compressor} = 18.19$ [ft^3/min]

$Volume_{Tank} = 0.6684$ [ft^3]

3 potential unit problems were detected.

APPENDIX O: DESIGN ASSEMBLY WITH BILL OF MATERIALS (DRAWING NO. A1)





NOTE:
1. ALL SOCKET CONNECTIONS WILL BE PREPAIRED WITH PVC PRIMER AND GLUED WITH PVC CEMENT.
2. ITEM 35 (GASKET FOR SIZE 4 FLANGES) IS SANDWHICHED BETWEEN EACH SET OF SIZE 4 FLANGES (ITEM 20)

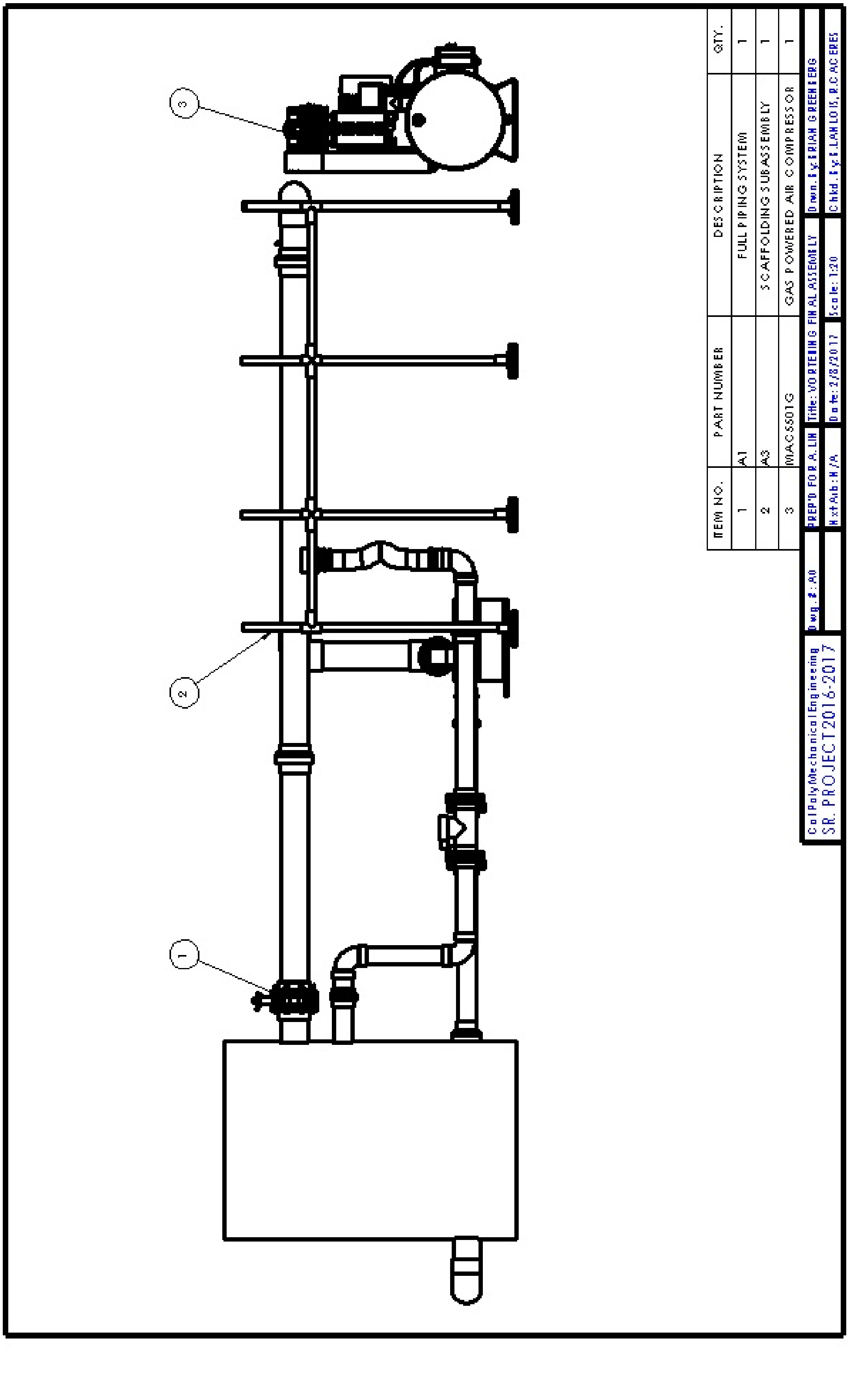
ITEM NO.	PART NUMBER	DESCRIPTION	MATERIAL	QTY.
1	PIPE6IN-12.00	12" LONG SIZE 6 SCHEDULE 40 PIPE	WHITE PVC	1
2	PIPE6IN-21.27	21.27" LONG SIZE 6 SCHEDULE 40 PIPE	WHITE PVC	1
3	PIPE6IN-58.00	58" LONG SIZE 6 SCHEDULE 40 PIPE	WHITE PVC	2
4	PIPE6IN-27.59	27.59" SIZE 6 SCHEDULE 40 PIPE	WHITE PVC	1
5	6534K46	AIR HOSE COUPLING 1/4 NPTF TO Q.D	ZINC PLATED STEEL	1
6	M1-TANK	MODIFIED WATER TANK	PLASTIC	1
7	4880K311	SIZE 4 UNTHREADED PVC UNION	WHITE PVC	2
8	5158K562	6" BUTTERFLY VALVE	DUCTILE IRON	1
9	A2-TESTSEC	CLEAR TEST SECTION ASSEMBLY	-	1
10	4880K101	SIZE 6 UNTHREADED PVC ELBOW	WHITE PVC	6
11	2389K95	4" SOCKET MALE TO NPT FEMALE	WHITE PVC	2
12	9431K22	4" NPT MALE TO 4" ID HOSE BARB	BRASS	2
13	4881K221	SIZE 6 SCHDL 80 FLANGE	GREY PVC	2
14	DuroMax XP904WP	9HP GAS POWERED TRASH PUMP 4" FITTINGS	-	1
15	4880K688	SIZE 6 TO SIZE 4 PVC REDUCER	WHITE PVC	2
16	4880K88	SIZE 4 SOCKET FEMALE TO 4" NPT FEMALE	WHITE PVC	2
17	2389K31	SIZE 4 ELBOW	WHITE PVC	3
18	4880K309	SIZE 4 PVC UNION	WHITE PVC	3
19	FTB740	600 GPM max 4" turbine flowmeter	PVC BODY	1
20	4881K219	SIZE 4 FLANGE SCHDL 80	GREY PVC	6
21	HOSE4IN	4" ID RUBBER HOSE	GUM RUBBER	1
22	PIPE6IN-6.00	6" LONG SIZE 6 PVC PIPE	WHITE PVC	3
23	PIPE6IN-54.00	54" LENGTH OF SIZE 6 SCHEDULE 40 PIPE	WHITE PVC	1
24	PIPE4IN-11.50	11.5" LENGTH OF SIZE 4 SCHEDULE 40 PIPE	WHITE PVC	2
25	PIPE4IN-20.00	20" LENGTH OF SIZE 4 SCHEDULE 40 PIPE	WHITE PVC	2
26	PIPE4IN-40.00	40" LENGTH OF SIZE 4 SCHEDULE 40 PIPE	WHITE PVC	2
27	PIPE4IN-6.00	6" LENGTH OF SIZE 4 SCHEDULE 40 PIPE	WHITE PVC	3
28	PIPE4IN-22.00	22" LENGTH OF SIZE 4 SCHEDULE 40 PIPE	WHITE PVC	1
29	45945K19	WORM DRIVE HOSE CLAMP 3.5-5"	STAINLESS STEEL	2
30	M2-AIRIN	PIPE TAPPED FOR AIR INLET	WHITE PVC	1
31	HOSE4IN	4" ID FLEXIBLE HOSE	GUM RUBBER	1
32	78077	3/4" STAINLESS LOCK WASHER	STAINLESS STEEL	8
33	70717	3/4-10 STAINLESS HEX NUT	STAINLESS STEEL	8
34	14375	3/4-10X6" GRADE 8 HEX CAP SCREW	STEEL	8
35	9473K621	GASKET FOR SIZE 4 PIPE FLANGE	VITON® RUBBER	2
36	ORIFACE PLATE	3" ID ORIFACE PLATE	STEEL	1
37	PIPE4IN-25.00	25" LENGTH OF SIZE 4 SCHEDULE 40 PIPE	WHITE PVC	1
38	5158K542	4" BUTTERFLY VALVE	DUCTILE IRON	1

Cal Poly Mechanical Engineering	For: A. LIN	DIABLO CANYON	Title: VORTEX ING RIG ASSEMBLY	Drwn. By: BRIAN GREENBERG
SR. PROJECT 2016-2017	Dwg. #: A1	Nxt Asb: N/A	Date: 2/1/2017 · Scale: 1:32	Chkd. By: B. LANGLOIS, R. CACERES

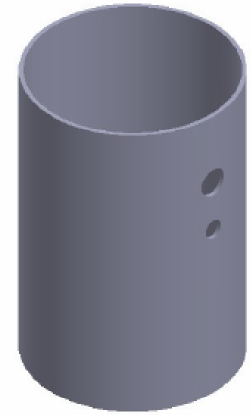
APPENDIX P: DETAIL PART DRAWING

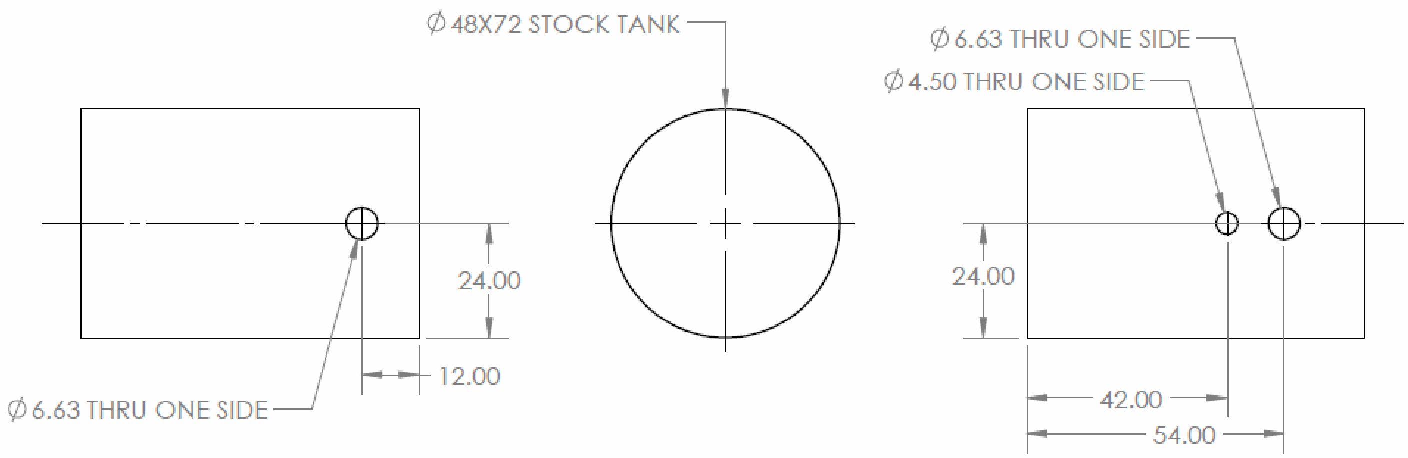
A0. Overall Assembly

- M1. Modified Plastic Tank
- M2. Tapped Pipe for Air Inlet
- HOSE4IN. 4” Flexible Hose for Branch
- PIPE4IN-XX.XX. Various Lengths of 4” Pipe
- PIPE6IN-XX.XX Various Lengths of 6” Pipe
- A2. Test Section
  - TS-1. Test Section Main Section
  - TS-2. Block to Mount Branch on Main
- A3. Scaffolding


1
2
3
ITEM NO.
PART NUMBER
DESCRIPTION
QTY.
1 A1 FULL PIPING SYSTEM 1
2 A3 SCAFFOLDING SUBASSEMBLY 1
3 MAC5501G GAS POWERED AIR COMPRESSOR 1
Cal Poly Mechanical Engineering
SR. PROJECT 2016-2017
Dwg. #: A0
PREP'D FOR: R.A. LIN
Title: VORTEXING FINAL ASSEMBLY
Drwn. By: BRIAN GREENBERG
Nxt Asb: N/A
Date: 2/8/2017
Scale: 1:20
Chkd. By: E. LANLOIS, R. CACERES

NOTES:
1. MATERIAL: PLASTIC TANK ON SITE
2. ALL DIMENSIONS IN INCHES
3. TOLERANCES X.XX = ±1/16
4. ALL HOLES ARE THROUGH ONE SIDE ONLY





Cal Poly Mechanical Engineering	Dwg. #: M1-TANK	PREP'D FOR A. LIN	Title: MODIFIED PLASTIC TANK	Drwn. By: BRIAN GREENBERG
SR. PROJECT - 2016-2017		Nxt Asb: A1	Date: 2/2/2017 / Scale: 1:32	Chkd. By: B. LANGLOIS, R. CACERES

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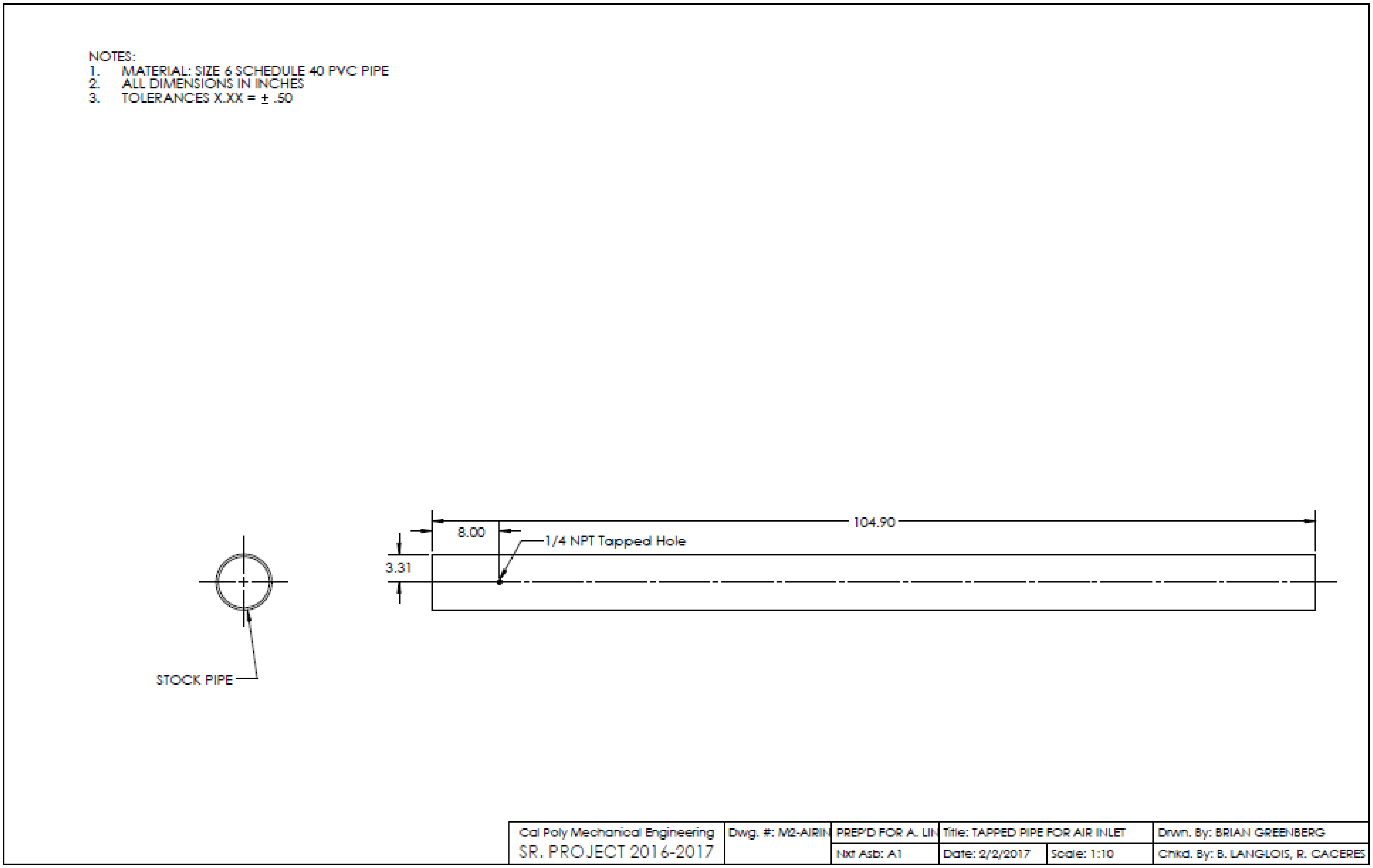
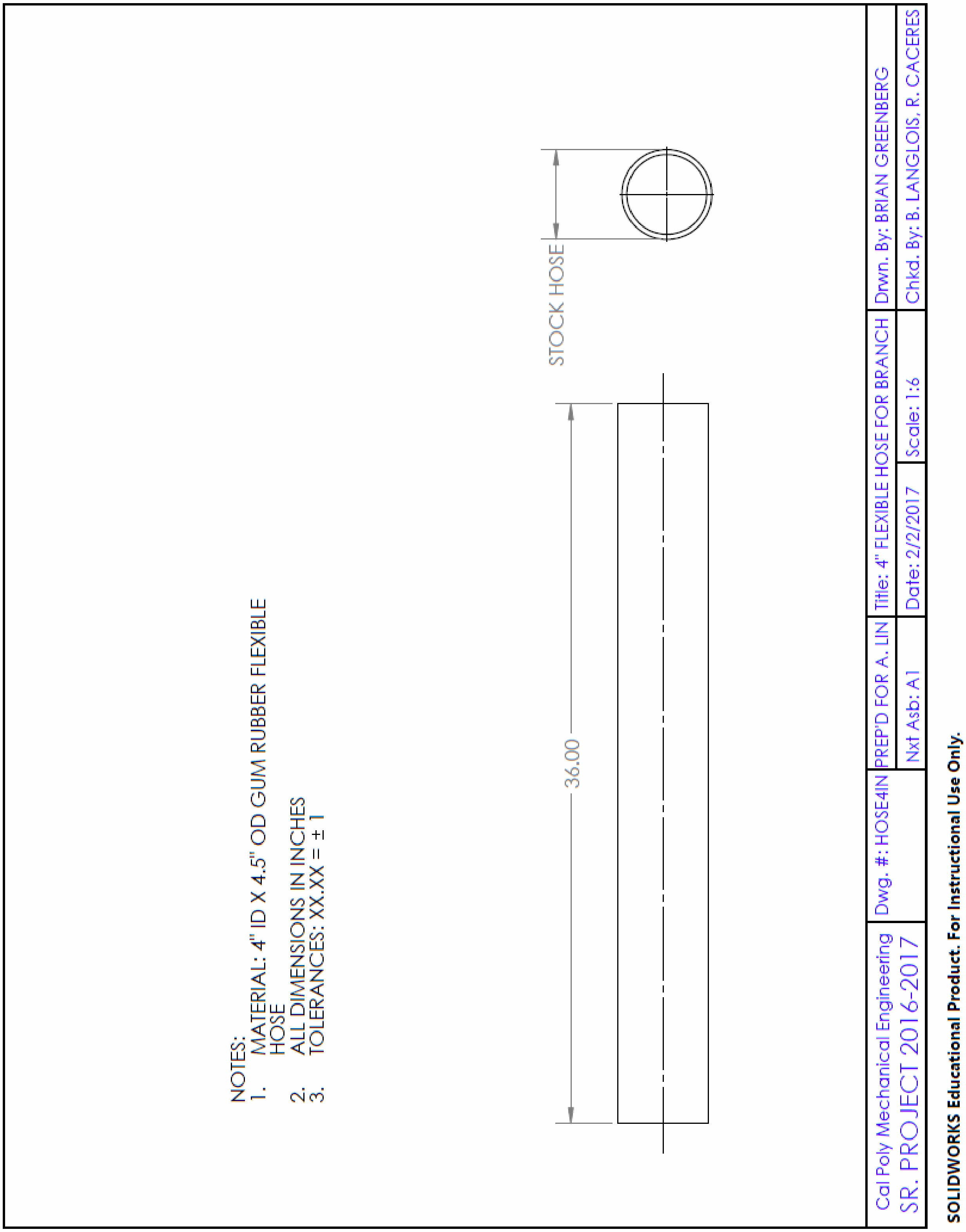

NOTES:
1. MATERIAL: SIZE 6 SCHEDULE 40 PVC PIPE
2. ALL DIMENSIONS IN INCHES
3. TOLERANCES X.XX = ± .50
104.90
8.00
1/4 NPT Tapped Hole
3.31
STOCK PIPE
Cal Poly Mechanical Engineering
SR. PROJECT 2016-2017
Dwg. #: M2-AIRIN
PREP'D FOR A. LIN
Nxt Asb: A1
Title: TAPPED PIPE FOR AIR INLET
Date: 2/2/2017
Scale: 1:10
Drwn. By: BRIAN GREENBERG
Chkd. By: B. LANGLOIS, R. CACERES


NOTES:
1. MATERIAL: 4" ID X 4.5" OD GUM RUBBER FLEXIBLE HOSE
2. ALL DIMENSIONS IN INCHES
3. TOLERANCES: XX.XX = ± 1
36.00
STOCK HOSE
Cal Poly Mechanical Engineering
SR. PROJECT 2016-2017
Dwg. #: HOSE4IN
PREP'D FOR A. LIN
Nxt Asb: A1
Title: 4" FLEXIBLE HOSE FOR BRANCH
Date: 2/2/2017
Scale: 1:6
Drwn. By: BRIAN GREENBERG
Chkd. By: B. LANGLOIS, R. CACERES
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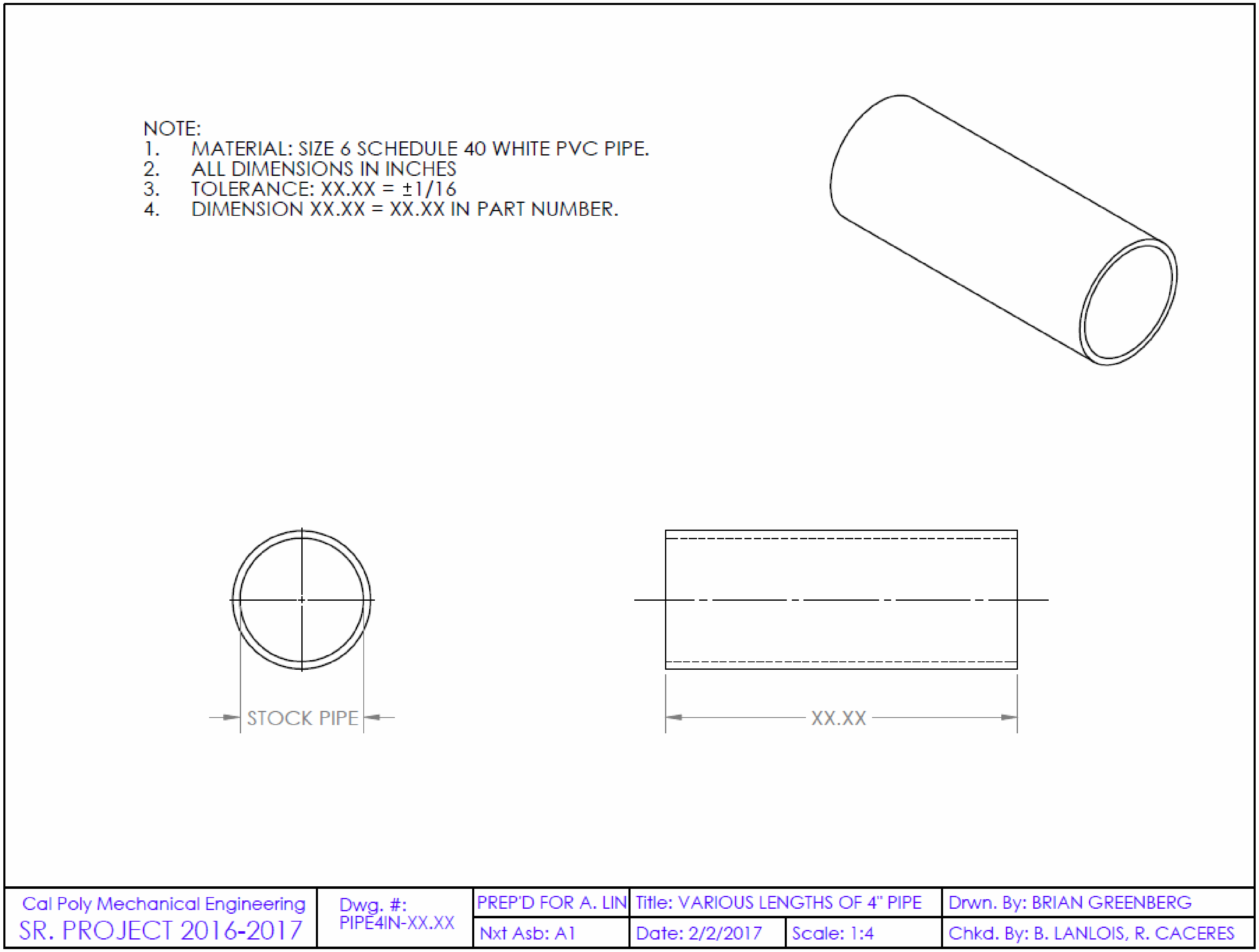

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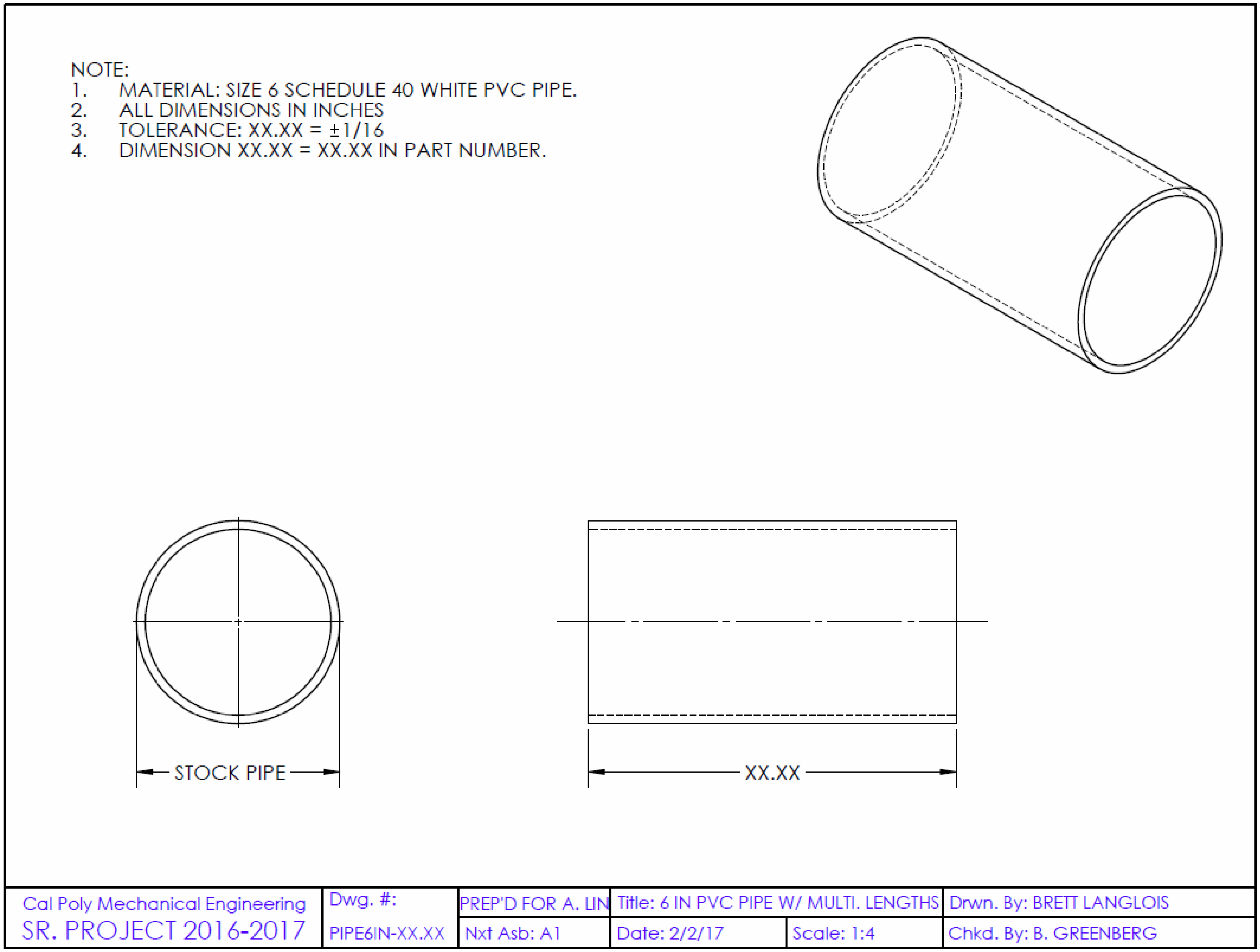
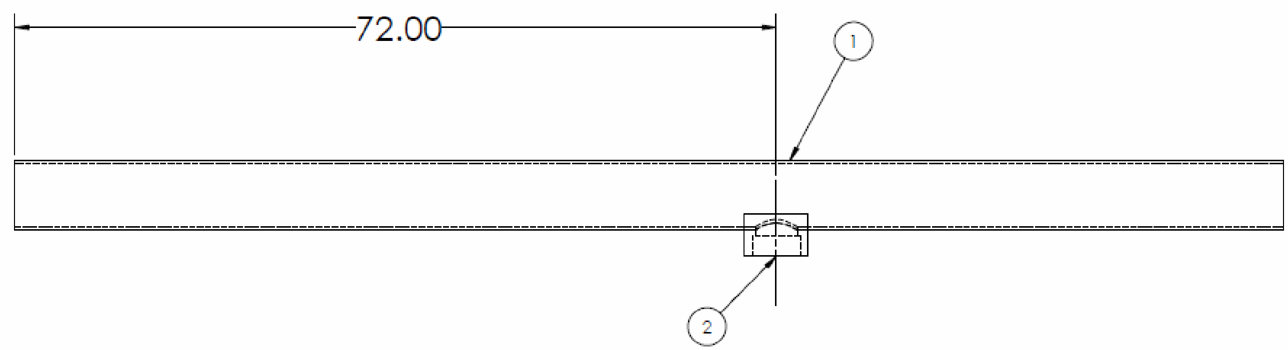
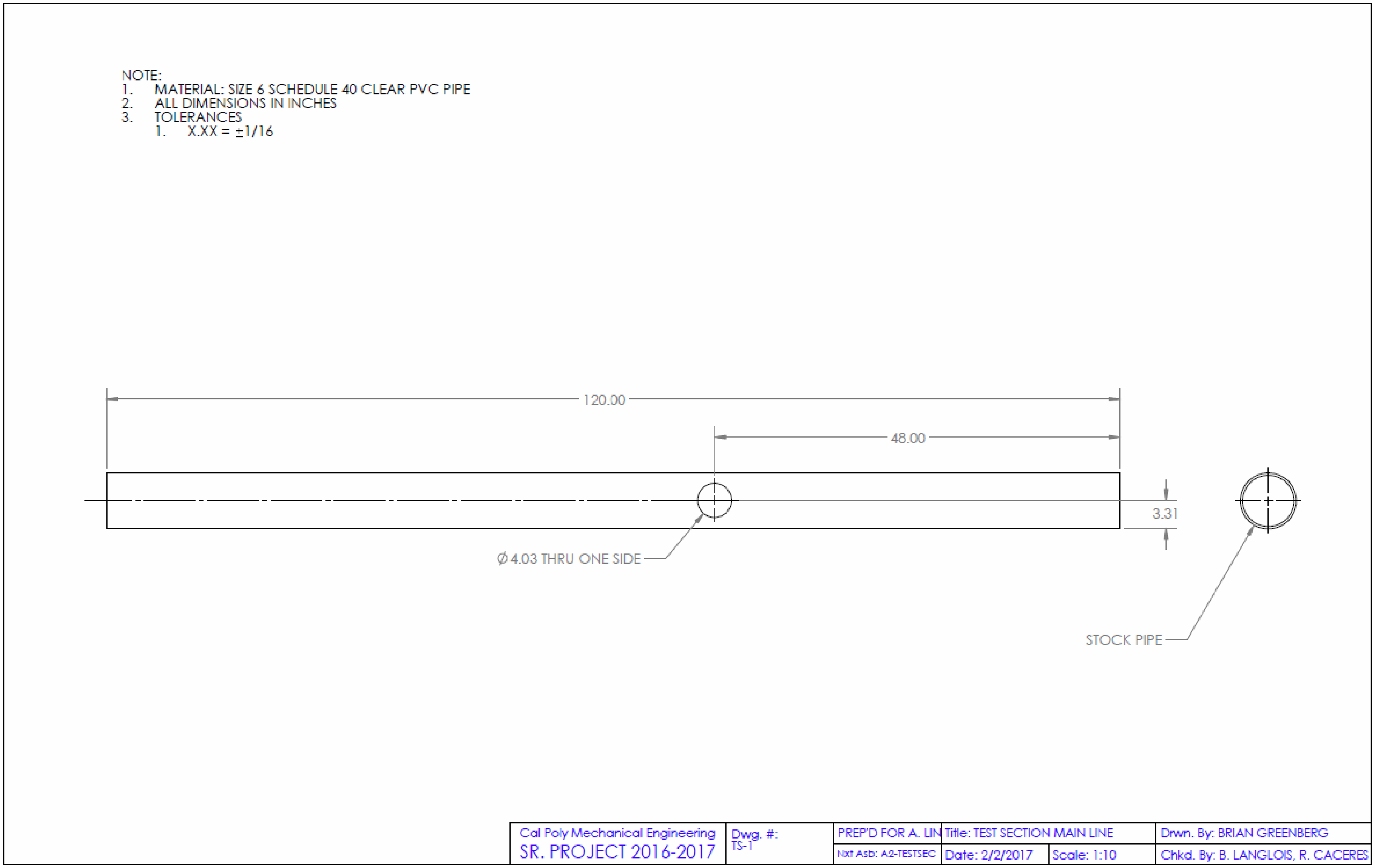

NOTE:
1. MATERIAL: SIZE 6 SCHEDULE 40 WHITE PVC PIPE.
2. ALL DIMENSIONS IN INCHES
3. TOLERANCE: XX.XX = ±1/16
4. DIMENSION XX.XX = XX.XX IN PART NUMBER.
STOCK PIPE
XX.XX
Cal Poly Mechanical Engineering
SR. PROJECT 2016-2017
Dwg. #:
PIPE6IN-XX.XX
PREP'D FOR A. LIN
Nxt Asb: A1
Title: 6 IN PVC PIPE W/ MULTI. LENGTHS
Date: 2/2/17
Scale: 1:4
Drwn. By: BRETT LANGLOIS
Chkd. By: B. GREENBERG

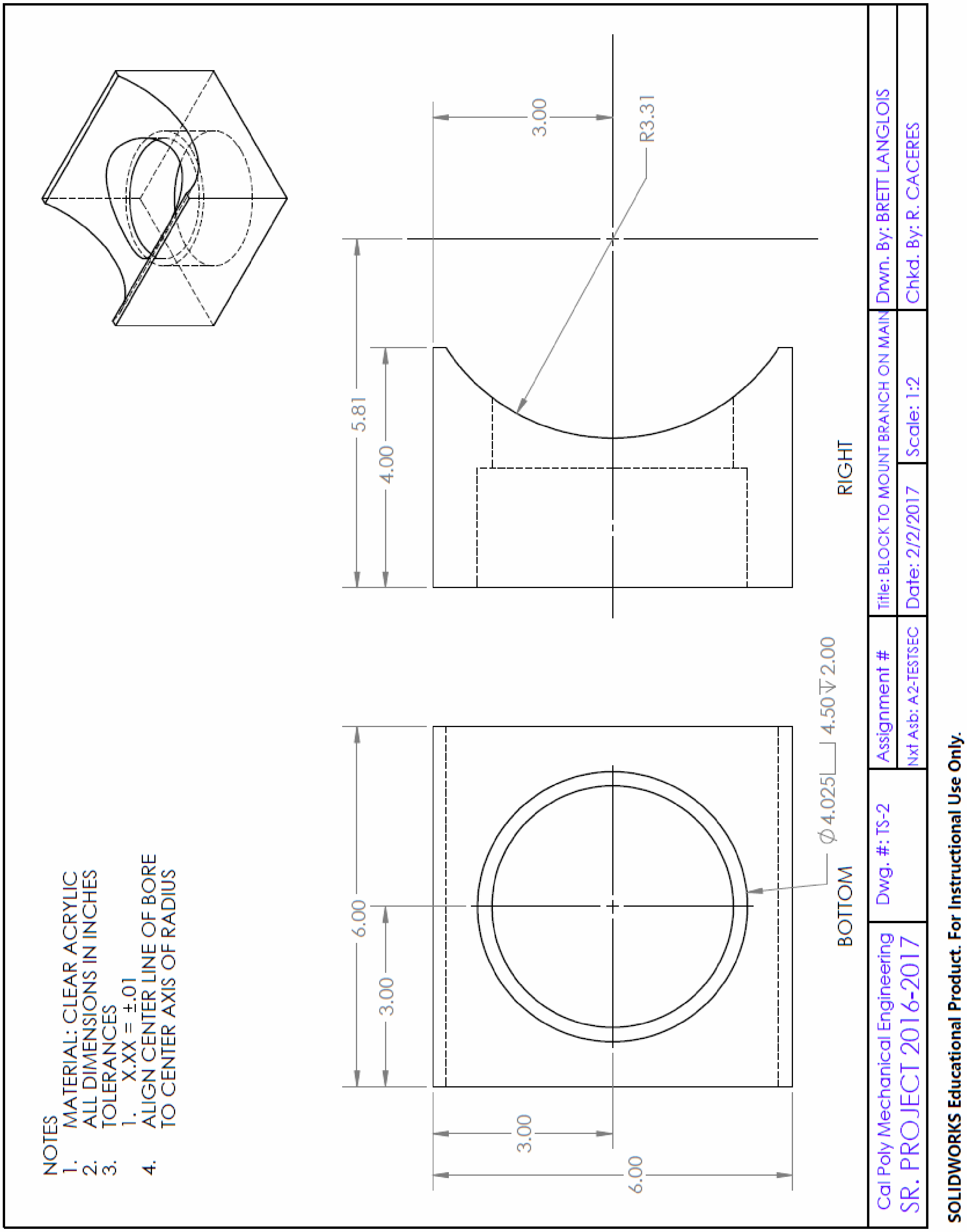
NOTE:
1. ATTATCH THE TWO PARTS WITH WELD-ON 40.
2. ALIGN PARTS SO THAT THE 4.03" DIAMETER HOLES ARE FLUSH.
3. TOLERANCES
   1. X.XX = ±1/16

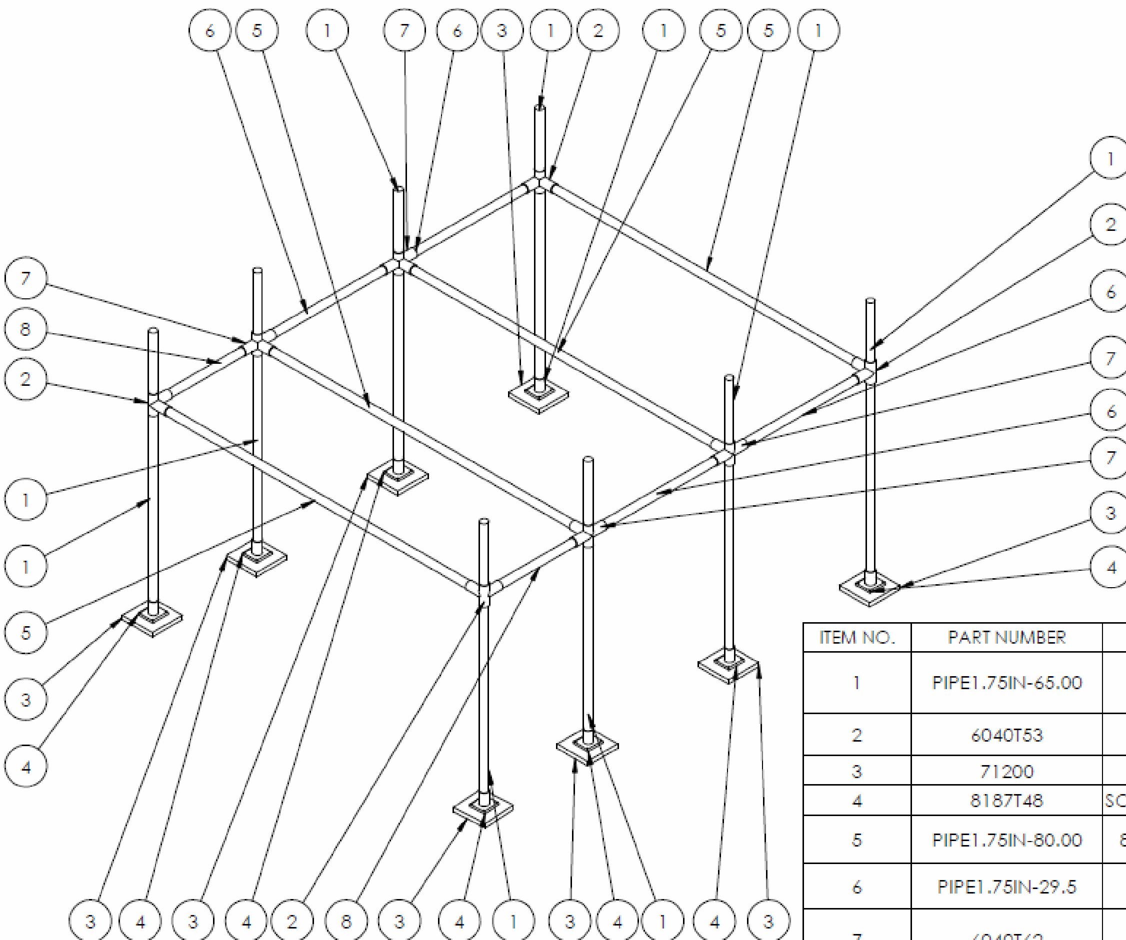


ITEM NO.	PART NUMBER	DESCRIPTION	MATERIAL	QTY.
1	TS-1	CLEAR PIPE TO SEE VORTEX	CLEAR PVC	1
2	TS-2	MOUNT TO CONNECT BRANCH TO MAIN	CLEAR ACRYLLIC	1

Cal Poly Mechanical Engineering	Dwg. #: A2-TESTSEC	Assignment #	Title: TEST SECTION ASSEMBLY		Drwn. By: BRIAN GREENBERG
SR. PROJECT 2016-2017		Nxt Asb: A-1	Date: 2/2/2017	Scale: 1:20	Chkd. By: B. LANGLOIS, R. CACERES


NOTE:
1. MATERIAL: SIZE 6 SCHEDULE 40 CLEAR PVC PIPE
2. ALL DIMENSIONS IN INCHES
3. TOLERANCES
1. X.XX = ±1/16
120.00
48.00
3.31
Ø4.03 THRU ONE SIDE
STOCK PIPE
Cal Poly Mechanical Engineering
SR. PROJECT 2016-2017
Dwg. #: TS-1
PREP'D FOR A. LIN
Nxt Asb: A2-TESTSEC
Title: TEST SECTION MAIN LINE
Date: 2/2/2017
Scale: 1:10
Drwn. By: BRIAN GREENBERG
Chkd. By: B. LANGLOIS, R. CACERES


NOTES
1. MATERIAL: CLEAR ACRYLIC
2. ALL DIMENSIONS IN INCHES
3. TOLERANCES
1. X.XX = ±.01
4. ALIGN CENTER LINE OF BORE TO CENTER AXIS OF RADIUS
3.00
6.00
5.81
4.00
R3.31
Ø4.025 ⌴ 4.50 ↧ 2.00
BOTTOM
RIGHT
Cal Poly Mechanical Engineering
SR. PROJECT 2016-2017
Dwg. #: TS-2
Assignment #
Nxt Asb: A2-TESTSEC
Title: BLOCK TO MOUNT BRANCH ON MAIN
Date: 2/2/2017
Scale: 1:2
Drwn. By: BRETT LANGLOIS
Chkd. By: R. CACERES
SOLIDWORKS Educational Product. For Instructional Use Only.



ITEM NO.	PART NUMBER	DESCRIPTION	MATERIAL	QTY.
1	PIPE1.75IN-65.00	SCAFFOLDING UPRIGHT	LOW CARBON STEEL	8
2	6040T53	3 WAY 90° ELBOW	316 STAINLESS STEEL	4
3	71200	CONCRETE BASE	CONCRETE	8
4	8187T48	SCAFFOLDING MOUNTING PLATE	STEEL	8
5	PIPE1.75IN-80.00	80" LENGTH OF SCAFFOLDING	LOW CARBON STEEL	4
6	PIPE1.75IN-29.5	29.5" SCAFFOLDING HORIZONTAL	LOW CARBON STEEL	4
7	6040T62	4-WAY FRAMING TEE	316 STAINLESS STEEL	4
8	PIPE1.75IN-19.50	19.5" SCAFFOLDING HORIZONTAL	LOW CARBON STEEL	2

Cal Poly Mechanical Engineering SR. PROJECT 2016-2017	Dwg. #: A3	PREP'D FOR A. LIN	Title: SCAFFOLDING SUBASSEMBLY		Drwn. By: BRIAN GREENBERG
		Nxt Asb: A0	Date: 2/3/2017	Scale: 1:20	Chkd. By: B.LANLOIS, R.CACERES

APPENDIX Q: COST ANALYSIS W/ LIST OF VENDORS & PRICING (INCL. TAX & SHIPPING)

ONLINE PURCHASES							
Vendor	Part name	Description	Manufacturer	Part #	Price/unit	Quantity	Subtotal
McMaster Carr	6" Flange	Schedule 80 flange	McMaster	4881K241	$ 26.31	4	$105.24
	6" gasket	Gasket for 6 inch flange, ANSI class 150, 1/16" thick	McMaster	9473K623	$ 13.84	2	$27.68
	4" flange	Schedule 80 flange	McMaster	4881K239	$ 20.64	2	$41.28
	4" to 6"	4" to 6" reducer, socket	McMaster	4880K688	$ 16.95	2	$33.90
	6" Elbow	size 6 elbow	McMaster	4880k101	$ 27.21	2	$54.42
	4" tube to pipe	4 inch adapter. Socket male to NPT female	McMaster	2389K95	$ 14.53	2	$29.06
	4" pipe to hose	Brass barbed fitting	McMaster	9431K22	$ 130.60	2	$261.20
	4" gasket	gasket for 4 inch flange, ANSI class 150, 1/16" thick	McMaster	9473K621	$ 10.27	6	$61.62
	4" Union	4" female to 4" female union	McMaster	4880K309	$ 41.90	2	$83.80
	4" Elbow	Size 4 elbow	McMaster	2389K31	$ 15.25	3	$45.75
	Valve	4" butterfly valve	McMaster	5158K542	$ 145.95	1	$145.95
	Valve	6" butterfly valve	McMaster	5158K562	$ 214.63	1	$214.63
	4" tube to pipe	4 inch adapter. Socket female to NPT female	McMaster	4880K88	$ 5.30	2	$10.60
	Air line to pipe	1/4" NPT male to industrial style QD plug	McMaster	6534K46	$ 1.15	3	3.45
	Air line QD	1/4" NPT female to industrial style QD socket	McMaster	6534K26	$ 7.67	3	23.01
	air valve	Precision flow control valve	McMaster	4076K25	$ 45.78	1	45.78
	4" flexible hose	Large-Diameter Gum Rubber Tubing	McMaster	9480T4	$ 33.90	4	$136
	air hose	1/4" male threaded air compressor hose, 15'	McMaster	1593N1	$ 21.07	1	$21.07
	6" tube	10' length of size 6 schedule 40 pvc	McMaster	48925K45	$ 81.78	3	$245.34
	4" tube	10' length of size 4 schedule 40 pvc	McMaster	48925K18	$ 41.45	2	$82.90
	Hose Clamp	3.5" to 5" stainless steel worm drive hose clamps for soft hose	McMaster	45945K19	$ 6.25	2	$13
	Acrylic Block	6" acrylic cube for machining	McMaster	8560K932	$ 81.26	2	$163
	Air Hose	1/4" male-female threaded air compressor hose, 25' length	McMaster	1593N2	$ 28.69	1	$28.69
	Copper Tubing	Copper Tubing 1/4 Tube Size, 3/8" OD, 0.032" Wall Thickness	McMaster	8967K89	$ 5.49	1	$5.49
	Copper Fitting	Copper Fitting, Adapter, Socket-End, for 1/4 Tube Size, 1/4 Male NPT	McMaster	5520K18	$ 5.73	1	$5.73
	Shutoff Valve	Brass On/Off Valve, Lever Handle, 1/4 NPT Female	McMaster	47865K21	$ 8.27	1	$8.27
	Hose Coupling	Tru-Flate-Shape Coupling to connect to shop hose, 3/8" coupling, 1/4 thread	McMaster	95815K54	$ 3.19	1	$3.19
	Primer	Purple Primer Pipe Cement - 32 oz.	McMaster	74605A26	$ 19.62	2	$39
	Acrylic Cement	Nonwhitening Acrylic Cement - Scigrip 4SC - 16 oz.	Scigrip	7517A4	$ 18.00	1	$18
	Subtotal						$1,847.30
Fasenal	3/4 Hex Bolt	3/4"-10 x 6" Grade 8 Plain Finish Hex Cap Screw	Fasenal	14375	$ 5.50	8	$44
	3/4 Hex Nut	3/4"-10 Stainless Steel Finished Hex Nut	Fasenal	70717	$ 1.60	8	$13
	3/4 Lock Washer	3/4" 316 Stainless Steel Medium Split Lock Washer	Fasenal	78077	$ 1.56	8	$12
	5/8-16 BOLT	3" LONG Grade 18-8 Stainless Steel Hex Cap Screw	Fasenal	70115	$ 1.42	16	$23
	5/8-16 NUT	5/8-16 HEX NUT	Fasenal	70712	$ 0.24	16	$4
	5/8 ID WASHER	5/8" Nominal stainless lock washer	Fasenal	71075	$ 0.57	16	$9
	Subtotal						$104.96
PVCFittings	6" unions	6" to 6" unthreaded union	PVCFittings	457-060	$ 59.34	2	$118.68
	Subtotal						$118.68
ALSCO	6" clear tube	10' length of size 6 clear PVC + shipping	ALSCO	1395-060	$ 507.90	1	$507.90
	Subtotal						$507.90
Amazon	Cement	P-12 PVC Heavy Bodied Clear Cement	Harvey	018220-12	$ 15.20	6	$91
	Subtotal						$91.20
Online Total							$2,670.04

IN STORE PURCHASES								
Receipt	**Part name**	**Description**	**Part #**	**Price/Unit**	**Quantity**	**Subtotal**	**Date Purchased**	**Purchased By**
Miner's ACE hardware 1	Silicone Sealant	Aquarium safe tube of silicone sealant	1012228	$ 6.99	1	$ 6.99	4/29/2017	Brett
	Headlight Polish	Automotive headlight restorer for acrylic block	8640533	$ 12.99	1	$ 12.99		
	320 grit sandpaper	Wet sand paper to clear acryllic	J36806677	$ 1.59	1	$ 1.59		
	1200 grit sandpaper	Wet sand paper to clear acryllic	WS1200	$ 1.79	1	$ 1.79		
	Total After Tax					$ 40.16		
Miner's ACE hardware 2 + 3	5/8 nuts		56	$ 0.50	8	$ 4.00	4/27/2017	Brett
	5/8 washers		56	$ 0.50	8	$ 4.00		
	5/8 washers pack	Pack of 25 galvalized steel washers	H811074	$ 14.49	1	$ 14.49		
	5/8 nuts		56	$ 0.50	8	$ 4.00	4/28/2017	
	5/8 washers		56	$ 0.50	8	$ 4.00		
	5/8" Threaded rod	5/8" x 3ft threaded rod to secure 4" valve	52110	$ 9.99	2	$ 19.98		
	3/4" Threaded rod	3/4" x 3ft threaded rod to secure 6" valve	52111	$ 12.99	2	$ 25.98		
	5/8x3" bolts pack	pack of 25 5/8x3" bolts	H190423	$ 36.99	1	$ 36.99		
	Total After Tax					$ 130.84		
Farm Supply 1	Sealent	PL Premium contruction Adhesive	493887	$ 5.49	1	$ 5.49	4/27/2017	Brett
	6" coupling	Schedule 40 size 6 coupling	704010	$ 12.99	1	$ 12.99		
	4" coupling		703990	$ 4.29	1	$ 4.29		
Home Depot 1	Sheet	Steel sheet for oriface plate	43374560381	$ 10.98	1	$ 10.98	4/20/2017	Brett
	Total After Tax					$ 11.83		
McMaster 1	1/2" Carbide end mill	Three flute carbide end mill, 6" overall length	88815A59	$ 86.05	1	$ 86.05	4/11/2017	Brett
	1/2" HHS end mill	HHS three-flute end mill. 2" length of cut	2849A64	$ 33.73	1	$ 33.73		
	1/4" ball end mill	Ball end three flute carbide end mill	88825A43	$ 23.46	1	$ 23.46		
	1/2" ball end mill	Ball end three flute carbide end mill	88825A45	$ 46.67	1	$ 46.67		
	Total After Tax + shipping					$ 209.42		
Farm Supply 2	6" Elbow	6" schedule 40 PVC elbow	703140	$ 26.99	4	$ 107.96	4/22/2017	Brian
	1/2 pint grey cement	1/2 pint gray heavy weight PVC cement	730210	$ 7.99	1	$ 7.99		
	4" flange	Size 4 schedule 80 PVC flange	713200	$ 22.49	4	$ 89.96		
	Total After Tax					$ 221.87		
Farm Supply 3	4" union	Size 4 schedule 80 PVC union	710387	$ 51.99	1		4/25/2017	Brian
	Total After Tax					$ 56.02		
Farm Supply 4	6" pipe	size 6 schedule 40 pipe per foot	734260	$ 3.41	2	$ 6.82	4/29/2017	Brian
	4" gaskets	size 4 flange ring gaskets	379040	$ 4.59	6	$ 27.54		
	6" coupling	Schedule 40 size 6 coupling	704010	$ 12.99	1	$ 12.99		
	Total After Tax					$ 51.02		
Farm Supply 5	1/4" Hose Barbs	1/4" NPT to 3/8" ID hose barbs	363097	$ 1.59	4	$ 6.36	5/4/2017	Brian
	Hose Clamps	Stainless steel hose clamps	792010	$ 1.19	4	$ 4.76		
	Clear PVC Primer		730335	$ 5.93	1	$ 5.93		
	3/8" Hose, 2ft	3/8" Clear braided hose	333436	$ 1.52	1	$ 1.52		
	4" coupling	Size 4 schedule 80 PVC coupling	703990	$ 4.29	1	$ 4.29		
	Total After Tax					$ 24.63		
In Store Total						$ 733.96		
Overall Total						$ 3,404.00		

APPENDIX R: WELD-ON LITERATURE & MSDS

SCIGRIP® | SMARTER ADHESIVE SOLUTIONS

TECHNICAL DATA SHEET

40

Low VOC Acrylic Plastic Adhesive

SUBSTRATE RECOMMENDATIONS

SCIGRIP® 40 is especially formulated to bond extruded, cast, and cross linked acrylic (poly-methyl methacrylate) sheets. It will also bond acrylic to polyester, cellulose acetate butyrate, polycarbonate, PVC, ABS, PETG and other materials.

BONDING RECOMMENDATIONS

SCIGRIP 40 is recommended for bonding of acrylic plastics especially where good clarity retention is required. It is versatile and can be used in many applications such as sign fabrication, the manufacturing and repair of aquariums, museum quality display cases and other plastic fabrication.

GENERAL DESCRIPTION

SCIGRIP 40 is a two-component, clear, medium syrupy, low VOC, reactive acrylic adhesive. It polymerizes at room temperature, forming high strength joints within a few hours. The cemented joint retains high clarity, good strength and resistance to the effects of weathering and aging. In cases where a lower viscosity is desired, SCIGRIP 3061 may be used as a reactive diluent. When adjusting viscosity, similar curing characteristics will be maintained when no more than 10% of SCIGRIP 3061 is added to SCIGRIP 40 Component "A." This product meets Military Spec A-8576C Type III.

TYPICAL BOND STRENGTH†

	Aged Bond Strength, lbs/in² (kg/cm²)	
Temperature	**24 Hours**	**1 Week**
Room temperature	2600 (182.8)	4000 (281.0)
120°F (49°C)	4500 (316.0)	5700 (400.8)
150°F (66°C)	5900 (414.8)	7000 (492.0)

†Substrate thickness: 0.25 inch (0.64 cm). Bond area: 1.0 in² (6.45 cm²)

ADHESIVE PROPERTIES AND CHARACTERISTICS

COLOR:	Clear*	FIXTURE TIME:	2 Hours
VISCOSITY:	2900 cps	TIME TO REACH 80% OF ULTIMATE BOND STRENGTH:	72 Hours
REACTIVITY:	35 to 40 Minutes	SPECIFIC GRAVITY:	1.03 ± 0.04
WORKING TIME:	20 Minutes		

*When viewed in large containers, it is not uncommon for the product to show a yellow tint - older product may have a greater propensity for this. However, this appearance is due to the concentration of material. Once applied to the substrate, the product will be clear. The very same clear transparency will be retained during and after curing.

DIRECTIONS FOR USE

SURFACE PREPARATION: Surfaces to be joined should be clean and fit without forcing. It should not be necessary to flex either piece more than a few thousandths of an inch to achieve complete contact. Surfaces should be sanded with 240 to 400 grit sandpaper before bonding. Do not flame polish surface to be bonded.

MIXING: Before mixing, bring both Components (A & B) to room temperature. To adjust viscosity, add no more than 10 cc or grams of SCIGRIP 3061 per 100 cc or grams of Component "A". Then, add 5 cc or 5 grams of Component "B". Stir until completely mixed. If base adhesive is above 85°F (29°C), pre-cool to 75°F (24°C) before mixing.

POT LIFE: When mixed, pot life at 75°F (24°C) is approximately 20 minutes. Note: shorter pot life may result where larger masses are used or when temperature is above 75°F (24°C).

PRELIMINARY ANNEALING: To prevent crazing during bonding, acrylics should be annealed following machining and forming. (Refer to acrylic sheet manufacturer's published Annealing Schedules.)

MAKING THE JOINT: Apply adhesive with suitable applicator to one or both surfaces and assemble immediately. If cellophane masking tapes are used, avoid contact of SCIGRIP 40 with the glue side of tape. Apply just enough pressure to remove air bubbles. Do not squeeze parts too hard as to force adhesive out of joint, a dry joint could result. If possible, cover joint with cellophane to prevent inhibition of cure by air.

CURE TIME: At 70°F (21°C), a film thickness of 0.020 inch (0.508 mm or 20 ml) will typically be tack free in 7 to 8 minutes. The bond will harden in 45 to 60 minutes, and for most applications it can be handled in approximately 4 hours. Machining of the assembly can usually be done after 24 hours.

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AVAILABILITY

This product is available in gallon (3.785 liters) and pint (473 ml) plastic containers. For detailed information on containers and applicators, refer to the current Assembly Adhesive Selection Guide and Price List.

SHELF LIFE

One year in tightly sealed containers stored away from direct sunlight in a cool 50º – 80ºF (10º – 27ºC) dry place. Storage near the ceiling in non air-conditioned warehouses is not recommended. Shelf life is reduced at higher temperatures and enhanced at lower temperatures. Keep away from sources of heat, open flame, sparks and sunlight. The date code of manufacture is stamped on the bottom of the container.

QUALITY ASSURANCE

SCIGRIP 40 is carefully evaluated to assure that consistent high quality is maintained. Fourier transform infrared spectroscopy, gas chromatography, and additional in depth testing ensures each batch is manufactured to exacting standards. A batch identification code is stamped on each can and assures traceability of all materials and processes encountered in manufacturing this plastic cement for its intended specific application.

SHIPPING

Shipping Information for One Liter Kit and Above*: Proper Shipping Name: Adhesive. Hazard Class: 3. Identification Number: UN 1133. Packing Group: II. Label Required: Flammable Liquid. **For Less than One Liter:** Proper Shipping Name: Consumer Commodity. Hazard Class: ORM-D

*If components are shipped separately, see MATERIAL SAFETY DATA SHEET for shipping instructions.

SAFETY AND ENVIRONMENTAL PRECAUTIONS

This product is a flammable, fast evaporating solvent cement. It is considered a hazardous material. In conformance with the Federal Hazardous Substance Labeling Act, the following hazards and precautions are given. Purchasers who may re-package this product must also conform to all local, state, and federal labeling, safety and other regulations. VOC emissions do not exceed 250 grams per liter.

WARNING! FLAMMABLE. VAPOR HARMFUL. MAY BE HARMFUL IF SWALLOWED. MAY IRRITATE SKIN OR EYES.

Keep out of reach of children. Do not take internally. Keep away from heat, spark, open flame and other sources of ignition. Keep container closed when not in use. Store away from direct sunlight in a cool 50º – 80ºF (10º – 27ºC) dry place. Use only in adequate ventilation. Avoid breathing of vapors. Atmospheric levels should be maintained below established exposure limit values. See Sections II and VIII of Material Safety Data Sheet. If airborne concentrations exceed those limits, use of a NIOSH-approved organic vapor cartridge respirator with full face-piece is recommended. The effectiveness of an air-purifying respirator is limited. Use it only for a single short-term exposure. For emergency and other conditions where short-term exposure guidelines may be exceeded, use an approved positive pressure self-contained breathing apparatus. Do not smoke, eat or drink while working with this product. Avoid contact with skin, eyes and clothing. May cause eye injury. Protective equipment such as gloves, goggles and impervious apron should be used. Carefully read Material Safety Data Sheet and follow all precautions.

Contains Methyl Methacrylate Monomer (80-62-6). Do not use this product for other than intended use.

"Title III Section 313 Supplier Notification:" This product contains toxic chemicals subject to the reporting requirements of Section 313 of the Emergency Planning and Community Right-to-Know Act of 1986 and of 40CFR372. This information must be included in all Material Safety Data Sheets that are copied and distributed for this material.

FIRST AID

Inhalation: If overcome with vapors, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Call physician.
Eye Contact: Flush with plenty of water for 15 minutes and call a physician.
Skin Contact: Wash skin with plenty of soap and water for at least 15 minutes. If irritation develops, get medical attention.
Ingestion: If swallowed, give 1 or 2 glasses of water or milk. Do not induce vomiting. Contact physician or poison control center immediately.

IMPORTANT NOTE

This product is intended for use by skilled individuals at their own risk. These suggestions and data are based on information we believe to be reliable. Users should verify by test that this product, as well as these methods, is suited to their application.

WARRANTY

IPS Corporation (IPS Corp.) warrants that all new IPS Corp. products shall be of good quality and free from defects in material and workmanship for the shelf life as indicated on the product. If any IPS Corp. product becomes defective, or fails to conform to our written limited warranty under normal use and storage conditions, then IPS Corp. will, without charge, replace the nonconforming product. However, this limited warranty shall not extend to, nor shall IPS Corp. be responsible for, damages or loss resulting from accident, misuse, negligent use, improper application, or incorporation of IPS Corp. products into other products. In addition, any repackaging of IPS Corp. products also shall void the limited warranty. IPS Corp. shall not be responsible for, nor does this limited warranty extend to, consequential damage, or incidental damage or expense, including without limitation, injury to persons or property or loss of use. Please refer to our standard IPS Corp. Limited Warranty for additional provisions.

CERTIFIED QUALITY MANAGEMENT SYSTEM ISO 9001 2008

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GHS SAFETY DATA SHEET

SCIGRIP® 40 2-Component Low VOC Adhesive (20:1 Mix Ratio)

Date Revised: **JAN 2012**
Supersedes: **OCT 2011**

SECTION I - PRODUCT AND COMPANY IDENTIFICATION

PRODUCT NAME: **SCIGRIP® 40 2-Component Low VOC Adhesive (20:1 Mix Ratio)**

PRODUCT USE: 2-Component Adhesive for bonding termoplastics, metals and other composites

SUPPLIER:

MANUFACTURER: IPS Corporation
600 Ellis Road, Durham,NC 27703 - USA
P.O. Box 12729, Research Triangle Park, NC 27709 - USA
Tel. 1-919-598-2400

EMERGENCY: Transportation: CHEMTEL Tel. 800.255-3924, 813-248-0585 (International)
Medical: Tel. 800.451.8346, 760.602.8703 3E Company (International)

SECTION 2 - HAZARDS IDENTIFICATION

GHS CLASSIFICATION:

Health		Environmental		Physical	
Acute Toxicity:	Category 4	Acute Toxicity:	Category 3	Flammable Liquid:	Category 2
Skin Irritation:	Category 2	Chronic Toxicity:	Category 4		
Skin Sensitization:	Category 1				
Eye:	Category 2				

GHS LABEL: OR

Signal Word: **Danger**

WHMIS CLASSIFICATION: CLASS B, DIVISION 2
CONTROLLED PRODUCT CLASS D, DIVISION 2B

Hazard Statements		Precautionary Statements	
H225 - Highly flammable liquid and vapor	H317 - May cause an allergic skin reaction	P233 - Keep container tightly closed	P262: Do not get in eyes, on skin, or on clothing
H312 - Harmful in contact with skin	H335 - May cause respiratory irritation	P260 - Do not breathe vapor	P271 - Use only outdoors or in a well-ventilated area
H315 - Causes skin irritation			

SECTION 3 - COMPOSITION/INFORMATION ON INGREDIENTS

	CAS#	EINECS #	REACH Pre-registration Number	CONCENTRATION % by Weight
Component "A" (Base Resin)				
Methyl Methacrylate Monomer (MMA),* Stabilized	80-62-6	201-297-1	05-2116297731-37-0000	40 - 65
Component "B" (Catalyst-Initiator)				
Benzoyl Peroxide (BPO)*	94-36-0	202-327-6	05-2116297715-31-0000	<15%

All of the constituents of this adhesive product are listed on the TSCA inventory of chemical substances maintained by the US EPA, or are exempt from that listing.
*Indicates this chemical is subject to the reporting requirements of Section 313 of the Emergency Planning and Community Right-to-Know Act of 1986 (40CFR372).
# indicates that this chemical is found on Proposition 65's List of chemicals known to the State of California to cause cancer or reproductive toxicity.

SECTION 4 - FIRST AID MEASURES

Contact with eyes: Flush eyes immediately with plenty of water for 15 minutes and seek medical advice immediately.
Skin contact: Remove contaminated clothing and shoes. Wash skin thoroughly with soap and water. If irritation develops, seek medical advice.
Inhalation: Remove to fresh air. If breathing is stopped, give artificial respiration. If breathing is difficult, give oxygen. Seek medical advice.
Ingestion: Rinse mouth with water. Give 1 or 2 glasses of water or milk to dilute. Do not induce vomiting. Seek medical advice immediately.

SECTION 5 - FIREFIGHTING MEASURES

Suitable Extinguishing Media: Dry chemical powder, carbon dioxide gas, foam, Halon, water fog.
Unsuitable Extinguishing Media: Water spray or stream.
Exposure Hazards: Inhalation and dermal contact
Combustion Products: Oxides of carbon, oxides of nitrogen, hydrogen chloride hydrocarbons, acrid smoke and gases.
Protection for Firefighters: Self-contained breathing apparatus or full-face positive pressure air-supply masks.

	HMIS	NFPA	
			0-Minimal
Health	2	2	1-Slight
Flammability	3	3	2-Moderate
Reactivity	2	2	3-Serious
			4-Severe

SECTION 6 - ACCIDENTAL RELEASE MEASURES

Personal precautions: Keep away from heat, sparks and open flame.
Provide sufficient ventilation, use explosion-proof exhaust ventilation eqiuipment or wear suitable respiratory protective equipment.
Prevent contact with skin or eyes (see section 8).
Environmental Precautions: Prevent product or liquids contaminated with product from entering sewers, drains, soil or open water course.
Methods for Cleaning up: Contain spill with sand or other inert adsorbent or absorbent material. Use non-sparking tools.
Transfer to a closable vessel (Metal or polyethylene [PE])

SECTION 7 - HANDLING AND STORAGE

Handling: Avoid breathing of vapor, avoid contact with eyes, skin and clothing.
Keep away from ignition sources, use only electrically grounded handling equipment and ensure adequate ventilation/fume exhaust hoods.
Do not eat, drink or smoke while handling.
Storage: Store between 50° - 80°F (10° - 27°C). Store in ventliated room or shade away from direct sunlight. Keep container tightly closed when not in use.
Keep away from ignition sources and incompatible materials. Follow all precautionary information on container label and product bulletins.

SECTION 8 - PRECAUTIONS TO CONTROL EXPOSURE / PERSONAL PROTECTION

EXPOSURE LIMITS:

Component	ACGIH TLV	ACGIH STEL	OSHA PEL	OSHA STEL
Methyl Methacrylate Mon.	50 ppm	100 ppm	100 ppm	N/E
Benzoyl Peroxide	5 mg/m^3	N/E	5 mg/m^3	N/E

Engineering Controls: Use local exhaust as needed.
Monitoring: Maintain breathing zone airborne concentrations below exposure limits.
Personal Protective Equipment (PPE):
Eye Protection: Avoid contact with eyes, wear splashproof chemical goggles, face shield, safety glasses (spectacles) with brow guards and side shields,
Skin Protection: Prevent contact with the skin as much as possible. Butyl rubber gloves should be used for frequent immersion.
Use of solvent-resistant gloves or solvent-resistant barrier cream should provide adequate protection when normal adhesive application practices and procedures are used for making structural bonds.
Respiratory Protection: Use in a well-ventilated room. Use local exhaust ventilation to remove airborne contaminants from employee breathing zone and to keep contaminants below levels listed above. With normal use, the Exposure Limit Value will not usually be reached.
When limits approached, use respiratory protection equipment.

GHS SAFETY DATA SHEET

SCIGRIP® 40 2-Component Low VOC Adhesive (20:1 Mix Ratio)

Date Revised: **JAN 2012**
Supersedes: **OCT 2011**

SECTION 9 - PHYSICAL AND CHEMICAL PROPERTIES

Appearance:	"A" - Clear, heavy viscous liquid, "B" - Clear low viscosity liquid
Odor:	"A" - Strong Solvent Odor, "B" - Mild
pH:	Not Applicable
Boiling Point:	"A" 100.5°C (212.9°F) Based on first boiling component: MMA "B" Decomposes
Flash Point:	"A" 11.5°C (52.7°F) T.C.C. based on MMA, "B" 84°C (184°F) for BPO
Specific Gravity:	"A" 1.03 @23°C (73°F) "B" 1.160 @23°C (73°F)
Solubility:	"A" - Slight in Water (MMA, MAA), "B" - Insoluble in Water
Auto-ignition Temperature:	"A" 421°C (789.8°F): MMA, "B": Not Established
Decomposition Temperature:	"A" - Not Applicable, "B" - 110ºC (230°F)
VOC Content:	"A" - ≤ 50 g/l mixed, "B" - None
Odor Threshold:	"A" 0.75 ppm: MMA, "B" Slight
Active Oxygen Content:	<1 %
Evaporation Rate:	"A" - > 1.0, "B" - <1 (BUAC = 1)
Flammability:	"A" - Category 2, "B" - Category 4
Flammability Limits:	**LEL:** "A" - 1.6% based on MMA **UEL:** "A" - 12.5% based on MMA **LEL & UEL:** "B" - Not Established
Vapor Pressure:	"A" 29 mm Hg @ 20°C (68°F): MMA
Vapor Density:	"A" - >3 (Air = 1), "B" - N/E

SECTION 10 - STABILITY AND REACTIVITY

Stability: Stable, unless heated

Hazardous decomposition products: None in normal use. Oxides of carbon, oxides of nitrogen, hydrogen chloride, hydrocarbons, acrid smoke and gases upon combustion.

Conditions to avoid: Keep away from direct sunlight, heat, sparks, open flame and other ignition sources.

Incompatible Materials: Reducing and oxidizing agents and metal contaminants

SECTION 11 - TOXICOLOGICAL INFORMATION

Likely Routes of Exposure: Inhalation, Eye and Skin Contact

Acute symptoms and effects:

Inhalation: Severe overexposure may result in nausea, dizziness, headache. Can cause drowsiness, irritation of eyes and nasal passages.

Eye Contact: Vapors slightly uncomfortable. Overexposure may result in severe eye injury with corneal or conjunctival inflammation on contact with the liquid.

Skin Contact: Liquid contact may remove natural skin oils resulting in skin irritation. Dermatitis may occur with prolonged contact.

Ingestion: May cause nausea, vomiting, diarrhea and mental sluggishness.

Chronic (long-term) effects: None known to humans

Toxicity:	**LD_{50}**	**LC_{50}**	**Target Organs**
Methyl Methacrylate Monomer (MMA)	Oral: 7900 mg/kg (rat), Dermal: >35000 mg/kg (rabbit)	Inhalation: 3 hrs. 7093 PPM (rat)	STOT SE3
Benzoyl Peroxide	Oral: 6400 mg/kg (rat)	Oral: 2 mg/l 96 hours (guppy)	

Reproductive Effects	Teratogenicity	Mutagenicity	Embryotyxicity	Sensitization to Product	Synergistic Products
Not Established	Not Established	Not Established	Not Established	Not Established	Not Established

SECTION 12 - ECOLOGICAL INFORMATION

Ecotoxicity: None known

Mobility: In normal use, emission of volatile organic compounds (VOC's) to the air takes place, typically at a rate of ≤50 g/l

Degradability: Not Established

BioAccumulation: Not Established

SECTION 13 - WASTE DISPOSAL CONSIDERATIONS

Follow local and national regulations. Consult local disposal expert.

SECTION 14 - TRANSPORT INFORMATION

Proper Shipping Name:	Adhesives
Hazard Class:	3
Secondary Risk:	None
Identification Number:	UN 1133
Packing Group:	PG II
Label Required:	Class 3 Flammable Liquid
Marine Pollutant:	NO

EXCEPTION for Ground Shipping

DOT Limited Quantity: Up to 5L per inner packaging, 30 kg gross weight per package.
Consumer Commodity: Depending on packaging, these quantities may qualify under DOT as "ORM-D" .

TDG INFORMATION	
TDG CLASS:	FLAMMABLE LIQUID 3
SHIPPING NAME:	ADHESIVES
UN NUMBER/PACKING GROUP:	UN 1133, PG II

SECTION 15 - REGULATORY INFORMATION

Precautionary Label Information: Highly Flammable, Harmful

Symbols: F, Xi

Ingredient Listings: USA TSCA, Europe EINECS, Canada DSL, Australia AICS, Korea ECL/TCCL, Japan MITI (ENCS)

Risk Phrases:
R-11 Highly Flammable
R-36/37/38 Irritating to eyes, respiratory system and skin
R-43 May cause sensitization by skin contact.

Safety Phrases:
S-2 Keep out of reach of children
S-3 Keep in a cool place
S-7 Keep container tightly closed
S-24/25 Avoid contact with skin and eyes.
S-26 In case of contact with eyes, rinse immediately with plenty of water and seek medical advice
S-36/37/39 Wear suitable protective clothing, gloves and eye/face protection
S-46 If swallowed, seek medical advise immediately and show this container or label

SECTION 16 - OTHER INFORMATION

Specification Information:

Department issuing data sheet: IPS, Safety Health & Environmental Affairs

E-mail address: <EHSinfo@ipscorp.com>

All ingredients are compliant with the requirements of the European Directive on RoHS (Restriction of Hazardous Substances).

Training necessary: Yes, training in practices and procedures contained in product literature.

Reissue date / reason for reissue: 01/12/2012 / Updated GHS Standard Format

Intended Use of Product: Structural adhesive bonding

This product is intended for use by skilled individuals at their own risk. The information contained herein is based on data considered accurate based on current state of knowledge and experience. However, no warranty is expressed or implied regarding the accuracy of this data or the results to be obtained from the use thereof.

APPENDIX S: HARVEY P-12 PVC CEMENT & PRIMER MSDS

Material Name: HARVEY P-12 or P12G PVC CEMENT

* * * Section 1 - Product and Company Identification * * *

MSDS #3102E

Product Numbers: clear - 018200, 018211, 018221, 018229, 018244, 018201, 018212, 018222, 018230, 018245, 018202, 018213, 018223, 018232, 018248, 018203, 018214, 018224, 018234, 018274, 018204, 018215, 018225, 018237, PV018244, 018205, 018216, 018226, 018240, PV018245, 018206, 018220, 018227, 018242, 018210, 018220, 018228, 018243 gray - 018250, 018260, 018262, 018270, 018272, 018280, 018282, 018290

Manufacturer Information

William H. Harvey Company
4334 South 67th Street
Omaha, NE 68117

Phone: 402-331-1175

For Emergency First Aid call 1-877-740-5015. For chemical transportation emergencies ONLY, call Chemtrec at 1-800-424-9300. Outside the U.S. 1- 703-527-3887.

* * * Section 2 - Hazards Identification * * *

GHS Classification:

Flammable Liquids - Category 2
Acute Toxicity Oral - Category 4
Acute Toxicity Dermal - Category 4
Acute Toxicity Inhalation - Category 4
Eye Damage/Irritation - Category 2A
Carcinogenicity - Category 2
Specific Target Organ Toxicity Single Exposure - Category 3

GHS LABEL ELEMENTS

Symbol(s)

Signal Word

Danger

Hazard Statements

Highly flammable liquid and vapor.
Harmful if swallowed.
Harmful in contact with skin.
Harmful if inhaled.

Material Name: HARVEY P-12 or P12G PVC CEMENT

Causes serious eye irritation.
Contains a chemical classified by the US EPA as a suspected possible carcinogen.
May cause respiratory irritation.
May cause drowsiness or dizziness.

Precautionary Statements

Prevention

Keep away from heat/sparks/open flames and hot surfaces. - No smoking.
Keep container tightly closed.
Use explosion-proof electrical/ventilating/lighting/equipment.
Use only non-sparking tools.
Take precautionary measures against static discharge.
Wear protective gloves/eye protection/face protection.
Wash thoroughly after handling.
Do not eat, drink or smoke when using this product.
Obtain special instructions before use.
Do not handle until all safety precautions have been read and understood.
Avoid breathing fume/gas/mist/vapors.
Use only outdoors or in a well-ventilated area.

Response

If on skin (or hair): Remove/Take off immediately all contaminated clothing. Rinse skin with water/shower. Wash contaminated clothing before reuse.
If swallowed: Call a poison center or doctor/physician if you feel unwell. Rinse mouth. Do not induce vomiting.
If inhaled: Remove victim to fresh air and keep at rest in a position comfortable for breathing. Call a poison center or doctor/physician if you feel unwell.
If in eyes: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. Immediately call a poison center or doctor/physician.
If exposed or concerned: Get medical advice/attention.
In case of fire: Use dry chemical, CO2, or foam to extinguish fire.

Storage

Store in a well-ventilated place. Keep cool.
Store locked up.

Disposal

Dispose of contents/container in accordance with local/regional/national/international regulations.

* * * Section 3 - Composition / Information on Ingredients * * *

CAS #	Component	Percent
109-99-9	Tetrahydrofuran	40-60
108-94-1	Cyclohexanone	10-25
67-64-1	Acetone	10-25
9002-86-2	PVC (Chloroethylene, polymer)	12-20
78-93-3	Methyl ethyl ketone	5-15
112945-52-5	Silica, amorphous, fumed, crystalline-free	1-4

* * * Section 4 - First Aid Measures * * *

First Aid: Eyes

If material gets into eyes or if fumes cause irritation, immediately flush eyes with plenty of water until chemical is removed. If irritation persists, get medical attention immediately.

First Aid: Skin

Remove contaminated clothing immediately. Wash all exposed areas with soap and water. Get medical attention if irritation develops. Remove dried cement with hand cleaner or baby oil.

First Aid: Ingestion

DO NOT INDUCE VOMITING. Rinse mouth with water. Never give anything by mouth to a person who is unconscious or drowsy. Get immediate medical attention by calling a Poison Control Center, or hospital emergency room. If medical advice cannot be obtained, then take the person and product to the nearest medical emergency treatment center or hospital.

First Aid: Inhalation

If symptoms of exposure develop, remove to fresh air. If breathing becomes difficult, administer oxygen. Administer artificial respiration if breathing has stopped. Seek immediate medical attention.

* * * Section 5 - Fire Fighting Measures * * *

General Fire Hazards

See Section 9 for Flammability Properties.

Highly flammable liquid and vapor. Keep away from heat and all sources of ignition including sparks, flames, lighted cigarettes and pilot lights. Containers may rupture or explode in the heat of a fire. Vapors are heavier than air and may travel to a remote ignition source and flash back. This product contains tetrahydrofuran that may form explosive organic peroxide when exposed to air or light or with age.

Hazardous Combustion Products

Combustion will produce toxic and irritating vapors including carbon monoxide, carbon dioxide and hydrogen chloride.

Extinguishing Media

Use dry chemical, CO2, or foam to extinguish fire. Cool fire exposed container with water. Water may be ineffective as an extinguishing agent.

Unsuitable Extinguishing Media

None.

Fire Fighting Equipment/Instructions

Firefighters should wear positive pressure self-contained breathing apparatus and full protective clothing for fires in areas where chemicals are used or stored.

* * * Section 6 - Accidental Release Measures * * *

Recovery and Neutralization

Stop leak if it can be done without risk.

Materials and Methods for Clean-Up

Remove all sources of ignition and ventilate area. Soak up spill with an inert absorbent such as sand, earth or other non-combusting material. Put absorbent material in covered, labeled metal containers.

Emergency Measures

Isolate area. Keep unnecessary personnel away.

Personal Precautions and Protective Equipment

Personnel cleaning up the spill should wear appropriate personal protective equipment, including respirators if vapor concentrations are high.

Material Name: HARVEY P-12 or P12G PVC CEMENT

Environmental Precautions

Prevent liquid from entering watercourses, sewers and natural waterways.

Prevention of Secondary Hazards

None

* * * Section 7 - Handling and Storage * * *

Handling Procedures

Avoid contact with eyes, skin and clothing. Avoid breathing vapors or mists. Use with adequate ventilation (equivalent to outdoors). Wash thoroughly after handling. Do not eat, drink or smoke in the work area. Keep product away from heat, sparks, flames and all other sources of ignition. No smoking in storage or use areas. Keep containers closed when not in use. Other: "Empty" containers retain product residue and can be hazardous. Follow all SDS precautions in handling empty containers. Do not cut or weld on or near empty or full containers.

Storage Procedures

Store in a cool, dry, well-ventilated area away from incompatible materials. Keep containers closed when not in use.

Incompatibilities

Oxidizing agents, alkalis, amines, ammonia, acids, chlorine compounds, chlorinated inorganics (potassium, calcium and sodium hypochlorite) and hydrogen peroxides. May attack plastic, resins and rubber.

* * * Section 8 - Exposure Controls / Personal Protection * * *

Component Exposure Limits

Tetrahydrofuran (109-99-9)

ACGIH: 50 ppm TWA
100 ppm STEL
Skin - potential significant contribution to overall exposure by the cutaneous route
OSHA: 200 ppm TWA; 590 mg/m3 TWA
NIOSH: 200 ppm TWA; 590 mg/m3 TWA
250 ppm STEL; 735 mg/m3 STEL

Cyclohexanone (108-94-1)

ACGIH: 20 ppm TWA
50 ppm STEL
Skin - potential significant contribution to overall exposure by the cutaneous route
OSHA: 50 ppm TWA; 200 mg/m3 TWA
NIOSH: 25 ppm TWA; 100 mg/m3 TWA
Potential for dermal absorption

Acetone (67-64-1)

ACGIH: 500 ppm TWA
750 ppm STEL
OSHA: 1000 ppm TWA; 2400 mg/m3 TWA
NIOSH: 250 ppm TWA; 590 mg/m3 TWA

PVC (Chloroethylene, polymer) (9002-86-2)

ACGIH: 1 mg/m3 TWA (respirable fraction)

Material Name: HARVEY P-12 or P12G PVC CEMENT

Methyl ethyl ketone (78-93-3)

ACGIH:	200 ppm TWA 300 ppm STEL
OSHA:	200 ppm TWA; 590 mg/m3 TWA
NIOSH:	200 ppm TWA; 590 mg/m3 TWA 300 ppm STEL; 885 mg/m3 STEL

Engineering Measures

Open doors & windows. Provide ventilation capable of maintaining emissions at the point of use below recommended exposure limits. If used in enclosed area, use exhaust fans. Exhaust fans should be explosion-proof or set up in a way that flammable concentrations of solvent vapors are not exposed to electrical fixtures or hot surfaces.

Personal Protective Equipment: Respiratory

For operations where the exposure limit may be exceeded, a NIOSH approved organic vapor respirator or supplied air respirator is recommended. Equipment selection depends on contaminant type and concentration, select in accordance with 29 CFR 1910.134 and good industrial hygiene practice. For firefighting, use self-contained breathing apparatus.

Personal Protective Equipment: Hands

Rubber gloves are suitable for normal use of the product. For long exposures chemical resistant gloves may be required such as 4H(tm) or Silver Shield(tm) to avoid prolonged skin contact.

Personal Protective Equipment: Eyes

Safety glasses with side shields or safety goggles.

Personal Protective Equipment: Skin and Body

No additional protective equipment needed.

* * * Section 9 - Physical & Chemical Properties * * *

Appearance:	Clear or Gray	**Odor:**	Ether-like
Physical State:	Liquid	**pH:**	NA
Vapor Pressure:	145 mmHg @ 20°C	**Vapor Density:**	2.5
Boiling Point:	151°F (66°C)	**Melting Point:**	NA
Solubility (H2O):	Negligible	**Specific Gravity:**	0.94 +/- 0.02 @ 20°C
Evaporation Rate:	(BUAC = 1) = 5.5 - 8.0	**VOC:**	80-84% Maximum 510 g/L per SCAQMD Test Method 316A.
Octanol/H2O Coeff.:	ND	**Flash Point:**	14-23°F (-10 to -5°C)
Flash Point Method:	CCCFP	**Upper Flammability Limit (UFL):**	11.8
Lower Flammability Limit (LFL):	1.8	**Burning Rate:**	ND
Auto Ignition:	ND		

* * * Section 10 - Chemical Stability & Reactivity Information * * *

Chemical Stability

This is a stable material.

Hazardous Reaction Potential

Will not occur.

Conditions to Avoid

Avoid heat, sparks, flames and other sources of ignition.

Incompatible Products

Oxidizing agents, alkalis, amines, ammonia, acids, chlorine compounds, chlorinated inorganics.

Hazardous Decomposition Products

Combustion will produce toxic and irritating vapors including carbon monoxide, carbon dioxide and hydrogen chloride.

* * * Section 11 - Toxicological Information * * *

Acute Toxicity

Component Analysis - LD50/LC50

Tetrahydrofuran (109-99-9)
Inhalation LC50 Rat 53.9 mg/L 4 h; Inhalation LC50 Rat 180 mg/L 1 h; Oral LD50 Rat 1650 mg/kg

Cyclohexanone (108-94-1)
Inhalation LC50 Rat 10.7 mg/L 4 h; Inhalation LC50 Rat 8000 ppm 4 h; Oral LD50 Rat 800 mg/kg; Dermal LD50 Rabbit 948 mg/kg

Acetone (67-64-1)
Oral LD50 Rat 5800 mg/kg

Methyl ethyl ketone (78-93-3)
Inhalation LC50 Mouse 32 g/m3 4 h; Oral LD50 Rat 2737 mg/kg; Dermal LD50 Rabbit 6480 mg/kg

Silica, amorphous, fumed, crystalline-free (112945-52-5)
Oral LD50 Rat 3160 mg/kg

Potential Health Effects: Skin Corrosion Property/Stimulativeness

May cause irritation with redness, itching and pain. Methyl ethyl ketone and cyclohexanone may be absorbed through the skin causing effects similar to those listed under inhalation.

Potential Health Effects: Eye Critical Damage/ Stimulativeness

Vapors may cause irritation. Direct contact may cause irritation with redness, stinging and tearing of the eyes. May cause eye damage.

Potential Health Effects: Ingestion

Swallowing may cause abdominal pain, nausea, vomiting and diarrhea. Aspiration during swallowing or vomiting can cause chemical pneumonia and lung damage. May cause kidney and liver damage.

Potential Health Effects: Inhalation

Vapors or mists may cause mucous membrane and respiratory irritation, coughing, headache, dizziness, dullness, nausea, shortness of breath and vomiting. High concentrations may cause central nervous system depression, narcosis and unconsciousness. May cause kidney, liver and lung damage.

Respiratory Organs Sensitization/Skin Sensitization

This product is not reported to have any skin sensitization effects.

Generative Cell Mutagenicity

Cyclohexanone has been positive in bacterial and mammalian assays. Acetone, methyl ethyl ketone and tetrahydrofuran are generally thought not to be mutagenic.

Material Name: HARVEY P-12 or P12G PVC CEMENT

Carcinogenicity

A: General Product Information

In 2012 USEPA Integrated Risk Information System (IRIS) reviewed a two species inhalation lifetime study on THF conducted by NTP (1998). Male rats developed renal tumors and female mice developed liver tumors while neither the female rats nor the male mice showed similar results. Because the carcinogenic mechanisms could not be identified clearly in either species for either tumor, the EPA determined that the male rat and female mouse findings are relevant to the assessment of carcinogenic potential in humans. Therefore, the IRIS review concludes that these data in aggregate indicate that there is "suggestive evidence of carcinogenic potential" following exposure to THF by all routes of exposure.

B: Component Carcinogenicity

Tetrahydrofuran (109-99-9)

ACGIH: A3 - Confirmed Animal Carcinogen with Unknown Relevance to Humans

Cyclohexanone (108-94-1)

ACGIH: A3 - Confirmed Animal Carcinogen with Unknown Relevance to Humans
IARC: Monograph 71 [1999]; Monograph 47 [1989] (Group 3 (not classifiable))

Acetone (67-64-1)

ACGIH: A4 - Not Classifiable as a Human Carcinogen

PVC (Chloroethylene, polymer) (9002-86-2)

ACGIH: A4 - Not Classifiable as a Human Carcinogen
IARC: Supplement 7 [1987]; Monograph 19 [1979] (Group 3 (not classifiable))

Silica, amorphous, fumed, crystalline-free (112945-52-5)

IARC: Monograph 68 [1997] (listed under Amorphous silica) (Group 3 (not classifiable))

Reproductive Toxicity

Methyl ethyl ketone and cyclohexanone have been shown to cause embryofetal toxicity and birth defects in laboratory animals. Acetone and tetrahydrofuran has been found to cause adverse developmental effects only when exposure levels cause other toxic effects to the mother.

Specified Target Organ General Toxicity: Single Exposure

May cause respiratory irritation. Inhalation of high concentrations may cause central nervous system depression, narcosis and unconsciousness. May cause kidney, liver and lung damage.

Specified Target Organ General Toxicity: Repeated Exposure

This product is not reported to have any specific target organ toxicity repeat exposure effects.

Aspiration Respiratory Organs Hazard

Aspiration during swallowing or vomiting can cause chemical pneumonia and lung damage. May cause kidney and liver damage.

* * * Section 12 - Ecological Information * * *

Ecotoxicity

A: General Product Information

This product is not expected to be toxic to aquatic organisms.

B: Component Analysis - Ecotoxicity - Aquatic Toxicity

Tetrahydrofuran (109-99-9)

Test & Species	Conditions

96 Hr LC50 Pimephales promelas	1970-2360 mg/L [flow-through]	
96 Hr LC50 Pimephales promelas	2700-3600 mg/L [static]	
24 Hr EC50 Daphnia magna	5930 mg/L	

Cyclohexanone (108-94-1)

Test & Species		Conditions
96 Hr LC50 Pimephales promelas	481-578 mg/L [flow-through]	
96 Hr LC50 Pimephales promelas	8.9 mg/L	
96 Hr EC50 Chlorella vulgaris	20 mg/L	
24 Hr EC50 Daphnia magna	800 mg/L	

Acetone (67-64-1)

Test & Species		Conditions
96 Hr LC50 Oncorhynchus mykiss	4.74 - 6.33 mL/L	
96 Hr LC50 Pimephales promelas	6210 - 8120 mg/L [static]	
96 Hr LC50 Lepomis macrochirus	8300 mg/L	
48 Hr EC50 Daphnia magna	10294 - 17704 mg/L [Static]	
48 Hr EC50 Daphnia magna	12600 - 12700 mg/L	

Methyl ethyl ketone (78-93-3)

Test & Species		Conditions
96 Hr LC50 Pimephales promelas	3130-3320 mg/L [flow-through]	
48 Hr EC50 Daphnia magna	>520 mg/L	
48 Hr EC50 Daphnia magna	5091 mg/L	
48 Hr EC50 Daphnia magna	4025 - 6440 mg/L [Static]	

Persistence/Degradability

No information available for the product.

Bioaccumulation

No information available for the product.

Mobility in Soil

No information available for the product.

* * * Section 13 - Disposal Considerations * * *

Waste Disposal Instructions

See Section 7 for Handling Procedures. See Section 8 for Personal Protective Equipment recommendations.

US EPA Waste Number & Descriptions

Material Name: HARVEY P-12 or P12G PVC CEMENT

Component Waste Numbers

Tetrahydrofuran (109-99-9)
RCRA: waste number U213 (Ignitable waste)

Cyclohexanone (108-94-1)
RCRA: waste number U057 (Ignitable waste)

Acetone (67-64-1)
RCRA: waste number U002 (Ignitable waste)

Methyl ethyl ketone (78-93-3)
RCRA: waste number U159 (Ignitable waste, Toxic waste)
200.0 mg/L regulatory level

Disposal of Contaminated Containers or Packaging

Dispose of contents/container in accordance with local/regional/national/international regulations.

* * * Section 14 - Transportation Information * * *

DOT Information

For Greater than 1 liter (0.3 gal):
Shipping Name: Adhesives
UN #: 1133 **Hazard Class:** 3 **Packing Group:** II
Required Label(s): Flammable Liquid

For Less than 1 liter (0.3 gal):
Shipping Name: Consumer Commodity, ORM-D

IMDG Information

For Greater than 1 liter (0.3 gal):
Shipping Name: Adhesives
UN #: 1133 **Hazard Class:** 3 **Packing Group:** II
Required Label(s): Flammable Liquid

For Less than 1 liter (0.3 gal):
Shipping Name: Adhesives
UN #: 1133 **Hazard Class:** 3 **Packing Group:** II
Required Label(s): None (Limited Quantites are expected from labeling)

* * * Section 15 - Regulatory Information * * *

Regulatory Information

US Federal Regulations

Material Name: HARVEY P-12 or P12G PVC CEMENT

Component Analysis

This material contains one or more of the following chemicals required to be identified under SARA Section 302 (40 CFR 355 Appendix A), SARA Section 313 (40 CFR 372.65) and/or CERCLA (40 CFR 302.4).

Tetrahydrofuran (109-99-9)

CERCLA: 1000 lb final RQ; 454 kg final RQ

Cyclohexanone (108-94-1)

CERCLA: 5000 lb final RQ; 2270 kg final RQ

Acetone (67-64-1)

CERCLA: 5000 lb final RQ; 2270 kg final RQ

Methyl ethyl ketone (78-93-3)

CERCLA: 5000 lb final RQ; 2270 kg final RQ

State Regulations

Component Analysis - State

The following components appear on one or more of the following state hazardous substances lists:

Component	CAS	CA	MA	MN	NJ	PA	RI
Tetrahydrofuran	109-99-9	Yes	Yes	Yes	Yes	Yes	No
Cyclohexanone	108-94-1	Yes	Yes	Yes	Yes	Yes	No
Acetone	67-64-1	Yes	Yes	Yes	Yes	Yes	No
PVC (Chloroethylene, polymer)	9002-86-2	No	No	No	Yes	No	No
Methyl ethyl ketone	78-93-3	Yes	Yes	Yes	Yes	Yes	No

This product contains trace amounts of chemicals known to the State of California to cause cancer. Under normal use conditions, exposure to these chemicals at levels above the State of California "No Significant Risk Level" (NSRL) are unlikely. The use of proper personal protective equipment (PPE) and ventilation guidelines noted in Section 8 will minimize exposure to these chemicals.

Component Analysis - WHMIS IDL

The following components are identified under the Canadian Hazardous Products Act Ingredient Disclosure List:

Component	CAS #	Minimum Concentration
Tetrahydrofuran	109-99-9	1 %
Cyclohexanone	108-94-1	0.1 %
Acetone	67-64-1	1 %
Methyl ethyl ketone	78-93-3	1 %

Material Name: HARVEY P-12 or P12G PVC CEMENT

Additional Regulatory Information

Component Analysis - Inventory

Component	CAS #	TSCA	CAN	EEC
Tetrahydrofuran	109-99-9	Yes	DSL	EINECS
Cyclohexanone	108-94-1	Yes	DSL	EINECS
Acetone	67-64-1	Yes	DSL	EINECS
PVC (Chloroethylene, polymer)	9002-86-2	Yes	DSL	ELINCS
Methyl ethyl ketone	78-93-3	Yes	DSL	EINECS
Silica, amorphous, fumed, crystalline-free	112945-52-5	No	DSL	No

* * * Section 16 - Other Information * * *

Key/Legend

EPA = Environmental Protection Agency; TSCA = Toxic Substance Control Act; ACGIH = American Conference of Governmental Industrial Hygienists; IARC = International Agency for Research on Cancer; NIOSH = National Institute for Occupational Safety and Health; NTP = National Toxicology Program; OSHA = Occupational Safety and Health Administration., NJTSR = New Jersey Trade Secret Registry.

Literature References

None

Other Information

NFPA and HMIS:
NFPA Hazard Signal: Health: 2 Flammability: 3 Reactivity: 1 Special: None
HMIS Hazard Signal: Health: 2* Flammability: 3 Reactivity: 1 PPE: G

Disclaimer:
The information herein has been compiled from sources believed to be reliable, up-to-date, and is accurate to the best of our knowledge. However, we cannot give any guarantees regarding information from other sources, and expressly do not make warranties, nor assume any liability for its use.

End of Sheet

HARVEY™

SAFETY DATA SHEET

1. Identification

Product identifier Harvey's Purple Primer

Other means of identification

Product code 3402E

Synonyms Part Numbers: 018255, 018256, 018267, 019002, 018003, 019038, 019041, 019044, 019045, 019046, 019048, 019049, 019050, 019051, 019052, 019053, 019054, 019055, 019056, 019057, 019060, 019062, 019063, 019064, 019065, 019066, 019067, 019068, 019069, 019070, 019071, 019072, 019073, 019074, 019075, 019076, 019077, 019078, 019079, 019080, 019081, 019082, 019083,019084, 019085, 019086, 019087, 019089, 019090, 019091, 019092, 019093, 019094, 019095, 019097, 019098, 019099, 019157, 019171, 019172, 019173, 019190, 019200, 019201, 019202, 019205, 019505, 019511, 019716, 019717, 405163, 458457, 458465, B15944, B15944A, B15944D, B15944F, MVP9912, MVP9913, MVP9914, PV019038, PV019041, PV019205

Recommended use Joining PVC Pipes

Recommended restrictions None known.

Manufacturer/Importer/Supplier/Distributor information

Company Name William H. Harvey Company

Address 4334 South 67th Street
Omaha, NE 68117

Telephone 402-331-1175

E-mail info@oatey.com

Transport Emergency Chemtrec 1-800-424-9300 (Outside the US 1-703-527-3887)

Emergency First Aid 1-877-740-5015

Contact person MSDS Coordinator

2. Hazard(s) identification

Physical hazards	Flammable liquids	Category 2
Health hazards	Acute toxicity, oral	Category 4
	Skin corrosion/irritation	Category 2
	Serious eye damage/eye irritation	Category 2A
	Specific target organ toxicity, single exposure	Category 3 respiratory tract irritation
	Specific target organ toxicity, single exposure	Category 3 narcotic effects
	Aspiration hazard	Category 1

OSHA defined hazards Not classified.

Label elements

Signal word Danger

Hazard statement Highly flammable liquid and vapor. Harmful if swallowed. May be fatal if swallowed and enters airways. Causes skin irritation. Causes serious eye irritation. May cause respiratory irritation. May cause drowsiness or dizziness.

Precautionary statement

Prevention Keep away from heat/sparks/open flames/hot surfaces. - No smoking. Keep container tightly closed. Ground/bond container and receiving equipment. Use explosion-proof electrical/ventilating/lighting equipment. Use only non-sparking tools. Take precautionary measures against static discharge. Avoid breathing mist or vapor. Wash thoroughly after handling. Do not eat, drink or smoke when using this product. Use only outdoors or in a well-ventilated area. Wear protective gloves/protective clothing/eye protection/face protection.

Response — If swallowed: Immediately call a poison center/doctor. If on skin (or hair): Take off immediately all contaminated clothing. Rinse skin with water/shower. If inhaled: Remove person to fresh air and keep comfortable for breathing. If in eyes: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. Call a poison center/doctor if you feel unwell. Rinse mouth. Do NOT induce vomiting. If skin irritation occurs: Get medical advice/attention. If eye irritation persists: Get medical advice/attention. Take off contaminated clothing and wash before reuse. In case of fire: Use appropriate media to extinguish.

Storage — Store in a well-ventilated place. Keep container tightly closed. Keep cool. Store locked up.

Disposal — Dispose of contents/container in accordance with local/regional/national/international regulations.

Hazard(s) not otherwise classified (HNOC) — Frequent or prolonged contact may defat and dry the skin, leading to discomfort and dermatitis. May form explosive peroxides. Contains a chemical classified by the US EPA as a suspected possible carcinogen.

Supplemental information

Not applicable.

3. Composition/information on ingredients

Mixtures

Chemical name	CAS number	%
Acetone	67-64-1	25-40
Cyclohexanone	108-94-1	25-40
Furan, Tetrahydro-	109-99-9	15-30
Methyl ethyl ketone	78-93-3	15-30

*Designates that a specific chemical identity and/or percentage of composition has been withheld as a trade secret.

4. First-aid measures

Inhalation — Remove victim to fresh air and keep at rest in a position comfortable for breathing. Call a POISON CENTER or doctor/physician if you feel unwell.

Skin contact — Take off immediately all contaminated clothing. Wash with plenty of soap and water. If skin irritation occurs: Get medical advice/attention.

Eye contact — Immediately flush eyes with plenty of water for at least 15 minutes. Remove contact lenses, if present and easy to do. Continue rinsing. If eye irritation persists: Get medical advice/attention.

Ingestion — Call a physician or poison control center immediately. Do not induce vomiting. If vomiting occurs, keep head low so that stomach content doesn't get into the lungs. Aspiration may cause pulmonary edema and pneumonitis.

Most important symptoms/effects, acute and delayed — Irritation of nose and throat. Aspiration may cause pulmonary edema and pneumonitis. Severe eye irritation. Symptoms may include stinging, tearing, redness, swelling, and blurred vision. May cause respiratory irritation. Vapors have a narcotic effect and may cause headache, fatigue, dizziness and nausea. Skin irritation. May cause redness and pain.

Indication of immediate medical attention and special treatment needed — Provide general supportive measures and treat symptomatically. Thermal burns: Flush with water immediately. While flushing, remove clothes which do not adhere to affected area. Call an ambulance. Continue flushing during transport to hospital. In case of shortness of breath, give oxygen. Keep victim warm. Keep victim under observation. Symptoms may be delayed.

General information — Take off all contaminated clothing immediately. Ensure that medical personnel are aware of the material(s) involved, and take precautions to protect themselves. Wash contaminated clothing before reuse.

5. Fire-fighting measures

Suitable extinguishing media — Alcohol resistant foam. Water fog. Dry chemical powder. Carbon dioxide (CO_2).

Unsuitable extinguishing media — Do not use water jet as an extinguisher, as this will spread the fire.

Specific hazards arising from the chemical — Vapors may form explosive mixtures with air. Vapors may travel considerable distance to a source of ignition and flash back. During fire, gases hazardous to health may be formed.

Special protective equipment and precautions for firefighters — Self-contained breathing apparatus and full protective clothing must be worn in case of fire.

Fire fighting equipment/instructions — In case of fire and/or explosion do not breathe fumes. Move containers from fire area if you can do so without risk.

Specific methods — Use standard firefighting procedures and consider the hazards of other involved materials.

General fire hazards Highly flammable liquid and vapor. This product contains tetrahydrofuran that may form explosive organic peroxide when exposed to air or light or with age.

6. Accidental release measures

Personal precautions, protective equipment and emergency procedures Keep unnecessary personnel away. Keep people away from and upwind of spill/leak. Keep out of low areas. Eliminate all ignition sources (no smoking, flares, sparks, or flames in immediate area). Wear appropriate protective equipment and clothing during clean-up. Avoid breathing mist or vapor. Do not touch damaged containers or spilled material unless wearing appropriate protective clothing. Ventilate closed spaces before entering them. Local authorities should be advised if significant spillages cannot be contained. For personal protection, see section 8 of the SDS.

Methods and materials for containment and cleaning up Eliminate all ignition sources (no smoking, flares, sparks, or flames in immediate area). Take precautionary measures against static discharge. Use only non-sparking tools. Keep combustibles (wood, paper, oil, etc.) away from spilled material. This product is miscible in water.

Large Spills: Stop the flow of material, if this is without risk. Use water spray to reduce vapors or divert vapor cloud drift. Dike the spilled material, where this is possible. Cover with plastic sheet to prevent spreading. Use a non-combustible material like vermiculite, sand or earth to soak up the product and place into a container for later disposal. Prevent entry into waterways, sewer, basements or confined areas. Following product recovery, flush area with water.

Small Spills: Absorb with earth, sand or other non-combustible material and transfer to containers for later disposal. Wipe up with absorbent material (e.g. cloth, fleece). Clean surface thoroughly to remove residual contamination.

Never return spills to original containers for re-use. For waste disposal, see section 13 of the SDS.

Environmental precautions Avoid discharge into drains, water courses or onto the ground.

7. Handling and storage

Precautions for safe handling Vapors may form explosive mixtures with air. Do not handle, store or open near an open flame, sources of heat or sources of ignition. Protect material from direct sunlight. Explosion-proof general and local exhaust ventilation. Take precautionary measures against static discharges. All equipment used when handling the product must be grounded. Use non-sparking tools and explosion-proof equipment. Avoid breathing mist or vapor. Avoid contact with eyes, skin, and clothing. Avoid prolonged exposure. Do not taste or swallow. When using, do not eat, drink or smoke. Wear appropriate personal protective equipment. Wash hands thoroughly after handling. Observe good industrial hygiene practices.

Conditions for safe storage, including any incompatibilities Store locked up. Keep away from heat, sparks and open flame. Prevent electrostatic charge build-up by using common bonding and grounding techniques. Store in a cool, dry place out of direct sunlight. Store in original tightly closed container. Store in a well-ventilated place. Store away from incompatible materials (see Section 10 of the SDS).

8. Exposure controls/personal protection

Occupational exposure limits

US. OSHA Table Z-1 Limits for Air Contaminants (29 CFR 1910.1000)

Components	Type	Value
Acetone (CAS 67-64-1)	PEL	2400 mg/m3
		1000 ppm
Cyclohexanone (CAS 108-94-1)	PEL	200 mg/m3
		50 ppm
Furan, Tetrahydro- (CAS 109-99-9)	PEL	590 mg/m3
		200 ppm
Methyl ethyl ketone (CAS 78-93-3)	PEL	590 mg/m3
		200 ppm

US. ACGIH Threshold Limit Values

Components	Type	Value
Acetone (CAS 67-64-1)	STEL	750 ppm
	TWA	500 ppm
Cyclohexanone (CAS 108-94-1)	STEL	50 ppm
	TWA	20 ppm

US. ACGIH Threshold Limit Values

Components	Type	Value
Furan, Tetrahydro- (CAS 109-99-9)	STEL	100 ppm
	TWA	50 ppm
Methyl ethyl ketone (CAS 78-93-3)	STEL	300 ppm
	TWA	200 ppm

US. NIOSH: Pocket Guide to Chemical Hazards

Components	Type	Value
Acetone (CAS 67-64-1)	TWA	590 mg/m3
		250 ppm
Cyclohexanone (CAS 108-94-1)	TWA	100 mg/m3
		25 ppm
Furan, Tetrahydro- (CAS 109-99-9)	STEL	735 mg/m3
		250 ppm
	TWA	590 mg/m3
		200 ppm
Methyl ethyl ketone (CAS 78-93-3)	STEL	885 mg/m3
		300 ppm
	TWA	590 mg/m3
		200 ppm

Biological limit values

ACGIH Biological Exposure Indices

Components	Value	Determinant	Specimen	Sampling Time
Acetone (CAS 67-64-1)	50 mg/l	Acetone	Urine	*
Cyclohexanone (CAS 108-94-1)	80 mg/l	1,2-Cyclohexanediol, with hydrolysis	Urine	*
	8 mg/l	Cyclohexanol, with hydrolysis	Urine	*
Furan, Tetrahydro- (CAS 109-99-9)	2 mg/l	Tetrahydrofuran	Urine	*
Methyl ethyl ketone (CAS 78-93-3)	2 mg/l	MEK	Urine	*

* - For sampling details, please see the source document.

Exposure guidelines

US - California OELs: Skin designation

Cyclohexanone (CAS 108-94-1) — Can be absorbed through the skin.

US - Minnesota Haz Subs: Skin designation applies

Cyclohexanone (CAS 108-94-1) — Skin designation applies.

US - Tennessee OELs: Skin designation

Cyclohexanone (CAS 108-94-1) — Can be absorbed through the skin.

US ACGIH Threshold Limit Values: Skin designation

Cyclohexanone (CAS 108-94-1) — Can be absorbed through the skin.
Furan, Tetrahydro- (CAS 109-99-9) — Can be absorbed through the skin.

US. NIOSH: Pocket Guide to Chemical Hazards

Cyclohexanone (CAS 108-94-1) — Can be absorbed through the skin.

Appropriate engineering controls

Explosion-proof general and local exhaust ventilation. Good general ventilation (typically 10 air changes per hour) should be used. Ventilation rates should be matched to conditions. If applicable, use process enclosures, local exhaust ventilation, or other engineering controls to maintain airborne levels below recommended exposure limits. If exposure limits have not been established, maintain airborne levels to an acceptable level. Eye wash facilities and emergency shower must be available when handling this product.

Individual protection measures, such as personal protective equipment

Eye/face protection	Face shield is recommended. Wear safety glasses with side shields (or goggles).
Skin protection	
Hand protection	Wear appropriate chemical resistant gloves.
Other	Wear appropriate chemical resistant clothing.
Respiratory protection	If engineering controls do not maintain airborne concentrations below recommended exposure limits (where applicable) or to an acceptable level (in countries where exposure limits have not been established), an approved respirator must be worn.
Thermal hazards	Wear appropriate thermal protective clothing, when necessary.
General hygiene considerations	When using, do not eat, drink or smoke. Always observe good personal hygiene measures, such as washing after handling the material and before eating, drinking, and/or smoking. Routinely wash work clothing and protective equipment to remove contaminants.

9. Physical and chemical properties

Appearance	
Physical state	Liquid.
Form	Translucent liquid.
Color	Purple
Odor	Solvent.
Odor threshold	Not available.
pH	Not available.
Melting point/freezing point	Not available.
Initial boiling point and boiling range	151 °F (66.11 °C)
Flash point	14.0 - 23.0 °F (-10.0 - -5.0 °C)
Evaporation rate	5.5 - 8
Flammability (solid, gas)	Not available.
Upper/lower flammability or explosive limits	
Flammability limit - lower (%)	1.8
Flammability limit - upper (%)	11.8
Explosive limit - lower (%)	Not available.
Explosive limit - upper (%)	Not available.
Vapor pressure	145 mm Hg @ 20 C
Vapor density	2.5
Relative density	0.84 +/- 0.02 @20°C
Solubility(ies)	
Solubility (water)	Negligible
Partition coefficient (n-octanol/water)	Not available.
Auto-ignition temperature	Not available.
Decomposition temperature	Not available.
Viscosity	Not available.
Other information	
Bulk density	7 lb/gal
VOC (Weight %)	505 g/l SQACMD Method 24

10. Stability and reactivity

Reactivity	The product is stable and non-reactive under normal conditions of use, storage and transport.
Chemical stability	Material is stable under normal conditions.
Possibility of hazardous reactions	No dangerous reaction known under conditions of normal use.

Conditions to avoid	Avoid heat, sparks, open flames and other ignition sources. Avoid temperatures exceeding the flash point. Contact with incompatible materials.
Incompatible materials	Acids. Strong oxidizing agents. Ammonia. Amines. Isocyanates. Caustics.
Hazardous decomposition products	No hazardous decomposition products are known.

11. Toxicological information

Information on likely routes of exposure

Inhalation	May be fatal if swallowed and enters airways. Headache. Nausea, vomiting. May cause irritation to the respiratory system. Vapors have a narcotic effect and may cause headache, fatigue, dizziness and nausea. Prolonged inhalation may be harmful.
Skin contact	Causes skin irritation.
Eye contact	Causes serious eye irritation.
Ingestion	May be fatal if swallowed and enters airways. Harmful if swallowed. Harmful if swallowed. Droplets of the product aspirated into the lungs through ingestion or vomiting may cause a serious chemical pneumonia.
Symptoms related to the physical, chemical and toxicological characteristics	Irritation of nose and throat. Aspiration may cause pulmonary edema and pneumonitis. Severe eye irritation. Symptoms may include stinging, tearing, redness, swelling, and blurred vision. May cause respiratory irritation. Skin irritation. May cause redness and pain. Symptoms of overexposure may be headache, dizziness, tiredness, nausea and vomiting.

Information on toxicological effects

Acute toxicity May be fatal if swallowed and enters airways. Narcotic effects. May cause respiratory irritation.

Components	Species	Test Results
Acetone (CAS 67-64-1)		
Acute		
Dermal		
LD50	Rabbit	20 ml/kg
Inhalation		
LC50	Rat	50 mg/l, 8 Hours
Oral		
LD50	Rat	5800 mg/kg
Cyclohexanone (CAS 108-94-1)		
Acute		
Dermal		
LD50	Rabbit	948 mg/kg
Inhalation		
LC50	Rat	8000 ppm, 4 hours
Oral		
LD50	Rat	1540 mg/kg

* Estimates for product may be based on additional component data not shown.

Skin corrosion/irritation	Causes skin irritation.
Serious eye damage/eye irritation	Causes serious eye irritation.
Respiratory or skin sensitization	
Respiratory sensitization	Not available.
Skin sensitization	This product is not expected to cause skin sensitization.
Germ cell mutagenicity	No data available to indicate product or any components present at greater than 0.1% are mutagenic or genotoxic.

Carcinogenicity In 2012 USEPA Integrated Risk Information System (IRIS) reviewed a two species inhalation lifetime study on THF conducted by NTP (1998). Male rats developed renal tumors and female mice developed liver tumors while neither the female rats nor the male mice showed similar results. Because the carcinogenic mechanisms could not be identified clearly in either species for either tumor, the EPA determined that the male rat and female mouse findings are relevant to the assessment of carcinogenic potential in humans. Therefore, the IRIS review concludes that these data in aggregate indicate that there is "suggestive evidence of carcinogenic potential" following exposure to THF by all routes of exposure.

IARC Monographs. Overall Evaluation of Carcinogenicity

Cyclohexanone (CAS 108-94-1) 3 Not classifiable as to carcinogenicity to humans.

OSHA Specifically Regulated Substances (29 CFR 1910.1001-1050)

Not listed.

Reproductive toxicity This product is not expected to cause reproductive or developmental effects.

Specific target organ toxicity - single exposure Narcotic effects. May cause drowsiness and dizziness. Respiratory tract irritation.

Specific target organ toxicity - repeated exposure Not classified.

Aspiration hazard May be fatal if swallowed and enters airways.

Chronic effects Prolonged inhalation may be harmful.

12. Ecological information

Ecotoxicity The product is not classified as environmentally hazardous. However, this does not exclude the possibility that large or frequent spills can have a harmful or damaging effect on the environment.

Components		Species	Test Results
Acetone (CAS 67-64-1)			
Aquatic			
Fish	LC50	Fathead minnow (Pimephales promelas)	> 100 mg/l, 96 hours
Cyclohexanone (CAS 108-94-1)			
Aquatic			
Fish	LC50	Fathead minnow (Pimephales promelas)	481 - 578 mg/l, 96 hours

* Estimates for product may be based on additional component data not shown.

Persistence and degradability No data is available on the degradability of this product.

Bioaccumulative potential No data available.

Partition coefficient n-octanol / water (log Kow)

Acetone (CAS 67-64-1)	-0.24
Cyclohexanone (CAS 108-94-1)	0.81
Furan, Tetrahydro- (CAS 109-99-9)	0.46
Methyl ethyl ketone (CAS 78-93-3)	0.29

Mobility in soil No data available.

Other adverse effects No other adverse environmental effects (e.g. ozone depletion, photochemical ozone creation potential, endocrine disruption, global warming potential) are expected from this component.

13. Disposal considerations

Disposal instructions Collect and reclaim or dispose in sealed containers at licensed waste disposal site. This material and its container must be disposed of as hazardous waste. Do not allow this material to drain into sewers/water supplies. Do not contaminate ponds, waterways or ditches with chemical or used container. Dispose of contents/container in accordance with local/regional/national/international regulations.

Local disposal regulations Dispose in accordance with all applicable regulations.

Hazardous waste code The waste code should be assigned in discussion between the user, the producer and the waste disposal company.

Waste from residues / unused products Dispose of in accordance with local regulations. Empty containers or liners may retain some product residues. This material and its container must be disposed of in a safe manner (see: Disposal instructions).

Contaminated packaging Empty containers should be taken to an approved waste handling site for recycling or disposal. Since emptied containers may retain product residue, follow label warnings even after container is emptied.

14. Transport information

DOT

UN number	UN1993
UN proper shipping name	Flammable liquids, n.o.s. (Methyl ethyl ketone RQ = 26274 LBS, Acetone RQ = 13130 LBS)
Transport hazard class(es)	
Class	3
Subsidiary risk	-
Label(s)	3
Packing group	II
Special precautions for user	Read safety instructions, SDS and emergency procedures before handling.
Special provisions	IB2, T7, TP1, TP8, TP28
Packaging exceptions	150
Packaging non bulk	202
Packaging bulk	242

IATA

UN number	UN1993
UN proper shipping name	Flammable liquid, n.o.s. (Methyl ethyl ketone, Acetone)
Transport hazard class(es)	
Class	3
Subsidiary risk	-
Packing group	II
Environmental hazards	No.
ERG Code	3H
Special precautions for user	Read safety instructions, SDS and emergency procedures before handling.

IMDG

UN number	UN1993
UN proper shipping name	FLAMMABLE LIQUID, N.O.S. (Methyl ethyl ketone, Acetone)
Transport hazard class(es)	
Class	3
Subsidiary risk	-
Packing group	II
Environmental hazards	
Marine pollutant	No.
EmS	F-E, S-E
Special precautions for user	Read safety instructions, SDS and emergency procedures before handling.

Transport in bulk according to Annex II of MARPOL 73/78 and the IBC Code Not available.

15. Regulatory information

US federal regulations This product is a "Hazardous Chemical" as defined by the OSHA Hazard Communication Standard, 29 CFR 1910.1200.
All components are on the U.S. EPA TSCA Inventory List.

TSCA Section 12(b) Export Notification (40 CFR 707, Subpt. D)

Not regulated.

OSHA Specifically Regulated Substances (29 CFR 1910.1001-1050)

Not listed.

CERCLA Hazardous Substance List (40 CFR 302.4)

Acetone (CAS 67-64-1)	LISTED
Cyclohexanone (CAS 108-94-1)	LISTED
Furan, Tetrahydro- (CAS 109-99-9)	LISTED
Methyl ethyl ketone (CAS 78-93-3)	LISTED

Superfund Amendments and Reauthorization Act of 1986 (SARA)

Hazard categories
Immediate Hazard - Yes
Delayed Hazard - No
Fire Hazard - Yes
Pressure Hazard - No
Reactivity Hazard - No

SARA 302 Extremely hazardous substance

Not listed.

SARA 311/312 Hazardous chemical No

SARA 313 (TRI reporting)

Not regulated.

Other federal regulations

Clean Air Act (CAA) Section 112 Hazardous Air Pollutants (HAPs) List

Not regulated.

Clean Air Act (CAA) Section 112(r) Accidental Release Prevention (40 CFR 68.130)

Not regulated.

Safe Drinking Water Act (SDWA) Not regulated.

Drug Enforcement Administration (DEA). List 2, Essential Chemicals (21 CFR 1310.02(b) and 1310.04(f)(2) and Chemical Code Number

Acetone (CAS 67-64-1)	6532
Methyl ethyl ketone (CAS 78-93-3)	6714

Drug Enforcement Administration (DEA). List 1 & 2 Exempt Chemical Mixtures (21 CFR 1310.12(c))

Acetone (CAS 67-64-1)	35 %WV
Methyl ethyl ketone (CAS 78-93-3)	35 %WV

DEA Exempt Chemical Mixtures Code Number

Acetone (CAS 67-64-1)	6532
Methyl ethyl ketone (CAS 78-93-3)	6714

US state regulations

US. Massachusetts RTK - Substance List

Acetone (CAS 67-64-1)
Cyclohexanone (CAS 108-94-1)
Furan, Tetrahydro- (CAS 109-99-9)
Methyl ethyl ketone (CAS 78-93-3)

US. New Jersey Worker and Community Right-to-Know Act

Acetone (CAS 67-64-1)
Cyclohexanone (CAS 108-94-1)
Furan, Tetrahydro- (CAS 109-99-9)
Methyl ethyl ketone (CAS 78-93-3)

US. Pennsylvania Worker and Community Right-to-Know Law

Acetone (CAS 67-64-1)
Cyclohexanone (CAS 108-94-1)
Furan, Tetrahydro- (CAS 109-99-9)
Methyl ethyl ketone (CAS 78-93-3)

US. Rhode Island RTK

Acetone (CAS 67-64-1)
Cyclohexanone (CAS 108-94-1)
Furan, Tetrahydro- (CAS 109-99-9)
Methyl ethyl ketone (CAS 78-93-3)

US. California Proposition 65

California Safe Drinking Water and Toxic Enforcement Act of 1986 (Proposition 65): This material is not known to contain any chemicals currently listed as carcinogens or reproductive toxins.

International Inventories

Country(s) or region	Inventory name	On inventory (yes/no)*
Canada	Domestic Substances List (DSL)	Yes
United States & Puerto Rico	Toxic Substances Control Act (TSCA) Inventory	Yes

*A "Yes" indicates this product complies with the inventory requirements administered by the governing country(s).
A "No" indicates that one or more components of the product are not listed or exempt from listing on the inventory administered by the governing country(s).

16. Other information, including date of preparation or last revision

Issue date 27-May-2015

Revision date -

Version # 01

HMIS® ratings
Health: 2
Flammability: 3
Physical hazard: 0

NFPA ratings

Disclaimer
The information in the sheet was written based on the best knowledge and experience currently available. William H. Harvey Company cannot anticipate all conditions under which this information and its product, or the products of other manufacturers in combination with its product, may be used. It is the user's responsibility to ensure safe conditions for handling, storage and disposal of the product, and to assume liability for loss, injury, damage or expense due to improper use.

APPENDIX T: RULER MATLAB CODE


```
clear
clc

D_o=6.625; % in inches; used outside diameter of nominal 6 pipe
r_o=D_o/2; % getting radius for outside diameter
D_i=6.065; %inner diameter
thickness=(D_o-D_i)/2;


h=[thickness:.0625:D_i] % making 93 increments of arc length s in increments of .0625
...from a vertical ruler
h_display = h-thickness;
theta=acos(1-(h/r_o)) % calculating angle theta to solve for s

s=theta*r_o % finding vertical height on ruler equivalent to chord length

for i=1:1:44 % find smallest difference that exists so i can space out increments
ruler
lowest_difference(i)=s(i+1)-s(i)
end


for i=1:4:93 % setting out increments so i don't mess up putting the numbers down in
drawing
first_s(i)=s(i)
end

for i=1:4:93 % setting out increments so i don't mess up putting the numbers down in
drawing
h_display1(i)=h_display(i)
end

for i=2:4:93 % setting out increments so i don't mess up putting the numbers down in
drawing
second_s(i)=s(i)
end

for i=2:4:93 % setting out increments so i don't mess up putting the numbers down in
drawing
h_display2(i)=h_display(i)
end

for i=3:4:93 % setting out increments so i don't mess up putting the numbers down in
drawing
third_s(i)=s(i)
end

for i=3:4:93 % setting out increments so i don't mess up putting the numbers down in
drawing
h_display3(i)=h_display(i)
end
```

```
for i=4:4:93
fourth_s(i)=s(i)
end

for i=4:4:93
h_display4(i)=h_display(i)
end
```

APPENDIX U: OMEGA FTB740 TURBINE FLOWMETER SPEC SHEET

Turbine Flow Meters

PVC Flange Mount

FTB700 Series

1 YEAR WARRANTY CE RoHS

FTB730, shown with DPF143P and DPF140-W2M sold separately, smaller than actual size.

- High-Accuracy Machined Turbine Internals Removable with Meter in Line
- Standard Meter Bodies are Flanged

OMEGA® FTB700 Series turbine meters have a unique system of precisely-machined helical rotors and high-quality jewel bearings. The rotor is the only moving part. Small magnets on the rotor hub are electronically detected by a solid state Hall-effect sensor outside the wetted area. The turbine rotor uses journal-type sapphire and ruby bearings for minimum friction and maximum life. These bearings are ideal for long life in water and water-based fluids, and they have exceptional low-flow characteristics. The entire rotor assembly (rotor, hubs, bearings, rotor strut) can be removed from the meter as a single unit without removing the meter from the pipe.

Specifications

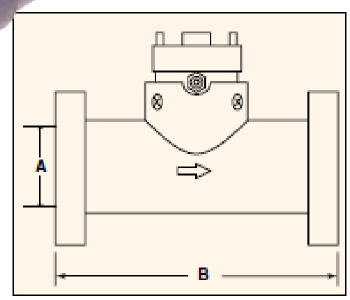
Maximum Working Pressure: 150 psi PVC
Maximum Temperature:
PVC: 49°C (120°F)
Accuracy: ±1% FS
Signal: Squarewave pulse
Power: 6 to 24 Vdc

Materials

Meter Body: PVC
Flanges: Van Stone with steel backing flange
Turbine Rotor: PVDF
Rotor Shafts: Zirconia ceramic
Bearings: Sapphire journal, ruby ball

FTB700-T (Optional Blind Transmitter)

Output: 4 to 20 mA
Loop Power: 12 to 26 Vdc (isolated)
Accuracy: ±1%
Response Time: 3 sec, 95% FS



Temperature/Pressure for PVC Body

Operating Temp °C (°F)	Maximum Operating Pressure bar (psi)
24 (75)	10 (150)
38 (100)	9 (124)
49 (120)	5 (75)
54 (130)	3 (50)

To Order

Model No. PVC	Flow GPM	Pulses/Gal	Pipe Size "A" mm (inch)	Length "B" mm (inch)
FTB720	2 to 150	60	51 (2)	254 (10)
FTB730	3 to 400	10	76 (3)	305 (12)
FTB740	6 to 600	5	102 (4)	356 (14)
FTB760	12 to 1200	2	152 (6)	457 (18)

Accessories

Model No.	Description
FTB700-T	Blind 4 to 20 mA transmitter
PSU-93	24 Vdc power supply

Comes complete with 5.5 m (18') cable and operator's manual.

Appendix V: Omega DPF701 Display Meter Spec Sheet

6-DIGIT RATEMETER/TOTALIZER

MONOGRAM™ SERIES

DPF701 Series

Starts at $260

5 YEAR WARRANTY · MADE IN USA · CE

DPF701, $260, shown smaller than actual size, with FP7000S, flow sensor, $200, sold separately, search omega.com.

- 5-Year Warranty
- Measures Rate from 0.5 Hz to 30 kHz
- Totalizes Up or Down from -99,999 to 999,999 or Acts as Accumulating Stopwatch
- Optional High and Low Setpoints for Control or Alarm
- ⅛ DIN Case with 5 Front-Panel Keys
- 6-Digit, 7-Segment, 14.2 mm (0.56") High LED
- NEMA 4 Front Bezel

Signal Input Choices (Selectable by DIP Switch)

- TTL Compatible with Protection to 25 V
- Low Level (25 mVrms)
- High-Level Signals Protected to 115 V
- NAMUR
- Open-Collector PNP or NPN

Sensor Excitation Output

- 12.5 V to 100 mA
- 8.2 V to 70 mA
- 5.0 V to 50 mA

Optional Communications and Control

- RS232 Output Optional
- Dual 5 A Form "C" Relays
- Analog Output: Scalable, 4 to 20 mA, 0 to 20 mA, 0 to 10 V

The DPF701 Series ratemeter/totalizer offers user programming via the 5 front-panel keys. Scale factor may be programmed from -99,999 to 999,999 (any decimal point, multiply or divide), while offset may be programmed from -99,999 to 999,999 (any decimal point).

Programs are stored in non-volatile memory, with 3 levels of program lockout for security. Optional features include high or low setpoints for control or alarm and RS232 communications. Fixed decimal point and auto-ranging are standard.

SPECIFICATIONS

Functions: Rate and totalize, menu selectable
Display: 6-digit, 7-segment, red LED
Inputs
Type: Single input; TTL, CMOS, NPN open collector, contact closure and magnetic pickup compatible; selected by DIP switch; non-isolated
Level: Max 60 V; min 25 mVrms
Frequency: 30 kHz max
Excitation: Regulated; 5.0, 8.2, or 12.5 V selected by DIP switch; 100 mA max
Accuracy: ±½ LSD of total; 0.01% of the rate ±1½ LSD
Setpoints: 2 (optional)
Alarm Outputs: Optional
Communications (Optional): RS232, analog output
Rate Measurement Technique: 1/x
Gate Time: 0.30 s
Decimal Point: Programmable or auto-ranging
Trigger Slope: Selectable by DIP switch
Leading Zeros: Blank
Power: 115 or 230 Vac ±15%
Dimensions: 48 H x 96 W x 152 mm D (1.9 x 3.8 x 6")
Panel Cutout: 45 H x 92 mm W (1.8 x 3.6")
Weight: 454 g (16 oz)

MOST POPULAR MODELS HIGHLIGHTED!

To Order *(Specify Model Number)*

MODEL NO.	PRICE	DESCRIPTION
DPF701	$260	115 Vac/7.5 to 13 Vdc powered
DPF702	260	230 Vac/7.5 to 13 Vdc powered
OPTION BOARDS (FIELD INSTALLABLE)		
DPF700-A	$100	Analog output board
DPF700-R	75	Dual 5 A relay board
DPF700-232	60	RS232 output board

Comes with gray BUMPER BAND® protective rubber guard and complete operator's manual.
***Ordering Example:** DPF701, ratemeter/totalizer with 115 Vac power, **DPF700-A**, analog output board, $260 + 100 = **$360**.*

ACCESSORY

MODEL NO.	PRICE	DESCRIPTION
ES-2070	$210	Reference Book: Hazardous Materials Handbook