ME 450 F12

FILTER MEDIA TEST UNIT

FINAL REPORT

Sponsored By: Dow Chemical

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EXECUTIVE SUMMARY

ABSTRACT

The Dow Chemical Company is currently designing flat filter media for use in future commercial and industrial water filtration products. Dow's product design group needs to characterize the performance of these media under various conditions to ensure their filters are designed for optimal performance. To achieve this, we have designed and manufactured a safe, portable, laboratory-suitable apparatus that subjects samples of flat filter media to particulate-contaminated water under controllable flow rates and various fixturing conditions, and then uses sensors to characterize the through-filter volumetric flow rate, pressure drop, and streamline angle relative to the filter.

DESIGN OBJECTIVES

The primary objective of our apparatus is to enable Dow to characterize the performance of their experimental filter media to allow them to develop the next generation of filter products. We sought to create a device that subjects samples of filter media to conditions similar to those found inside actual filter designs and records the resulting filter media performance for analysis by Dow. Beyond performance, our design objectives include ensuring user safety, ease of use, and durability.

SPECIFICATIONS

The unit is capable of holding a filter coupon with a thickness ranging from 0.004 to 0.040 in and a footprint measuring 3 in. x 3 in. (with retooling capability allowing up to 1 in. x 1in. to 4 in. x 4in.). The unit is capable of supplying up to 1 gpm/in^2 (of filter) and 2psi of contaminated water to the filter, and is capable of producing an angle between the flow and the filter normal ranging from 0° to at least 60° in 15° increments, and is equipped with sensors capable of measuring pressure drop across the filter to ±0.005psi and flow rate through the filter to ±0.03gpm/in^2. Additional specifications concerning safety, the user interface, contaminated water capacity, durability, and portability are contained within the report.

METHODOLOGY

Our group met with Dow several times to determine their exact customer specifications, and from there developed a variety of concepts to fulfill each design sub-function. Upon assessing each of these designs against Dow's criteria and technical feasibility, we developed a prototype idea. This concept was refined with engineering optimization, and then manufactured by our group. This final design consisted of two main modules. The filter is mounted into a pressurized chamber which is placed in a complete channel module which develops the flow conditions that are necessary (laminar and relative filter angles), and this channel allows for the mounting of the necessary flow and pressure sensors. The other major module of this design is the cart module. This module contains the water reservoir, the system's pump, and the VFD, which allows the pump to create the range of flows required of the unit. Once these modules were assembled, the completed device was then wired with sensors and tested to ensure that all specifications (of physical construction, codes, and performance).

OUTCOMES

Through numerous tests and measurements we verified that the unit does meet its physical requirements. Through flow observations we verified that the unit produces flows that meet the flow requirements and are sufficiently laminar. Though initial testing indicates full functionality, due to limited resources we were unable to definitively verify that the unit accurately characterizes flat filter media. Overall, to the best of our ability to measure, our final unit meets its required specifications, and exceeds them in its: filter angling ability, by-pass feature, and its lab adaptability, among others. However, the unit's filter fixturing could be more ergonomic, its controllers and sensors could be more fully integrated into LabVIEW, and more of Dow's "wish list" features could be integrated into the design. But these shortcomings, if proven to be detrimental, can easily be incorporated in to the unit at a later time. With the features that are present on our final design, Dow will be able to characterize the flow and pressure drop characteristics of flat filter media.

ABSTRACT

The Dow Chemical Company is currently designing flat filter media for use in future commercial and industrial water filtration products. Dow's product design group needs to characterize the performance of these media under various conditions to ensure their filters are designed for optimal performance. The purpose of this project is to design and fabricate a safe, portable, workshop-suitable apparatus that will subject their samples of filter media to particulate-contaminated water under LabVIEW-controllable flow and various fixturing conditions, and then use sensors to characterize the through-filter volumetric flow rate, pressure drop, media deformation/displacement, and streamline angle relative to the filter.

BACKGROUND

Demand for clean water is a pressing concern worldwide. Water borne diseases are infectious diseases spread primarily through contaminated water, which threaten human lives. Reports have shown that 1.1 billion people did not have safe drinking water in 2010 and 2 million people die from contaminated water every year [1]. The increasing demand for clean water is also driven by growing agricultural and industrial fields. With an increasing world population and populous economies rapidly developing, more productive ways of water treatment need to be found to avoid a water shortage. Water filtration is one promising and widely used method for water treatment.

Dow Chemical Company

Dow Chemical Company is a multinational chemical company with headquarters located in Midland, Michigan [2]. It is a provider of plastics, chemicals, and agricultural products with about 197 facilities and 50,000 employees in 36 countries worldwide. Dow aims to connect chemistry and innovation together with a principal of sustainability. As an industrial leader in water purification and separation, Dow excels in providing reliable, viable, and effective water treatment [3].

PROBLEM DESCRIPTION

Our project aims to design and fabricate a test unit that will allow Dow to evaluate the performance of their new filter media products, which will be essential for their filter system development. The filter media is the "heart" of a filter device, as it performs the actual work of separating particulates from contaminated water. Dow requires accurate and precise measurements of its performance capabilities to aid in the development of devices for industrial or commercial uses.

This project initiated from Dow Process & Water Solutions, which is a business unit of Dow in Minnesota. We will work closely with our sponsor, ****** ******, and his group from Dow's department of product prototyping and development in Midland, Michigan to develop the design of this novel device.

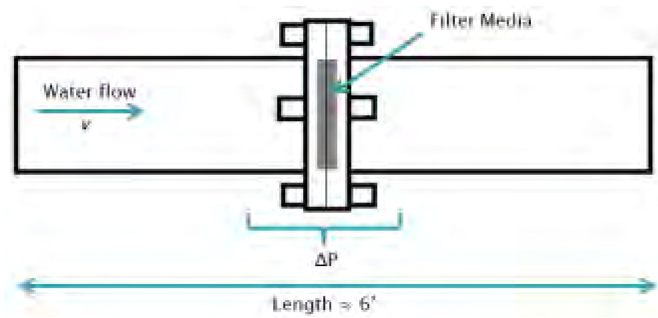
LITERATURE REVIEW

By researching through journals, patents, and other available resources online, we found that there is no existing testing unit that addresses all of the specific requirements laid out by Dow for this project. Therefore, we focused on single component functional research and found three devices that share certain functionalities with the device that we plan to build and are discussed below.

Simple Water Testing Device

Our sponsor described a simple device currently used for media testing in one of Dow's subsidiaries, which is roughly sketched in Fig. 1. This device has filter media fixed between two pipe flanges, which are mounted in the middle of a pipe about six feet long. This testing unit measures incoming water flow rate and the resulting pressure drop across the filter media, though it is only capable of providing water flow normal to the media.

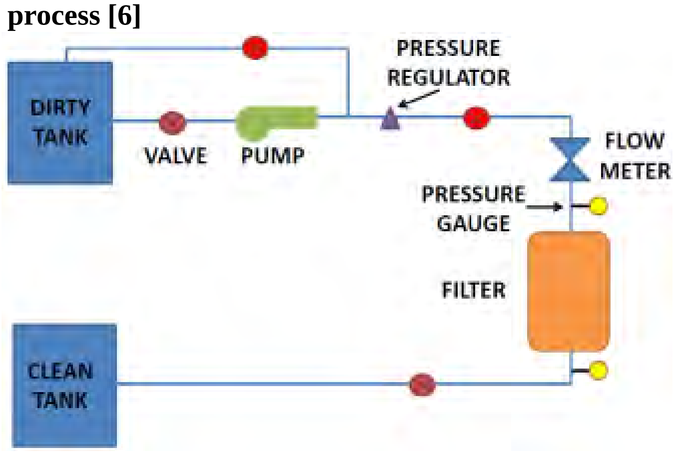
Fig. 1: Existing Dow filter media test unit. The media is sandwiched between two pipe flanges.



Crumb Rubber Pre-filter w/Test Stand

We consider a senior project from three students from Rochester Institute of Technology most close to what we are working on. The primary goal of their project was to design a water filter media test stand able to be used with any water filter that is created, and to test filters under various temperatures and running times (Fig. 2) [6]. The importance of this device to our project is their proposed pumping and controls system (shown in Fig. 2) that could be adapted in part or whole to our design. Their pressure regulator and valve regulate the output pressure and flow rate from their pump into their test chamber, similar to what we seek to do. The students of this project also tested various filter media using their device, and their testing documentation is potentially useful to us as well. However, since our project goal is significantly different from theirs, we still need to address concerns raised from our own problems with unique solutions corresponding to our customer's requirements.

Fig. 2: Water filtration process [6]



CUSTOMER REQUIREMENTS AND ENGINEERING SPECIFICATIONS

To simulate the actual modes in which filter media is used in Dow's filter devices, as well as to make sure the testing unit measures the needed filter media parameters, we have been in close contact with Dow. Through four teleconferences with our main contact at Dow, ****** ****** [7,8, and 9], a visit to the Dow facility [10], and several emails to ******, a list of customer requirements for the filter media testing unit was given to us, many of which directly translated into engineering specifications. Values for other specifications were directly adapted from real conditions in which Dow uses filter media, and how they want to integrate the test unit within their laboratory. We ranked the subsequent design specifications using a Quality Functional Deployment (QFD) Chart, which is included as Appendix A. Dow's requirements and the corresponding engineering specifications are shown in Table 1.

Table 1. Dow's Requirements for the Filter Media Test unit and the Corresponding Engineering Specifications

Spec. Rank	**Dow's Requirement**	**Engineering Specification**	**Value**
1 2	Safe in the Workplace (follows pertinent MIOSHA standards)	Follows MIOSHA part 93 (Air Receivers- see Appendix B for standard) Follows MIOSHA Part 39 (Design Safety Standards for Electrical Systems - see Appendix C for excerpted standard)	Yes 4 Yes
3	Able to vary system flow rate	Laminar unit flow rates upstream of the filter	From 0 to at least 16 gpm through the filter or 0 to 2 psi pressure drop across filter media
4 (Tie) 4 (Tie)	Able to measure flow rates Able to measure pressure drop across filter media	Flow rate accuracy (in a range from 2 to 16 gpm) Pressure drop accuracy	$\pm$ 0.03 gpm / in^2 $\pm$ 0.0125 psi
6	Able to vary water flow angle relative to filter media for a specified range	Relative flow angles	0^o to at least 60^o (in increments of 15^o or less, where 0^o is normal flow)
7	Leave room in the design for a sensor to measure the filter flex measurement (This specification is modified by our sponsor due to budget limitations and feasibility concerns)	Have mounting location for filter flex sensor directly behind the center of the filter	Yes
8	Data output for flow rate and pressure drop (This specification is modified by our sponsor due to budget limitations and excess complexity when using	~~record the system's flow rate, pressure drop across the filter and filter flex~~ Direct digital readout display or LabVIEW data logging for flow rate and pressure drop	Yes

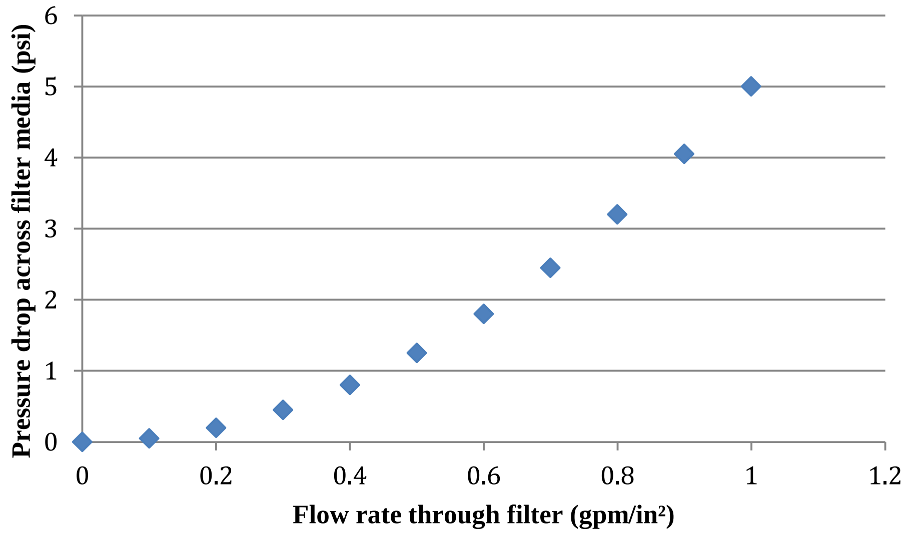
	LabVIEW to control the whole system)		
9	Document validity of testing unit	Demonstrate ability to accurately quantify known media	Yes
10	Unit instructions	Provide detailed user instructions	Yes
11	Quick filter change time	Time to drain the test tunnel and change filter media sample	< 10 min
12	Physically user friendly	Common controls height	36 in. – 73 in.
13	Unit can withstand dirty water	Minimum hours of use before water contaminant abrasion related failures	360 hrs.
14	Unit compatible with various sized filter media samples	Retoolable to hold filter sizes ranging from:	1 in. x 1 in. to 4 in. x 4 in.
15	Hold specified filter sample size	Able to securely hold a filter of specified size	3 in. x 3 in. Thickness of 0.004 in. to 0.04 in
16	Easily movable by one person	Lifting required to move unit	~~< 35 lbs~~ No assembled component requiring lifting will exceed 35 lbs, the non-lifting parts will be placed on wheels
17	Able to purge contaminated water	Time to drain all water from the system ~~completely~~	<10 min
18	Does not damage filter media	No plastic deformation of the filter when fixturing the filter media	Yes
19	Compatible with hot water	Can handle working fluid temps up to and including at least	140ºF
20	Self-contained	System has the ability to store and recirculate contaminated water (filtered and by-pass)	Yes
21	Allow user to add contaminants	Water in system is user accessible and access point allows addition of Arizona Dust in amounts of up to 20,000 ppm loading	Yes

Safety
Though the unit needs to be able test specific filter media parameters in specific methods, safety is a top priority of Dow. Since this unit will be used in the Dow laboratory workplace, it is necessary that it meets all of the pertinent MIOSHA standards. Since parts of the unit will be pressurized, it is necessary that the system meets MIOSHA part 93 (Air receivers), which is provided in Appendix B. The other pertinent MIOSHA regulation is part 39 (Design Safety Standards for Electrical Systems), which is excerpted in Appendix C. This standard enforces that electrical components are properly wired, grounded and protected, as to minimize the risk of a user being shocked or injured by electricity.

Variable Laminar Flow Rates/ Pressures
In order to test the filter media's entire range of behavior, the unit should be able to vary the through-filter flow rates and filter pressure drop. To match the working conditions of the filter media in a Dow device, ****** informed us that the system must be capable of generating through-filter flow rates from 0-1 gpm/ in^2 of media being tested and pressure drops of 0-~~5~~ 2 psi across the filter. Pressure drop and flow rate will be dependent on each other, and that dependence will be a function of the filter material. Since the unit should be able to test filter sizes up to 4in.x 4in., a unit flow rate of at least 16gpm is needed (for smaller filter sizes, maximum flow rates of 1 gpm/in^2 of filter media will by virtue be included in this range). Unit flow rates beyond this amount would be acceptable, as Dow approves of a design that has the ability to create by-pass flow around the filter media. Some by-pass flow is required in certain testing situations, as some of Dow's filter devices allow local by-pass on a particular filter section in order to improve filter performance. A pressure drop of ~~5~~ 2 psi was specified because, per correspondence with Dow, as a pressure drop representative of what they might see at a flow rate of 1gpm/in^2. Due to proprietary confidentiality they could not give us any more information on the relationship.

Dow wants to be able to use either target filter pressure drop or flow rate as an input, and sweep the laminar flow regime with that parameter, and generate a curve; an example of what that curve might look like is shown in Fig. 3. Dow wants to use this test unit to parameterize the filter media for the laminar flow regime because, per correspondence with Dow, it is easy to characterize filter performance in the turbulent flow regime if it is characterized in the laminar flow regime, but hard to do the reverse. Therefore, any turbulence in the flow through the filter needs to have been caused by the filter media, and not by the fixture or upstream channel. This requirement is what drove the 1gpm/in^2 flow specification, as flow higher than this will cause turbulence (as determined by the calculation of the Reynolds number and comparison to established laminar-turbulent Reynolds values).

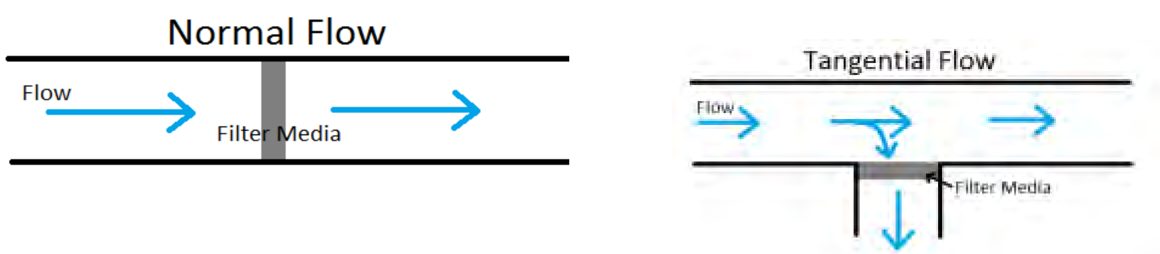
Fig. 3 Example schematic of flow rate through filter and resulting pressure drop across filter curve



Flow Rate and Pressure Drop Measurements
Measuring the flow rate and the pressure drop across the filter is equally important, and is the most values that the unit needs to be able to measure. Knowing how Dow wants to be able to use this data, ****** specified that the unit should be accurate to ± 0.03gpm/ in^2 for flow rate, and ± 0.01psi for the pressure drop across the filter media. These accuracies are needed so that the data precision meets the input precision Dow needs for designing complete filter units; because of confidentiality Dow could not be any more specific.

Flow Angle
Dow uses filter media in many novel and unusual geometries, and many times the water flow relative to the media is not purely normal; instead there is a tangential water flow, where a limited portion of the flow passes through the filter media while the rest by-passes it. Diagrams of the normal flow and the tangential flow are shown in Fig. 4. These tangential flows are often used to help filter out small particulates. Different Dow filter units use different filter angle orientation, and by being able to test different flow angles with the unit, Dow plans to determine how the filter performance is dependent on the flow angle. Our filter media testing unit should be able to characterize the performance of the filter media in flows ranging from pure normal flow to at least 60 degrees off from normal, and preferably all the way to pure tangential flow (90°), with a increments of 15 degrees or less. Dow's experience indicates that the relationship between filter angle and filter performance will be monotonic, therefore the 15 degree increments will be sufficient to interpolate between.

Fig. 4: Schematic view of normal and tangential flow regimes. Notice how in normal flow all the water goes through the filter (no bypass), while in tangential flow most all the water bypasses the filter.



Per our conversations with ******, our design only needs to be able to test the filter media samples while allowing no water to by-pass the filter. However, to add additional functionality to the design, a parameterized by-pass system would be helpful. To make the data useful, this by pass functionality should be as independent from the angle of flow as possible. Parameterizing the functionality of filter media with respect to the filter angle will help Dow better utilize geometrical features in their filter units.

Document Testing Unit's Validity

To make sure that the unit correctly measures filter media parameters, the testing unit should be validated. Per Dow's instruction, this should be done by confirming the device can correctly quantify the performance of a known filter media. The unit should be able to create the correct flow rate versus pressure drop curve for normal flow through a Dow specified filter media.

Unit Instructions

Every facet of this device may not be intuitive. Because Dow wants to accurately measure the performance of the tested filter media, instructions on how to use the unit are required. To make sure the entire data output system is understood and to make sure any of the necessary user interfaces with mechanical components are properly known, a detailed set of instructions on how to use the unit must be provided. These instructions will explain, among other things, how to adjust the input parameters, access the stored data, and drain the system.

Quick Change

Since Dow wants to test many different filter media with this device, and laboratory personnel is valuable, the time required to change between different filter media should be minimal. Dow specified that it should take no more than 10 minutes to perform both the necessary draining to access the filter media, and the filter changing itself, with a preference that the operation should take less than two minutes, because these are typical specimen change times for other Dow lab units.

Physically User Friendly

Because of the large amount of data which Dow intends to collect, users could be operating this device for extended periods of time. To minimize user fatigue the unit should be physically user friendly. The common controls, through which the operator will have their main interaction with the device, should be in easy reaching distance from either a sitting or standing position. Using an ergonomics handbook [17], it was found that for stand-up usage, the main controls heights should be between 36 in. to 73 in. high so that the operation of the device is comfortable to the user; standards for sitting operation were not used because they were more restrictive. Continued use of this handbook will also allow correct selection of control handles and switches to be made.

Unit Can Withstand Dirty Water

The unit needs to run dirty water through the filter; therefore, to ensure the longevity of the device, the resistant to dirt in the water. Using Dow's minimum product life expectancy, which is five years, and the fact that they expect to use the device for at least 18 hours a quarter, it was calculated that the device needs to last at least 360 hours before failure. Therefore, the unit should not fail due to Arizona dust contaminants with a maximum of 20,000 ppm loading before 360 hours of use.

Holds Specified Filter Sample Size

Dow has specified that the filter media coupons they intend to test, measure 3 in. x 3 in, with thickness ranging from 0.004in to 0.040 in Our device must be able to secure a piece of filter media this size securely enough that the pressure of the tests will not dislodge them, but also keep at least 50 % of the surface area of the filter coupon exposed to water flow to ensure that the unit can accurately characterize the filter media.

Unit Compatible with Various Sized Filter Media Sizes
To allow Dow to test differing filter media sizes in the future, the unit should be able to accommodate a range of filter media sizes. Per the specifications of Dow, the maximum filter media coupon size that would need to be tested is a 4 in. x 4 in. sample, and the minimum size is 1in.x1in. Also per Dow, it is acceptable if they have to perform some retooling of the device (eg: building a different sized sub-structure to hold the filter in the flow, which can be placed into the rest of the testing unit) before alternate sizes can be accepted.

Easily Movable
Dow wants to make this testing unit a standard laboratory machine, and as such they want it to be easily moveable. Their main concern with moving the unit is that the operator should be able to move the unit by themselves and that they do not have to do excessive lifting. Because the exact nature of Dow's moving and lifting requirements are not known (eg: the horizontal and vertical distances which the unit will be moved), we could not use the OSHA lifting equation to specify this requirement. However, a more general OSHA standard [11] recommends that lifting should be limited to 35lbs or less for tabletop items. For convenience, the device should be able to be moved without module disassembly and for safety, the individual modules should not exceed 35lbs. unless it they are mounted on wheels. Since the Dow facilities have floors with good surface finishes, wheeled device components would not need to meet this weight restriction.

Able to Purge Contaminated Water
Since Dow wants to vary the concentration of the contaminants in the closed-loop water system, the test unit should be able to purge itself of the water it contains. Since the timeliness of the filter testing is a concern for Dow, a time constraint equal to that of changing filter (under 10 minutes) should be used for this requirement. This time constraint includes the time to drain the necessary components for accessing the filter, and the time it takes to change the filter. This specification does not need to be any stricter because of the intermittent nature of Dow's expected use of this unit.

Does not Damage Filter Media
In order to maintain the integrity of the filter media's structure, and to make sure the filter media is not punctured, the filter holding device in the testing unit should not damage the filter media. This is of particular importance to Dow because some of the media which they plan to test may be one-of-a-kind. Per our conversation with ****** ******, the damage we seek to avoid includes puncturing (causing new holes to form in the filter material) and permanently deforming the media, so that the material does not spring back to its original dimensions once it is taken out of the device.

Compatible with Hot Water
To allow Dow to do further filter media characterization based on fluid temperature interactions, the unit should be able to handle hot water. Dow has indicated that they can run filters in working fluid temperatures up to and including 140^{o} F, therefore, our unit should be able to handle water temperatures up to and including this level, for the previously stated minimum life span of 360 hours of operation.

Self-Contained
Dow wants this testing device to not need excessive amounts of water when in use; the system should be self-contained. The device should not have excessive water requirements because it should be able to be used in a wide range of locations throughout their facility. To make sure the device is self-contained it should contain both its supply and waste waters. Since the dirt particle concentration will not be unacceptably affected as specified by our sponsor, if the filtered and bypassed water are reused in the testing device, the system's waste water can be its supply water. The concentration of the contamination should not be unacceptably effected, because per consultation with Dow, contaminates should not accumulate in the filter media.

Allows User to Add Contaminates
In order to minimize unit complexity, Dow has indicated the formulation of dirty water will be completed by the operator; however, the system needs to allow the user to change the concentration of dirt particles in the water by adding more Arizona dust to the water in the unit. To allow the addition of contaminates, the system should have an access point that allows the user to add Arizona dust to the water.

PROJECT CHALLENGES

Though many of the requirements for this testing unit are not exceptionally novel, there are some innovative aspects to the project and attention to detail will be necessary on all of the requirements so that the testing unit accurately characterizes the media being tested by the unit and that the unit is user friendly. A key engineering challenge will be making a flow delivery system that will supply a steady but user/computer variable flow rate to meet the specified flow rate or pressure drop. A fluctuation damping system will need to be implemented in the system so steady flow rates can be achieved. Either variable loop feedback or some type of variable flow restrictor will be needed to make sure that flow rates and consequently pressure drops can vary, so the filter characteristics can be known for the specified range of operation.

Attention to detail will help make sure other requirements are met. To measure flow rates and pressure drops accurately, special attention will have to be used to make sure that there is strictly laminar flow where these measurements are taken. Similarly, to make sure that the device is safe, attention to detail will have to be exercised, making sure safety factors are accounted (especially on pressurized sections), wiring and electronics are safely isolated from all wet components, and moving parts are properly shielded. Making a fixture that will hold the filter media correctly is expected to be another challenge, as the media cannot be physically damaged nor majorly occluded by the fixture (to allow at least 50% of the filter media area to be exposed). To make sure the filter media is not damaged or structurally deformed, it will be necessary to calculate the holding pressure which the unit will exert on the filter when holding it in place, and make sure this does not exceed the filter materials physical limits.

A novelty of this device that will take special engineering innovation will be the requirement that the angle of flow needs to vary from 0° to 60°, and possibly all the way to 90°. The solution is likely to involve complex fixturing geometry and/or interchangeable fixtures, which must be engineered to both perform the basic testing operation but also be robust and leakproof. Performing these operations – especially while working around the requirement to add sensors for filter flex, pressure drop, and flow rate – has proven to be difficult and has required extensive iterative design within CAD and collaboration with our sponsor.

CONCEPT GENERATION

In order to generate a fully functional filter media testing device, we decomposed the system into basic functional components. These components were directly generated from Dow’s requirements for the unit. A detailed functional decomposition diagram is provided in Appendix D, showing the information, material and energy flows for each functional design and the interactions between them.
The major functions the system needs to perform are:

- Measure pressure drop across the filter media
- Vary laminar flow rates
- Secure hold filter media
- Vary flow angle
- Measure flow rate through filter
- Purge contaminated water
- Allow the user to add and manage contaminants

With a clear functional decomposition, we brainstormed ideas and concepts for each functional design; research on product selection and detailed sketches for each sub components included in Appendix E.

CONCEPT SELECTION PROCESS

After compiling the list of functions that our unit needs to have, we individually brainstormed ideas on how to meet those sub-functions. Gathering all our individual ideas together, we examined these concepts first using "GO/NOGO" criteria based on concept technological readiness, budget limitations and whether the concepts would meet our specific customer requirements. From there, we discarded all ideas that received a "NOGO" assessment.

For each function, we created a list of criteria which could be used to critique the remaining feasible concepts and developed a Pugh chart to help us select the best concept. These criteria were developed using the overall requirements that Dow gave us (eg: system durability), the specific requirements for each function, and ME 450 feasibility requirements (eg: manufacturability).

In order to incorporate each member's engineering judgment, we weighted each criterion individually out of 100%, and individually rated how well each design met the various criteria using a scale from 1 (poor) to 5 (excellent). We then compiled and averaged our weights for each criteria and design. When conflicts arouse (eg: one member ranked a particular design-criteria match 1 when another ranked it a 5), we shared our concerns about the concept, ensured we were all of the same understanding, and negotiated a final more consistent score.

To finalize our Pugh chart, we multiplied our averaged ratings for each criterion by the averaged weight of each criteria, and then added all of these weighted rankings together for a final score. The design for each function with the highest score was chosen as the best design, and the top scoring designs for each function were investigated more thoroughly. The detailed criteria for GO/NOGO charts and the Pugh Chart with personal weightings and rankings for each functional design are given in Appendix F. A summary of the results for each functional design follows.

Measure pressure drop across the filter media: Our concepts for measuring the pressure drop across the filter included using two pressure transducers to read out upstream and downstream pressure values and calculate the difference and using a differential pressure transducer to measure the difference directly Based on our Pugh chart (Appendix F, results excerpted in Table 3), a differential pressure transducer surpasses two pressure transducers because it will ensure a pressure drop measurement accuracy to 0.01psi as required by Dow, while being simpler and easier to install in the filter system (Table 3). Some possible products are shown in Fig. 5 (a) and (b) [12].

Table 2. GO – NOGO decision for pressure drop measurement

Device	Two Pressure Transducers	Differential Pressure Transducer
DECISION	GO	GO

Table 3. Evaluation results for pressure drop measurement concepts

Two Pressure Transducers	Differential Pressure Transducer
3.71	4.08

Fig. 5 Different differential pressure transducers.[12]

(a) (b)

Vary flow rate and pressure: With a variety of initial ideas generated, we first eliminated ideas that were not feasible (Table 4). The reason why air driven is a No Go is that with this design the user is unable to access water within the system. The water column is unable to meet our engineering specification of delivering flows which have pressures ranging from 0 to 5 psi, because using a static water, a height of 11.5ft would be needed, which as we saw in our visit to Dow would not fit in the Dow laboratories. This height was simply calculated using the Bernoulli equation along a stream line ($P = \rho g h$), where flow area is constant (Eq. 1); ρ is the density of water, P is the difference in pressure, g is gravitational acceleration, and h is the drop in height.

We scored each of these "first iteration" concepts with a Pugh Chart (Appendix F) to produce initial rankings (Table 5). Realizing that the entire design space was not explored and that there was room for improvement, we combined ideas and created a second iteration of designs (Table 6). From this process it was found that the best concept is a pump with a duty cycle and an expansion tank. This design outscored the rest of devices because pressure and flow rate produced by the pump are accurately modulated using a duty cycle on a motor controller. The pressure tank, partially filled with pressurized air and partially filled with water, is fluid equivalent of a capacitor which damps out the pulsing from pumping system to deliver a smooth and laminar flow into the testing channel (Fig. 6).

Table 4. Go – NOGO decision for vary flow rate and pressure generation

Device	Pump w/ Duty Cycle	Pump w/ Varistor	Pump w/ Throttle Valve	Pump w/ Throttle and Bypass	Air Driven	Centrifuge	Pumped Water Tank w/ Air Head	Water Column
Decision	GO	GO	GO	GO	**NOGO**	GO	GO	**NOGO**

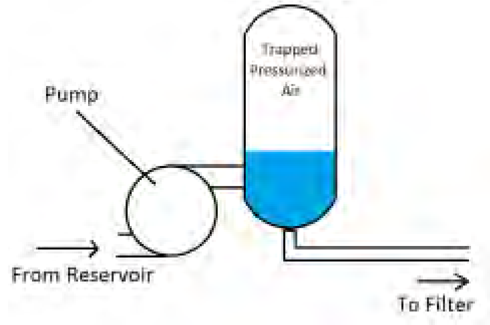
Table 5. Iteration 1: Evaluation results for vary flow rate and pressure generation. Full weights and ranks in Appendix F.

Pump w/ Duty Cycle	Pump w/ Varistor	Pump w/ Throttle Valve	Pump w/ Throttle and Bypass	Centrifuge	Pumped Water Tank w/ Air Head
4.02	4.02	3.76	3.79	2.85	3.38

Table 6. Iteration 2: Evaluation results for vary flow rate and pressure generation. Full weights and ranks in Appendix F.

Pump w/ Duty Cycle and a Colum w/ Weighted Piston	Pump w/ Duty Cycle and an Expansion Tank
3.18	4.03

Fig. 6 Components and mechanism of pump with duty cycle and an expansion tank



Fixture filter media: Our requirements call for a filter media fixture that will secure the filter in place without or damaging or permanently deforming the filter media. The design must be compatible with multiple thicknesses as required. Since the fixture can be retooled, it is acceptable if it only accepts one size filter coupon for a certain fixture size. Keeping these basic ideas in mind, we evaluated our initial concepts (shown in Table 7). The reason for NOGO on the Book Style concept is due to the hinge in the design, which made it incompatible with various filter thicknesses. This is the same reason for a NOGO decision for the Bump concept. Securing the filter media using magnets in a channel (dubbed "Magnachannel") was deemed infeasible because the magnetic field would interfere ~~with sensor signals~~ with other laboratory devices within their facility. The rest of the concepts were further evaluated in a Pugh chart (excerpt in Table 8, full in Appendix F).

We performed a second iteration of designs and analysis using the initial results, and from this developed a Bolted Retaining Ring concept that scored well (Table 9). The Bolted Retaining Ring outperforms other concepts due to its excellence in holding filter media securely and its compatibility with different filter thicknesses by adjusting how far the retaining bolts are screwed in. The rubber layer between the filter media and the retaining ring helps keep an approximately even pressure on filter media, even if retaining ring deflects slightly. (Fig. 7)

Table 7. Go – NOGO decision for fixture filter media

Device	Two Part Clamp	Book Style	Spring Tension	Fine Thread Nut	Square Washer	Edge Spring Clamp	Bump	Bolted Gasket	Magna-channel
DECISION	GO	NO GO	GO	GO	GO	GO	NO GO	GO	NOGO

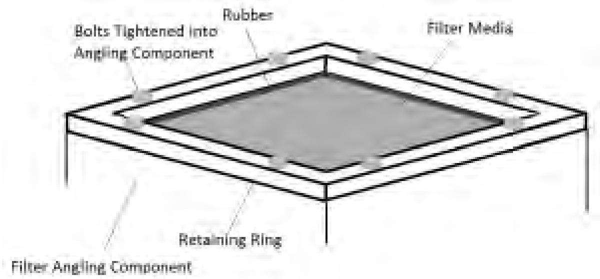
Table 8. Iteration 1: Evaluation results for fixture filter media. Full weights and ranks in Appendix F.

Flange	Spring Tension	Fine Thread Nut	Square Washer	Edge Spring Clamp	Bolted Gasket
3.38	3.57	3.44	3.47	3.22	2.91

Table 9. Iteration ~~1~~ 2: Evaluation results for fixture filter media. Full weights and ranks in Appendix F.

Spring Handle	Bolted Retaining Ring
3.53	3.73

Fig. 7. Schematic of the bolted retaining ring concept



Vary incoming flow angle: With a variety of possible ideas to generate various incoming flow angles (Table 10), we discarded the Roto-Nozzle concept as a "NOGO" since it is unable to produce laminar flow upstream. We scored the rest of concepts (Table 11) and came up with the best idea, the Rotating Chamber (Table 12), which is a combination of the Hinged Door and Channel in a Channel designs from iteration 1. The rotating chamber excels Channel in a Channel because it can be rotated around pivot point which allows the flow angle to vary from 0 to 90 degrees and it allows by-pass, allowing it to meet and exceed the customer requirement and engineering specifications (Fig. 8). It exceeds the rest of ideas because of its ease of sealing and its wide flow angle range.

Table 10. Go – NOGO decision for varying incoming flow angle

Device	Cassette	Roto-Nozzle	Hinged Door	Hinged Door w/ Secondary door	Rotating Hallway	Channel in a Channel
DECISION	GO	NOGO	GO	GO	GO	GO

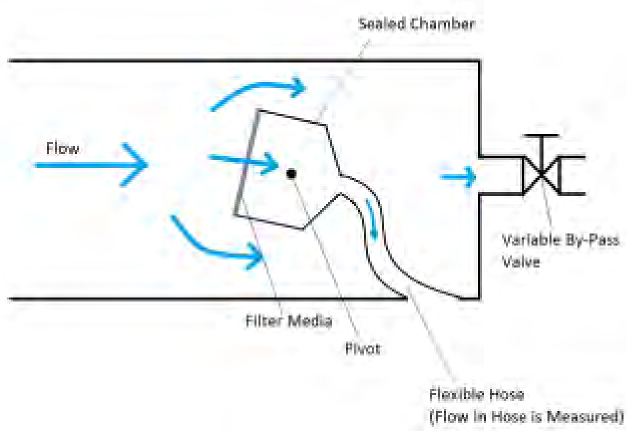
Table 11. Iteration 1: Evaluation results for varying incoming flow angle. Full weights and ranks in Appendix F.

Cassette	Hinged Door	Hinged Door w/ Secondary door	Rotating Hallway	Channel in a Channel
3.83	3.98	3.98	3.99	3.92

Table 12. Iteration 2: Evaluation results for varying incoming flow angle

Rotating Chamber
4.39

Fig. 8. Components and mechanism of rotating chamber



Measure Flow Rate: We researched a variety of possible flow meters and flow measurement techniques. The vortex flow meter we found was eliminated since this device inherently creates turbulence in the flow. The ultrasonic sensor was deemed a NO GO (Table 13) because it is unable to detect the flow rate for all of the Arizona Dust solutions that may be used in the unit. This is because an ultrasonic sensor only measures the speed of abnormalities suspended in the flow (for example particles); however, these anomalies must be within a certain size range for the sensor to pick up their movement and our expected contaminants will sometimes dip below this threshold. Lastly, the thermal flow meter was dropped because it would cause the temperature of the fluid to change. In the future Dow may want to use this device to measure filters performance dependence on temperature, and this device would alter the temperature of the flow.

We scored the remaining concepts and the Venturi Tube w/ Pressure Sensor had the highest rank (Table 14). The Venturi sensor is suitable for the system we are designing because it does not disturb flow, is dirt resilient, and is accurate even for low flow rates (Fig. 9 (a) and (b)). [13] [14]

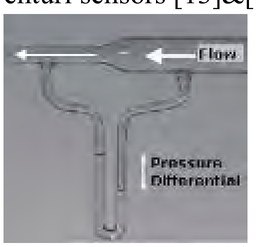
Table 13. Go – NOGO decision for measuring flow rate

Device	Turbine	Vortex	Paddle wheel	Vane	Magnetic	Venturi	Ultrasonic	Thermal
DECISION	GO	NOGO	GO	GO	GO	GO	NOGO	NOGO

Table 14. Evaluation results for varying incoming flow angle

Turbine	Paddle wheel	Vane	Magnetic	Venturi
2.99	2.97	2.72	3.57	3.63

Fig. 9 Venturi sensors [13]&[14]



(a)

(b)

Purge Contaminated Water In order to drain all contaminated water from the system, we proposed that a gravity fed valve or a drain valve downstream of the pump could be utilized (Table 15). Taking advantage of gravity, with a simple gravity fed valve, all of the water can be easily drained from the system within 10 minutes as required by DOW. The superiority of the gravity fed valve was proved in our Pugh chart (Table 16). A schematic diagram of the selected setup is shown in Fig 10.

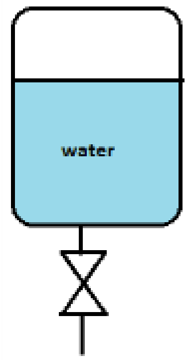
Table 15. Go – NOGO decision for purging contaminated water

Device	Gravity Fed Valve	Drain Valve Upstream to Valve
DECISION	GO	GO

Table 16. Evaluation results for measuring filter screen deflection. Full weights and ranks in Appendix F

Gravity Fed Valve	Drain Valve Upstream to Valve
4.08	3.84

Fig. 10 Gravity fed valve



Add/ Manage Contaminants: The unit must be designed to allow the operator to add contaminants to the system. Dow has stated that mixing can be done either automatically or manually. As specified by our sponsor, the dirt concentration will not be unacceptably affected if the system's waste water is used as its supply water; therefore, all our proposed ideas are GO. We ended up choosing the reservoir without an agitator as the best concept for this functional design (Table 18). The user can easily add contaminants to the reservoir and also manually control the Arizona Dust concentration.

Table 17. Go – NOGO decision for adding/ managing contaminants

Device	Reservoir w/ Agitator	Reservoir w/o Agitator	Reservoir w/ Return Water Pumped into Bottom
DECISION	GO	GO	GO

Table 18. Evaluation results for adding/ managing contaminants. Full weights and ranks in Appendix F

Reservoir w/ Agitator	Reservoir w/o Agitator	Reservoir w/ Return Water Pumped into Bottom
4.13	4.25	3.12

Concept Generation and Selection for Fully Functional Devices

After ranking all functional designs, we picked from the top 3 ideas from each sub category to generate whole functional devices. Together, we thought that a concept which combined all of the top ranking functional components into a single design would be a good final concept, however, to more fully explore the design space each team member came up with two full concepts by combing various functional designs. As all of the functional designs for the various functions work with all the other functional designs of the other functions, all pairings for final designs were possible, and the main goal was finding the combination whose components worked the best individually and collectively, this was done through brain storming and team discussion. With a total of seven systems generated (Tables 19 and 20), it was found that our best concept was assembly "A" (Fig. 14).

Functional designs	**A**	**B**	**C**
Pressure Measurement	Differential Transducer	Differential Transducer	Differential Transducer
Deliver Flow	Pump with duty cycle and expansion tank	Rheostat Pump with Piston	Duty Cycle with Piston
Fixture	Bolted Retaining Ring	Spring Handle	Spring Handle
Angle variation	Chamber	Channel in Channel	Chamber
Measure flow rate	Venturi	Venturi	Venturi
Purge Contaminated Water	Valve	Valve	Valve

Add Contaminants	Tank	Tank	Tank

Table 19. Fully functional system concepts A through C

Table 20. Fully functional system concepts D through G

D	E	F	G
Differential Transducer	Differential Transducer	Differential Transducer	Differential Transducer
Pump with duty cycle and expansion tank	Pump with duty cycle and expansion tank	Pump with duty cycle and expansion tank	Throttle and Relief Valve
Spring Handle	Bolted Retaining Ring	Bolted Retaining Ring	Bolted Retaining Ring
Channel in Channel	Hinged door	Channel in Channel	Chamber
Paddlewheel	Venturi	Venturi	Turbine
Valve	Valve	Valve	Valve
Tank	Tank	Tank	Tank

The chart below (Fig. 10) gives a visual comparison of the various devices and demonstrates why assembly "A" was chosen as the best option. The left column shows the individual criteria, and the column just right of it shows the weights associated with each criteria. More important functions are listed at the top and highlighted in blue, while less important functions are listed at the bottom and highlighted in red.

The columns to the right are associated with designs A through G, and contain the rankings of how well each assembly meets the criteria. Deep green highlighting corresponds to a 5 (Excellent) ranking, while a deep red highlighting corresponds to a 1 (poor) ranking. As can be seen, Assembly "A" has the most amount of green cells in the heavily weighted top part of the chart. The few places where Assembly "A" has deep yellow or orange colored cells, they are on relatively less importance criteria, and most all of the other devices scored poorly as well. With the greatest number of high-scoring ranks in the heavily weighted sections and with good rankings almost everywhere else, Assembly "A" easily came out as the winner with the highest weighted average score, (shown in the bottom row of Fig. 10).

Fig. 10 Evaluation results for fully functional devices

Design	W	A	B	C	D	E	F	G
Ability to vary system flow rates/pressures	0.09	5.00	4.67	4.00	4.67	4.33	4.67	4.00
Ability to measure flow rates	0.09	4.67	4.33	4.33	3.67	4.33	4.33	3.00
Ability to measure pressure drop across filter media	0.09	4.67	4.67	4.33	4.67	4.00	4.33	4.33
Ability to vary water flow angle	0.07	5.00	4.00	4.67	4.00	4.33	4.00	4.67
Ability to measure filter flex	0.07	4.67	4.00	4.33	4.00	4.00	3.00	4.33
Safety (prevent tipping)	0.06	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Easy LabVIEW interface	0.06	4.67	4.33	3.67	4.33	4.33	4.00	3.33
Hold specified filter sample size	0.05	4.33	3.67	3.33	3.67	4.67	4.33	4.67
Electrical Safety	0.05	4.00	4.33	4.00	4.00	4.00	4.00	3.67
Unit can withstand dirty water	0.04	4.33	3.67	3.67	3.67	4.00	4.00	3.67
Allow user to add contaminants	0.04	5.00	4.67	4.67	4.67	5.00	4.67	4.67
Compatible with various sized samples	0.04	3.00	2.67	3.00	2.67	3.33	2.67	3.00
Durability	0.04	4.33	3.33	3.00	3.67	4.33	4.00	4.33
Quick filter change time	0.03	3.00	4.00	4.67	4.00	2.67	3.00	3.00
Compatible with various samples thicknesses	0.03	5.00	4.67	4.67	5.00	4.67	4.67	4.67
Does not damage filter media	0.03	5.00	4.67	4.67	4.67	4.67	4.33	4.67
Compatiable with hot water	0.02	5.00	5.00	5.00	5.00	5.00	4.67	5.00
Ability to purge contaminated water	0.02	4.67	4.33	4.67	4.33	4.33	4.33	4.67
Self-contained	0.02	4.67	4.67	5.00	4.67	5.00	4.67	5.00
Physically user friendly	0.02	4.67	4.00	4.00	4.33	4.33	4.33	4.33
Easily movable	0.02	4.33	4.00	4.00	4.00	4.00	4.00	4.33
Cost	0.02	4.00	3.33	3.33	3.33	4.00	3.33	4.33
Energy Requirements	0.01	4.33	2.33	4.33	4.33	4.33	4.33	3.33
	1	**4.51**	**4.16**	**4.12**	**4.13**	**4.22**	**4.07**	**4.05**

The detailed Pugh chart with personal rankings of the 7 whole functional devices is shown in Appendix G. The descriptions, scores, advantages, and disadvantages of our five top-scoring devices are listed below.

Advantages and Disadvantages of Top Five Ideas

The whole concept ideas are ordered from the highest ranking to fifth ranking in the following explanation, and the top concept is more comprehensively analyzed, since the rest of the designs are the same as the top design except for the differences which are mentioned in each of the following descriptions.

First Place – A: A review of system "A" components is presented in Table 21, and is followed by the advantages and disadvantages of the design.

Table 21. Functional designs in system A

Functional designs	**System A**
Pressure Measurent	Differential Transducer
Deliver Flow	Pump with duty cycle and expansion tank
Fixture	Bolted Retaining Ring
Angle variation	Chamber
Measure flow rate	Venturi
Purge Contaminated Water	Valve
Add Contaminants	Tank

Advantages:
- The differential pressure transducer ensures an accurate and precise measurement of pressure differences in the range of 0 – 5 psi. It is also easier to install than two separate pressure gauges for ease of installation.
- The pump with a duty cycle enables the system to customize flow rates per user input and it saves energy. With this design we are able to directly change pulsing frequency which will influence the expansion tank effectiveness. The expansion tank acts as a fluid capacitor that will damp out the pulsing from the pump so that constant laminar flow can be provided to the flow channel.
- For filter fixtureing, a bolted retaining ring will hold the filter piece in place without damaging it since the filter is pressed against a rubber piece, which also keeps the filter from slipping or leaking. The two pieces are connected with bolts, makes it compatible with a wide range of filter media thicknesses.
- The chamber can be rotated from 0 to 90 degrees to allow the optional by-pass flow.
- The Venturi flow meter enables all of our system flow rates to be measured accurately.
- The unagitated reservoir allows the dirt concentration inside the tank to remain stays constant while also being cost effective.
- All of these functional designs perform well with each other.

Disadvantages
- The single fixture is not compatible with various filter sizes, and retooling will be required for different filter coupon sizes.
- Flow patterns and properties will be changed slightly as water deflects around the collection chamber.

Second Place – E: A review of system E's components is given in Table 22; the advantages and disadvantages of this design are listed below. For brevity, where the design is the same as design A, those advantages and disadvantages are omitted.

Table 22. Functional designs in system E

Functional Designs	**System E**
Pressure	Differential Transducer
Deliver Flow	Pump with duty cycle and expansion tank
Fixture	Bolted Retaining Ring
Angle variation	Hinged door
Measure flow rate	Venturi
Purge Contaminated Water	Valve
Add Contaminants	Tank

The only difference between System E and System A is that it uses a hinged door for angle variation.

Advantages

- The hinged door allows the filter angle to vary between 0 and 90 degrees.

Disadvantages

- It may be hard to generate laminar flow upstream of the filter.
- It is hard to seal the hinged section.
- The area for by-pass in the channel changes with the change in filter angle.

Third Place – B: A review of system B's components is given in Table 23; the advantages and disadvantages of this design are listed below. For brevity, where the design is the same as design A, those advantages and disadvantages are omitted.

Table 23. Functional designs in system B

Functional Designs	**System B**
Pressure	Differential Transducer
Deliver Flow	Rheostat Pump with Piston
Fixture	Spring Handle
Angle variation	Channel in Channel
Measure flow rate	Venturi
Purge Contaminated Water	Valve
Add Contaminants	Tank

The differences between this concept and concept A are the: Rheostat pump with Piston, spring handle and Channel in Channel.

Advantages

- The rheostat pump with piston regulates the output flow and pressure from the pump. Rheostat works as a resistor to control electrical resistant without interrupting current flow and it serves to control flow rate. The piston with a heavy weight on top makes sure the set pressure in the system is constant, despite the pump's inherent pulsing. It is an excellent choice for an AC pump.
- The spring handle allows the user to quickly change filter samples.
- The Channel in Channel is easy to seal and it has small effects on the flow patterns.

Disadvantages

- The piston is would be hard to seal and it would be difficult to control the pressure of the system, since, the weight on the piston would have to be simultaneously adjusted with the pump.

- The spring handle will stick out into the flow, disturbing it. Also the force with which the filter media is held down would be limited by the spring stiffness.
- It would require that there would be a different channel for each filter angle.
- The Channel in channel is unable to vary the filter angle while the system is running, and it would only be able to test a certain discrete set of filter angles.

Fourth Place – D: A review of system D's components is given in Table 24; the advantages and disadvantages of this design are listed below. For brevity, where the design is the same as design A, those advantages and disadvantages are omitted.

Table 24. Functional designs in system D

Functional Designs	**System D**
Pressure	Differential Transducer
Deliver Flow	Pump with duty cycle and expansion tank
Fixture	Spring Handle
Angle variation	Channel in Channel
Measure flow rate	Paddlewheel
Purge Contaminated Water	Valve
Add Contaminants	Tank

The difference between this design and design A is that D uses a spring handle to hold the filter and a paddlewheel to measure the flow rate.

Advantages
- The paddle wheel is dirt resistive, low cost and easy to install.
- The spring handle allows the user to quickly change the filter media.

Disadvantages
- The paddle wheel is not sensitive to low flow rates.
- The spring handle will stick out into the flow, disturbing it. Also the force with which the filter media is held down would be limited by the spring stiffness.

Fifth Place – C: A review of system C's components is given in Table 25; the advantages and disadvantages of this design are listed below. For brevity, where the design is the same as design A, those advantages and disadvantages are omitted.

Table 25. Functional designs in system C

Functional Designs	**System C**
Pressure	Differential Transducer
Deliver Flow	Duty Cycle with Piston
Fixture	Spring Handle
Angle variation	Chamber
Measure flow rate	Venturi
Purge Contaminated Water	Pumped
Add Contaminants	Tank

The only difference between system C and system D is that it is using a pump with a duty cycle with a piston to deliver flow to filtration chamber.

Advantages

- The duty cycle with piston acts as a fluid damper, and as the friction of the piston approaches zero, it is able to provide absolutely constant pressure flow.

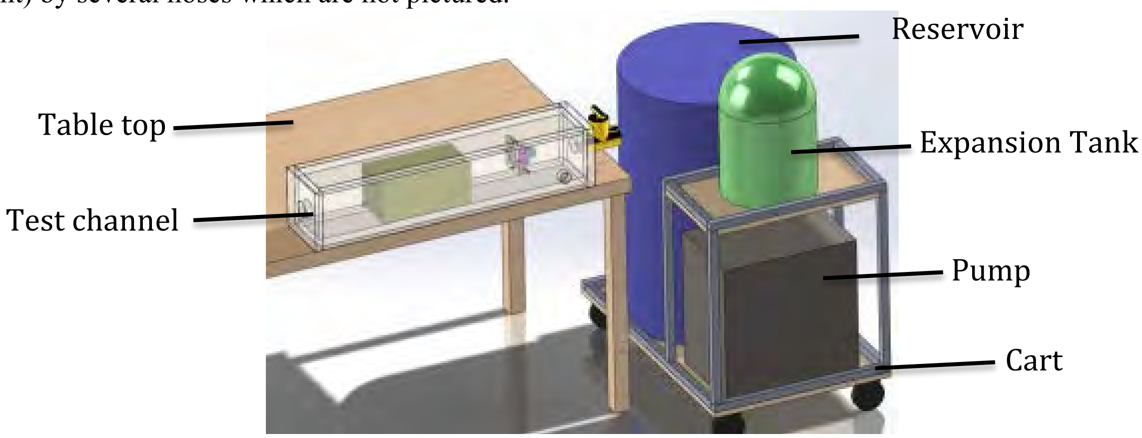
Disadvantages

- The piston is would be hard to seal and it would be difficult to control the pressure of the system, since, the weight on the piston would have to be simultaneously adjusted with the pump.

Final Alpha Design

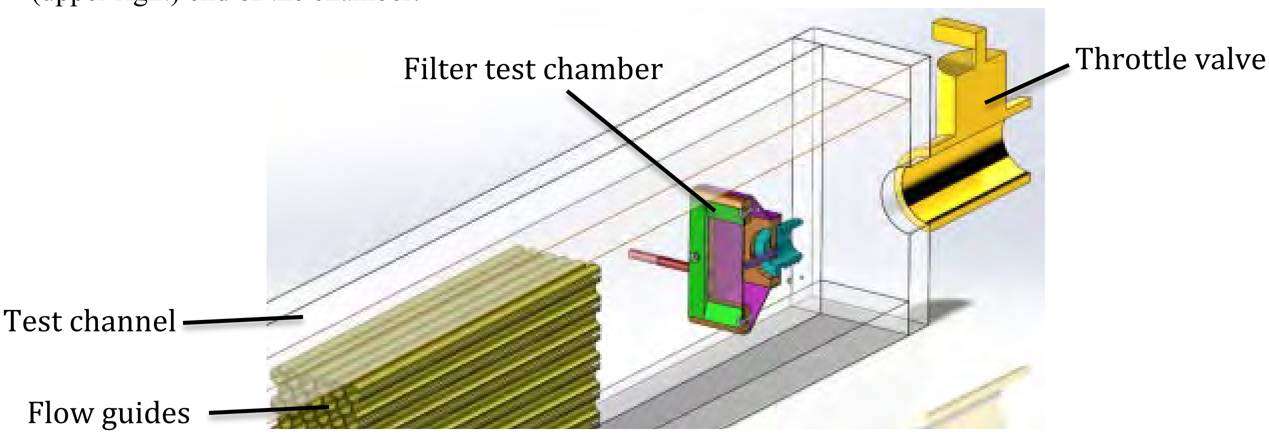
Our final alpha design consists of two main sections: a testing channel which sits on a tabletop, and a cart section which sits on the floor and contains the water storage tank and pump. A rendering of this setup is shown in Figure 11.

Figure 11. Isometric view of the final alpha design. The test channel (left) is connected to the cart unit (right) by several hoses which are not pictured.



Test Channel. The test channel is a 3-foot long box with internal sides measuring 6 in x 6 in. Pumped water enters one end of the channel via a hose from expansion tank on the cart, and then flows through laminar flow guides to ensure that smooth flow hits the filter. Some of this water does not go through the filter, and instead flows around the test chamber. This bypassed water exits the test chamber through a valve downstream of the test chamber which can be partially or fully closed to increase the pressure in the chamber, and reduce or eliminate by-pass. When there is by-pass, the by-pass water is returned to the supply tank using a hose. A rendering of this setup is shown in Figure 12.

Figure 12. Water enters the chamber from the lower left corner, passes through the laminar flow guides, goes through or around the filter test chamber, then exits through the throttle valve at the downstream (upper right) end of the chamber.



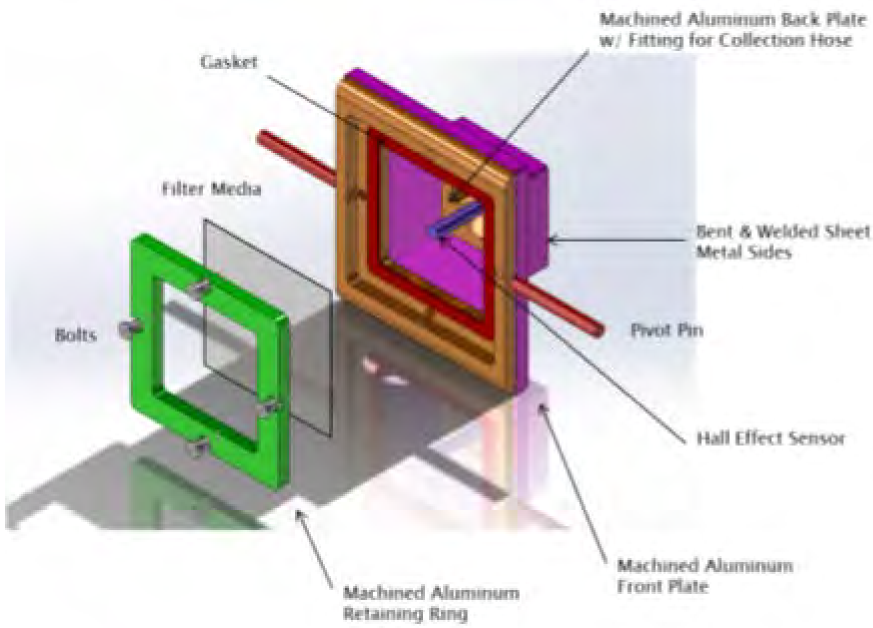
Test Chamber. The filter media is secured into a shallow recess in a plate by bolting a retaining ring over top of it. An elastomer gasket underneath the filter ensures an even distribution of clamping force and makes sure that the media is not damaged. The ring's center is hollowed out to allow water to flow though, and the bolt holes are on the outer edge of the retaining ring so that they do not touch the filter. The ring also chamfers to a thin edge as it approaches the exposed filter surface, which minimizes test fixture-induced pressure drops and flow separations, at the filters surface.

As water flows through the filter, it causes the filter media to flex. This displacement is measured by a Hall Effect sensor, which is mounted behind the filter media. The sensor will have a non-contact interaction with either the filter media itself, or with a small removable target (a piece of metal or magnet) attached to the media.

Water that flows through the filter does not rejoin the bypass stream; instead, it gathers in a chamber attached to the back of the plate. This chamber directs the flow into a hose mounted at the back of the chamber. This hose snakes out of the chamber to a flow rate sensor and one end of the differential pressure sensor (the other being inside the channel just before the filter). After being quantified, the filtered water flows through another hose back to the supply tank.

The chamber is secured in the middle of the test channel using pins mounted on its edge. These allow the unit to rotate within the channel so the filter media can be positioned for flow angle ranging from normal all the way to tangential (0^o to 90^o). The leading edge of the chamber is rounded to minimize flow separation at large flow angles, and the filtered water hose is flexible enough to reposition to any angle. A locking mechanism along the channel wall allows the user to set what angle the chamber is positioned at. An overall rendering of the test chamber is shown in Figure 13.

Figure 13. The test chamber, in exploded view. The filter media is squeezed against a gasket on the base plate by the bolting force exerted on the retaining ring. Bent sheet metal panels on the side divert the through-filter flow to a hose outlet, while a Hall effect sensor is placed in close proximity to the media for deflection sensing



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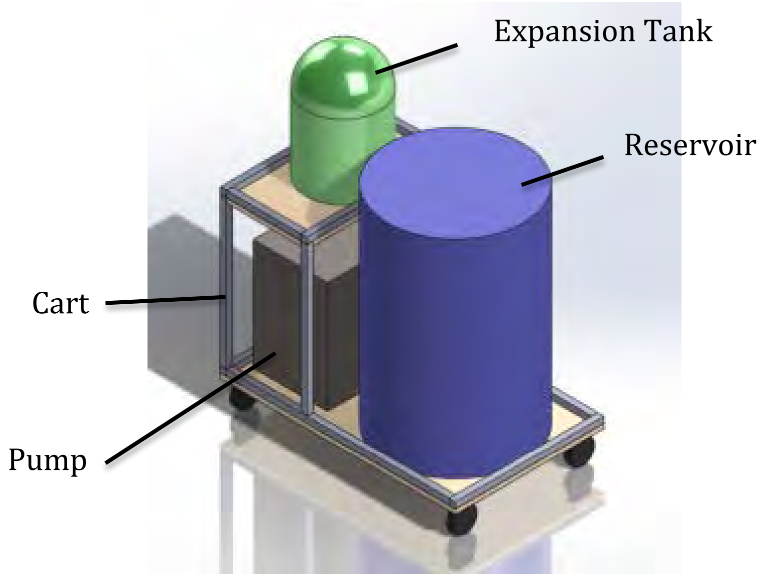
Cart. The cart houses three major components: the storage tank, the pump, and the expansion tank. Contaminated water is stored and mixed in the storage tank, and can be drained from the system using a valve on the bottom of the cart. The tank is connected by a hose to the pump, which is controlled using an electronic speed controller. Upon activation, the pump draws water from the bottom of the storage tank and forces it up into the expansion tank. A flexible diaphragm in the expansion tank separates the pumped water from a pressurized pocket of air; as the pump forces water through the system, the diaphragm flexes back and forth to ensure that the pressure coming out of the expansion tank is non-pulsating. The output from the expansion tank is run through a hose to the inlet of the test chamber. The bare cart itself is on casters to increase movability, and is partially two-leveled to minimize the footprint required. A rendering of the cart with all components installed is shown in Figure 14.

Figure 14. The cart unit, with storage tank (right), pump (lower left), and expansion tank (upper left). Not shown are the hoses connecting each component, the data acquisition unit, and the sensor measuring the flow in the hose from the test chamber.



INFORMATION SOURCES

To make informed design selections we have continued research on sensors, and continued to refine our specifications through continued correspondence with ****** and by consulting relevant resources. Through correspondence with ****** [7, 8 9 and 10], we have refined our specifications on the minimum product life span, the maximum working fluid which the device needs to withstand, and the fact that we do not need to provide a brush design for the system. Further research of MIOSHA standards [16] has allowed us to better define what is required of the unit so that the unit is safe for use in the workplace. Since MIOSHA does not have specific standards for the height of controls, we used an ergonomics handbook [17] to develop a standard for how high commonly used controls should be on the unit.

Though internet searches we have investigated which sensors are compatible with water, and abrasives in that water. For flow sensors, we determined which types can maintain accuracy at low flow rates, which will be important, since our device needs to measure flow rates that approach ~~0~~ 2gpm. We found that the Venturi tube-style sensor was the most accurate at low flow rates, and could provide us with the ±0.01gpm accuracy that our system needs [18]. Our research also showed that differential pressure transducers are available and can provide the accuracy in differential pressure measurement which is needed [20].

We will continue to perform research on sensors through web vendor literature to aid in our sensor selection from a capability and cost point of view. Using web vendor literature we also will determine which pumps are rated to handle particulates in the water, deliver our required flow rate/ pressure, and fit within the budget Dow has given us. We will also continue to use web vendors and local hardware/material vendors to determine the price, availability, and material properties of the raw materials and components which will be needed in the construction of our design.

PARAMETER ANALYSIS

With an alpha design proposed, we now had to perform analysis on the design so that it can meet the specifications we created. One particular area we had to focus on is fluid dynamics, so a pump could be properly sized and so adequate pressures and flow rates can be delivered to the system, even when the flow areas change throughout the system. Fluid dynamics also was important for correctly assembling, shaping and sizing the unit features that are upstream of the filter media, so that laminar flow is provided to the filter media. Also we needed to use system dynamics to size our expansion tank. Simple fluid dynamics equations were needed to size our drains. Another important part of our analysis was structural engineering, making sure that the system does not yield when the system is pressurized, preventing catastrophic failure and system leaks. Also we needed to look into creep and fracture toughness material properties for the materials we used, to make sure the system withstands the hot working fluid temperatures, and to make sure the system is durable when exposed to real-life usage. We also needed to apply general engineering analysis and budgeting skills to choose the exact sensors for the system. For each portion of this analysis, we used our best engineering judgment and the results of the analysis, to help gauge if our analysis was detailed enough.

Since many aspects of the engineering analysis are dependent on the pressures and resistances associated with the fluid flow through the system, pressure drop analysis was the first analysis performed on our proposed system. Using the head loss equation (Eq. 2) we estimated the pressure and velocity of the flow as it travels through our system, as the flow area changes, and as piping and fittings in the system induce losses in the system. In the head loss equation the 1 and 2 subscripts, denote the location of the flow along a single flow system, P is the pressure, ρ is the density of the fluid, α is the kinetic energy coefficient, V is the average velocity of the flow, g is gravity, h is the vertical position of the flow, and h_l is the head loss from point 1 to point 2.

- $P_1 + .5\rho\alpha_1 V_1^2 + \rho g h_1 = P_2 + .5\rho\alpha_2 V_2^2 + \rho g h_2 + \frac{h_l}{\rho g}$ Eq. 2

To allow for easier subsequent analysis of the system, namely for the system dynamics analysis of the system, the system was broken into sections, and the pressure drop across each section was calculated. The first section was, the section from the pump to the expansion tank, the second section was from the expansion tank to the filter face, and the last section of the system was from the filter face to the return to the reservoir. For each section h_l was calculated using the sum of the major and minor head losses, which are dependent on the length and diameter of the piping, and the fittings and features in the system, respectively. The velocity of the flow at each location was simply calculated by dividing the volumetric flow rate by the pipe area at that location. Since the head loss associated with the filter will vary with each sample, to find the maximum pressure drop across the system, this pressure drop was directly taken from the specifications from Dow, which stated the maximum pressure drop across the filter would be 2psi. For our analysis, the vertical position of the flow was neglected, because it will only vary by about 3ft, which corresponds to a pressure variation of ≈1psi. Evaluating the head loss equation was necessary for, piping optimization, pump sizing, and system dynamics analysis.

This quantitative head loss equation helped us qualitatively improve our piping system. From the head loss equation it is seen that the pressure drop across the system is directly proportional to h_l. In order to reduce the pump size that our system needs, therefore reducing cost, pressure drop across the system should be minimized. Therefore both major, h_{lmajor} (Eq. 3), and minor, h_{lminor} (Eq. 4), losses should be minimized, where f is the friction factor, l is the length of the pipe, D is the hydraulic diameter of the pipe, and K_l is the loss coefficient.

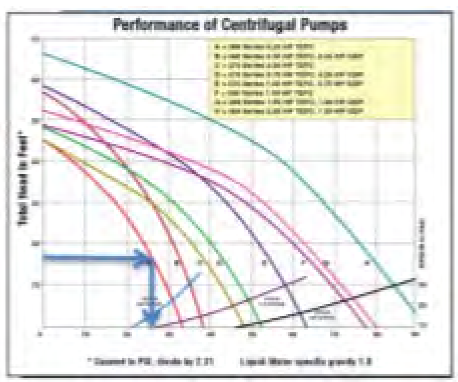
$$h_{l(major)} = f\frac{l}{D}\frac{V_2^2}{2g} \quad \text{Eq. 3}$$

$$h_{l(minor)} = \frac{K_L V_2^2}{2g} \quad \text{Eq. 4}$$

After fully expressing major head loss as a function of pipe diameter, it is seen that for a given flow rate, major head loss is inversely proportional to D^5, therefore to reduce pressure losses, piping diameters should be as large as possible. Major head loss is also dependent on the friction factor which is dependent on the Reynolds number (*Re*), which is dependent on the pipe diameter, for a given flow rate. By transitioning from laminar to transitional to fully turbulent flow, f can either increase or decrease with an increase in *D*, however, engineering practice has established that the highly inverse relationship between D and h_{lmajor}, makes h_{lmajor} always decrease within an increase in diameter. Also to reduce major head loss, piping length should be decreased. To reduce the pressure drop across the system, the sum of all of the minor head losses should be reduced. To do this, the number of fittings, for example, elbows, should be minimized, and for each one of these features preference should be given to individual fittings which preform the desired manipulation of the flow but have lower K_l values. As a general rule of thumb flanged fittings have lower loss coefficients than threaded fittings, and long radius fittings have lower loss coefficients than regular fittings. However, the complex interaction between system costs, pump cost, availability, manufacturability, space limitations, and implications on user friendliness, reduced these quantitative equations into qualitative engineering guidelines. Using these guidelines we developed and refined a piping system for the unit.

To size a pump for the system the maximum pressure drop across the system needed to be calculated. Since pressure drop increases with flow rate, the maximum pressure drop across the system was calculated using the maximum necessary flow, 16 gpm; the corresponding pressure drop across the system is 9.04psi (Appendix H.1). Using this pressure drop, pumps were evaluated via pump performance curves. Since the system is eventually venting to the ambient (at the reservoir tank), the pressure drop associated with the system and the filter is the pressure the pump needs to provide. As shown in Fig 15, this pressure value was used to see if a given pump would provide enough flow.

Fig 15. Pump performance curve showing how design pressure evaluates whether a pump is sufficiently sized



If the pump has more flow than the 16gpm, at the design pressure, it only means that the pump would have extra capacity, which is beneficial to the design because it allows the system to produce by-pass. Pumps with enough capacity were then evaluated on price, durability, and their pulsation characteristics.

Another requirement for the flow provided to the filter, is that the flow is laminar. To evaluate for laminar flow in a pipe, or in our case a square channel, the Reynolds number (*Re*) of the flow needs to be ≤ 2100, where Reynolds Number is shown in Eq.5. In the equation D is the hydraulic diameter, Q is the volumetric flow velocity, and v is the kinematic viscosity of the fluid, and A is the area of the flow diameter.

$$Re = \frac{QD}{\nu A} \text{ Eq. 5}$$

To find the maximum *Re* of the flow in the test channel, *Re* was evaluated using the maximum necessary flow rate, the diameter of the proposed test channel, the area of the proposed test channel, and the minimum kinematic viscosity, which corresponds to the highest fluid temperature. The kinematic viscosity of the fluid in the test channel was assumed to be the kinematic viscosity of water, since the maximum Arizona Dust concentration, per correspondence with Dow should not exceed 20,000ppm, which is a fairly low concentration, and it would only increase the viscosity of the fluid, therefore neglecting its effect would create an upper bound for *Re* in the system. Evaluating the *Re* for this worst case scenario, the test channel has a *Re* value of 14559.7 (Appendix H.2). This *Re* number is well above the 2100 which bounds laminar flow. However, our design already incorporated flow guides upstream of the filter to help straighten the flow as it entered the flow channel. Seeing that laminar flow in the channel would not be developed by the channel under all of the flow rates, we needed to design the flow guides so that they developed the laminar flow.

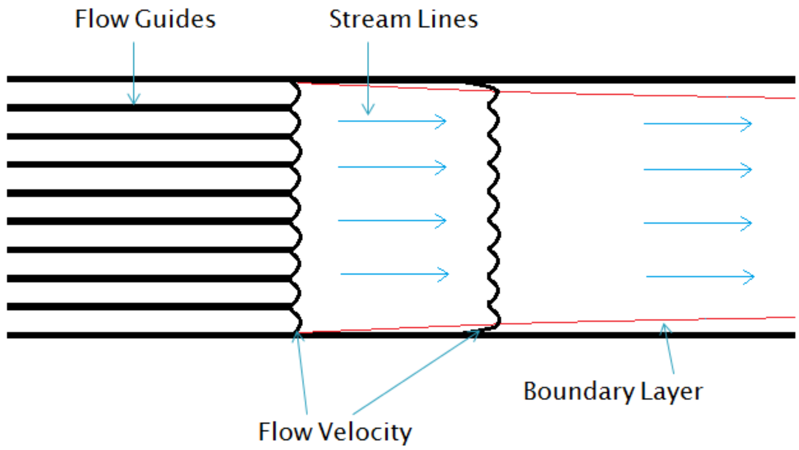
In order to develop laminar flow, the flow guides' *D* has to be small enough to have a *Re* less than 2100 even at the highest flow rates, and at the lowest kinematic viscosity. The maximum diameter that these flow guides could be is 0.144in. (Appendix H.3). Also, laminar flow needs to be fully developed in the flow guides. The entrance length equation for laminar flow is shown in Eq. 6, where the entrance length, l_e, describes how far it takes for laminar flow to fully develop in the pipe.

$$l_e = 0.06 * D * Re \quad \text{Eq. 6}$$

As it is shown in Eq. X the entrance length is proportional to the *Re* of the flow in the flow guides. Therefore to make the laminar flow guides of a reasonable length, and therefore the entire test channel, of a reasonable length, the *Re* number of the laminar flow guides should be minimized. However, these flow guides are basically small pipes in parallel and therefore as the pipe diameters decrease, the viscous losses associated with them increase. Using these competing parameters, manufacturing considerations and availability limitations, square laminar flow guides with hydraulic diameters of 0.314in. were used for our design. Evaluating the entrance length equations it was found that the laminar flow guides need to be at least 13.84in. long to develop laminar flow for the worst case scenario (Appendix H.3).

However, after the flow exits these laminar flow guides the flow begins to degrade, into a developing flow, corresponding to the characteristic flow of the channel for the specified flow rate. However, this degradation will only begin to propagate inward from the channel walls, in what are known as boundary layers which are shown in Fig. 16

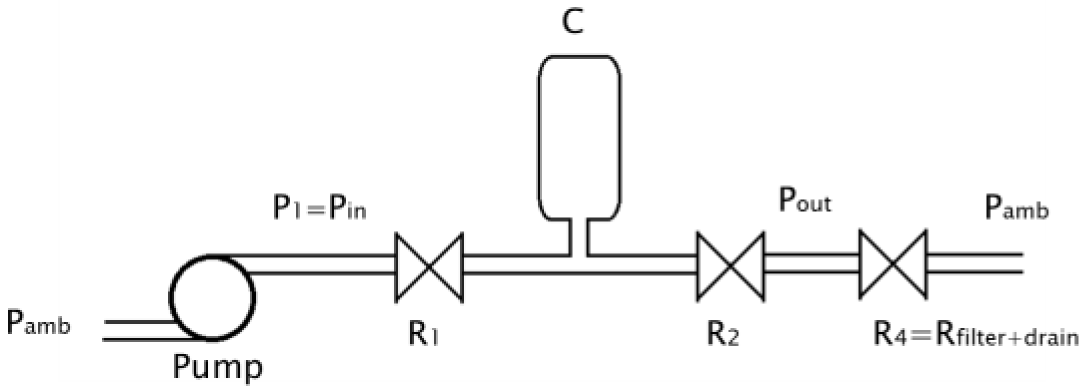
Fig 16. Schematic of the boundary layers present in the flow in the channel, showing their effect on flow velocities, and streamlines



This boundary layer is described by the Navier-Stokes equations, which are non-linear differential equations, and have not been solved for complex geometric shapes. However, the solution to the boundary layer phenomenon has been solved for flat plates, and since the flow outside of the boundary layers is largely unaffected by the flow in the boundary layers, and since our chamber consist of four flat plates. It was assumed that the equations describing the boundary for flat plates would adequately capture the physical phenomenon of the flow occurring in our channel. Fluid dynamics refrence [21] qualitatively states that there will be a rounding of the intersecting boundary layers as they converge in the corners of the channel, however, knowing that the boundary layers are localized phenomenon, the flat plate equations can give us a general idea of what would occur in our channel. Analysis of the flat plate interaction shows that the boundary layer is initially laminar, until a critical Reynolds number based on x, Re_x, is meet, at which point the boundary layer area becomes turbulated, where x is the distance along the flat plate (in our case it would be the distance past the flow guide). Re_x is the same as Re except x replaces Q/A. At a critical Re_x the boundary layer degrades into a turbulent boundary layer, this exact number depends somewhat on the turbulence of the upstream flow and on the roughness of the surface, but a good estimate of the minimum critical Re_x is 2×10^5 [21]. Evaluating our channel for the highest flow rates, and minimum viscosities, it is found that the boundary layer does not become turbulent until 13.74in. downstream (Appendix H.4), which is longer, than the distance between the laminar flow guides and the filter face, and even longer than the distance between the laminar flow guides and the end of the channel.

To make sure that the flow provided to the filter does not have excessive pulsations, a system dynamics analysis was performed on the system. The purpose of this analysis was to size a fluid capacitor to our system. For this analysis, fluid inertance was ignored because fluid inertance in piping systems is often ignored because the kinetic energy of the fluid is small compared to the resistance and capacitance of the system. Then dividing the system into the previously stated three subsections, along with the fluid capacitor and the pump, the system can be modeled as the fluid system that is shown in Fig. 17

Fig. 17 Diagram of the modeled fluid system



The input pressure to the capacitance and resistance system is taken as the pump pressure and the output pressure is the pressure directly in front of the filter face. All of the system pressures are gauge pressures because the system takes in water at the ambient pressure and returns water to the ambient, as it is pulled from and returned to the reservoir tank. The fluid resistances for each portion of the system were developed using the corresponding pressure drop associated with that section of the system. For an expansion tank as a fluid capacitor the capacitance of the tank is dependent on the initial pressure of the tank, P_i, and the tank volume, V_i, as shown Eq. 7., where ρ_{fluid} is the density of the fluid in the system, and P is the pressure of the system at the capacitor.

$$C = \frac{\rho_{fluid} V_i P_i}{P^2} \text{ Eq. 7}$$

To allow the system to be shut down, the initial pressure in the tank is taken as ambient pressure, and it is assumed that the Arizona Dust does not change the density of the water. Using an equivalent electrical circuit, and the corresponding electrical impedances, a differential equation was developed, were the input voltage was the voltage across the entire system, and the output voltage was the voltage across R_4 (Appendix H.5). From this differential equation a transfer function was created, and the magnitude of this transfer function was computed in terms of the input frequency, w, the fluid resistance from the pump to the expansion tank, R_1, the fluid resistance from the expansion tank to the filter face, R_2, the fluid resistance from the filter face to the reservoir, R_3, and C as shown in Eq. 8

$$M(w) = \frac{R_4}{sqrt(R_1{}^2 + 2R_1R_2 + 2R_4R_1 + R_2{}^2 + 2R_4R_2 + R_4{}^2 + R_1{}^2 R_2{}^2 C^2 w^2 + 2R_1{}^2 R_2 C^2 R_4 w^2 + R_1{}^2 R_4{}^2 C^2 w^2} \text{Eq. 8}$$

To initially see how the system would behave without a capacitor, this equation can be evaluated for a capacitance equal to zero. Evaluating this equation it is seen that the system behaves as a voltage divider, showing that a certain degree of pulsation damping may be achieved even when a fluid capacitor is not used. Since the fluid resistances are dependent on flow rate the system was probed by evaluating the magnitude of the transfer function for flow rates of 16gpm, and 1gpm, and for expansion tank sizes of 20 and 2000in^3. As shown in Figure 18, and Figure 19, the flow rate has little effect on how the system behaves.

Fig. 18 The magnitude of the transfer function as function of input frequency, *w*, for a flow rate of 1gpm, and an expansion tank size of 20in^3

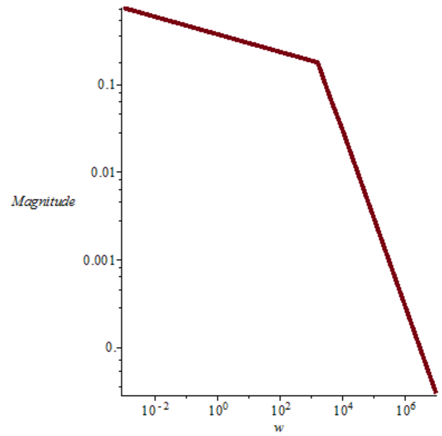
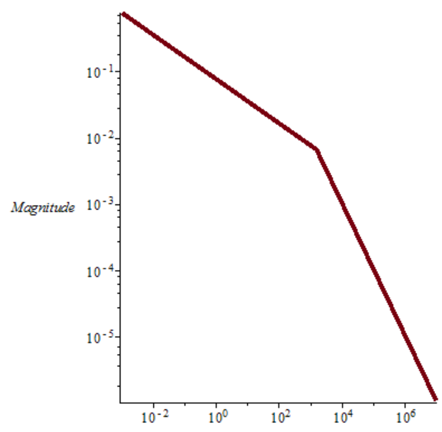


Fig. 19 The magnitude of the transfer function as function of input frequency, *w*, for a flow rate of 16gpm, and an expansion tank size of 20in^3



However, to bring this analysis to a conclusion the input needs to be known, the allowable output needs to be known, and the input frequency needs to be known. For example, if the pump, has a six impeller blades that, each cause a pulsation per revolution, and the pump provides the 16gpm at a full speed of 3450RPM, and the output/input ratio needs to be .01, and the pump follows pump infinity laws, it is seen that limiting case is the 16gpm case, which is good since, this is a definitive upper bound which the system needs to meet. For this case an expansion tank volume of 95 in^3 would be needed for the system. However, the input is not known, the exact geometry of the pump is not known, and our sponsor does not know what an allowable output would be. Our sponsor believes that the centrifugal pump that we choose for our design will not cause more pulsations in the flow than would be experienced by the filter media under normal operating conditions. Therefore we are not currently including an expansion tank in our design. However, if we find that pulsations in the flow indeed are too high, we can easily use this analysis to design a vertically oriented, capped PVC expansion pipe for our system, which could be easily added to the piping system at a later time.

We also used a qualitative fluid dynamics analysis to help shape the obstructions in the flow upstream of the flow, in order to reduce turbulence caused by these features. Since the thickness of the laminar flow guides, compared to their diameters is small <.1, and their wall thickness is small, <.04in. these should not cause noticeable wake in the flow. However, when the chamber is rotated to the 90º position, to test tangential flow, one side of the retaining ring will be directly upstream of the filter, and therefore can cause wake and turbulence directly in front of the filter face. Therefore, we used a qualitative streamlining process to design the profile view of the retaining ring. A cut view of the retaining ring is shown in Fig. 20, and it can be compared to a streamlined object shown in Fig. 21

Fig 20. Cut View of the filter retaining ring

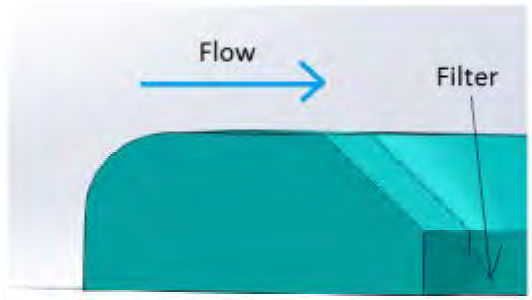
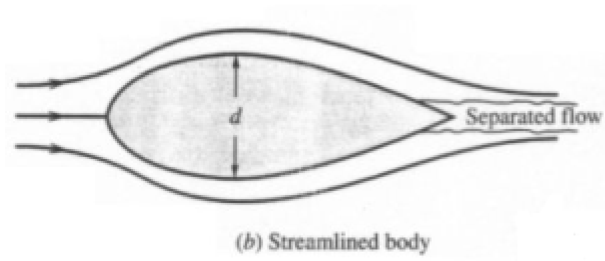


Fig 21. Streamlined Body [22]



By rounding the upstream side of the retaining ring and slanting the downstream side of the retaining ring the water flow has minimal separation zones, and most of the filter face experiences unturbulated flow.

To design the size of the drain valves for the reservoir tank and the channel we used Torcelli's law, and the known volumes of the channel and the tank, and the specified ten minutes for the draining time, to find a minimum size for the drain valves (Appendix H.6). Expressing the flow rate as a function of water height, and integrating this with respect to time an equation is developed where, time for draining is a function of the drain diameter (Eq. 9). In Eq. 9, A is the plan view area of the tank, a is the area of the drain, C is a constant depending on the drain geometry, g is gravity, and H_i is the initial height of the fluid above the drain.

$$t = \frac{A}{aC}\sqrt{\frac{2H_i}{g}} \text{ Eq. 9}$$

Using the appropriate parameters, and a drain time of ten minutes, the minimum drain diameters for the tank and the channel are 0.542in. and 0.367in. respectively. However, these calculations only imperially account for viscosity in this draining process through the drain constant C, where for our calculations we assumed a "short drain pipe". Therefore if our final design needs to include considerable drain piping to help direct the draining flow, larger drain pipe diameters will be needed. Also since the channel needs to be drained, in order to change the filter media, and this needs to take less than 10 minutes in total, the time to drain the channel should be considerably less than 10 minutes. To account for these factors both our tank and channel drain diameters are 1in.

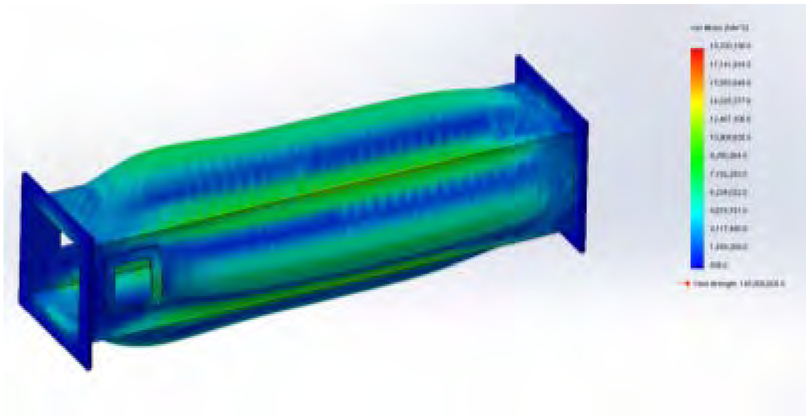
We also used several general fluid dynamics guidelines and equations to guide the designing of our system. To allow the flow to properly expand [21], in the channel, before being confined in the laminar flow guides more than two channel diameters of free space are provided in the channel. Also per the manufacturer's recommendations, to allow the flow to be uniform in the flow meter, allowing accurate flow measurements to be taken, there are more than 10 pipe diameters of straight pipe upstream of the flow meter, and more than five diameters of straight pipe downstream of the flow meter. Also, to properly calibrate the pressure drop across the filter media, the change in the flow areas will be accounted for in either our labVIEW code, or a corresponding equation, based on the Bernoulli equation, that will be given to the operator, since as the flow area decreases, as the flow goes from the full channel area to the smaller filter media area, there is a corresponding pressure drop (Appendix H.7). The corresponding equation is given below (Eq. 10), where $\Delta P$is the pressure drop across the filter independent of the filter, $A_{channel}$ is the flow area of the channel, and A_{filter} is the exposed area of the filter.

$$\Delta P = .5\rho\alpha Q^2(A_{channel}^{-2} - A_{filter}^{-2}) \text{ Eq. 10}$$

As the flow area decreases the flow velocity will increase and therefore there will be a pressure drop independent of the filter media.

Another important analysis that was completed on our design was material selection for, and analysis on, the pressurized chamber. In order to meet the MIOSHA part 93 standards the system needs to withstand the harshest conditions which it will see in service. In order to test the filter media the channel will be pressurized with the flow. Though cylindrical pressure vessels can with stand much higher internal pressures than rectangular extrusions, since the material in cylindrical pressure vessels only experience tension, while the material in rectangular extrusions experience multi axial bending, we used a rectangular extrusion to form our test channel due to significant concerns about sealing the filter angling shaft that needs to penetrate the side wall of the tube. Also, due to concerns about sealing, we decided that along the length of the chamber there should be no seams. From there, a product survey was completed, of what materials are available on the market that meet these requirements, and meet our size requirements. The only two materials that were, available, resisted water corrosion, and were priced within our budget, were stainless steel tubing and aluminum tubing. However, due to weight requirements, the stainless steel tubing could not be used. Further weight analysis was done on the two aluminum products that were available, 6063 T5 aluminum 6”x6” tubing with a wall thickness of ¼”, and 6063 T5 aluminum 6”x6” tubing with a wall thickness of 1/8”, it was seen that for the length of tubing that our design needs, the tubing with ¼” wall thickness weighs over 20lbs., which is a very large portion of the 35lbs which the table top channel and chamber module could weigh. Therefore the 6”x6” aluminum tubing with a wall thickness of 1/8”, was pursued for our design. To accurately evaluate the performance of this product we ran a finite element analysis (FEA) on this tube. For the FEA analysis a uniform pressure was applied to the inside of the channel, and the safety factor of the design was evaluated. The pressure applied to the inside of the chamber was the maximum pressure within the chamber. Since the fluid pressure drops along the flow, the inlet pressure was used as this design pressure (Appendix H.1); to find the maximum inlet pressure the system was evaluated at the highest design flow rates. For our FEA analysis a design pressure of 4.16psi was used. Initial FEA analysis showed that this channel tube would have a minimum factor of safety of 10.6. Therefore this channel tube was used in our design, and once all of our modifications were completed on this tube, a final FEA analysis was completed on the final channel, the results are shown in Fig. 22. The FEA results measured the minimum factor of safety on this design to be 7.76.

Fig. 22 Finite element analysis on the fully modified chamber, showing were the maximum stresses occur; the design has a minimum factor of safety of 7.76



Therefore the maximum pressure which the channel can with stand is 33.6 psi, which even exceeds the 19.48 psi which our selected pump can create. Though this somewhat course meshed FEA analysis could have some error, this analysis shows that with a significant margin for error, our channel should not yield, or explode when in use, under standard operating temperatures.

Since our material options for the channel were limited, we didn't have the liberty to use material creep, and toughness properties as drivers for material selection. However, aluminum does have good enough toughness properties to be used for laboratory equipment. Also a general rule of thumb for metals is that if the metal temperature when loaded is less than 30% of its melting temperature then, creep is not a factor. The maximum loading temperature for the channel is 140ºF, and the melting temperature for 6063 T5 aluminum is 1140 ºF[23], therefore the maximum loading temperature is 35% of the melting temperature of the material, which is slightly above the general threshold for considering creep, however, the fact that this testing device will only be used intermittently and the design criteria for other components only requires us to design for a use time of 360hrs.; good engineering judgment allows us to ignore creep. However, it should be noted to the user, through operator instructions, or an initial disclaimer that if the scope of the use of this device was to change, creep analysis should be performed on the channel, to mitigate system failure, most importantly catastrophic failure.

Another component which we had wanted to preform analysis on was the retaining ring, which holds the filter media onto the filter chamber. However, due to proprietary issues, and the fact that a wide range of materials may be used as filter medias, the exact behavior of the filter media could not be described, and therefore the pressure necessary to hold the filter media in place could not be calculated. However, our sponsor has stated through continuing design consultation that our stainless steel retaining ring with six #10-24 bolts though it, mating onto a rubber gasket would be sufficient to hold the filter material which will be tested by the device. Also analysis was done, on the bolts on the end flanges which hold the ends on the channel (Appendix H.8). This analysis showed that if there is uniform tension on each bolt, each bolt would need to hold 11.46lbs, which is much less than their rated clamping force of 723lbs. Our initial analysis shows that the design should not yield when in use.

Material and Manufacturing Process Selection/ Design for Environmental Sustainability/ Design for Safety

As shown in Appendix I, we performed material and manufacturing process selection in CES, designed for environmental sustainability in Simapro and applied Designsafe for safety reporting. We will summarize what we have learned from this process in this section while the detailed analysis is provided in the Appendix.

From these analyses, we learned that detailed analysis and planning is crucial prior to actually machining and building. These software packages guided us through a variety of material and selections and provided us with some top choices that are suitable for us to use in our design.

In the material process selection, the top choice that is recommended may not be our final choice due to vendor availability, machining restrictions and other system requirements applying to our system. We needed to incorporate each useful piece of information before finalizing our decision rather than just going with one of the top choices.

The CES software helped us compare different types of materials that we could use in our design for the channel and the piping on the side of the channel. Once applying all of the corrosion, strength and weight restrictions of our design, we ended up comparing different types of aluminum for the construction of the channel. However, due to the inability to procure these exact materials in the dimensions which we needed (6"x6" square tubing), we ended up using 6061 aluminum which was not among the top choices, but had characteristics nearly as optimal as these top choices. A similar process was used for finding optimal piping materials. Using the CES software we also looked into the case where our product would be developed for commercialization, where a relatively large amount of production is needed. To insure quality in the product, proper manufacturing processes are needed. With the probable batch sizes in mind, using the CES software we received a better idea of the possible manufacturing process that could be used for mass production and how the possible choices ranked to pick the best one for each material.

From the sustainable design point of view, we compared our design's use of aluminum to a replacement of stainless steel and our design's use of PVC to a replacement of HDPE. The Eco indicator is a scale to measure the eco-burden of using a certain material. The energy stored inside of the material is actually reflected by the value of eco indicator. From there, we became more aware of our design from a whole system point of view. Rather than a single piece, we might find the component will have more environmental impact when considering all consequences. From this analysis it was found that the use of aluminum in our design was better for the environment than using stainless steel. On the other hand, this software showed that the HDPE piping would have a lower impact on the environment than the PVC that we used, however due to manufacturing constraints we used the PVC piping.

Safety is always a priority, thus we evaluated the whole system in Designsafe. With the detailed guide of the software, we examined our system thoroughly, pointed out any possible dangers and proposed the solutions that are actually reflected in our final design. It was an insightful tool to guide us through the details that we might ignore during design and address every point of safety issue we might run into. For example the software really brought to light the full safety implications that may occur if the channel module is over pressurized, and it allowed us to realize how a pressure relief valve, which we included in the system, could help mitigate these concerns.

Overall, these softwares are really useful tools and let us keep checking various aspects of our projects from different ways, eg. material, sustainability and safety. While these are beneficial for us, we should still be aware that they are many more constraints and impacts of the design that are not captured in these software packages. For example, other factors, such as price, vendor availability, etc, need to be taken into consideration before a final design is decided on.

The success of the system depends on many independent, but essential components. A major analysis component is sizing a pump that can provide the flow rates and pressures needed by the system. Also making sure that the filter holder does not significantly agitate the flow is another important part of the design. Also a controller and pulsation damper will need to be designed, so that the pump delivers the steady flow that the Dow desires. A final critical design parameter is making sure that no part of the system leaks once it is under pressure. After completing this analysis, and where necessary in conjunction with this analysis, a final design was developed that built upon this analysis.

PUMP AND SENSOR SELECTION

To evaluate the filter performance, a flow meter is required to measure upstream flow rate and a differential pressure transducer will be mounted to measure the pressure drop across the filter media. After completing a product survey, it was found that the cost of Venturri sensors were several thousand dollars, and that left too small of a budget for our pump, pump controller and pressure sensor. We were only given a $3000 budget by Dow for the pump, pump controller and sensors. As we had already found out from our initial research on flow sensors the alternatives had lower accuracy, therefore, with Dow's approval our flow measurements specifications were lowered. Therefore, instead of using the Venturi flow meter we investigated our second best choice, a turbine flow sensor. After completing a product survey, we selected a configurable differential pressure transducer, for our differential pressure sensor. Using the procedure outlined in the parameter analysis section, while comparing costs, a centrifugal pump was selected for our design.

Flow Meter

After comparing prices and accuracies, we selected the GPI ¾ inches TM series water meter with an LCD display for readout (Fig.33) [24]. This turbine flow meter has a ± 3% reading, accuracy which satisfies the engineering specification for measuring flow rate accuracies as specified by our sponsor, which is ± $0.03 gpm/in^2$. This flow meter is able to measure flow rate ranging from 2 to 20 GPM, which covers the specification which states that the flow needs to be measured in the range from 2 to 16 gpm. Also this model it is able to handle operating temperatures ranging from 32 to 140 ºF which ensures its compatibility with hot water up to 140 ºF. Furthermore, this item is designed to have the ability handling dirty water which is important for our system. With a reasonable price of $ 302 this product fit in our budget and per the manufactures specifications (Appendix J) this sensor is suitable to use in our system and will meet all of the relevant specifications.

Fig. 23 GPI ¾ Inches TM series water meter with LCD TM075 – N [24]

Differential Pressure Transducer

After comparing the prices and accuracies, of the available differential pressure sensors we picked the Honeywell FP 2000 series differential pressure transducer (Appendix K) [25]. This series of differential pressure transducers are configurable. Using the manufactures options we built up our own transducer according to prescribed engineering specifications. To incorporate all requirements, we specified this transducer to have a differential pressure range from 0 to 5 psi which not only meets the proposed maximum pressure drop across the filter media: 2 psi, but also provides flexibility for handling larger pressure drop values. With 0.25% FS (Full scale) accuracy, the resolution is 0.25%*5 = 0.0125 psi which is slightly out of the original engineering specification which was 0.01 psi. However, via consultation with our sponsor our specifications for pressure drop accuracy have been reduced to include this value. With an operation temperature ranging from -40 to 240 ºF, and its stated durability in dirty water, this sensor should perform even in the system's demanding circumstances. With a maximum operating line pressure of 500 psi, this sensor will have no problem withstanding the approximately 5psi pressures which our system will exert on it. The price of this sensor is $ 447, which fits in our $3000 budget limit for the sensors and pumping system.

Fig. 24 Honeywell Model FP2000 Configurable Pressure Transducer [25]

Pump and VFD

Using the pump sizing analysis which is detailed in the parameter analysis section, a pump search was under taken. During this search special emphasis was given to making sure that the pump inherently had minimal pulsations in the flow which it created. Also when searching for pumps, it was made sure that the pumps could withstand fluid temperatures up to 140ºF, could withstand more than 360hrs. of pumping with Arizona Dust loading of 20000ppm. Due to the wide number of models, and the limited data which pump vendors initially provide about their products, we gave these pump specifications to 11 pump vendors, and seven vendors returned quotes for pumps which meet our specifications, and three of these quotes exceeded our budget. Initially we had planned to control the pump speed by coupling it to a DC motor, which would be modulated by a DC duty cycle. However, after consultation with the pump vendors it was determined this system would be too expensive, and a pump with an AC motor controlled by a variable frequency drive, VFD, would fit in our budget. Using capacitors inductors and resistors, a VFD takes incoming AC current and turns that into what appears to the motor as a variable frequency 3 phase current. By varying this frequency of this quasi-3phase current the speed of the motor is altered After comparing prices, and functionality, it was found that an AMT 370F-95 centrifugal pump from Corrosion Fluids Inc (Appendix L)(Fig. 25). would meet our specifications, would be able to be controlled by a VFD, and would have reasonable price of $415. This pump is able to be operated by a VFD because it is close coupled to a 3-phase 220V 0.5HP motor, and as stated by the vendor the motor is inverter duty. Also this pump withstands fluid temperatures up to 200ºF, has a self-cleaning impeller, so the Arizona dust does not accumulate in the impeller, and has silicon carbide mechanical seals, which should resist failure due to fluid contaminate abrasion. Knowing the size of the pump motor, a VFD was sized, and a low cost, industry recommended VFD from AutomationDirect was selected (GS2-10P5). This unit has the beneficial feature that it only needs 110V AC input, allowing Dow additional flexibility in where they can use this system.

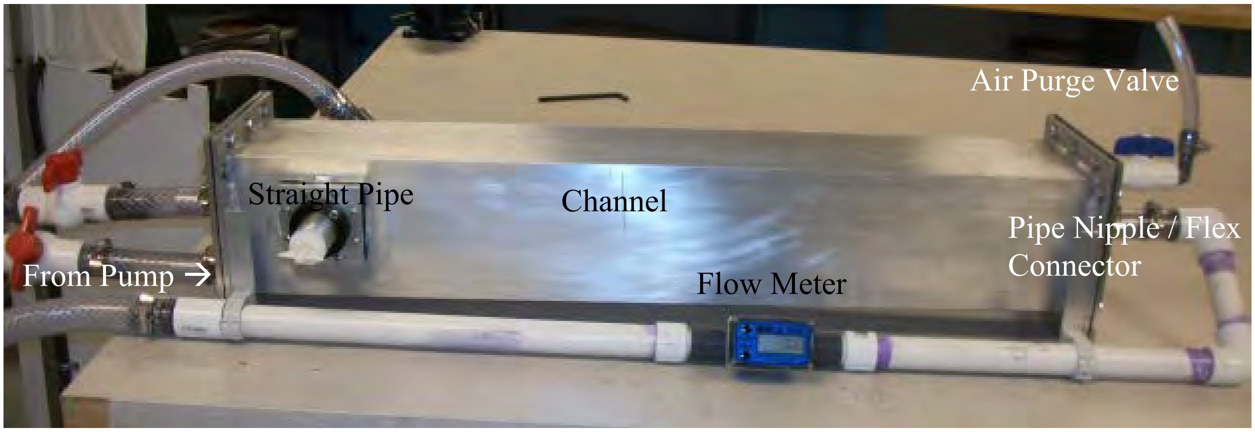
Fig. 25 Centrifugal AMT370F-95 pump from Corrosion Fluids Inc.

FINAL DESIGN DESCRIPTION
Having completed engineering analysis, and pump and sensor selection, we refined our alpha design into a final design. The final design, as amended slightly throughout the building process, is shown in Fig. 26 on pg. 42.

Figure 26. Overall rendering of the design. The channel module (detailed in Figure 27, 28, and 29) is shown at right and the cart module (detailed in Figure 33) is shown at left. ~~The wooden table is not a provided part of our design~~ It is expected that the channel sits ~~this device is to be used~~ on a user-supplied tabletop. (The various hoses connecting the channel to the cart are ~~Hosing not~~ shown)

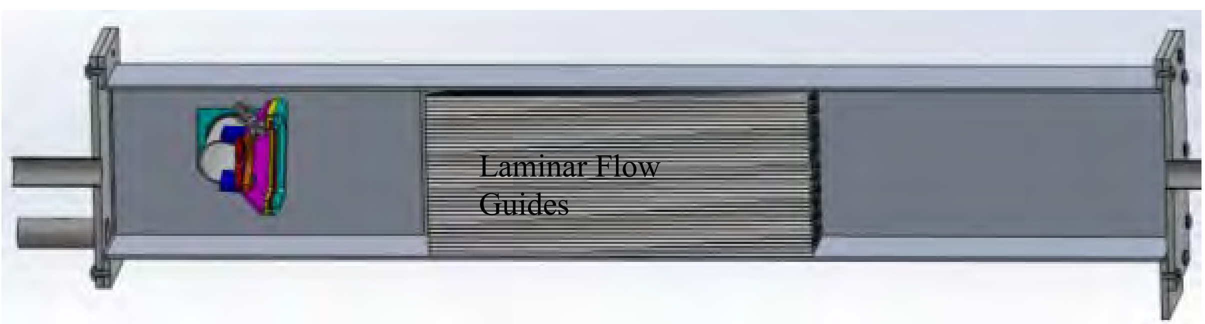
At the center of our design is a sealed 6” x 6” x 36” square aluminum channel with 1/8” walls. Water, fed from a storage tank, passes through a straight 1” PVC pipe running alongside this channel containing a flow meter. As water passes through the meter its volumetric flow rate is quantified. The pipe continues on to the end of the channel, makes a turn, and enters the chamber through a flexible connector and a pipe nipple on the channel endcap. These details are shown below in Fig. 27.

Figure 27. Exterior of channel with approach pipe.



As water fills the channel, a valve on the upstream endcap is left open to allow air to escape. This valve is manually closed once the channel is filled, at which point the flow travels through a length of vacant channel to allow the flow to expand. The flow continues~~, and then flows~~ through a bank of corrugated plastic laminar flow guides, which feature~~s~~ openings of .315” x .315” to straighten the streamlines~~,~~ and develop laminar flow (show in Fig. 28, pg 43). Upon exit from the guides, the flow remains laminar until after it passes over the filter. These laminar flow conditions have been verified through analysis (on pg. 30 and 31) of the Reynolds number at various points in the channel at the worst-case-scenario flow rates.

Figure 28. Channel: longitudinal cutaway showing positioning of laminar flow guides and void



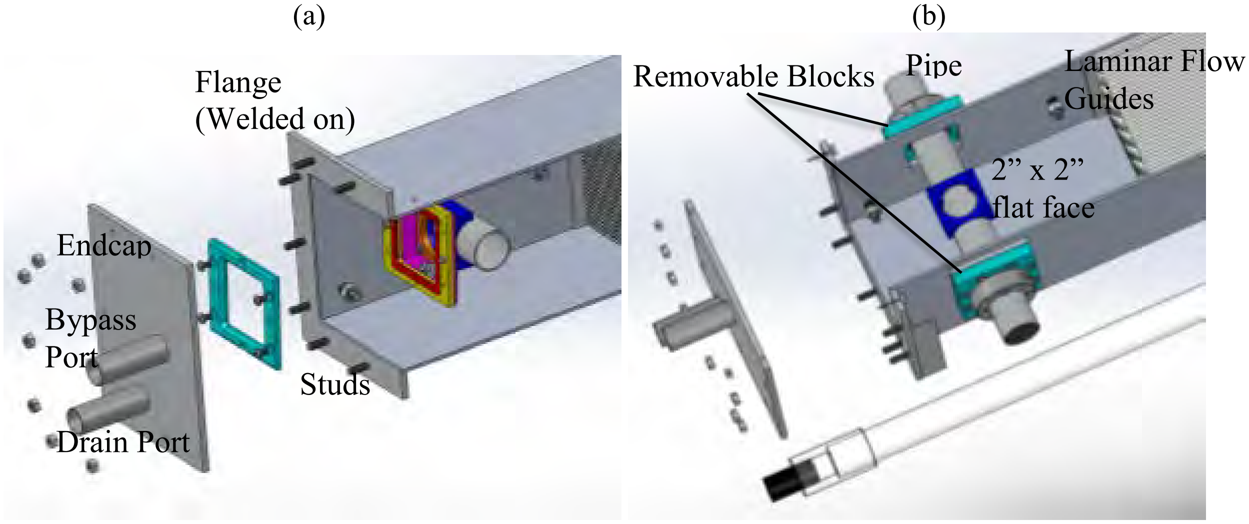
The channel has flanges welded to each end which each feature 12 threaded studs extending outwards. A neoprene gasket is fitted around the stud pattern at each end, and a channel endcap is slipped over each set of studs and tightened into place with nuts. The ends are thus removable to allow for maintenance of the internal components and for the filter media to be changed. (detail shown in Fig. 29a, on Pg. 44. The upstream flange is taller than the downstream flange such that the channel is inclined towards the downstream, which allows the system to take advantage of gravity when draining the entire channel through the welded-in drain port located on the downstream endcap. Such draining is assisted by opening the air-purge valve~~.~~

Within the channel, and downstream of the laminar flow guides, lies the filter testing chamber. This apparatus is built off of a 1.5” diameter pipe, which runs out through the walls of the channel and is supported/sealed by two removable, gasket-sealed blocks (one on each outside face of the channel). A 2” x 2” flat face with four tapped holes is welded into the middle of the pipe, and allows interchangeable filter chambers to be bolted on to it, allowing different filter sizes to be tested by the system with minimal retooling (just different chambers have to be built to test different filter sizes). Details of this design are shown below in Fig. 29b on pg. 44. The pipe is supported by these removable pieces instead of by a round hole cut in the channel wall because the pipe has a non-round profile (due to the 2x2 welded flat), and as such requires a larger hole for installation. Additionally, by bolting the removable gasket sealed blocks to tapped pieces welded to the outside of the channel (instead of tapping holes through the channel), we avoid drilling holes through the channel that cannot be sealed with gaskets.

The interchangeable filter chambers are based off of a machined aluminum back plate, which has holes that match up to the pipe interface. Onto the chamber back piece are welded four trapezoidal aluminum side panels (1/8" thick), which are in turn welded to a machined aluminum front plate such that the front and back plates are parallel and concentric. The dimensions of the front plate and side panels vary based on the size of filter being tested, though the back piece remains 2" x 2" for all sizes to ensure compatibility with the through-channel pipe. These details are shown in Figure 30.

Figure 29. (a) Exploded detail of downstream end of channel (shallow longitudinal cutaway) showing flange attachment, endcap, and filter positioned for changing. (b) Top-cutaway view of channel showing downstream end of laminar flow guides and pipe assembly.

(a) (b)



A bulkhead fitting sized for 1/8" tubing is secured through one of the side panels of the chamber to allow for the pressure inside the chamber to be read; a bulkhead fitting in the channel wall allows this tubing to leave the channel without compromising waterproofness, and a third bulkhead fitting through the channel allows the pressure upstream of the chamber to be read. Outside of the channel, both of these 1/8" tubes are connected to a differential pressure transducer. A view of this installation is shown in Figure 31 on pg. 45.

Fig. 30. Isometric view of interchangeable filter chamber. A gasket fits into the recess in the yellow plate to secure the filter media, and a bulkhead fitting is installed through the side. The orange 2x2 back plate (which mates to the pipe) is visible. The holes on the top of the yellow top ring are tapped and used for securing the retaining ring, which is aligned with the visible dowel pins.

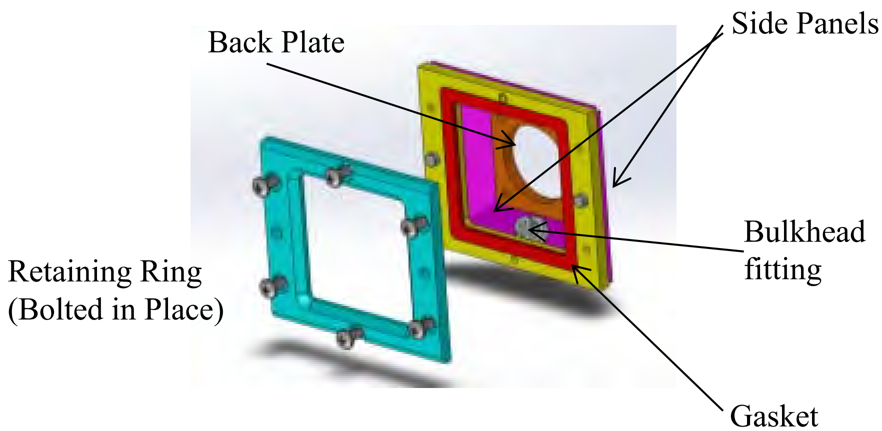
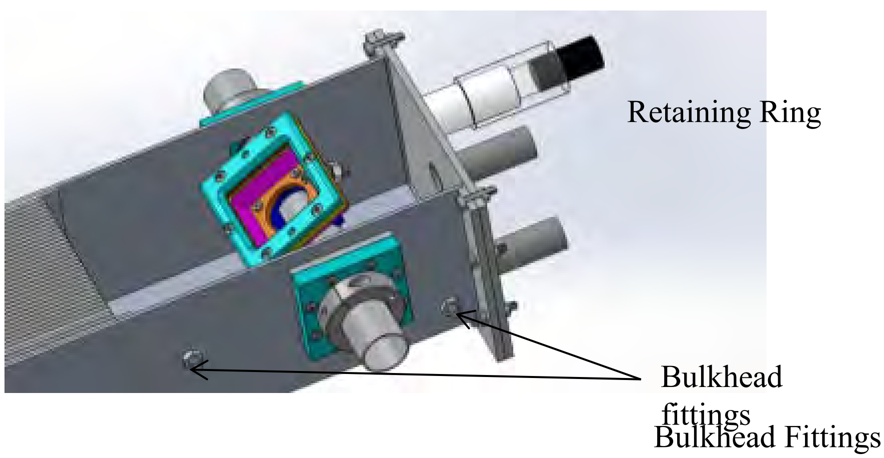


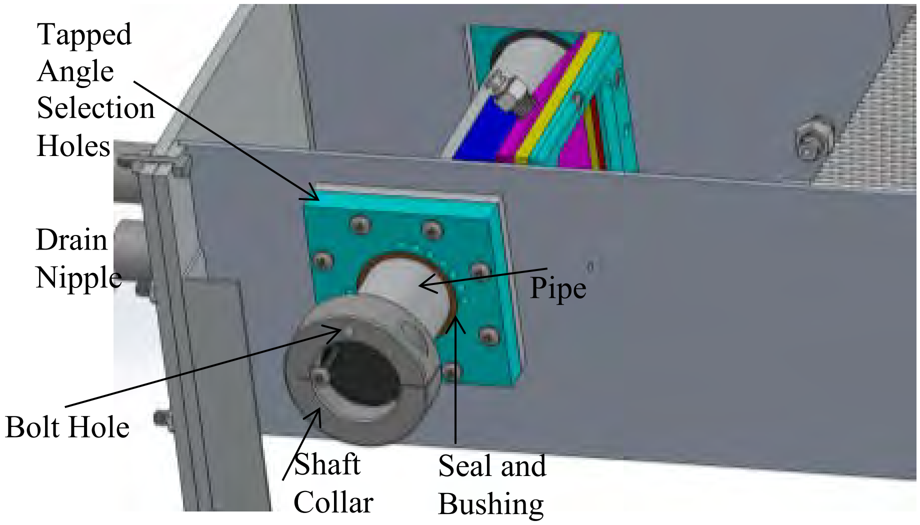
Fig. 31. Top cutaway view of the downstream end of the channel showing installation of the filter chamber.



With the chamber fully assembled and mounted to the pipe, water that passes through the filter is directed through the chamber (and over a pressure sensor tap) and out through the pipe for eventual return to the supply tank via a hose. Water that does not flow through the filter is smoothly directed around the chamber by the smoothed edges of the ring. A pipe nipple is welded into the downstream endcap and runs back to the supply tank via a user-selectable valve. Flow that has bypassed the filter is allowed to take this path back to reservoir tank.

Outside the channel, a shaft collar is secured to the chamber-supporting pipe. A hole is drilled near the outside radius of the collar, which will align with seven drilled and tapped holes in the piece that contains the shaft seal and bushing, each spaced 15-degrees apart. This allows the user to set the angle at which the filter media interfaces with the laminar streamlines – as the filter rotates one-to-one with the pipe, a screw placed through the collar hole and into the first tapped hole sets the angle between filter and streamline at 0 degrees (normal), while moving to each subsequent hole increases the angle by 15 degrees. This mechanism is shown below in Figure 29.

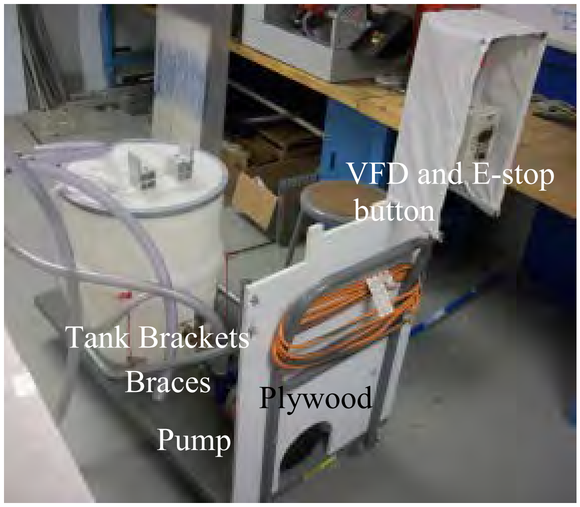
Figure 32. Exploded view of angle selection mechanism.



The aforementioned reservoir tank is positioned on a 48" x 24" hand cart. Four holes are drilled in the lid of the tank, allowing the return hoses for the filtrate, bypassed water, the drain, and the relief flow to enter the tank. The tank is secured to the cart with four brackets, which are bolted through the cart deck and tied to the rim of the tank with rope. An elbow is connected to a hole drilled near the bottom of the tank, which feeds a manually operated tank draining valve. The other hole in the tank is connected via barbed fittings and flexible hose to a 1/2HP centrifugal pump. The outlet of this pump is fed into a tee, which directs the flow to both the hose that supplies the flow meter and a pressure relief valve, which vents back into the tank through a hole in the tank lid.

A contoured piece of plywood is attached to the inside of the handle of the cart, and braced against the cart deck with bent pieces of electrical conduit. An additional brace – a piece of 1" x 1" x 0.125" square aluminum tubing, is secured to the plywood through one of the handle's vertical members. The Variable Frequency Drive and the emergency stop button are mounted on the outside of the plywood with screws, centered around this vertical aluminum brace. Additional pieces of bent conduit surround the VFD and E-Stop, allowing both to be shrouded in plastic sheet for increased splash resistance. In addition to holding the electronics, the plywood features a cutout which mates with one end of the channel. In conjunction with two angled brackets mounted to the lid of the tank, this allows the cart to carry the channel module during transport. An overview of the entire cart assembly is show in Figure 33.

Figure 33. Cart containing tank, pump, and controls circuitry.



A schematic showing the fluid flow path through the entire assembled device is provided as Appendix M, and layout drawings showing rough dimensions of the assembly are provided as Appendix N. This final design differs from the design presented in design review 3, by the changes outlined in Appendix S.

IMPROVEMENTS OVER DR2

This design was shaped heavily by the results of our engineering analysis, but factors from design and manufacturing principles also played an important part. Although our design is heavily based on the alpha design, several important changes were made as a result of this analysis.

One major change over the alpha design is the construction of the channel. The alpha concept showed that six separate pieces were used to construct the channel. However, we determined that joining such pieces together into a watertight assembly was going to require machining with a tolerance beyond what we could deliver in a reasonable time frame with the equipment available to us. Therefore, we changed to an extruded channel. This design eliminated the need for machining long, flat seams, and also eliminated the number of fasteners (and thus, number of possible places for failure) in the channel. A FEA analysis of this new channel proved that it was strong enough to support the expected pressure loads with a safety factor of 7.76.

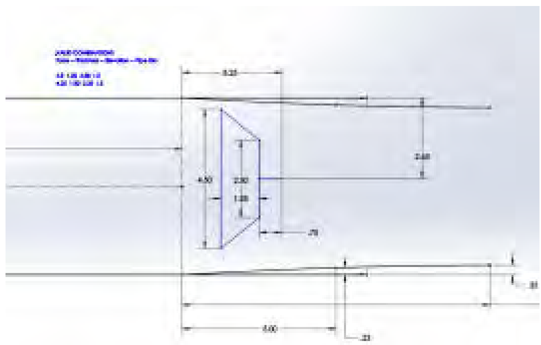
Sealing the channel was also assessed in finalizing our design, and changes were made to ensure that the odds of water leaking out are minimized. Specifically, we identified holes and straight threads through the wall of the channel as locations where water would likely egress. We redesigned all penetrations into the channel to consist of either tapered threads, blind threads that aren't in contact with the water, or a compressive joint sealed with a flange. These methods can all be sealed readily, and reduce the probability of the device leaking.

The transition from the alpha design's use of a flexible hose to route the filtered water away from the chamber, to a rigid pipe that both conducts water and holds the position of the chamber was based on multiple factors. One major one was the fact that we could not find a hose that was flexible enough to bend yet resilient enough to resist flow stopping kinking. Other concerns included not being able to find a place to attach the old style rotation pins, wanting to reduce the number of channel penetrations, and wanting to reduce the number of parts involved. The new design fulfills all these criteria.

DESCRIPTION OF PROTOTYPE

As we will be building a completed one-off device as part of the manufacturing phase of this project, our prototype is the CAD model we developed, which aided our design process throughout every stage of development and allowed us to verify that all the designed parts physically fit together. For example, an early use of CAD in our design allowed us to verify that the largest possible interchangeable chamber would be able to fit inside the channel, and that the edges of the chamber would have sufficient clearance from the boundary layers along the sides of the channel under all conditions. We constructed a 2D model to represent a cutaway of the channel (shown below in Figure 34), applied constraints based on proposed channel geometry and filter size, and iterated the remaining unconstrained dimensions until viable solutions were discovered.

Figure 34. Sketch model used to devise chamber sizes that worked in a 5.75” ID channel.



The final CAD model consists of all components modeled at actual size, and constrained together the same way that they’ll be mated in the full assembly. By assigning material properties to each part we were able to use this model to calculate the expected weights of our various components, which guided us to design to ensure that we remained under our weight specification. Fastener sizes were similarly easy to identify, as the SolidWorks program we used has a utility that automatically detects interference between components. The program even allowed us to visualize what the assembled device would look like at a workstation during day-to-day use, which allowed us to reconsider some item placements for the sake of ergonomics.

The model does contain several differences from our final design. The most obvious is that it does not contain hoses, which as flexible elements are difficult to model and constrain. We addressed this issue by taking digital measurements of the distances between the hose connections and calculating by hand the expected lengths we’d need for all connections, adding considerations for bending radii. Another major difference between the CAD and the expected reality is that weld beads are not shown – joints to be fused are represented as simply in contact. To manually verify that these connections would work, we consulted welding theory to ensure that the joints were theoretically viable (they are) and consulted our machine shop’s veteran welder to ensure that he could perform the required operations (he can).

A minor difference between the prototype CAD and the real model is the lack of realistic threading, PVC adhesive, pipe tape, and thin gaskets. These elements are generally too small or hidden to see under normal conditions, and were omitted from the prototype to decrease modeling time. However, clearances for all these items were considered when designing the visible parts, and they have been included in the Bill of Materials and (for the gaskets) in the engineering drawings.

Fabrication Plan

The first fabrication step for our project will consist of ordering all of the required parts and raw materials, which will be done using our Bill of Materials (provided as Appendix O. With that step completed, machining will commence. Renderings, engineering drawings, and machining process descriptions for all of our parts that need to be produced in-house are provided as Appendix P. We will be utilizing milling, drilling, tapping, bandsaw cutting, laser cutting, and turning processes in completion of these parts.

This manufacturing will be performed in the University's Mechanical Engineering student shop in compliance with their safety standards. Standards that we will follow during production include, but are not limited to: use of safety glasses in the shop; wearing long pants with tucked in clothing in the shop; secure fixturing of all materials; selection of correct tooling, feeds, and speeds for all processes; use of additional PPE when performing more hazardous processes (such as welding); not machining while impaired (by tiredness or otherwise); and deburring sharp edges and holes.

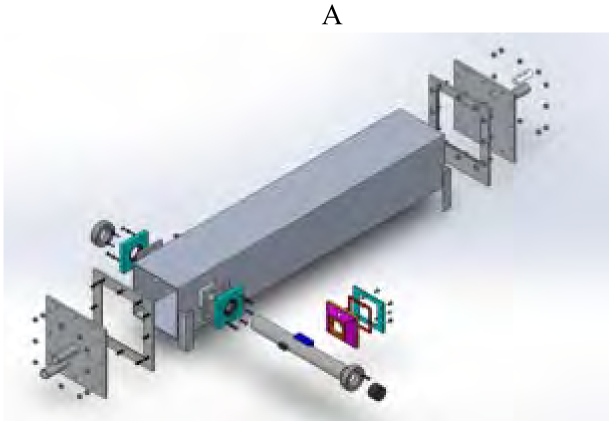
Generally, individual component manufacturing will proceed in three parallel processes: one for the channel components, one for the cart components, and one for the chamber components. These three systems share generally no parts between them, and only need to interact once final assembly is occurring. Within those parallel processes, several hierarchies must be observed, as certain parts and sub-assembly processes must occur before others. This is especially true when welding is involved.

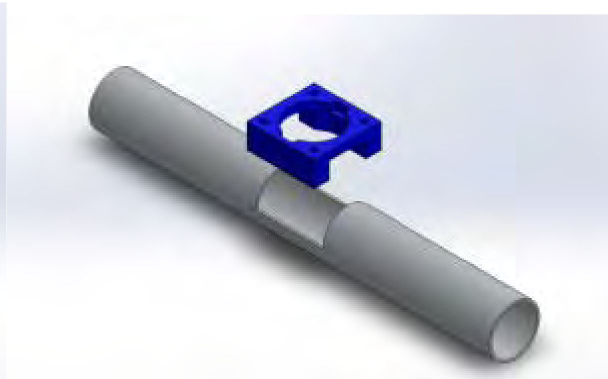
Those welding processes come in to play when sub-assembly and assembly processes begin, which occur after all of the individual components are machined. The three main areas that receive welding are the pipe and adapter block (Fig 35.b), the Chamber (Fig 35.c), the end flanges and end caps (Fig 35.d, typ.), and the tapped rings on the side of the channel (visible in Fig 35.a). Specific welding instructions and locations are provided in Figure 35, though in all cases the welds are made using GTAW and are watertight.

Figure 35. a) Side rings are tacked in place with fillets on their outside diameters, and then butt welded to the channel along their entire inside circumference. b) The adapter block is set into the cut in the pipe, centered, and then welded in place along its entire outside periphery. Due to the lack of fixture, significant cold work and plastic deformation will be required to straighten the pipe out after it deforms under the heating. c) The chamber is welded after being secured to a fixture (not pictured), which holds the front and back pieces rigidly in position while allowing the sides to sit loose while being welded. The sides are all butt welded together, and to the front and back pieces. d) The end flanges sit on the end of the channel, are tacked in to place with fillets on the outside edge, then butt welded to the channel along the entire length of the inside edge of the flange. The pipe nipples in the endcaps are secured with fillet welds along their entire outside diameter.

A

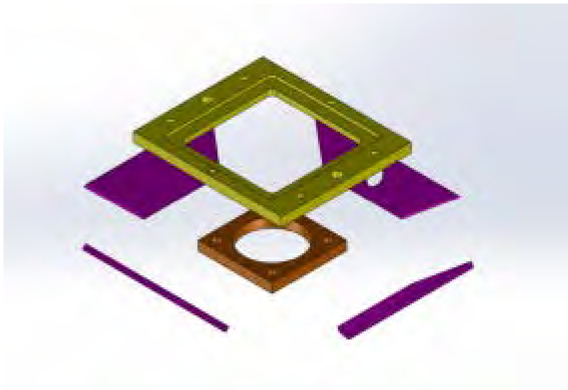
B

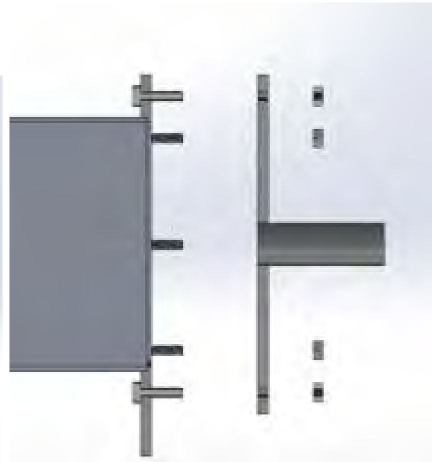




C

D

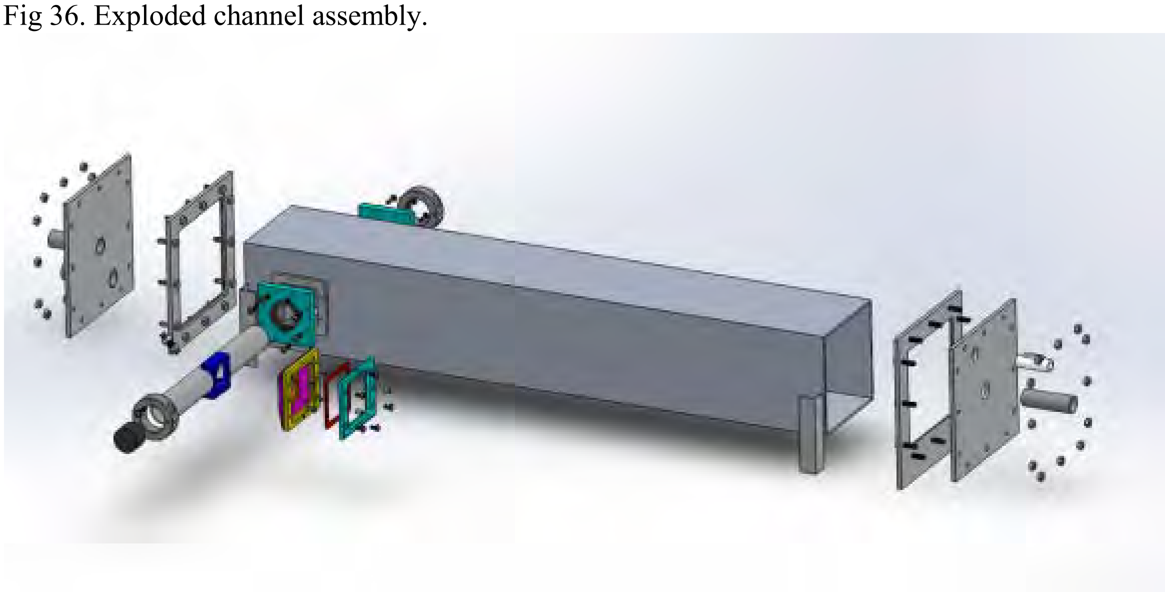




The current plan is to have Bob Coury, the shop manager of the Undergraduate shop, to perform the welding for our project due to our inexperience with GTAW. All other processes will be performed by the core three team members.

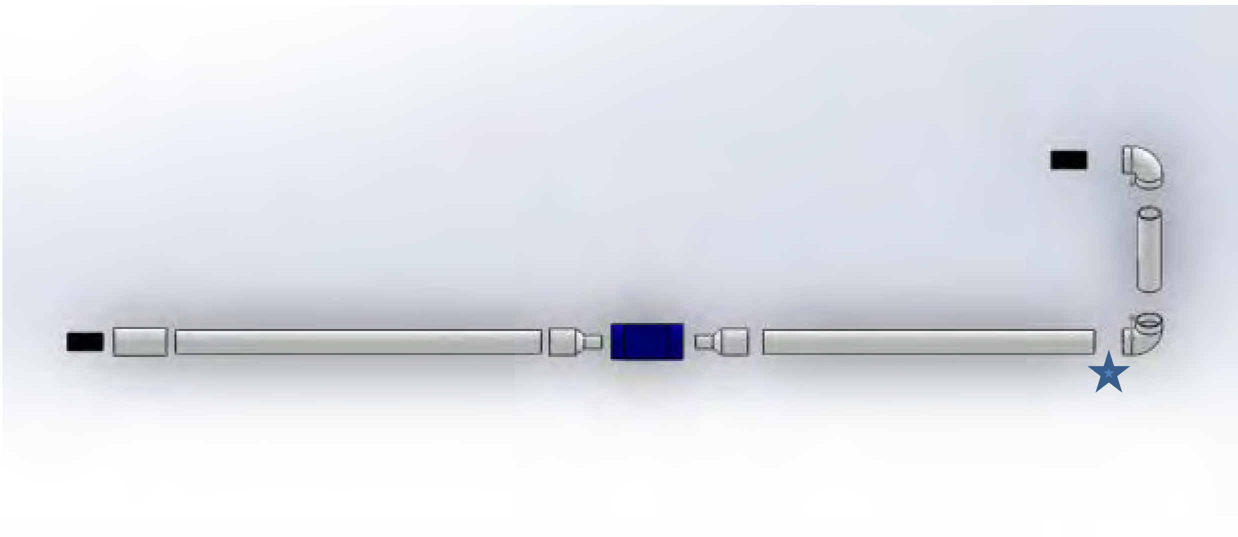
Once welding is completed, assembly will be completed using wrenches and screwdrivers. Figure 36 shows an exploded view of how the channel and chamber will all come together. The pipe piece will be placed into position first, and will be secured by installing the shaft seal blocks and there corresponding gaskets over the ends of the shaft, and then screwing them to the welded tapped rings using screws. The lock collar and plug are installed on the pipe next, followed by the chamber (which is screwed to the adapter block through the open end of the channel. With the chamber installed, the laminar flow guide stops are glued into position and the guides themselves are slid in to position through the channel through the upstream end (neither pictured). As a final step before the channel is closed, the pressure taps are installed in the channel wall and chamber. To close the channel, studs are installed in the tapped holes on the flanges and gaskets are placed over them. The endcaps are fitted over the studs, and secured in place by threading nuts onto the exposed studs.

Fig 36. Exploded channel assembly.



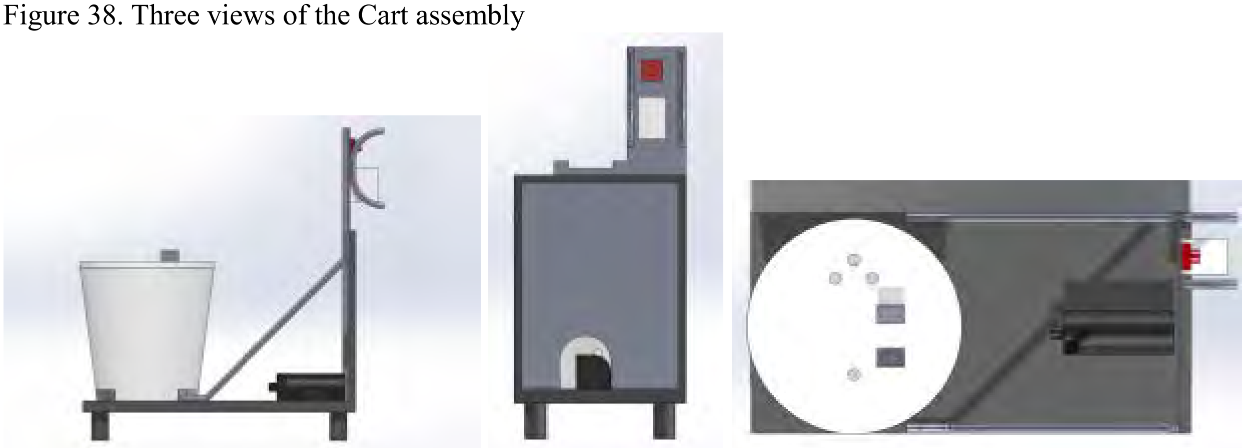
The pipe assembly which runs along the side of the channel has a relatively straightforward assembly process. Once its pieces are cut, they are either socket welded together (for most joints) or screwed together with PFTE tape (NPT fittings on flow sensor). The one exception to this straightforward process is the starred joint in Figure 37. That joint is at an usual angle relative to the flow meter and the rest of the pipe, and should only be socket welded after dry fitting the connection into the clips on the side of the channel and verifying that the angle is correct (allows flow meter to be visible with the pipe laying snugly into the clips).

Figure 37. Exploded Side Pipe assembly. The starred joint should be dry fit and positioned before it is socket welded.



The cart (Figure 38) has a much more straightforward assembly process than the channel and chamber. All connections for the tank brackets, plywood, pump, and braces are bolted through the cart, and can more-or-less be made in any desired order. The VFD and E-Stop button should be installed, centered over the vertical brace after the plywood and brace are fully installed, at which point the wiring can occur. The final steps of cart assembly are installation of the plastic shroud (not pictured) around the VFD, and plumbing of the flow systems (see Appendix M).

Figure 38. Three views of the Cart assembly



Assembly will be performed on-the-go as components are completed to ensure that parts interface as they should and that there are no tolerance issues. A final assembly will be performed once all machined components are completed and all off-the-shelf components (some of which have a lead time almost as long as our three-week manufacturing window) have arrived. The final pre-testing steps of manufacturing will be wiring up the signal wires for the sensors and ~~the power lines for~~ energizing the pump's variable speed controller. As the pump and VFD ~~will~~ utilize three-phase current (which is significantly more dangerous than conventional 120VAC single phase), we will seek the consultation of a University electrician in completing that step.

DESCRIPTION OF VALIDATION APPROACH

The validation plan outlined in the following section is the original validation plan that was intended to be used, and for the most part these plans were followed. The unit's validation differed from these tests in several regards due to several limitations (Dow only supplied us with one filter sample, rather than the several that we requested). Also several testing procedures were improved. A complete description of how the unit was validated and the results of these tests are supplied in the subsequent "Validation Results" portion of the report. Our system has been designed to meet all engineering specifications. However, we are still going test our water filter media testing unit experimentally to make sure this system meets all of its requirements. The proposed testing procedure will be discussed in the following section while for those engineering specification that cannot be tested through experiments, corresponding engineering analysis will be provided.

The testing procedure will be started with static and dynamic leak tests to ensure that it is safe to proceed with other engineering specification evaluations.

Static Leak Test

This test will be done both statically and dynamically. For the purpose of safety and in case there are any accidental leaks, this test location need to be level, flat, equipped with floor drain and should be isolated to avoid damaging the work area due to water exposure. No electricity will be involved in this test process. For instance, the pump will not be present to avoid direct contact of electricity and water. We will use a water tap instead of a pump for the supply water. The channel will be connected to the tap using a hose, with the channel being held vertically, and the bottom endcap sealed, while the water is supplied an open upper end cap. Once the channel is filed the upper end will be put on and the channel will be oriented in to the horizontal position. Then the channel will be examined to see if water leaking exist. Special attention will be given to joints and hose connection, to make sure they are sealed. The exact location is to be determined as we are still in process of finalizing available work areas.

Dynamic Leak Test This test will be performed with the pumping system used to pressurize the channel and will be only conducted after all leaks are rectified and retested in the static test. First the pump will be connected to the testing channel and it the pump will be started up at its lowest flow setting, and with the by-pass valve open on the channel. If there are no leaks at this point the by-pass valve will slowly be closed, and if there are no leaks at this point the test will be stopped, and the chamber outlet will be capped and the procedure will be repeated. If there is any leaks detected during this process, the pump will be immediately shut down, and the leak will be rectified, and the test will be started over again. After that, we will place the pressurized tunnel, and close all of the openings and allow the pressurized channel to sit for at least 24 hours to ensure that no leaks occur over time. In case of leaking and flooding, a physical barrier should separate the direct line from the channel to the pump. No exposed power supply or cord is allowed in the immediate testing environment. After supplying water to the enclosed system, the pump will be removed from the testing area to avoid any danger related with electricity. The area for this testing will need to have the same requirements as the previous test except, 110V GFI outlet will be needed in addition. Also we will need a drain or a tarped containment area for this test.

When the whole system is proved to be safe and without leaking, we will continue testing the following engineering specifications individually.

Laminar Unit Flow Rates Upstream of the Filter
Due to the sealed nature of the chamber, we are going to implement CFD simulation to model the scenario that happens inside the flow channel to show the upstream flow is laminar (eg. Model speed versus distance curve). To test the flow delivery rate, we will calibrate the flow sensor according to the manufacturer's specifications, and will measure the flow rate through the system using this calibrated flow sensor, making sure the system can deliver flow rates from 0 to 16 gpm. This test will need the same environmental requires as the dynamic leak test.

Flow Rate Accuracy of 0.03gpm/in^2 and Pressure Drop Accuracy of 0.01psi
For this test the lab setting should be equipped with same features as where needed for the dynamic leak test. Connect the flow meter with the hose into a water tap for initial testing before integrate it into the whole system to make sure the flow meter is functional. The sensors are being calibrated or detailed procedure of calibration will be provided in manual. The flow meter has calibration button so we can follow the guide to calibrate in order to achieve the required precision. The calibration information on the pressure transducer is still in process. The resolution is half of the least reading increment so we can test this criterion directly from data ouput. For very rare case, if the expected accuracy is not achieved, further calibration can still be done in LabVIEW panel to adjust output digits to reach the required accuracy.

Vary Flow Angles from 0 to at least 60 Degrees
For this test, we will set the testing channel on the table top. No water will be running and no electricity will be involved. The angle variation system will be tested using a protractor to ensure the correct increment of angles – 15 degrees - with respect to midline of the channel. To make sure the filter is at the same angle as the external angling system, we are can flip the filter chamber to the filter changing position, which is nominally the 180 degree position, and at this position we can make sure the filter has the correct orientation, if it does not, the angling shaft collar can be adjusted.

Demonstrate Ability To Accurately Quantify Know Media
Gathering known filter media from our sponsor and the corresponding testing documentation for the filter media, we are going to repeat the experiment which we are given data for (as far as what pressures or flow rates are tested and, and angle of testing) in order to validate our testing system accordingly. We will notice any difference between their data and our data so we can analyze our test unit performance critically. If there are discrepancies, we will trouble shoot our system to see if there are any modifications that would need to be completed to make our system more accurate. Since this documentation has not been provided to us yet we cannot provide any more detail on what the test will consist of.

Provide Detailed User Instructions
A manual of detailed instructions and safety procedures will be provided to ensure that the operator understands how to use the system.

Filter Change Time Needs to be Less than 10 mins.
For this test, a drainage system is required but no electricity will be used. Tap water will be used to fill the channel, and then each of one of the team mates will complete three timed trails, of draining the channel, and unscrewing and re-screwing the necessary screws to change the filter, each one of these trials should be less than ten minutes. All three teammates will complete this to give the test a breadth of tooling experience for the test participants.

Common Controls Height between 36 in and 73 in

We have designed our system to fit in this ergonomic range. This lets any operator to control both the test channel, and the valves on the cart.

Retoolable to Filter Sizes Ranging from 1 in.x1 in to 4 in.x 4 in.
A detailed manufacturing plan and bill of materials for retooling procedure will be provided. We will also address any possible difficulties we encounter during manufacturing and state these in the manufacturing plan provided to Dow, to make sure the different sized filter chambers can be built by Dow.

Able to Securely Hold a Filter Media with Thickness Ranging from 0.004 in to 0.04 in.
We are going to obtain a certain sample size of 3 in x3 in with various sizes from 0.004 in to 0.04 in from DOW and test all of them individually inside of filter chamber for at least two hours continuous testing, at full flow speed, to simulate the most rigorous use of the system which Dow has indicated that they will use the system in. During this time the filter should not dislodge.

Lifting Required to Move Unit Should be Less Than 35 lbs. and Non-lifting Parts Will be Place on Wheels
We will weigh the completely assembled channel module, with the hoses attached, and make sure that it does not weigh over 35lbs. Also it will be made sure that everything else is mounted on the wheeled cart.

Drain the Whole System in less than 10 mins
Just as it would be done in a Dow lab, the channel and the reservoir tank, once they are filled, will have their drain valves opened over a floor drain, at the same time, and stop watch will record how long it takes to drain the entire system. This will be done ten times to make sure any slight changes in how the valves where opened, or exactly how full the components were, does not allow use to incorrectly validate this.

No Plastic Deformation When Fixturing Filter
Initially we will test the fixture with the filter media that will be provided by DOW for 2 hours outside of the channel, and then the filter will be removed and inspected for deformation. If no plastic deformation is observed, then we will repeat this under normal testing conditions (where the filter is in the channel, and water is flowing through the filter.

Systems has the Ability to Recirculate Water
We will make sure that when the system is in operation that no water leaks or drains out of the system.

Water in System is User Accessible and Access Point Allows Addition of Arizona Dust
This test associates with the tank water reservoir only. This will be tested by adding Arizona dust to the water in the reservoir, to a loading value of 20000ppm.

For the rest of the engineering specifications as prescribed, there is no direct way to experimentally test them. However, supporting documentation or analysis will ensure that our sponsor’s requirement will be met.

Follows MIOSHA Part 93 and Part 39 for Electrical System
To address electric safety, we will follow the installation of sensors and pumping system sections of MIOSHA Part 39 to make sure the system is free of electrical hazards. Also the unit instructions will give guidelines for always check the systems wiring before plugging in the power supply one.

Minimum Hours of Use before Water Contaminant Abrasion Related Failure is 360 hrs
According to Dow’s specification, a normal session will take approximately 2 hrs. Under normal testing condition, even in the hot water condition, the flow sensor has a Lithium battery life of 5 years; the pump has a life span of 6000hrs under appropriate operation. The whole strength of the system is restricted by

its weakest part. Because the pump has the highest cycling rate per time when the system is in operation therefor the pump will be the first to fail.

Handle Working Fluid Temperature at least 140 F

All sensors, materials, pumping system have been selected to meet this criterion so they can maintain normal performance under fluid temperature up to and including 140º F.

DESCRIPTION OF VALIDATION RESULTS

Our system has been designed to meet all of its engineering specifications. However, we still needed to experimentally show that our water filter media testing unit actually met all of the design specifications that were required of it. The testing procedure used to validate these requirement and the results from these tests are outlined in the following section while for those engineering specification that cannot be tested through experiments, corresponding engineering analysis or verification is provided. For all of the tests were electrical power was used two people were present during testing. Also, due to safety concerns on the part of Dow, all tests requiring water in the system were completed with tap water that did not contain any Arizona Dust.

Follows MIOSHA Part 39 for Electrical System

To address electrical safety, we followed the MIOSHA standards for the installation of the electrical components of our system, including the installation of the VFD and pump (the sensors have too low of power demands to be included). To meet the MIOSHA standards, an E-Stop button was installed in series with the pump and VFD. Also the system was wired using manufacturer specified wire gauges. The system was wired with multi-colored wires (to allow for proper detection of ground, positive, negative, etc.). Proper knock-out protection fixtures, cable clamps, and strain relieving fixtures were used to properly protect the system's cables. With these safe guards in place, which allowed the system to comply with MIOSHA part 39, a final inspection was completed by a licensed electrician, with e-mail documentation provided to the section instructor (e-mail is documented in Appendix Q).

Follows MIOSHA Part 93 for Air Receivers

Our design's channel module is a low pressure, pressure vessel, to maintain safety we followed MIOSHA part 93 and the corresponding ASME Section VIII. Since our design included a rectangular pressure vessel and which is termed a "special shape" pressure vessel, there were limited construction procedures to follow, it was stated that it "shall be designed for at least the most sever condition of coincident pressure expected in normal operation" and a pressure relief valve could be used to make sure that this design pressure is not exceeded. To meet this MIOSHA standard, the system's pump was sized so that the channel had a safety factor of 1.72 on yield even if the pump was running at full speed and the flow was blocked off downstream of the channel. To safe guard the system even more a pressure relief valve was installed in between the pump and the channel and the relief pressure was set below the maximum pressure of the pump, keeping the system from unnecessarily coming near these higher pressures. The procedure for setting the relief valve is outlined in dynamic leak test portion of the validation results. By making sure that the system is sized so that the channel is not over pressurized, and by installing a pressure relief valve up stream of the channel our system more than adequately meets MIOSHA part 93.

Leak Testing

Since our system needs to be filled with pressurized water when in use, a key validation that was necessary for further validation was making sure our system did not leak, first unpressurized and then pressurized.

Static Leak Test

For the purpose of safety, leak testing of our system was initially tested without the system being pressurized. This test was completed in a location where water spills would not be a facility issue, were there was a water source, and where an spills would not cause safety hazards (electrical, nearby equipment failure, etc.). Since a location with a floor drain was not able to be secured, this test was done with absorbent materials on-hand, and our design's cart on-hand so either the channel module loaded onto it or the water holding components on the cart module itself could be quickly expedited outside, while the absorbent material contained the leak, and once outside they could be safely drained. To test the channel all of the channel module's fixtures were attached, all of the channel module's gaskets were installed, and the channel was fully assembled, and placed on a level surface. Then capping the input and filtrate pipes, the channel was filed through the by-pass hose and air was purged from the channel using the air purge valve. As soon as water was present in the air purge valve's vertical tube the air purge valve was quickly closed and the filling faucet was quickly shut-off, to avoid spills. For this process the input water was open to the atmosphere to avoid pressurization of the channel. In a similar manner, the cart module was statically leak tested, with all of the fittings in place, and with the output from the cart module capped. Several leaks were detected at this point, both in the channel and the cart modules. Several where fixed by additional torqueing of fasteners which clamped two components to an intermediate seal, or by additional torqueing on threaded fittings, or in the case of the of the filtrate output fitting, where unavailability of proper drill sizes lead to reduced threading length/depth on the output (because tapered threads where used there were plenty of threads, but they weren't deep enough to properly accommodate more than four threads on the original mating fitting), therefore a different fitting was used which, though nominally the same size had a smaller thread diameter, allowing it to thread into the filtrate output pipe to a proper depth. Also on the channel module it was determined that several weld joints were not fully sealed. The channel was then disassembled and these root cause of these leaks was easily detected in the welds when a closer inspection was made and these locations were re-welded. Following these corrections both the cart and the channel modules were re-tested; when neither module leaked, the two modules were connected and the whole system was statically tested for leaks. To allow for full detection of leaks under this static pressure, the system was filled with water and allowed to sit for two hours, catching any final leaks at this point. Once all leaks were corrected at this stage, a dynamic leak test was undertaken.

Dynamic Leak Test

Once our wiring system was inspected by a licensed electrician to mitigate electrical failures, injury or fire, we completed our dynamic leak test, to make sure the system would not leak during operation. Since this test as designed, required both electricity and water, several precautions were taken. Similar to the static leak test this test was located where any unintended spills, sprays or leaks would not cause facility or nearby equipment damage, or hazards. Though we originally planned to use a GFCI circuit to protect against unintended shorts due to water spills, when we tried to operate the system with a GFCI, the GFCI continued to trip, and further inspection of the VFD's lengthy manual informed us that the VFD could not be operated on a normal GFCI circuit, and that it had its own, however less sensitive ground fault detection built in, and that it needed a specialty GFCI if it was to be run on a GFCI circuit. Since the VFD did have its own ground fault detection, an E-stop button was in series with the VFD, and the pump motor was a totally enclosed model, we proceeded with the powered testing with some safety precautions incorporated with our testing set-up. For the set-up, the unpowered channel module was located as far from the powered cart module, and the VFD and E-stop button were located so that their mounting board and a mounted tarp kept them protected from any unintended leaks or sprays emanating from the pump or channel. With these precautions in place, the filter media provided by Dow was installed in the test unit and the channel was set-up so that only the by-pass and the filtrate hoses were open (and returning to the reservoir tank). Then the pump was started up at its lowest setting and then slowly increased, and would be immediately shut off any leaks were detected. No leaks were detected as the pump slowly swept its entire range with the by-pass open. With the pump running at full-speed the by-pass was slowly closed. No immediate leaks were detected. To protect the pump and to stop over pressurization of the channel the pressure relief valve was set so that it was relieving pressure at this setting. This pressure relief setting corresponded to a flow rate of ≈21gpm which is more than twice the 9 gpm flow rate that is necessary to test the 3in.x 3in. filters that the unit is currently tooled to test. This setting allows plenty of testing range but keeps the system from being unnecessarily pressurized. If this relief setting pressure is too low for proceeding tests the relief setting can be increased, however it would be recommended that a pressure gauge be tapped into the system on the upstream side of the channel so that if the pump is over preforming, the channel is not pressurized above its yield pressure of 33.6 psi. The system was left in this state for two hours to check for leaks. One leak was detected, and was rectified, and then the system was retested, and no-leaks were detected. With the system safe from over pressurization and free of leaks we continued with the following testing.

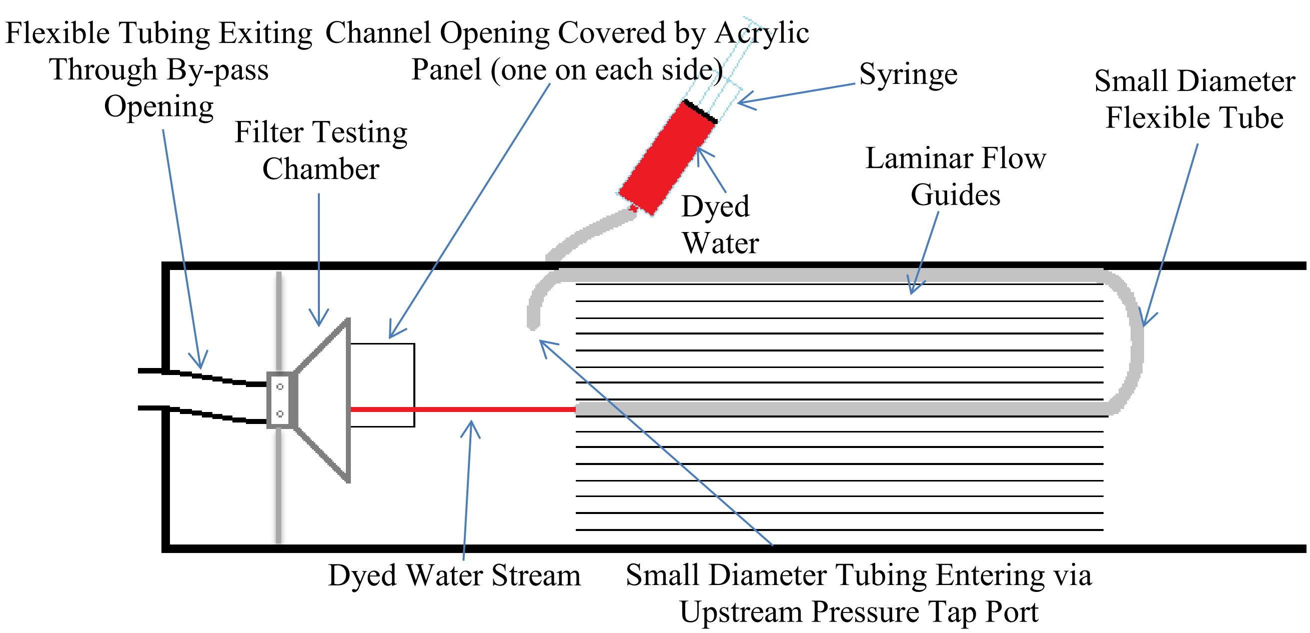
Laminar Unit Flow Rates Upstream of the Filter

With the filter media that Dow provided us with installed in the unit, the flow rate of the unit was tested. For this test the by-pass valve was closed and all flow was being passed through the filter. Using the unit's pre-calibrated (factory calibrated) flow rate sensor, the flow rate range of the system was recorded. When the pump was off, no flow rate was observed. By slowly increasing the frequency of the VFD's 3 phase 220V AC output current from 0 Hz. to 60 Hz. the flow rate of the system was slowly increased from 0gpm to 20+gpm. The maximum value for the system's flow rate was unable to be characterized because it exceeded 20gpm, and the system's flow meter only has a range of 2-20gpm. This 0-20+gpm range exceeds the 0-16gpm range that the system needs to have. Also it was noted that the system's motor had no indications of over-heating, even when operated with low frequency current, as the supplier cautioned possibly could occur.

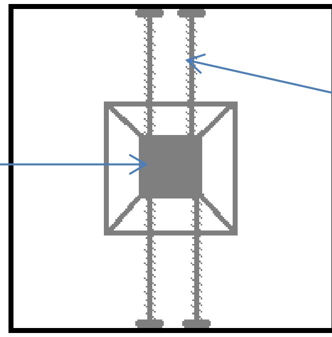
The other part of this flow specification that needed to be validated was that the system needed to produce laminar flow in front of the filter face in this 0-16gpm flow range. To test this we conducted a dye test, where a schematic for the set-up is shown in Figure 39. For the set-up a 0.5"x 3"x3" aluminum

Figure 39. Schematic of Test Set-up for Testing Laminar Flow

a. Cut View of Entire Channel Showing Laminar Flow Test Set-up



b. Rear View of Chamber in Channel Showing Test Fixturing



base was constructed to mount the chamber on. In the center of the base a hole was drilled and tapped to accommodate a 0.5" NPT threaded fitting. On the top and bottom of the base ¼-20 tapped holes were drilled and tapped to a depth of 1". Also on the face of the base holes were drilled and tapped to accommodate ¼-20 bolts which mated to the holes on the back of the filter chamber. From the 0.5" NPT threaded hole, a 0.5" male threaded to male barb fitting was inserted. On the barb fitting was attached 0.5" flexible hosing. As seen in Figure 39 this tubing connected to the rear of the chamber was feed out the by-pass hose, allowing the system to have a quasi no-bypass setting, where the hose from the chamber filled most of the by-pass hose. This whole chamber module was then clamped in the channel by unscrewing the bolts on the top and bottom of the chamber base, clamping the unit in the channel. The pipe and bushing mounts that normally hold the chamber were removed and ½" thick acrylic windows replaced them. To feed dye into the channel a small diameter tube was connected to the upstream pressure tap port and the tube was feed up to the upstream end of the laminar flow guides through a laminar flow tube near the corner of the channel and was then feed back towards the filter via a tube in the laminar flow guides that was near the center of the chamber, and it then terminated just past the end of the laminar flow guides. On the outside of the channel small diameter hosing was used to connect the up-stream pressure tap to a syringe filled with dyed water. The set-up for the test is fully illustrated in Figure 35.

With the channel fully reassembled in this test configuration, the channel was filed with water. Since the by-pass hose was the exit for the filtered water the by-pass valve was left completely open. Slowly increasing the speed of the pump the following flow rates were evaluated at steady state: 4,6,8,10,12,14, and 16 gpm. At each of these flow rates the system was allowed to come to steady state and then dye was injected into the flow directly downstream of the laminar flow guides via the small diameter tube. The flow was observed through the acrylic windows which replaced the pipe bearing components. The dye being injected into the flow for flow rates of 4, 8, 12, and 16 gpm are shown in Figure 40, 41, 42, and 43 respectively. As seen in Figure 44 which also corresponds to a flow rate of 4 gpm, except that it captures

Fig. 40 Dye test for a flow rate of 4 gpm showing a slightly transitional flow

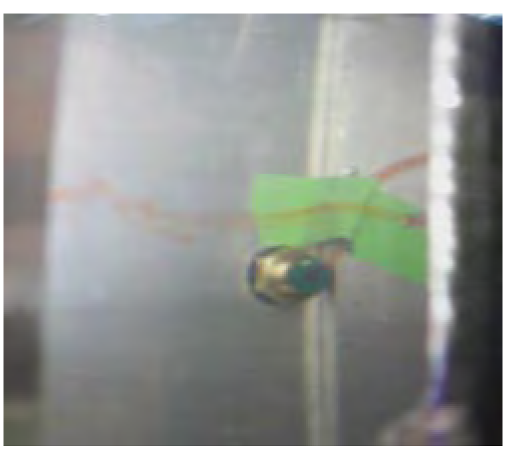


Fig. 41 Dye test for a flow rate of 8 gpm showing a transitional flow

Fig. 42 Dye test for a flow rate of 12 gpm showing a transitional flow

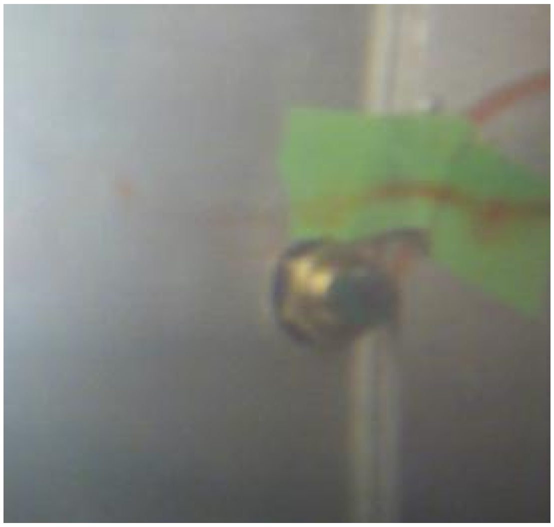
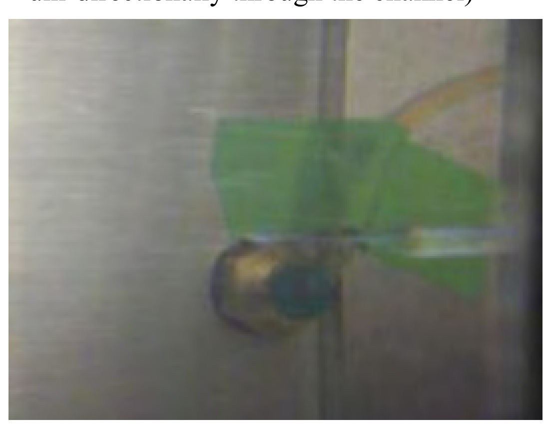


Fig. 43 Dye test for a flow rate of 16 gpm showing a transitional flow

the flow farther downstream, farther downstream of the injection site, nearing the filter face in the test set-up, it can be seen that the flow is beginning to convolute, demonstrating a more transitional flow than a laminar flow. However, the Reynolds number associated with this 4 gpm flow in the full channel regardless of the laminar flow guides is 1768, which is below the 2100 Reynolds number that bounds laminar flow. The fact that these flows that are known to be laminar were exhibiting non-laminar characteristics left us questioning the validity of these tests. Another observation that made us question the validity of these tests was that miniscule bubbles developed by the laminar flow guides and the small debris coming from cleaning out the pump could be observed in the flow and these particulates had very organized uni-directional flow from the laminar flow guides to the filter, and as expected, in a thin region on the sides of the channel theses bubbles and debris had chaotic unorganized flow until they drifted toward the area in front of the filter where they again regained linear motion. To make this observation more observable we re-ran the laminar flow tests at the previously described flow rates, except oil droplets were injected into the stream. As seen in Figure 45, the flow was observed to be laminar or possibly slightly transitional even up to a flow rate of 16 gpm.

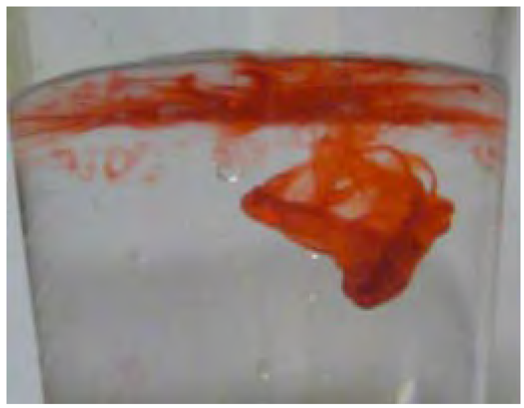
Fig. 44 Dye test for a flow rate of 4 gpm showing what appears to be a transitional flow developing

Fig. 45 Oil droplet test for a flow rate of 16 gpm showing what appears to be a laminar flow (also note the horizontal streaks through the image these are debris and miniscule bubbles moving uni-directionally through the channel)



The discrepancy between the dye tests and the oil tests is most likely due to the fact that the oil is immiscible in water and the dye was water soluble. As seen in figure 46, were the water soluble dye that we used is being slowly dropped into a glass of quiescent water there is a chaotic diffusion process happening rather than the completely organized diffusion process that might be expected where the dye would be expanding in a completely spherical, or somewhat hemispherical direction due to gravity causing the dye to have some inertia in the drop as it comes from the dropper and enters the water. Instead, as shown in figure 42, there is a more wavy diffusion process that occurs, causing the validity of the water-soluble dye tests to be uncertain. However, the oil droplet tests show that laminar flow is certainly maintained up to a flow rate of 8, and reviewing the results with our sponsor, they have verified that the flow is "laminar enough" at least up to the 16gpm flow rate that is necessary.

Figure 46. Diffusion process of the water soluble dye used in the dye tests, showing the somewhat chaotic diffusion process most likely do to Brownian motion



Flow Rate Accuracy of 0.03gpm/in^2 and Pressure Drop Accuracy of 0.01psi

To make sure that the flow rate and the pressure drop are being measured to these accuracies both of the sensors we selected had accuracies that met these values, and both sensors were purchased pre-calibrated. The flow sensor has an accuracy of ± 3% reading which corresponds to a maximum error of 0.03gpm/in^2 of filter media for the maximum flow rates the system was designed to provide to the filter (1gpm/in^2 of filter media). The accuracy of the pressure sensor also meets its specification, by having an accuracy of ±0.005psi.

Vary Flow Angles from 0 to at least 60 Degrees

To test the unit's possible filter angles, we set the testing channel on a table top. With the channel fully drained the end of the channel was removed, and the chamber was fastened in the filter changing location. Using a protractor the angle of the front face of the chamber relative to the bottom of the channel was measured. Loosening the angle varying collar on the chamber pipe the angle of the chamber was varied until it was exactly at a 90^o position, at that point, the angle varying screw was fastened in this 180^o position, and the angle varying collar was clamped to the filtrate pipe. Then using the protractor on the outside of the channel, the angle of the angle varying collar was measured when it was fixed into each of the angle holes, relative to its initial 180^o position, and the difference between the initial 180^o and the measured value was recorded as the actual angle of each of each setting. As shown in Table 26 each angle had the correct value and the error associated with each angle is only due to the resolution of the protractor. The filter angling specification was more than met by our unit, with the additional 75^o and 90^o filter angle settings being provided in our unit.

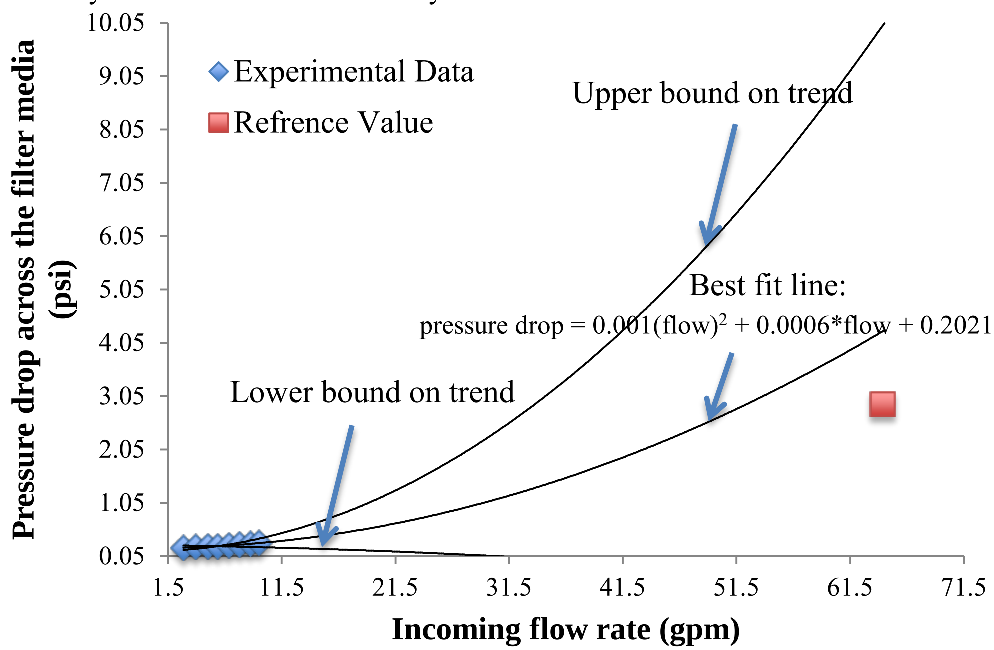
Table 26. The required and the measured filter angles relative to the flow for the test unit

Required angle	15^o	30^o	45^o	60^o	Not Required	Not Required
Measured angle	15 ± 0.5^o	30 ± 0.5^o	45 ± 0.5^o	60 ± 0.5^o	75 ± 0.5^o	90 ± 0.5^o

Demonstrate Ability To Accurately Quantify Know Media

To validate our unit, Dow provided us with a sample of filter media which had a documented pressure drop for a flow rate of 10.3 gpm/ in^2 of filter media with a filter angle of 0^o. To verify that our system accurately quantifies the same filter media, we tested the filter media Dow provided us with for seven flow rates between 2gpm and 9gpm which is the range of flow rates which the unit is designed to test for its current tooling, (which corresponds to a maximum flow rate of 1.44 gpm/ in^2 of filter media exposed to flow). As shown in figure 47, the flow rates which the unit is designed to test are far below the flow rate which Dow provided data for. However, it can be seen that the reference value given by Dow is within the upper and lower bounds of an extrapolation of our data, and is fairly close to best fit polynomial for our data. However, due to the highly incomparable flow range that our unit is able to test relative to the data that Dow provided, we are unable to definitively confirm that the unit does indeed accurately quantify known media. To definitively confirm this, Dow will need to procure a filter sample that has known flow rate and pressure drop data for a flow rate within the 0.32(bounded by lower value of the flow sensor) to 1 gpm/ in^2 filter media, which the unit is designed to test.

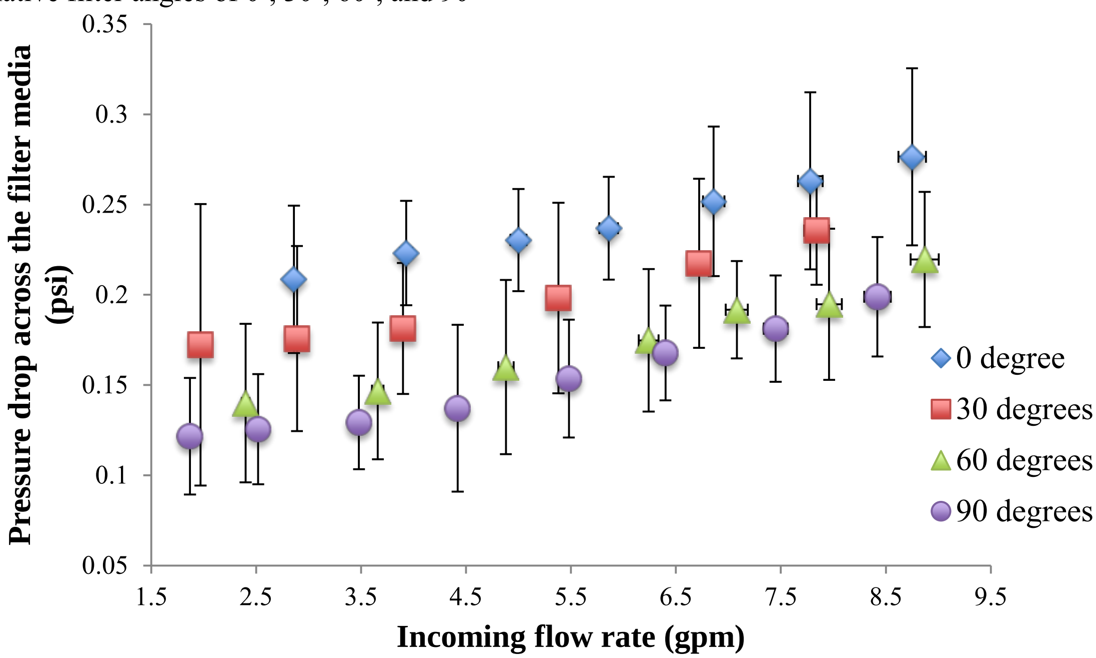
Fig. 47 As shown the reference value for flow rate versus pressure drop that Dow provided is well outside of the range of flow rates which our unit is designed to test, and therefore we are unable to definitely state that our unit accurately characterizes known filter media



However, on a qualitative level, the trend that is generated by the data, described by the best fit line in figure 47 seems very reasonable, since a large portion of the trend is accounted for by the squared portion of the equation, which corresponds with the minor headloss equation, which one might try to at least roughly model a filter as. The other linear and offset portions of the trend may be coming from the fact that some of the filter's characteristic dimensions are very small, and effects like surface tension may be coming into, effect, rather than just the velocity of the flow, as the minor headloss equation assumes. It could be imagined that a 5.6" head of water could be supported by the very fine meshed filter which was tested, where the 5.6" head would correspond to the .2021psi offset in the trend line. The data collected by the unit seems to be reasonable.

The unit was also validated in its ability to collect data by repeating this sweep of flow rates and recording of pressure drops for three other filter angles, which included 30°, 60°, and 90°. This data is recorded in figure 48. Error in the in the flow measurements comes from the error associated with the flow meter's accuracy, and error in the pressure drop comes from the accuracy error of the pressure sensor and from the precision error associated with measuring the pressure drop at steady state for 2000 samples. As it can be seen in the figure there are large errors in the pressure drop measurements, however most of the error results from the spread of the measured pressure drop samples which is most likely comes from signal noise. Through further refinement of the Labview code, or additional electronic signal conditioning, most of this noise could likely be filtered out. Per correspondence with Dow they will undertake this additional signal conditioning, so that this signal conditioning technique is parallel to the signal conditioning that they perform on other data collected at their facility.

Figure 48. Pressure drop across the filter versus low rate for the filter sample provided by Dow, for relative filter angles of 0°, 30°, 60°, and 90°



Due to limited data supplied by our sponsor we were unable to decisively validate that our system accurately quantifies known filter media, however, the trends that we were able to capture with our unit indicates that our unit could be accurately characterizing filter media. Through the procurement of additional documented filter medias and a repetition of this validation, Dow will be able to definitively validate that the system accurately characterizes filter media.

Provide User Instructions
A manual of user instructions and safety procedures is provided in Appendix R, to ensure that the operator understands how to use the system.

Filter Change Time Needs to be Less than 10 mins.
To make sure that the change time needed to change filters in the unit is less than ten minutes, the filter provided by Dow was changed three times. To test this time the channel was completely filled with water, and then the pump was shut off. Then with a nut driver, a Philips screw driver, and a stop watch on hand, the air purge and the drain valves on the channel were opened, and the stop watch began recording time as soon as the first valve was opened. Once the channel was completely drained, using the nut driver, the nuts from the end cap of the channel on the end of the channel nearest the filter chamber were removed. Then the angling screw was removed, the filter chamber was rotated to the filter change position and the angling screw was replaced. Then the screws retaining the filter were removed and the filter was fully removed, and then fully fitted back into its correct position. With the filter in position again, on chamber face, the retaining ring was put back into place and the screws holding the retaining ring and filter were reinstalled. With the filter in place the chamber was repositioned to its original testing angle. Then the end cap was reinstalled and all of the nuts holding the end cap on, were tightened using the nut driver. With the end-cap being reinstalled, total filter change time was recorded. Repeating the trial three times, and completing the process with two different people, the following filter change time was measured, 8 min. 27 ± 30sec. This filter change time is less than maximum 10 minute filter change time allowed by the unit's specifications.

Common Controls Height between 36 in and 73 in
Though we designed the unit to have common control heights between the specified 36in. and 73in., to make sure that this specification was actually met in the final unit, we measured the height of the unit's common controls. To measure the height of the common controls present on the channel module, the channel was placed on a common 32" tall table. Though various valves and controls may be used on the unit, most of the time will be spent adjusting the actual flow conditions presented to the filter (flow rates, and flow angle which was validated when we characterized the filter media provided by Dow) therefore the commonly used controls on the unit are the VFD (to vary flow rate), the angle varying screw (to vary the angle of the filter), and the by-pass valve (to vary the flow). Heights of these components were measured using a tape measure, however, due to the finite height of each component (for example the thickness of the valve handle), only a resolution of 1in. was used on the tape measure. The height of the control knob on the VFD was measured to be 45 ± 0.5 in. The height of the by-pass valve was measured to be 39 ± 0.5 in., and the height of the angle varying screw was measured to be 37 ± 0.5 in. It is also interesting to note that these height requirements were specified to allow the system to be ergonomic when the user is standing, however, for most of the time while we were operating the system for the system's validation we found it very ergonomic to use the system while sitting in a rolling chair. All of the common controls are within the specified 36in. to 73in. range.

Retoolable to Filter Sizes Ranging from 1 in.x1 in to 4 in.x 4 in.
A retooling guide for constructing chambers to fit different sized filter media is provided in Appendix T. The different chamber sizes can be manufactured in the same way that the original chamber was manufactured. Different sized chambers can then be easily mounted on the chamber receiving block on the filtrate pipe. As shown in figure 34, the channel is capable of receiving chamber sizes that correspond to filter sizes up to and including 4in.x 4 in.

Able to Securely Hold a Filter Media with Thickness Ranging from 0.004 in to 0.04 in.
Though we asked for multiple filter samples with varying thicknesses which we could test in the unit, Dow only provided us with one sample, which we tested. Mounting the filter sample in the unit, the unit was started up and the flow rate was set to its maximum value for the 3in.x 3in. filter size, which the unit

is tooled for, which was 9 gpm. The filter was positioned in the 0^o position, allowing it to observe the maximum pressure difference across it (as shown in the filter's performance curves). This flow rate was maintained for two hours, the normal testing time expected by Dow (even though multiple filter samples would likely be tested in this time frame). After two hours expired, the pump was shut off, the channel was drained, and the channel end-cap was removed and the chamber with the mounted filter was inspected. The filter was still securely clamped in place. Through this test we showed that the unit can securely hold the filter media which Dow intends to test.

Lifting Required to Move Unit Should be Less Than 35 lbs. and Non-lifting Parts Will be Place on Wheels

To test this specification, after the test unit was completely assembled, we weighed the non-wheeled portions of the unit. As planned the only non-wheeled portion of the unit was the channel module. Using a scale the weight of the drained channel and the portion of flexible hosing that it supports was measured. Since the exact amount of hosing that is supported by the channel varies as its relative position to the cart varies and as the exact positioning of the hosing varies, the weight of the channel module and the hosing which it supports was weighed three times. A channel module weight of 29.5 ± 1.0 lbs was measured, which is below the 35 lb. limit specified for the unit. Also, through recent change orders, the specifications for channel holding features on the cart were dictated, and these modifications are present on the final unit, which allows the user to only need to transfer the channel from the table top to the top of the cart module when preparing for transit, and when the unit is in transit everything is mounted on the cart. We found this feature very ergonomic during our testing use of the unit. By weighing the channel module we established that are unit does not require lifting outside of our specified 35 lb. range.

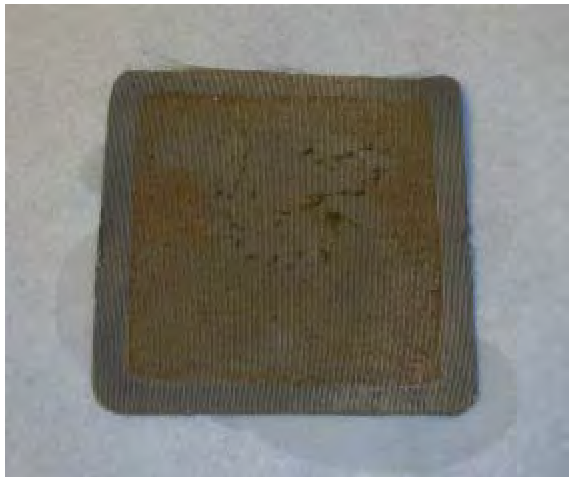
Drain the Whole System in less than 10 mins

Just as it would be done in a Dow lab, the reservoir tank was fully filled with water, and then the unit was started and some of the water from the reservoir was used to completely fill the channel. Then using a stop watch the drain time of the unit was recorded. Time was recorded as soon as the reservoir valve was opened, and then the channel's air purge and drain valves were opened and the channel was drained into the reservoir as the reservoir was draining. The channel completely drained into the reservoir before the reservoir drained, so the end time for the drain period was signified by the last amount of water in the reservoir exiting out of the reservoir drain. This process was repeated three times. A whole system drain time of 2 min. 38 ± 11 sec. was recorded which is well within the 10 minutes allowed by the unit's specifications.

No Plastic Deformation When Fixturing Filter

This test was completed at the same time as the "securely hold" validation test was validated. Using the procedure outlined in the "securely hold" validation test, the filter media provided by Dow, was tested under the harshest testing conditions specified by Dow. After it was validated that the filter was still securely held in place, the filter retaining ring was removed, and the filter was inspected for damage or deformation. As shown in Figure 49, the filter was undamaged and did not have any permanent deformation, though it did collect some debris!

Figure 49. Filter media after two hours of harshest testing conditions, showing that no damage or permanent deformation had occurred to the filter media



Systems has the Ability to Recirculate Water
As outlined in the static and then dynamic leak tests, the unit was found to be without any leaks when fully complete, and the unit recirculated the water through the channel and reservoir, as designed.

Water in System is User Accessible and Access Point Allows Addition of Arizona Dust
Due to safety concerns on the part of Dow, Dow did not provide us with Arizona Dust, with which we could test the unit with. Therefore, this specification was validated just by making sure the lid on the reservoir tank is removable. The lid on the tank is removable. Validating this specification did not require us to make sure that when in actual use that the Arizona dust present in the reservoir does not settle out over time. Dow has informed us on numerous occasions that such requirements are out of the scope of this project.

Minimum Hours of Use before Water Contaminant Abrasion Related Failure is 360 hrs
This specification was met by making sure that the pump, the flow meter and the pressure sensor would have life spans that exceed 360hrs. even if the unit is operated under maximum contaminate loading situations (specified by an Arizona Dust loading of 20000ppm). Per verification with all of the vendors, all of these components will have life spans that exceed 360 hrs. even if subjected to conditions were the water is loaded with Arizona Dust at a concentration of 20000ppm. Besides the filtrate pipe bearings, all of the other components on the unit are static and there should be unaffected by particulate loading in the unit over in the scope of using the unit for 360 hrs., and the filtrate bearings are protected from particulate intrusion via the shaft seals on the pipe. By making sure that the unit's sensors and pump were able to withstand the harshest particulate loadings for the specified minimum life span, the unit was verified to have a life span of at least 360 hrs.

Handle Working Fluid Temperature at least 140 F
All sensors, materials, and the pumping system have been selected to meet this criterion so they can maintain normal performance under fluid temperature up to and including 140º F.

DESIGN CRITIQUE

Design Strengths

Though this design has many unique faucets that coalesce to form one functioning filter testing unit, there are several features of the design which standout as exceptionally proficient, or exceeding the requirements given for the design.

One important feature where Dow's requirements were exceeded was the filter angling capability of the device. Dow only required the ability to be able to test the filter in angles ranging from 0^o to 60^o, however the delivered unit is able to test filters in the full 0^o to 90^o range which Dow originally desired. This capability allows Dow to measure filters' performance in the full range of angling arrangements that could be present in the filter fixtures that they design. Also to expedite testing, the angle of the filter can be changed while the unit is running.

Another exceptional feature that our unit has is its fully adjustable by-pass option. By just opening a throttling valve downstream of the filter some of the flow in the channel can be by-passed around the filter. Dow specifically asked for this option if it could be included. This feature allows some of the flow to flow past the filter and not through it, altering the flow at the filter's face, and consequently changing the performance of the filter. This feature was especially desired for the filter angles approaching 90^o because when the filter media is mounted in certain types of tangential flow utilizing filter units, this type of flow would be present at the filter's face. With this feature, Dow is able to better understand how different filter media would perform in the actual filter units that they are designing.

The fact that the VFD, which is required to output what appears to the pump as 220V 3 phase AC current, only needs a 110V AC supply power is another great feature. This allows the unit to not require any specialized lab space. Also the ability to adjust the flow rate supplied to the filter just by adjusting the frequency knob on the VFD really makes the unit user friendly (rather than trying to adjust the flow rate by trying to position a valve at the correct angle). Also if Dow desires to, VFD has the option of being controlled remotely via a signal voltage, which allows Dow to further integrate the unit within LabVIEW, which they have expressed interest in. Also, through vendor supplied modifications, the flow meter could also be incorporated into LabVIEW, allowing a closed-loop control system to be implemented on the system, where flow set points could be input by the user and the unit, through the closed-loop control could find this flow rate and then record data. Also, the pressure sensor which is already incorporated in LabVIEW could be further integrated into LabVIEW through enhanced data-logging capabilities.

Also, though the system was not required to be able to be moved by a single person, the delivered unit is able to be moved by a single individual. By incorporating innovative retaining fixtures on the cart, the channel module securely fits on the top of the cart and together, both the channel and the cart module can easily be moved from place to place on the cart. However, the somewhat stiff hoses coming from the channel does make the loading process a bit cumbersome.

Design Weaknesses

Though the system does allow the filter to be changed within the specified 10 minutes, this filter changing process is somewhat involved. The filter changing process requires the use of a nut driver and a Phillips screw driver, and the removal of 18 nuts/bolts for the filter to be removed, and then the reinstallation of these same fasteners to allow the new filter to be tested. The unit would be more user friendly and the filter change process could be expedited if this process was simplified. The process could be simplified and expedited through the use of fixtures like over center clamps, or spring loaded clamps. We had considered such fastening methods, but due to a judgment based on the ability to manufacture and install such clamps in the manufacturing time allotted we discount these designs.

Also, due to time and budget limitations, our final product did not include all of the “wish list” items that Dow had expressed interest in. Dow had originally desired that a brushing feature be installed in the unit which could brush the face of the filter as flow was passing through the filter. Due to time restraints no brushing feature was added to the system. However, the modular nature of the chamber and the filtrate pipe would allow such a device to be easily mounted to the chamber and cantilevered in front of the filter. This single fixture would allow brushing to occur at all of the filter angles (as long as space constraints are incorporated into the design). Another feature that Dow had originally desired was the ability to measure the deflection of the filter as flow was being passed through it. Due to budget limitations (the water proof proximity sensor was going to cost >$1000), no filter deflection sensor was included in the design. However, space was saved for such a proximity sensor in the chamber behind the filter face, and the sensor could be mounted to the chamber. Also, due to budget limitations a flow rate sensor on the by-pass flow was not incorporated in the design. Such a flow rate sensor would help parameterize by-pass flow, independent of the filtered flow. If such a sensor would be desired in the future it could be incorporated at the end of the channel, where the by-pass flow exits. If these features are deemed necessary in the future all are able to be incorporated in the unit at a later date.

As mentioned in the design strengths, the unit does not have full sensor and flow controller integration in Labview, which is something that Dow would be appreciative of, but as stated in the previous section, further integration is completely possible. Also, as mentioned earlier the hosing present on the unit is somewhat cumbersome when moving the unit. If the hosing proves to be too cumbersome during extended use of the unit, more lightweight and flexible hosing can be sourced, though pressure and temperature requirements should be kept in mind when sourcing replacement hosing.

As described in the unit’s validation results another weakness maybe that the unit possibly does not create completely laminar flow up to the specified 16gpm. Modification of the flow guides may be necessary if “more laminar” flow is needed by Dow at the unit’s upper flow rates. Though the laminar flow guides were specified to have more than a safety factor of two on generating laminar flow at normal fluid temperatures and maximum flow rates, downstream disturbances in the flow may have influenced how the laminar flow developed. However, the current laminar flow guides can easily be replaced with similar sheeting materials that have smaller channel diameters, or if necessary a module of circular tubes of smaller diameter could replace the current flow guides. Smaller diameter tubes would help to more fully develop laminar flow and the unit’s pump was sufficiently oversized that the inclusion of such flow guides would not cause the unit to have insufficient flow.

Though the unit we created does have several weaknesses, none of these cannot be overcome with further unit modification. And even with the limited time and resources that were available to us, through ingenuity and creativity we were able to design and manufacture a unit that exceeded its requirements in several regards.

RECOMMENDATIONS

A foremost recommendation that we make to our sponsor is that they definitively verify that the unit accurately characterizes known filter media. To make sure that the data that Dow collects with this device is valid, Dow should procure filter media that has verified flow and pressure drop data for flow rate(s) in the .32 to 1gpm/ in^2 filter media flow rate range that the unit was designed and tooled to test. Also, to make their testing more accurate and to more precisely verify that unit is accurately quantifing known filter media, additional signal filtering should be designed and incorporated for the pressure sensor. Per correspondence with Dow, they have expertise in this, and most likely will implement electrical and LabVIEW level filtering that is beyond our ability (both in resources and expertise).

As described in the previous sections, it is unclear if laminar flow is present in channel as the flow approaches the filter face, when the unit is running at its higher flow rates. Due to the somewhat vague details given to us on the exact reason why laminar flow is necessary, we are unable to discern whether the possible presence of transitional flow should be of concern to Dow. If the presence of transitional flow would invalidate the data collected by the unit, additional laminar flow tests should be completed, where a non-buoyant immiscible fluid is injected into the flow in a similar manner to which was used for our laminar dye tests. If such tests indeed show that the flow is transitional at the unit's upper flow rates, the units flow guides should be replaced with similar plastic sheeting with smaller channel diameters or a suitable replacement should be found that has smaller channel diameters than are present in the current laminar flow guides. These laminar flow guides should be of the same length as the laminar flow guides that are currently in the system, to allow the flow to fully expand to the full channel diameter, otherwise mixing may occur downstream of the flow guides due to uneven pressure distributions across the diameter of the channel. If the possible presence of transitional flow at the unit's upper flow rates is not alarming then the unit can be used without modification of the flow guides.

CONCLUSION

In September 2012, our group was tasked by Dow with creating a laboratory apparatus capable of quantifying the performance of their new flat water filter media under a variety of conditions. After meeting with Dow several times, we developed a list of the functions that needed to be integrated into the final design for it to be successful. These functions were presented in our first design review. After developing assessment criteria for these functions, we generated multiple working designs for each function.

These various functional solutions were assessed for viability, and low-performing designs were discarded. Several full-device permutations were then assembled from the various functional designs. Each of these full designs was assessed in a similar manner to the functional designs, and eventually a final design was chosen. This design – the channel with rotating filter chamber fed by a cart – was determined by our scoring to be most capable of fulfilling all of Dow's criteria to the greatest extent possible. This design was presented in our second design review.

This design was then researched and optimized using engineering methods. Computer simulations, mathematical derivations, and references to engineering codes and standards were used to make sure that the chosen design would not only fulfill all engineering requirements, but also be safe to operate. During this time, the list of required features and functionalities was shortened by mutual agreement of Dow and the team, in an effort to ensure the viability of the project and ensure that the device could be manufactured. The design of the product changed slightly throughout this process, and eventually a final set of dimensions was established. This design was presented in our third design review.

With the design approved, the device was manufactured by the team. This process went relatively smoothly through major construction (as presented in our fourth design review), though some minor elements were modified through engineering change orders during this time to improve manufacturability, user friendliness, or safety). With the device completed, testing began, to ensure that the device met all required criteria.

The device passed all tests of physical construction, including weight, power/space requirements, portability, self-containment, filter change time, and safety. The device proved capable of delivering the required flow rate, pressure drop, and fixture angles. The requirement of laminar flow generation was tested through various dye and oil droplet tests. Though the original dye testes showed transitional flows for most of the unit's flow rates, the validity of these tests was brought into question. To better parameterize the flow oil droplet tests were completed and these showed laminar flows for most of the flows though when the unit produced flows near its upper 16gpm limit the flow was unable to be conclusively determined that laminar flow was being generated. However, showing our results to Dow, they have stated that the unit creates “laminar enough” flows to be fully functional for all of the unit’s required flow rates.

The system, having proven itself capable of meeting the operating specifications, was advanced to validation and field testing. The pressure sensor and flow meter proved capable of reading data within the required accuracies, though the pressure sensor featured a noisy signal when connected to LabVIEW, which likely could have been eliminated using digital or physical filters. However, due to our sponsors inability to provide us with a filter media that has documented flow and pressure characteristics for the flow rates which are unit was designed to test, we were unable to conclusively verify that our unit properly parameterizes filter media, though initial tests indicate that the unit is correctly parameterizing test samples of filter media. Before using the unit, Dow should conclusively verify that the unit properly parameterizes filter media by procuring filter media with documented flow characteristics within the flow rates that our unit is designed to test.

Overall, the device we have built functions as expected for quantifying the performance of flat water filter media. Although the system lacks some of the original scope desired (eg: deflection measurement), it remains overall a complete, usable system that can produce performance data (though it’s accuracy should be further validated) within the full range of flow rates, pressure drops, and filter angles specified. The system is well-suited for a laboratory setting, though it will require some basic hand tools to perform filter changes. The system comes complete with all components required to run testing except (per agreement with Dow) a computer running LabVIEW and a Data Acquisition Module. We believe that our device, though it has room for improvement/expansion, represents the best possible outcome for this project given its timeframe, budget, and extensive list of requirements.

ACKNOWLEDGEMENTS

We would like to thank The Dow Chemical Company for sponsorship of this project. Their intellectual and financial resources made this endeavor possible. Specific thanks go out to our helpful and patient contact.

Additional thanks go out to the ME450 instructional staff, led by our section leader [REDACTED PROFESSORS AND GSIs]

We would also like to thank the staff of the ME X50 machine shop, assembly room, and mechatronic lab for their support and guidance. Particular gratitude is owed to [Redacted] for his welding skills and to [Redacted] for his knowledge of LabVIEW. The aid of [multiple Redacted] and the machine tool crib attendants is also greatly appreciated.

Finally, we would like to thank the staff of the GG Brown Laboratory for their logistical support of this project, including [Redacted].

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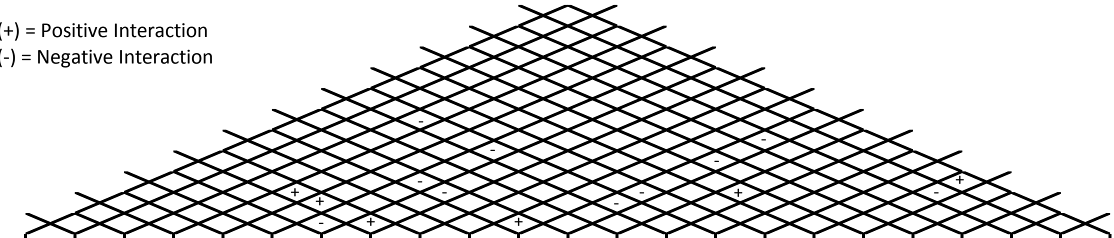
Appendix A

Quality-Functional-Deployment

(+) = Positive Interaction
(-) = Negative Interaction



(+) = More is better
(-) = Less is better

	Weight	Use Safety factors in design	Complies with NEC 250 (electrical safety standards) (+)	Unit flow rates (+)	Flow rate measurement accuracy (+)	Pressure drop measurement accuracy	Relative flow angles (+)	Filter flex measurement accuracy (+)	Data needs to be saved by Labview	Document unit accurately quantifying known media(+)	Provide detailed user instructions (+)	Time to change filter (-)	Common controls height(+)	Dirt resistant components (+)	Max filter size (+)	Filter Size	Lifting required to move unit (-)	Time to drain unit (-)	No permenant filter deformation (+)	Max fluid temp (+)	Brush Design (+)	Closed loop (+)	Water reservoir user accessible(+)
Safety	22	5	5	3			3					3		3			5	3		5			1
Electrical Safety	22		5	3	3	3		3						1				5					
Able to vary system flow rates/ pressures	21	5	3	5	5	5	3	1	3				1		5	5	5		3			3	
Able to measure flow rates	20	3	5	5	5	1	3		5	5	3		1	5						3			
Able to measure pressure drop across filter media	20	3	3	5	1	5	3	1	5	5	3		1	3						3			
Able to vary water flow angle	20	5		3	3	3	5	3		5	5	3	5	3	5	5			3		5		
Able to measure filter flex	20	3	5	3			3	5	5	5	3	3	1	3	3	3			3	3	5		
Labview interface	20		5	5	5	5		5	5	3	5		5										
Document validity of test unit	15				5	5		5	3	5													
Unit Instructions	15						3		3		5	5						3					1
Physically user friendly	12	5	3				3					5	5				5	3	1				5
Easily movable	12																5					3	
Unit can withstand dirty water	10			1	3	3	1	1				1		5								3	
Allow user to add contaminants	10	3									3		3					1					5
Able to have a brushing system added	10		3		3	3		3				3			5	5							
Compatible with hot water	8	5		3	3	3	1	3															
Hold specified filter sample size	8	3					3	3		1	3	5			3	5			5				
Compatible with various sizedsamples	8	3					5	3							5				3				
Does not damage filter media	8						3	3				5			3	5			5				
Able to purge contaminated water	8	3											5	1				5					
Quick filter change time	8	5									3	5	5										
Self-contained	8	5															3					5	
	Total	777	709	691	610	610	596	578	553	543	533	481	451	426	403	395	359	307	299	290	200	169	147
5 strong interaction	Norm.	7.79	7.1	6.92	6.11	6.11	5.97	5.79	5.54	5.44	5.34	4.82	4.52	4.27	4.04	3.96	3.6	3.08	3	2.91	2	1.69	1.47
3 interaction	Rank	1	2	3	4	4	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1 weak interaction	Units	NA	Y/N	gpm	gpm	psi	Deg.	in.	Y/N	Y/N	Y/N	min.	in.	Y/N	in.	in.	lbs.	min.	Y/N	°F	Y/N	Y/N	Y/N

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DEPARTMENT OF LICENSING AND REGULATORY AFFAIRS

DIRECTOR'S OFFICE

GENERAL INDUSTRY SAFETY STANDARDS

Filed with the Secretary of State on January 1, 1975 **(as amended July 28, 2000)**
This rule takes effect 7 days after filing with the Secretary of State

(By authority conferred on the director of the department of consumer and industry services by sections 16 and 21 of 1974 PA 154 and Executive Reorganization Order No. 1996-2, MCL 408.1016, 408.1021, and 445.2001)

R 408.19301 is added to the Michigan Administrative Code as follows:

PART 93. AIR RECEIVERS

R 408.19301 Adoption by reference of federal standard.

Rule 9301. The provisions of 29 C.F.R. §1910.169, as published in the Federal Register on June 27, 1974, p. 23502, and as amended in the Federal Register on February 10, 1984, p. 5322 and March 7, 1996, p. 9227 are adopted by reference in this rule. The adopted regulations are available from the United States Department of Labor, Occupational Safety and Health Administration, 801 South Waverly, Room 306, Lansing, Michigan, 48917, at no charge as of the time of adoption of this rule, or from the Michigan Department of Consumer and Industry Services, Standards Division, 7150 Harris Drive, P.O. Box 30643, Lansing, Michigan 48909, at no charge as of the time of adoption of this rule.

(a) General requirements

(1) Application. This section applies to compressed air receivers, and other equipment used in providing and utilizing compressed air for performing operations such as cleaning, drilling, hoisting, and chipping. On the other hand, however, this section does not deal with the special problems created by using compressed air to convey materials nor the problems created when men work in compressed air as in tunnels and caissons. This section is not intended to apply to compressed air machinery and equipment used on transportation vehicles such as steam railroad cars, electric railway cars, and automotive equipment.

(2) New and existing equipment.

(i) All new air receivers installed after the effective date of these regulations shall be constructed in accordance with the 1968 edition of the A.S.M.E. Boiler and Pressure Vessel Code Section VIII, which is incorporated by reference as specified in Sec. 1910.6.

(ii) All safety valves used shall be constructed, installed, and maintained in accordance with the A.S.M.E. Boiler and Pressure Vessel Code, Section VIII Edition 1968.

(b) Installation and equipment requirements

(1) Installation. Air receivers shall be so installed that all drains, handholes, and manholes therein are easily accessible. Under no circumstances shall an air receiver be buried underground or located in an inaccessible place.

(2) Drains and traps. A drain pipe and valve shall be installed at the lowest point of every air receiver to provide for the removal of accumulated oil and water. Adequate automatic traps may be installed in addition to drain valves. The drain valve on the air receiver shall be opened and the receiver completely drained frequently and at such intervals as to prevent the accumulation of excessive amounts of liquid in the receiver.

(3) Gages and valves.

(i) Every air receiver shall be equipped with an indicating pressure gage (so located as to be readily visible) and with one or more spring-loaded safety valves. The total relieving capacity of such safety valves shall be such as to prevent pressure in the receiver from exceeding the maximum allowable working pressure of the receiver by more than 10 percent.

(ii) No valve of any type shall be placed between the air receiver and its safety valve or valves.

(iii) Safety appliances, such as safety valves, indicating devices and controlling devices, shall be constructed, located, and installed so that they cannot be readily rendered inoperative by any means, including the elements.

(iv) All safety valves shall be tested frequently and at regular intervals to determine whether they are in good operating condition.

[39 FR 23502, June 27, 1974, as amended at 49 FR 5322, Feb. 10, 1984; 61 FR 9227, March 7, 1996]

MIOSHA-STD-1129 (07/07)
40 Pages

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DEPARTMENT OF LICENSING AND REGULATORY AFFAIRS
DIRECTOR'S OFFICE
GENERAL INDUSTRY SAFETY STANDARDS

Filed with the Secretary of State on June 1, 1994 **(as amended June 11, 2007)**

These rules take affect 15 days after filing with the Secretary of State

(By authority conferred on the director of the department of consumer and industry services by sections 16 and 21 of Act No. 154 of the Public Acts of 1974, as amended, and Executive Reorganization Order No. 1996-2, being §§408.1016, 408.1021, and 445.2001 of the Michigan Compiled Laws)

PART 39. DESIGN SAFETY STANDARDS FOR ELECTRICAL SYSTEMS

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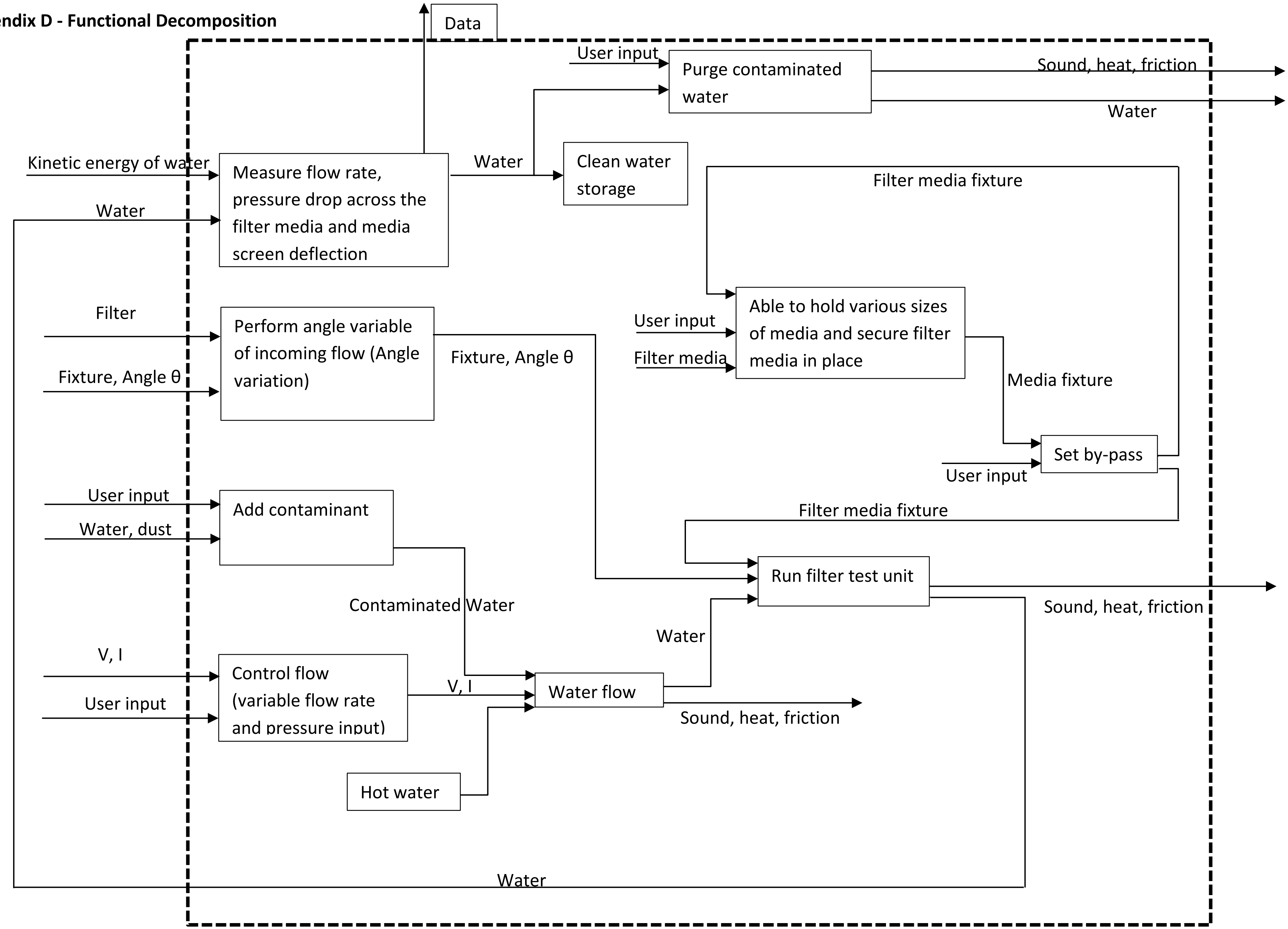
R 408.13901 Scope.

Rule 3901. These rules establish the minimum electrical safety requirements that are necessary for the practical safeguarding of the employees in their workplaces. These rules cover design safety standards for electric utilization systems and include all electric equipment and installations used to provide electric power and light for employee workplaces. These rules are divided into eight major divisions as follows:

(a) Electric utilization systems - 1910.302.
(b) General requirements - 1910.303.
(c) Wiring design and protection - 1910.304.
(d) Wiring methods, components, and equipment for general use - 1910.305.
(e) Specific purpose equipment and installations - 1910.306.
(f) Hazardous (classified) locations - 1910.307.

Appendix D - Functional Decomposition



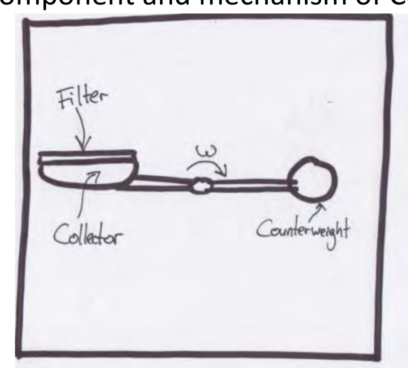
Appendix – Sketches and Concepts

We collected product selection and our original ideas for each sub function described in the main text with sketches in this appendix.

Variable Flow Rate and Pressure Control

- Duty Cycle- Run a pump at variable rpms using a duty cycle on a connected DC motor.
- Variable Resistor- Run a pump at variable rpms by varying a resistor in series with the pump
- Controlled valve/throttle- Use a variable valve in series with the pump to vary flow rate
- Controlled valve and bypass-Same as previous idea except allow a restricted stream to by-pass the valve and return to reservoir
- Pressure vessel On/Off switch- Pump water into a pressure vessel partially filled with water and partially filled with air, use upper and lower pressure limits to turn pump on and off; regulate output flow with a pressure regulator
- Submerged centrifuge (Fig. 1)
    - Back of filter covered by enclosure which captures filtered water
    - Entire filter/enclosure assembly placed in bath of dirty water and spun to create pressure on filter

Fig. 1 Component and mechanism of Centrifuge



- Water tank with compressed air head
    - Air compressor fills a tank of high-pressure air
    - Pressure regulator steps down the pressure of the air as it enters the top of a water storage tank
    - Air pressure on top drives drives water through filter
- Water head
    - Pump a constant amount of water to a variable head height and let excess water return to reservoir
    - Use a float to turn pump on and off to maintain desired height
- Compressed Air Tank- supply regulated flow into a tank partially filled with water and partially filled with air, allow compressibility of air to minimize variability in pressure

Measure Flow Rate

- Product selection
    - Turbine (Fig. 2)

- Vortex frequency device (Fig. 3)
- Differential Pressure
- Vane Style

Fig. 2 Turbine flow meter components

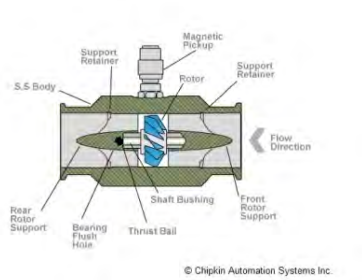


Fig. 3 Vortex frequency device

Measure Pressure Drop across Filter

- Product Selection
  - Two pressure Transducers
  - Differential pressure transducer

Measure Filter Deflection

- Extra-Long Foil Strain Gauge (Fig. 4)
  - Gauge mounted underneath filter
  - Filter deflects middle of gauge as it flexes
  - Use math to figure out deflection from change in resistance
- Linear Transducer (Fig. 5)
  - Attach a linear potentiometer to the upstream or downstream side of the filter, and attach it non-destructively.
- Hall Effect Sensor (Fig. 6)
  - Add some metal to the filter sample and aim a Hall Effect sensor at it
- Mounted Strain Gauges (Fig. 7)
- Feeler Arm (Fig. 8)
  - Could mount roller on end of arm to minimize snag
- String Gauge (Fig. 9)
- Reflectance Time (Fig. 10)
- Camera (Fig. 11)

Fig. 4 Strain Gauge (Cantilevered)

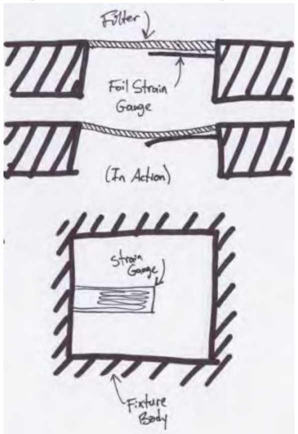


Fig. 5 Linear transducer

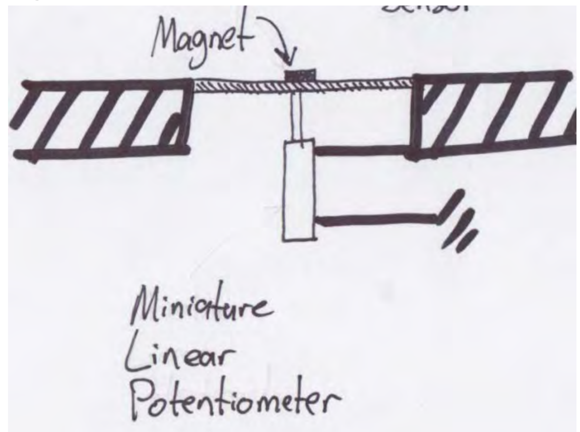


Fig. 6 Hall Effect position sensor

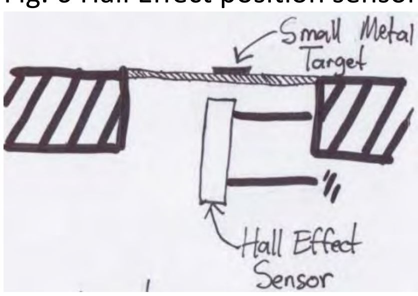


Fig. 7 Mounted strain gauges

Fig. 8 Feeler Arm

Fig. 9 String gage

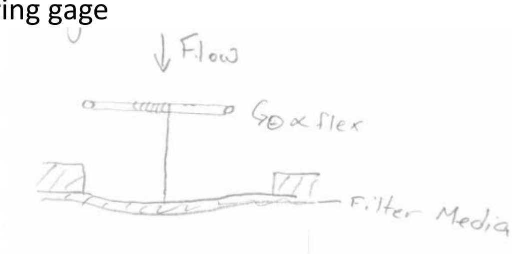


Fig. 10 Reflectance time

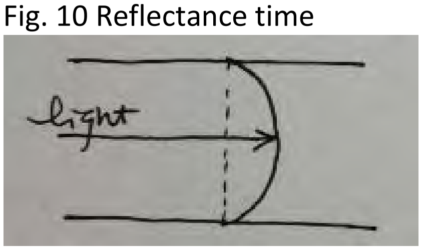
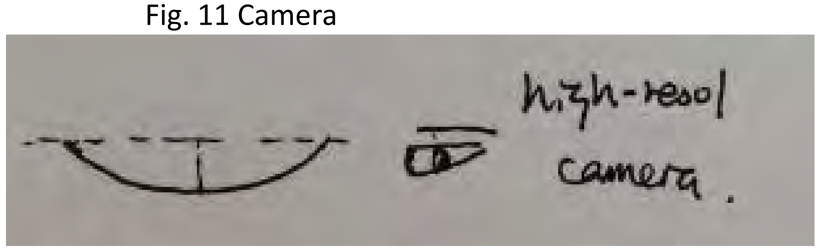


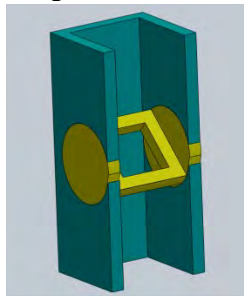
Fig. 11 Camera



Vary Angle of Incoming Flow

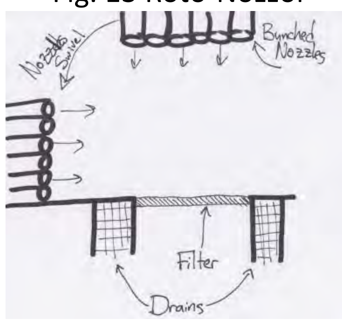
- Rotatable In-Stream Cassette (Fig. 12)
    - Filter is attached to one side of the cassette.
    - The other side is sealed off (not shown) so no mixing occurs between filtrate and bypass

Fig. 12 Cassette



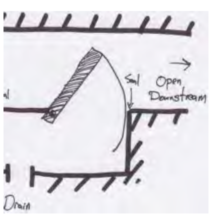
- Fixed Filter, Variable position deluge
    - Water supply moves around stationary filter
    - Drains around filter allow for runoff

Fig. 13 Roto-Nozzol

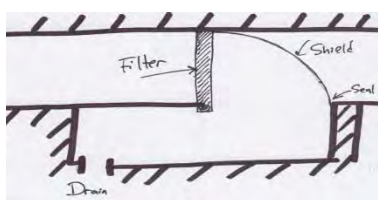


- Hinged Door (Fig. 14 (a), (b) and (c))

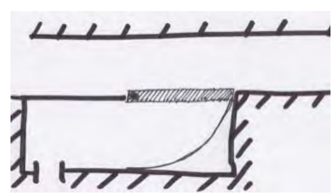
Fig. 14 Hinged door



(a)



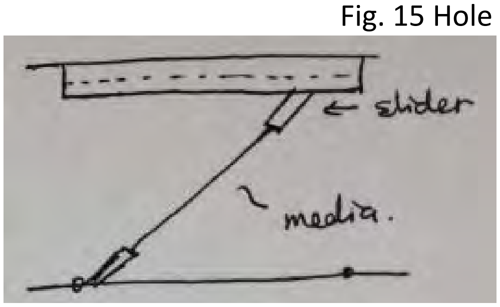
(b)



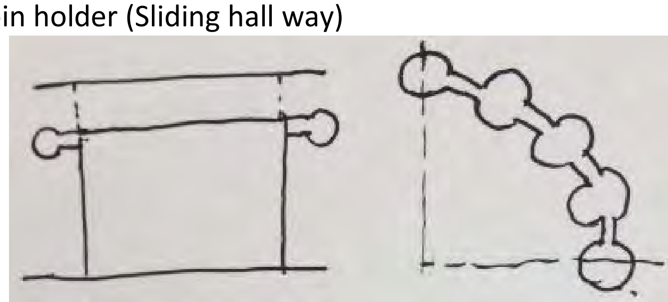
(c)

- Hole and pin holder (Fig. 15 (a) and (b))

Fig. 15 Hole and pin holder (Sliding hall way)



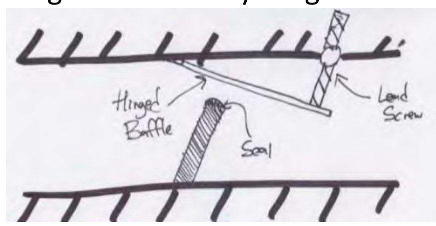
(a)



(b)

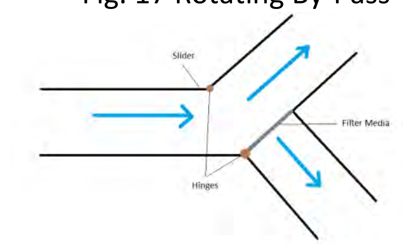
- Secondary Hinged Door (Fig. 16)
  - Screw-adjustable secondary door that comes down from the other side of the channel
  - Seal on the filter mount allows for 0% bypass

Fig. 16 Secondary Hinged Door



- Rotating By-Pass (Fig. 17)

Fig. 17 Rotating By-Pass



Temperature-Handle Hot Water

- Product Selection
  - Make sure material can withstand temperatures up to 140º F

Fixture of Filter Media

- Two-Part Plate Clamp (Fig. 18)
  - Filter sits in recess on knurled surface
  - Plate sits on top, bolts poke through holes to the back
  - Nuts attached to backside to secure plate and press filter into knurling
- Book Style (Fig. 19)
  - Lay filter on flat, roughened surface
  - Close identical surface over top of it
  - Squeeze hinged halves together in fixture which attaches it to the unit

Fig. 18 Two –Part plate clamp

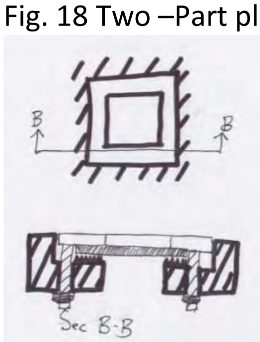
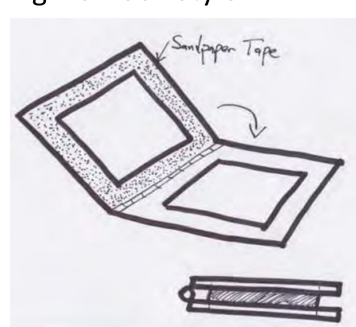
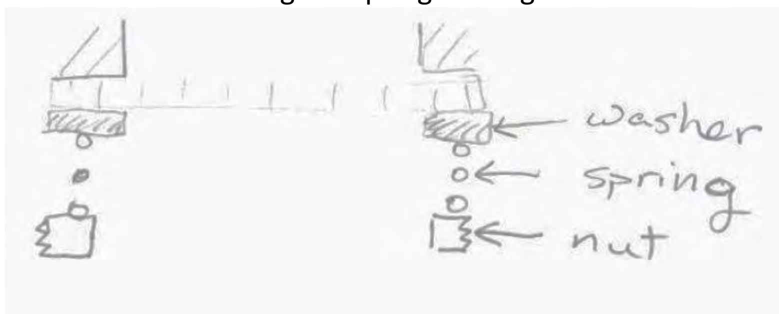


Fig. 19 Book Style



- Spring Tension (Circular Flow section) (Fig. 20)

Fig. 20 Spring loading

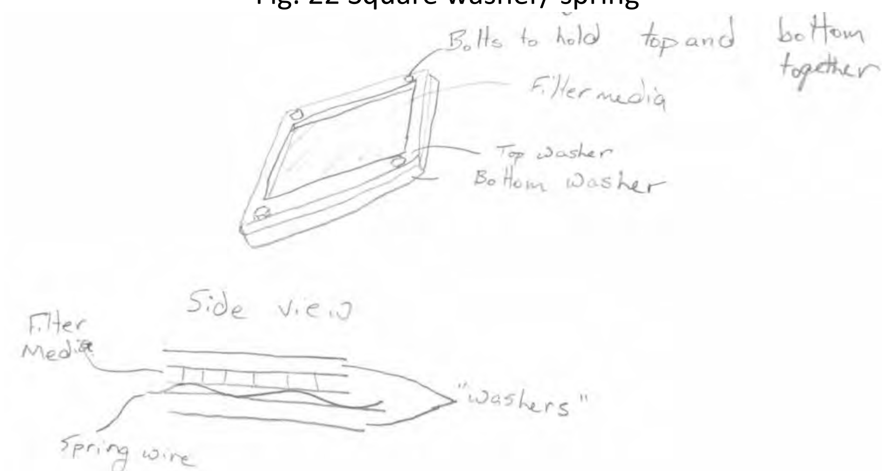


- Fine Thread Nut (Circular Flow section) (Fig. 21)

Fig. 21 Fine thread nut

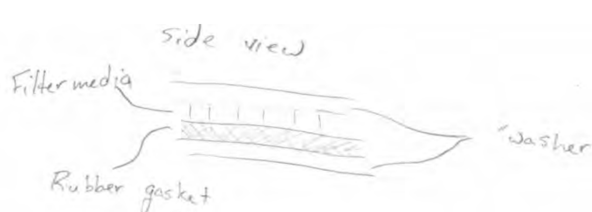
- Square Washer, Square Spring (Fig. 22)

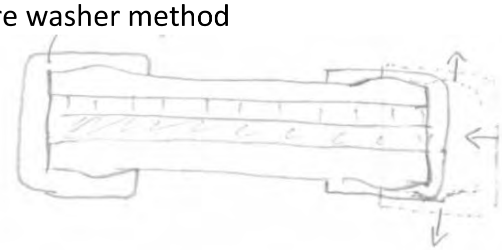
Fig. 22 Square washer/ spring



- Variations on Square Washer Method (Fig. 23 (a) and (b))
    - Use a rubber material instead of spring wire
    - Use a spring clamp to hold the washers together

Fig. 23 Variation on square washer method





(a) (b)

- Bump Holder (Fig. 24)
- Bolted Gasket Method (Fig. 25)

Fig. 24 Bump Holder

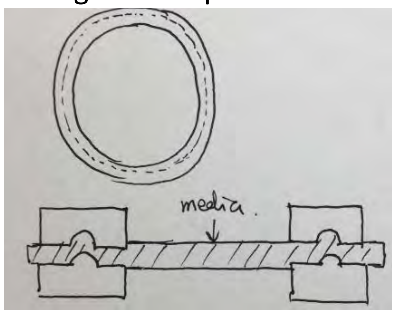
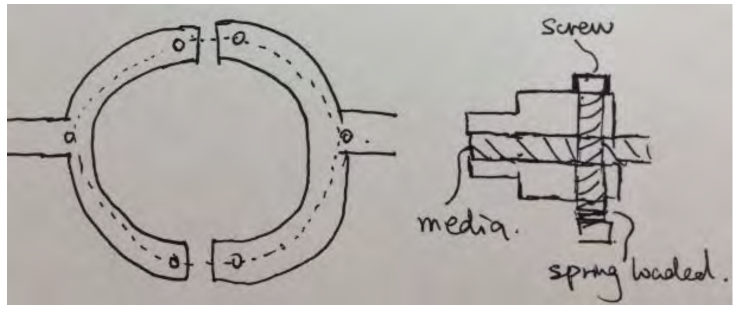


Fig. 25 Bolted Gasket



Add Contaminants

- Agitated Tank with opening
    - Add contaminants and have them mixed in automatically
    - Can mix contaminants back in if they settle out
- Tank with Opening
    - User keeps contaminates agitated

Purge Contaminated Water

- Drain Valve (Gravity Fed)
    - Put a valve at the lowest point of the hydraulic circuit.
    - Position the valve so it can dump right in to a floor drain
    - May need valve on either side of pump
- Drain Valve upstream of pump
    - Be able to disconnect the supply pump and reconnect it to a drain hose

Appendix F- Functional Design Pugh Charts and Go-NO Go charts

We performed GO-NOGO chart and Pugh chart for each of sub functions first and then repeat the procedure for the fully functional devices to figure out the best choices. The original work and details are demonstrated in this section.

Add/Manage Contaminants

1. GO-NOGO chart

Contaminants	Reservoir with agitator	Reservoir with no agitator	Reservoir with return water pumped into bottom
Ensures even dispursion	GO	GO	GO
Allows user to add contaminants	GO	GO	GO
Doesn't change in concentration over time	GO	GO	NO GO
Water Resistant	GO	GO	GO
DECISION	GO	GO	NO GO

2. Pugh chart for all feasible concepts

Contaminants					Reservoir with Agitator					Reservoir without agitator				
CRITERIA	Wt AF	Wt JH	Wt JG	Averaged Weight	R AF	R JH	R JG	Averaged Rating	Weighted Rating	R AF	R JH	R JG	Averaged Rating	Weighted Rating
Ensures even dispursion	0.1	0.1	0.05	0.08	5	5	5	5.00	0.42	4	3	3	3.33	0.28
Ease of Adding Contaminants	0.25	0.35	0.35	0.32	5	3	5	4.33	1.37	5	3	5	4.33	1.37
Doesn't change in concentration over time	0.23	0.2	0.2	0.21	5	5	5	5.00	1.05	5	3	5	4.33	0.91
Water Resistance	0.1	0.1	0.2	0.13	2	3	5	3.33	0.44	4	3	5	4.00	0.53
Cost	0.05	0.05	0.05	0.05	3	3	3	3.00	0.15	4	5	5	4.67	0.23
Manufacturability	0.12	0.1	0.05	0.09	3	3	3	3.00	0.27	4	5	5	4.67	0.42
Durability	0.15	0.1	0.1	0.12	3	3	5	3.67	0.43	5	3	5	4.33	0.51
SCORE	1.00	1.00	1.00	1.00					4.13					4.25

Fixture of Filter Media

1. GO-NOGO chart

Fixture of Filter Media	Two-Part Plate Clamp	Book Style	Spring Tension	Fine thread nut	Square washer, Square spring	Edge Spring Clamp	The Bump	Bolted Gasket	Magna channel
Does not release sample under pressure	go	go	go	go	go	go	go	go	go
Compatible with mutliple sizes (if retooled, if necessary)	go	go	go	go	go	go	go	go	go
Compatible with 0.004 to 0.04 in thickness	go	no go	go	go	go	go	go	go	go
Has minimal impact on flow	go	go	go	go	go	go	go	go	go
Changeable in 10 minutes or less	go	go	go	go	go	go	go	go	go
Does not crush media	go	go	go	go	go	go	go	go	go
Can be manufactured	go	go	go	go	go	go	go	go	go
Water Resitsant	go	go	go	go	go	go	go	go	go
Compatible with multi-angle	go	go	go	go	go	go	go	go	go
Do not disturb sensor signals	go	go	go	go	go	go	go	go	nogo
DECISION	Go	No Go	Go	Go	Go	Go	Go	Go	NOGO

2. Pugh chart for all feasible concepts

Fixture of Filter Media					Two-Part Plate Clamp					Spring					Fine Thread Nut				
CRITERIA	Wt AF	Wt JH	Wt JG	Averaged Weight	R AF	R JH	R JG	Averaged Rating	Weighted Rating	R AF	R JH	R JG	Averaged Rating	Weighted Rating	R AF	R JH	R JG	Averaged Rating	Weighted Rating
Sample Holding Strength	0.15	0.05	0.15	0.12	4	3	3	3.33	0.39	5	5	4	4.67	0.54	5	5	4	4.67	0.54
Size Compatibility	0.15	0.1	0.1	0.12	2	3	1	2.00	0.23	2	3	2	2.33	0.27	2	3	2	2.33	0.27
Thickness compatibility	0.15	0.1	0.12	0.12	5	3	4	4.00	0.49	5	3	5	4.33	0.53	5	5	5	5.00	0.62
Flow Impact	0.15	0.1	0.12	0.12	3	3	4	3.33	0.41	3	3	4	3.33	0.41	4	3	4	3.67	0.45
Change Time	0.05	0.1	0.1	0.08	4	3	3	3.33	0.28	3	3	4	3.33	0.28	4	3	4	3.67	0.31
Amount of Media Crushage	0.15	0.15	0.08	0.13	4	3	3	3.33	0.42	5	3	5	4.33	0.55	3	3	2	2.67	0.34
Manufacturability	0.05	0.05	0.05	0.05	4	3	4	3.67	0.18	3	3	4	3.33	0.17	2	3	4	3.00	0.15
Cost	0.02	0.05	0.01	0.03	4	3	4	3.67	0.10	4	3	4	3.67	0.10	4	3	4	3.67	0.10
User Friendliness	0.02	0.05	0.02	0.03	4	3	3	3.33	0.10	4	3	5	4.00	0.12	3	3	5	3.67	0.11
Durability	0.02	0.05	0.05	0.04	4	3	4	3.67	0.15	3	3	5	3.67	0.15	2	3	3	2.67	0.11
Water Resistance	0.02	0.05	0.05	0.04	5	3	5	4.33	0.17	4	3	5	4.00	0.16	4	3	5	4.00	0.16
Multi-angle compatibility	0.07	0.15	0.15	0.12	4	3	4	3.67	0.45	3	3	1	2.33	0.29	3	3	1	2.33	0.29
									3.38					3.57					3.44

Fixture of Filter Media	Square Washer, Square Spring					Edge Spring Clamp					Bolted Gasket				
CRITERIA	R AF	R JH	R JG	Averaged Rating	Weighted Rating	R AF	R JH	R JG	Averaged Rating	Weighted Rating	R AF	R JH	R JG	Averaged Rating	Weighted Rating
Sample Holding Strength	3	5	3	3.67	0.43	3	5	3	3.67	0.43	3	5	3	3.67	0.43
Size Compatibility	2	3	1	2.00	0.23	2	3	1	2.00	0.23	2	3	1	2.00	0.23
Thickness compatibility	4	5	4	4.33	0.53	3	3	2	2.67	0.33	4	3	4	3.67	0.45
Flow Impact	3	3	4	3.33	0.41	2	3	4	3.00	0.37	2	3	4	3.00	0.37
Change Time	3	3	3	3.00	0.25	4	3	5	4.00	0.33	3	1	3	2.33	0.19
Amount of Media Crushage	5	3	5	4.33	0.55	4	3	3	3.33	0.42	4	2	3	3.00	0.38
Manufacturability	3	1	3	2.33	0.12	3	3	4	3.33	0.17	2	1	2	1.67	0.08
Cost	4	3	4	3.67	0.10	3	3	4	3.33	0.09	3	3	4	3.33	0.09
User Friendliness	3	3	3	3.00	0.09	4	3	3	3.33	0.10	3	3	3	3.00	0.09
Durability	4	3	4	3.67	0.15	3	3	4	3.33	0.13	5	3	4	4.00	0.16
Water Resistance	4	3	5	4.00	0.16	4	3	5	4.00	0.16	5	3	3	3.67	0.15
Multi-angle compatibility	4	3	4	3.67	0.45	4	3	4	3.67	0.45	3	3	1	2.33	0.29
					3.47					3.22					2.91

Fixture of Filter Media	Spring Handle					Botted Retaining Ring				
CRITERIA	R AF	R JH	R JG	Averaged Rating	Weighted Rating	R AF	R JH	R JG	Averaged Rating	Weighted Rating
Sample Holding Strength	3	5	4	4.00	0.47	5	4	5	4.67	0.54
Size Compatibility	3	3	2	2.67	0.31	3	3	4	3.33	0.39
Thickness compatibility	5	3	5	4.33	0.53	5	4	5	4.67	0.58
Flow Impact	3	2	4	3.00	0.37	4	4	5	4.33	0.53
Change Time	5	3	5	4.33	0.36	3	2	2	2.33	0.19
Amount of Media Crushage	4	4	5	4.33	0.55	3	3	4	3.33	0.42
Manufacturability	1	2	3	2.00	0.10	4	3	5	4.00	0.20
Cost	3	2	4	3.00	0.08	4	3	4	3.67	0.10
User Friendliness	4	3	5	4.00	0.12	3	3	2	2.67	0.08
Durability	3	3	4	3.33	0.13	4	3	4	3.67	0.15
Water Resistance	3	3	4	3.33	0.13	5	3	5	4.33	0.17
Multi-angle compatibility	3	3	3	3.00	0.37	3	4	4	3.00	0.37
					3.53					3.73

Measure filter media surface deflection

1. GO-NOGO chart

Measure Filter Deflection	Strain Gauge (Long Cantilevered)	Linear Transducer	Hall Effect Sensor on metal target	Magnetometer on magnetic target	Strain Gauges on Filter	Feeler Arm	String Gauge	Camera	Ultrasonic	Laser
Accurate to 0.005"	GO	GO	GO	GO	GO	GO	GO	GO	GO	GO
Cost	GO	GO	GO	GO	GO	GO	GO	GO	GO	GO
Durable	GO	GO	GO	GO	GO	GO	no go	GO	GO	GO
Dirt Resistant	GO	GO	GO	GO	GO	GO	GO	GO	GO	GO
Able to interface with LabVIEW	GO	GO	GO	GO	GO	GO	GO	GO	GO	GO
Ease of Installation	GO	GO	GO	GO	GO	GO	GO	GO	GO	GO
Compatible with different angles	GO	GO	GO	GO	GO	GO	GO	GO	GO	GO
Water resistant	GO	GO	GO	GO	GO	GO	GO	GO	No Go	GO
Does not impact filter performance	GO	GO	GO	GO	GO	GO	GO	GO	GO	GO
Manufacturability	GO	GO	GO	GO	GO	GO	GO	GO	GO	GO
Does not damage filter	GO	GO	GO	GO	no go	GO	GO	GO	GO	GO
Simplicity	GO	GO	GO	GO	GO	GO	GO	GO	GO	GO
DECISION	Go	Go	Go	Go	No Go	Go	No Go	Go	No Go	Go

2. Pugh chart for all feasible concept

Measure Filter Deflection					Strain Gauge (Long Cantilevered)					Linear Transducer					Hall Effect				
CRITERIA	Wt AF	Wt JH	Wt JG	Averaged Weight	R AF	R JH	R JG	Averaged Rating	Weighted Rating	R AF	R JH	R JG	Averaged Rating	Weighted Rating	R AF	R JH	R JG	Averaged Rating	Weighted Rating
Accuracy	0.15	0.2	0.17	0.17	4	3	3	3.33	0.58	3	3	4	3.33	0.58	4	3	3	3.33	0.58
Cost	0.05	0.05	0.01	0.04	5	5	4	4.67	0.17	4	3	2	3.00	0.11	4	3	2	3.00	0.11
Durability	0.05	0.05	0.07	0.06	4	3	2	3.00	0.17	2	3	4	3.00	0.17	3	3	4	3.33	0.19
Dirt Resistance	0.1	0.05	0.07	0.07	5	3	5	4.33	0.32	2	3	3	2.67	0.20	4	3	4	3.67	0.27
Ease of Interfacing with LabVIEW	0.05	0.05	0.04	0.05	4	3	2	3.00	0.14	4	3	4	3.67	0.17	4	3	4	3.67	0.17
Ease of Installation	0.03	0.05	0.02	0.03	3	1	3	2.33	0.08	3	3	3	3.00	0.10	4	3	4	3.67	0.12
Compatibility with angles	0.05	0.1	0.06	0.07	5	3	4	4.00	0.28	3	1	3	2.33	0.16	3	1	3	2.33	0.16
Water Resistance	0.05	0.1	0.12	0.09	4	3	2	3.00	0.27	3	1	3	2.33	0.21	3	1	3	2.33	0.21
Impact on Filter Performance	0.15	0.1	0.09	0.11	3	1	3	2.33	0.26	3	2	2	2.33	0.26	4	3	5	4.00	0.45
Manufacturability	0.02	0.05	0.03	0.03	4	3	3	3.33	0.11	4	3	4	3.67	0.12	5	3	3	3.67	0.12
Does not damage filter	0.15	0.05	0.09	0.10	4	3	5	4.00	0.39	3	2	4	3.00	0.29	4	3	5	4.00	0.39
Simplicity	0.05	0.05	0.09	0.06	5	3	2	3.33	0.21	4	3	3	3.33	0.21	4	3	2	3.00	0.19
Does not affect deflection	0.1	0.1	0.14	0.11	3	2	2	2.33	0.26	3	2	3	2.67	0.30	5	5	5	5.00	0.57
	1.00	1.00	1.00	1.00					3.24					2.89					3.53

Measure Filter Deflection	Magnetometer					Feeler Arm					Camera					Laser				
CRITERIA	R AF	R JH	R JG	Averaged Rating	Weighted Rating	R AF	R JH	R JG	Averaged Rating	Weighted Rating	R AF	R JH	R JG	Averaged Rating	Weighted Rating	R AF	R JH	R JG	Averaged Rating	Weighted Rating
Accuracy	4	3	2	3.00	0.52	4	3	2	3.00	0.52	4	3	2	3.00	0.52	4	3	2	3.00	0.52
Cost	1	3	2	2.00	0.07	4	3	3	3.33	0.12	2	2	2	2.00	0.07	2	2	4	2.67	0.10
Durability	3	3	4	3.33	0.19	4	3	3	3.33	0.19	4	3	3	3.33	0.19	4	3	3	3.33	0.19
Dirt Resistance	4	3	4	3.67	0.27	4	3	4	3.67	0.27	4	3	4	3.67	0.27	4	3	4	3.67	0.27
Ease of Interfacing with LabVIEW	4	3	4	3.67	0.17	4	3	3	3.33	0.16	4	3	3	3.33	0.16	4	3	3	3.33	0.16
Ease of Installation	4	3	4	3.67	0.12	3	1	3	2.33	0.08	3	1	3	2.33	0.08	3	1	3	2.33	0.08
Compatibility with angles	3	1	3	2.33	0.16	5	3	4	4.00	0.28	5	3	4	4.00	0.28	5	3	4	4.00	0.28
Water Resistance	3	1	3	2.33	0.21	4	3	4	3.67	0.33	4	3	4	3.67	0.33	4	3	4	3.67	0.33
Impact on Filter Performance	3	2	4	3.00	0.34	3	1	3	2.33	0.26	3	1	3	2.33	0.26	3	1	3	2.33	0.26
Manufacturability	5	3	3	3.67	0.12	4	3	4	3.67	0.12	4	3	4	3.67	0.12	4	3	4	3.67	0.12
Does not damage filter	2	1	1	1.33	0.13	3	3	4	3.33	0.32	3	3	4	3.33	0.32	3	3	4	3.33	0.32
Simplicity	4	3	2	3.00	0.19	5	3	2	3.33	0.21	5	3	2	3.33	0.21	5	3	2	3.33	0.21
Does not affect deflection	5	5	5	5.00	0.57	2	1	2	1.67	0.19	2	1	2	1.67	0.19	2	1	2	1.67	0.19
					3.07					3.05					3.00					3.03

Measure flow rate

1. GO-NOGO chart

Measure Flow Rate	Turbine	Paddle wheel	Vortex Frequency	Vane	Differential Pressure	Ultrasonic	Magnetic	Thermal
Does not significantly disturb flow	GO	GO	No Go	GO	GO	GO	GO	No Go
Compatible with Hot water to 180F	GO	GO	GO	GO	GO	GO	GO	No Go
Accurate to 0.1gpm	GO	GO	GO	GO	GO	GO	GO	GO
Can interface to LabVIEW	GO	GO	GO	GO	GO	GO	GO	GO
Dirt resistant	GO	GO	GO	GO	No Go	No Go	GO	GO
Durable	GO	GO	GO	GO	GO	GO	GO	GO
Water Resistant	GO	GO	GO	GO	GO	GO	GO	GO
DECISION	Go	Go	No Go	Go	No Go	No Go	Go	No Go

2. Pugh chart for all feasible concept

Vary Angle					Turbine					Paddle Wheel					Vane					Magnetic					Venturi				
CRITERIA	Wt AF	Wt JH	Wt JG	Averaged Weight	R AF	R JH	R JG	Averaged Rating	Weighted Rating	R AF	R JH	R JG	Averaged Rating	Weighted Rating	R AF	R JH	R JG	Averaged Rating	Weighted Rating	R AF	R JH	R JG	Averaged Rating	Weighted Rating	R AF	R JH	R JG	Averaged Rating	Weighted Rating
Does not significantly disturb flow	0.3	0.1	0.18	0.19	3	3	3	3.00	0.58	4	3	3	3.33	0.64	2	3	2	2.33	0.45	5	5	5	5.00	0.97	5	5	4	4.67	0.90
Compatible with Hot water to 180F	0.15	0.1	0.08	0.11	4	3	4	3.67	0.40	4	3	4	3.67	0.40	4	3	4	3.67	0.40	4	3	4	3.67	0.40	4	3	4	3.67	0.40
Accurate to 0.1gpm	0.3	0.2	0.22	0.24	4	2	2	2.67	0.64	3	2	2	2.33	0.56	3	2	4	3.00	0.72	5	5	3	4.33	1.04	3	3	4	3.33	0.80
Ease of LabVIEW interface	0.02	0.1	0.12	0.08	5	3	4	4.00	0.32	5	3	4	4.00	0.32	5	3	4	4.00	0.32	2	3	3	2.67	0.21	4	3	4	3.67	0.29
Dirt Resistance	0.15	0.05	0.15	0.12	4	3	3	3.33	0.39	4	3	3	3.33	0.39	2	1	2	1.67	0.19	3	3	4	3.33	0.39	4	4	5	4.33	0.51
Durable	0.02	0.1	0.12	0.08	3	3	3	3.00	0.24	3	3	4	3.33	0.27	3	3	3	3.00	0.24	5	3	4	4.00	0.32	4	3	5	4.00	0.32
Cost	0.02	0.05	0.05	0.04	4	3	4	3.67	0.15	4	3	4	3.67	0.15	4	3	4	3.67	0.15	1	3	1	1.67	0.07	4	4	4	4.00	0.16
Size	0.02	0.05	0.05	0.04	4	3	4	3.67	0.15	3	3	3	3.00	0.12	3	3	3	3.00	0.12	1	3	3	2.33	0.09	3	2	4	3.00	0.12
Able to measure low flow rate		0.2				1	1				1	1				2	3					2			3	2	4	3.00	
Energy Requirements	0.02	0.05	0.03	0.03	4	3	4	3.67	0.12	4	3	4	3.67	0.12	4	3	4	3.67	0.12	1	3	3	2.33	0.08	4	3	4	3.67	0.12
SCORE	1.00	1.00	1.00	0.93					2.99					2.97					2.72					3.57					3.63

Measure Pressure Drop across the filter media

1. GO-NOGO chart

Measure Pressure Drop	Two pressure Transducers	Differential Pressure Transducer
Does not significantly disturb flow	GO	GO
Compatible with Hot water to 180F	GO	GO
Accurate to 0.01psi	GO	GO
Can interface to LabVIEW	GO	GO
Dirt resistant	GO	GO
Durable	GO	GO
DECISION	GO	GO

2. Pugh chart for all feasible concept

Pressure Drop					Differential Pressure Transducer					Two Pressure Transducers				
CRITERIA	Wt AF	Wt JH	Wt JG	Averaged Weight	R AF	R JH	R JG	Averaged Rating	Weighted Rating	R AF	R JH	R JG	Averaged Rating	Weighted Rating
Impact on flow	0.2	0.3	0.15	0.22	4	3	4	3.67	0.79	4	3	4	3.67	0.79
Compatible with Hot water to 180F	0.05	0.1	0.10	0.08	5	3	5	4.33	0.36	5	3	5	4.33	0.36
Accuracy	0.28	0.3	0.20	0.26	4	5	5	4.67	1.21	4	3	3	3.33	0.87
Ease of LabVIEW interface	0.09	0.05	0.10	0.08	5	3	4	4.00	0.32	5	3	4	4.00	0.32
Dirt resistance	0.14	0.05	0.10	0.10	4	3	5	4.00	0.39	5	3	5	4.33	0.42
Durable	0.14	0.05	0.10	0.10	3	3	5	3.67	0.35	4	3	4	3.67	0.35
Cost	0.05	0.05	0.10	0.07	4	3	5	4.00	0.27	4	3	4	3.67	0.24
Size	0.02	0.05	0.10	0.06	4	3	4	3.67	0.21	3	3	4	3.33	0.19
Energy Requirements	0.03	0.05	0.05	0.04	4	3	5	4.00	0.17	4	3	4	3.67	0.16
SCORE	1	1	1	1					4.08					3.71

Purge Contaminated Water

1. GO-NOGO chart

Purge Contaminated Water	Gravity Fed Valve	Drain Valve upstream fo valve
Can rid system of all water	GO	GO
Water resistant	GO	GO
Dirt resistant	GO	GO
Works in 10 minutes or less	GO	GO
DECISION	GO	GO

2. Pugh chart for all feasible concept

Purge Contaminated					Gravity Fed Valve					Drain Valve Upstream of Pump				
CRITERIA	Wt AF	Wt JH	Wt JG	Averaged Weight	R AF	R JH	R JG	Averaged Rating	Weighted Rating	R AF	R JH	R JG	Averaged Rating	Weighted Rating
% of system purged	0.22	0.25	0.20	0.22	4	5	3	4.00	0.89	4	3	5	4.00	0.89
Water Resistance	0.17	0.1	0.10	0.12	5	3	5	4.33	0.53	4	3	5	4.00	0.49
Dirt Resistance	0.17	0.2	0.05	0.14	5	3	5	4.33	0.61	3	3	5	3.67	0.51
Time Required	0.22	0.23	0.20	0.22	4	5	3	4.00	0.87	5	3	5	4.33	0.94
Cost	0.03	0.1	0.05	0.06	4	3	4	3.67	0.22	4	3	4	3.67	0.22
Durability	0.12	0.1	0.15	0.12	4	3	4	3.67	0.45	4	3	3	3.33	0.41
Energy Requirements	0.03	0.01	0.05	0.03	5	5	5	5.00	0.15	2	3	4	3.00	0.09
Ease of Use	0.04	0.01	0.20	0.08	5	4	4	4.33	0.36	3	3	4	3.33	0.28
Score	1	1	1	1					4.08					3.84

Vary flow rate and pressure

1. GO-NOGO chart

Variable Flow Rate & Pressure Drop	Pump w/ Duty Cycle	Pump w/ Varistor	Pump w/ Throttle Valve	Pump w/ Throttle and Bypass	Air-Driven	Centrifuge	Pumped Water Tank w/ Air Head	Water Column
Can use safety factors / is safe	GO	GO	GO	GO	GO	GO	GO	GO
Follow NEC 250 and other electrical safety	GO	GO	GO	GO	GO	GO	GO	GO
Can deliver 0-1+ gpm	GO	GO	GO	GO	GO	GO	GO	GO
Can deliver 0-5+ psi	GO	GO	GO	GO	GO	GO	GO	NO GO
Dirt Resistant	GO	GO	GO	GO	GO	GO	GO	GO
Can be mounted to avoid lifting	GO	GO	GO	GO	GO	GO	GO	NO GO
Hot Water Compatible to 180F	GO	GO	GO	GO	GO	GO	GO	GO
Can be drained	GO	GO	GO	GO	GO	GO	GO	GO
Can work with closed loop	GO	GO	GO	GO	GO	GO	GO	GO
Allows user to access water reservoir	GO	GO	GO	GO	NO GO	GO	GO	GO
DECISION	GO	GO	GO	GO	NO GO	GO	GO	NO GO

2. Pugh chart for all feasible concept

Variable Flow Rate					Pump w/ Duty Cycle					Pump w/ Varistor				
CRITERIA	Wt AF	Wt JH	Wt JG	Averaged Weight	R AF	R JH	R JG	Averaged Rating	Weighted Rating	R AF	R JH	R JG	Averaged Rating	Weighted Rating
# of Components Req'd	0.05	0.02	0.10	0.06	4	3	5	4.00	0.23	4	3	4	3.67	0.21
Simplicity to control	0.15	0.1	0.10	0.12	4	5	5	4.67	0.54	4	5	5	4.67	0.54
Accuracy of Adjustment	0.1	0.2	0.10	0.13	3	3	5	3.67	0.49	3	5	3	3.67	0.49
Resolution of Adjustment	0.2	0.2	0.15	0.18	4	3	5	4.00	0.73	5	5	3	4.33	0.79
Avoid High Pressures	0.05	0.1	0.10	0.08	4	3	5	4.00	0.33	4	3	5	4.00	0.33
Steady Output	0.2	0.2	0.15	0.18	4	3	4	3.67	0.67	4	3	5	4.00	0.73
Size	0.02	0.04	0.05	0.04	4	3	5	4.00	0.15	4	3	5	4.00	0.15
Energy Requirement	0.03	0.03	0.05	0.04	5	5	4	4.67	0.17	2	3	2	2.33	0.09
Cost	0.05	0.03	0.05	0.04	4	3	4	3.67	0.16	4	3	4	3.67	0.16
Manufacturability	0.05	0.03	0.10	0.06	5	3	5	4.33	0.26	5	3	5	4.33	0.26
Durability	0.1	0.05	0.05	0.07	5	3	5	4.33	0.29	4	3	5	4.00	0.27
SCORE	1.00	1.00	1.00	1.00					4.02					4.02

Variable Flow Rate	Pump w/ Throttle Valve					Pump w/ Throttle and Bypass					Centrifuge				
CRITERIA	R AF	R JH	R JG	Averaged Rating	Weighted Rating	R AF	R JH	R JG	Averaged Rating	Weighted Rating	R AF	R JH	R JG	Averaged Rating	Weighted Rating
# of Components Req'd	3	3	3	3.00	0.17	2	3	2	2.33	0.13	2	3	2	2.33	0.13
Simplicity to control	4	5	3	4.00	0.47	4	5	4	4.33	0.51	3	1	1	1.67	0.19
Accuracy of Adjustment	4	5	4	4.33	0.58	4	5	3	4.00	0.53	2	1	3	2.00	0.27
Resolution of Adjustment	4	5	5	4.67	0.86	4	5	5	4.67	0.86	4	3	5	4.00	0.73
Avoid High Pressures	2	3	1	2.00	0.17	4	3	3	3.33	0.28	2	3	5	3.33	0.28
Steady Output	5	3	4	4.00	0.73	5	3	4	4.00	0.73	3	3	5	3.67	0.67
Size	4	3	3	3.33	0.12	3	3	3	3.00	0.11	3	3	3	3.00	0.11
Energy Requirement	2	3	2	2.33	0.09	2	3	2	2.33	0.09	3	1	3	2.33	0.09
Cost	3	3	4	3.33	0.14	3	3	3	3.00	0.13	3	3	2	2.67	0.12
Manufacturability	5	3	3	3.67	0.22	4	3	3	3.33	0.20	2	1	1	1.33	0.08
Durability	5	3	2	3.33	0.22	4	3	3	3.33	0.22	2	3	3	2.67	0.18
SCORE					3.76					3.79					2.85

Variable Flow Rate	Pumped Water Tank w/ Air Head					Piston Column					Pump with Expansion Tank and some sort of Pump Modulation				
CRITERIA	R AF	R JH	R JG	Averaged Rating	Weighted Rating	R AF	R JH	R JG	Averaged Rating	Weighted Rating	R AF	R JH	R JG	Averaged Rating	Weighted Rating
# of Components Req'd	3	1	3	2.33	0.13		3		3.00	0.17	3	3	3	3.00	0.17
Simplicity to control	3	3	2	2.67	0.31		3		3.00	0.35	4	5	5	4.67	0.54
Accuracy of Adjustment	4	3	3	3.33	0.44		3		3.00	0.40	4	3	5	4.00	0.53
Resolution of Adjustment	5	3	3	3.67	0.67		3		3.00	0.55	4	3	5	4.00	0.73
Avoid High Pressures	5	3	4	4.00	0.33		3		3.00	0.25	4	3	4	3.67	0.31
Steady Output	5	3	4	4.00	0.73		4		4.00	0.73	5	4	5	4.67	0.86
Size	2	1	3	2.00	0.07		3		3.00	0.11	3	3	3	3.00	0.11
Energy Requirement	3	1	4	2.67	0.10		3		3.00	0.11	5	5	4	4.67	0.17
Cost	3	1	3	2.33	0.10		3		3.00	0.13	3	4	4	3.67	0.16
Manufacturability	4	3	5	4.00	0.24		3		3.00	0.18	3	3	4	3.33	0.20
Durability	3	3	5	3.67	0.24		3		3.00	0.20	3	3	5	3.67	0.24
SCORE					3.38					3.18					4.03

Vary incoming flow angle

1. GO-NOGO chart

Vary Angle	Cassette	Roto-Nozzle	Hinged Door	Hinged Door w/ Secondary Door	Rotating Hallway	Channel in a Channel
Varies angle from 0 to 60,	go	go	go	go	go	go
Adjustable in 15-degree increments	go	go	go	go	go	go
Water resistant	go	go	go	go	go	go
Allows for fixturing of filter media	go	go	go	go	go	go
Allows laminar flow developed upstream	go	no go	go	go	go	go
DECISION	Go	No Go	Go	Go	Go	Go

2. Pugh chart for all feasible concept

Vary Angle					Cassette					Hinged Door				
CRITERIA	**Wt AF**	**Wt JH**	**Wt JG**	Averaged Weight	R AF	R JH	R JG	Averaged Rating	Weighted Rating	R AF	R JH	R JG	Averaged Rating	Weighted Rating
Varies angle from 0 to 60,	0.22	0.25	0.20	0.22	5	5	5	5.00	1.12	5	5	5	5.00	1.12
Adjustable in 15-degree increments	0.16	0.15	0.20	0.17	5	5	5	5.00	0.85	5	5	5	5.00	0.85
Water resistant & doesn't leak	0.15	0.1	0.10	0.12	2	3	1	2.00	0.23	4	3	3	3.33	0.39
Ease of fixturing filter	0.10	0.05	0.05	0.07	3	3	4	3.33	0.22	4	3	4	3.67	0.24
Quality of upstream flow	0.14	0.25	0.20	0.20	1	3	4	2.67	0.52	4	2	2	2.67	0.52
Goes up to 90 degrees	0.05	0.05	0.05	0.05	4	5	4	4.33	0.22	5	5	5	5.00	0.25
Cost	0.02	0.03	0.05	0.03	3	3	4	3.33	0.11	4	3	3	3.33	0.11
Ease of Manufacturing	0.03	0.02	0.05	0.03	2	3	3	2.67	0.09	3	3	3	3.00	0.10
Durability	0.05	0.05	0.05	0.05	3	3	4	3.33	0.17	3	3	3	3.00	0.15
Speed of adjustment	0.08	0.05	0.05	0.06	5	5	5	5.00	0.30	4	3	5	4.00	0.24
SCORE	1.00	1.00	1.00	1.00					3.83					3.98

Vary Angle	Hinged Door w/ Secondary Hinged Door					Moving Hallway				
CRITERIA	R AF	R JH	R JG	Averaged Rating	Weighted Rating	R AF	R JH	R JG	Averaged Rating	Weighted Rating
Varies angle from 0 to 60,	5	5	5	5.00	1.12	5	5	5	5.00	1.12
Adjustable in 15-degree increments	5	5	5	5.00	0.85	5	5	5	5.00	0.85
Water resistant & doesn't leak	4	3	3	3.33	0.39	3	3	3	3.00	0.35
Ease of fixturing filter	3	2	4	3.00	0.20	3	5	4	4.00	0.27
Quality of upstream flow	4	3	3	3.33	0.66	4	3	3	3.33	0.66
Goes up to 90 degrees	5	5	5	5.00	0.25	5	5	5	5.00	0.25
Cost	4	3	3	3.33	0.11	3	3	3	3.00	0.10
Ease of Manufacturing	3	1	3	2.33	0.08	2	3	3	2.67	0.09
Durability	3	3	3	3.00	0.15	2	3	3	2.67	0.13
Speed of adjustment	3	2	4	3.00	0.18	3	3	3	3.00	0.18
SCORE					3.98					3.99

Vary Angle	Channel in a Channel					Chamber(channel - channel hinged door hybrid				
CRITERIA	R AF	R JH	R JG	Averaged Rating	Weighted Rating	R AF	R JH	R JG	Averaged Rating	Weighted Rating
Varies angle from 0 to 60,	5	5	5	5.00	1.12	5	5	5	5.00	1.12
Adjustable in 15-degree increments	5	5	5	5.00	0.85	5	5	5	5.00	0.85
Water resistant & doesn't leak	3	3	3	3.00	0.35	4	5	4	4.33	0.51
Ease of fixturing filter	3	2	4	3.00	0.20	3	3	4	3.33	0.22
Quality of upstream flow	4	5	3	4.00	0.79	4	3	5	4.00	0.79
Goes up to 90 degrees	2	1	1	1.33	0.07	5	5	5	5.00	0.25
Cost	3	3	3	3.00	0.10	3	3	4	3.33	0.11
Ease of Manufacturing	2	1	3	2.00	0.07	3	2	5	3.33	0.11
Durability	4	3	3	3.33	0.17	4	3	5	4.00	0.20
Speed of adjustment	3	5	3	3.67	0.22	4	3	5	4.00	0.24
SCORE					3.92					4.39

Appendix G- Fully device scoring and Pugh Charts

	Sub - Functions	A	B	C	D
Final Design Concepts Generation	Pressure	Diff Transducer	Diff Transducer	Diff Transducer	Diff Transducer
	Deliver Flow	Pump w/ Duty and Exp. Tank	Rheostat Pump w/ Piston	Duty Cycle w/ Piston	Pump w/ Duty and Exp. Tank
	Fixture	BRR	Spring Handkle	Spring Handle	Spring Handle
	Angle	Chamber	channel in chanel	Chamber	Channel in Channel
	Measure Flow	Venturi	Venturi	Venturi	Paddlewheel
	Measure Deflect	Hall	Hall	Hall	Hall
	Drain	Valve	Valve	Pumped	Valve
	Contaminants	Tank	Tank	Tank	Tank

Design	W_AF	W_JG	W_JH	W_average	A_AF	A_JG	A_JH	A_Average		B_AF	B_JG	B_JH	B_Average		C_AF	C_JG	C_JH	C_Average		D_AF	D_JG	D_JH	D_Average	
Ability to vary system flow rates/pressures	0.1	0.1	0.08	0.09	5	5	5	5.00	0.47	5	5	4	4.67	0.44	4	4	4	4.00	0.37	5	5	4	4.67	0.44
Ability to measure flow rates	0.08	0.09	0.1	0.09	4	5	5	4.67	0.42	4	5	4	4.33	0.39	4	5	4	4.33	0.39	4	3	4	3.67	0.33
Ability to measure pressure drop across filter media	0.07	0.09	0.1	0.09	5	4	5	4.67	0.40	5	5	4	4.67	0.40	5	4	4	4.33	0.38	5	5	4	4.67	0.40
Ability to vary water flow angle	0.07	0.07	0.08	0.07	5	5	5	5.00	0.37	3	5	4	4.00	0.29	5	5	4	4.67	0.34	3	5	4	4.00	0.29
Ability to measure filter flex	0.07	0.07	0.08	0.07	4	5	5	4.67	0.34	4	4	4	4.00	0.29	4	5	4	4.33	0.32	4	4	4	4.00	0.29
Safety (prevent tipping)	0.07	0.05	0.07	0.06	4	4	4	4.00	0.25	4	4	4	4.00	0.25	4	4	4	4.00	0.25	4	4	4	4.00	0.25
Easy LabVIEW interface	0.06	0.07	0.04	0.06	4	5	5	4.67	0.26	5	4	4	4.33	0.25	4	3	4	3.67	0.21	4	5	4	4.33	0.25
Hold specified filter sample size	0.07	0.04	0.05	0.05	4	5	4	4.33	0.23	3	4	4	3.67	0.20	3	4	3	3.33	0.18	3	4	4	3.67	0.20
Electrical Safety	0.05	0.05	0.05	0.05	4	4	4	4.00	0.20	5	4	4	4.33	0.22	4	4	4	4.00	0.20	4	4	4	4.00	0.20
Unit can withstand dirty water	0.05	0.03	0.04	0.04	4	4	5	4.33	0.17	3	4	4	3.67	0.15	3	4	4	3.67	0.15	3	4	4	3.67	0.15
Allow user to add contaminants	0.03	0.03	0.05	0.04	5	5	5	5.00	0.18	5	5	4	4.67	0.17	5	5	4	4.67	0.17	5	5	4	4.67	0.17
Compatible with various sized samples	0.04	0.04	0.03	0.04	3	3	3	3.00	0.11	2	3	3	2.67	0.10	3	3	3	3.00	0.11	2	3	3	2.67	0.10
Durability	0.05	0.03	0.03	0.04	4	5	4	4.33	0.16	3	4	3	3.33	0.12	3	3	3	3.00	0.11	3	4	4	3.67	0.13
Quick filter change time	0.03	0.04	0.02	0.03	3	3	3	3.00	0.09	3	5	4	4.00	0.12	4	5	5	4.67	0.14	3	5	4	4.00	0.12
Compatible with various samples thicknesses	0.04	0.02	0.03	0.03	5	5	5	5.00	0.15	5	5	4	4.67	0.14	5	5	4	4.67	0.14	5	5	5	5.00	0.15
Does not damage filter media	0.03	0.03	0.03	0.03	5	5	5	5.00	0.15	5	5	4	4.67	0.14	5	5	4	4.67	0.14	5	5	4	4.67	0.14
Compatiable with hot water	0.01	0.03	0.02	0.02	5	5	5	5.00	0.10	5	5	5	5.00	0.10	5	5	5	5.00	0.10	5	5	5	5.00	0.10
Ability to purge contaminated water	0.02	0.02	0.02	0.02	5	4	5	4.67	0.09	5	4	4	4.33	0.09	4	5	5	4.67	0.09	5	4	4	4.33	0.09
Self-contained	0.02	0.02	0.02	0.02	5	5	4	4.67	0.09	5	5	4	4.67	0.09	5	5	5	5.00	0.10	5	5	4	4.67	0.09
Physically user friendly	0.01	0.02	0.02	0.02	4	5	5	4.67	0.08	3	5	4	4.00	0.07	3	5	4	4.00	0.07	4	5	4	4.33	0.07
Easily movable	0.01	0.02	0.02	0.02	4	4	5	4.33	0.07	4	4	4	4.00	0.07	4	4	4	4.00	0.07	4	4	4	4.00	0.07
Cost	0.01	0.03	0.01	0.02	4	4	4	4.00	0.07	4	3	3	3.33	0.06	4	3	3	3.33	0.06	4	3	3	3.33	0.06
Energy Requirements	0.01	0.01	0.01	0.01	5	4	4	4.33	0.04	3	2	2	2.33	0.02	5	4	4	4.33	0.04	5	4	4	4.33	0.04
	1	**1**	**1**	**1**					**4.51**					**4.16**					**4.12**					**4.13**

	Sub - Functions				**E**					**F**					**G**				
Final Design Concepts Generation	Pressure				Diff Transducer					Diff Transducer					Diff Transducer				
	Deliver Flow				Pump w/ Duty and Exp. Tank					Pump w/ Duty and Exp. Tank					Throttle & Relief Valve				
	Fixture				BRR					BRR					BRR				
	Angle				Hinged Door					Channel in Channel					Chamber				
	Measure Flow				Venturi					Venturi					Turbine				
	Measure Deflect				Hall					Strain Gauge					Hall				
	Drain				Valve					Valve					Valve				
	Contaminants				Tank					Tank					Tank				
Design	W_AF	W_JG	W_JH	W_average	E_AF	E_JG	E_JH	E_Average		F_AF	F_JG	F_JH	F_Average		G_AF	G_JG	G_JH	G_Average	
Ability to vary system flow rates/pressures	0.1	0.1	0.08	0.09	5	4	4	4.33	0.40	5	5	4	4.67	0.44	5	3	4	4.00	0.37
Ability to measure flow rates	0.08	0.09	0.1	0.09	4	5	4	4.33	0.39	4	5	4	4.33	0.39	3	3	3	3.00	0.27
Ability to measure pressure drop across filter media	0.07	0.09	0.1	0.09	5	3	4	4.00	0.35	5	4	4	4.33	0.38	5	4	4	4.33	0.38
Ability to vary water flow angle	0.07	0.07	0.08	0.07	4	5	4	4.33	0.32	3	5	4	4.00	0.29	5	5	4	4.67	0.34
Ability to measure filter flex	0.07	0.07	0.08	0.07	4	4	4	4.00	0.29	3	3	3	3.00	0.22	4	5	4	4.33	0.32
Safety (prevent tipping)	0.07	0.05	0.07	0.06	4	4	4	4.00	0.25	4	4	4	4.00	0.25	4	4	4	4.00	0.25
Easy LabVIEW interface	0.06	0.07	0.04	0.06	4	5	4	4.33	0.25	3	5	4	4.00	0.23	4	3	3	3.33	0.19
Hold specified filter sample size	0.07	0.04	0.05	0.05	4	5	5	4.67	0.25	4	5	4	4.33	0.23	4	5	5	4.67	0.25
Electrical Safety	0.05	0.05	0.05	0.05	4	4	4	4.00	0.20	4	4	4	4.00	0.20	3	4	4	3.67	0.18
Unit can withstand dirty water	0.05	0.03	0.04	0.04	4	4	4	4.00	0.16	4	4	4	4.00	0.16	3	4	4	3.67	0.15
Allow user to add contaminants	0.03	0.03	0.05	0.04	5	5	5	5.00	0.18	5	5	4	4.67	0.17	5	5	4	4.67	0.17
Compatible with various sized samples	0.04	0.04	0.03	0.04	4	3	3	3.33	0.12	2	3	3	2.67	0.10	3	3	3	3.00	0.11
Durability	0.05	0.03	0.03	0.04	4	5	4	4.33	0.16	4	4	4	4.00	0.15	4	5	4	4.33	0.16
Quick filter change time	0.03	0.04	0.02	0.03	2	3	3	2.67	0.08	3	3	3	3.00	0.09	3	3	3	3.00	0.09
Compatible with various samples thicknesses	0.04	0.02	0.03	0.03	5	5	4	4.67	0.14	5	5	4	4.67	0.14	5	5	4	4.67	0.14
Does not damage filter media	0.03	0.03	0.03	0.03	5	5	4	4.67	0.14	4	5	4	4.33	0.13	5	5	4	4.67	0.14
Compatiable with hot water	0.01	0.03	0.02	0.02	5	5	5	5.00	0.10	5	5	4	4.67	0.09	5	5	5	5.00	0.10
Ability to purge contaminated water	0.02	0.02	0.02	0.02	5	4	4	4.33	0.09	5	4	4	4.33	0.09	5	4	5	4.67	0.09
Self-contained	0.02	0.02	0.02	0.02	5	5	5	5.00	0.10	5	5	4	4.67	0.09	5	5	5	5.00	0.10
Physically user friendly	0.01	0.02	0.02	0.02	4	5	4	4.33	0.07	4	5	4	4.33	0.07	4	5	4	4.33	0.07
Easily movable	0.01	0.02	0.02	0.02	4	4	4	4.00	0.07	4	4	4	4.00	0.07	5	4	4	4.33	0.07
Cost	0.01	0.03	0.01	0.02	4	4	4	4.00	0.07	4	3	3	3.33	0.06	5	4	4	4.33	0.07
Energy Requirements	0.01	0.01	0.01	0.01	5	4	4	4.33	0.04	5	4	4	4.33	0.04	3	3	4	3.33	0.03
	1	**1**	**1**	**1**					**4.22**					**4.07**					**4.05**

Appendix H.1

Head loss equation

> $P1 + .5 \cdot p \cdot alpha1 \cdot V1^2 + pgh1 = P2 + .5 \cdot p \cdot alpha2 \cdot V2^2 + pgh2 + \frac{hl}{pg}$

Kinematic viscosity (in^2/s)

> $v140 := .511\mathrm{e}{-5} \cdot 144;$

$$v140 := 0.00073584$$

> $v70 := 1.052\mathrm{e}{-5} \cdot 144;$

$$v70 := 0.00151488$$

Density of water at 70 degrees Fahrenheit

> $p := \frac{1.94}{12^4};$

$$p := 0.00009355709877$$

Flow rate, pipe diameters, pipe areas, pipe lengths, number of elbows and reducers, head loss coefficients for, Reynolds Numbers, friction factors, and corresponding resistances (1 is from pump to expansion tank, 2 is from expansion tank to channel, 3 is the free channel, lf is the laminar flow guides, 4 is from the filter to the reservoir)(all lengths are in inches, all pressures are in psi)

> $Qins := \frac{16 \cdot 231}{60};$

$$Qins := \frac{308}{5}$$

> $d1 := 1;$

$$d1 := 1$$

> $d2 := 1;$

$$d2 := 1$$

> $d3 := 5.75;$

$$d3 := 5.75$$

> $dlf := .315;$

$$dlf := 0.315$$

> $d4 := 1;$

$$d4 := 1$$

> $A1 := \frac{\mathrm{Pi} \cdot d1^2}{4};$

$$A1 := \frac{1}{4}\pi$$

> $A2 := \frac{d2^2 \cdot \mathrm{Pi}}{4};$

$$A2 := \frac{1}{4}\pi$$

> $A3 := d3^2;$

$$A3 := 33.0625$$

> $Af := 3^2;$

$$Af := 9$$

> $A4 := \frac{d4^2 \cdot \mathrm{Pi}}{4};$

$$A4 := \frac{1}{4}\pi$$

> $l1 := 24;$

$$l1 := 24$$

> $l2 := 8 \cdot 12;$

$$l2 := 96$$

> $l3 := 12;$

$$l3 := 12$$

> $llf := 18;$

$$llf := 18$$

> $l4 := 60;$

$$l4 := 60$$

> $Nel1 := 2;$

$$Nel1 := 2$$

> $Nel2 := 2;$

$$Nel2 := 2$$

> $Nel4 := 1;$

$$Nel4 := 1$$

> $Nred := 1;$

$$Nred := 1$$

> $Kel := 1.5;$

$$Kel := 1.5$$

> $Kred := 1.5;$

$$Kred := 1.5$$

$$Kf := 2883.119766$$

> $Re1 := evalf\left(\frac{Qins \cdot d1}{v70 \cdot A1}\right);$

$$\Re 1 := 51774.10482$$

> $Re2 := evalf\left(\frac{Qins \cdot d2}{v70 \cdot A2}\right);$

$$\Re 2 := 51774.10482$$

> $Re3 := evalf\left(\frac{Qins \cdot d3}{v70 \cdot A3}\right);$

$$\Re 3 := 7071.875977$$

> $Re4 := evalf\left(\frac{Qins \cdot d4}{v70 \cdot A4}\right);$

$$\Re 4 := 51774.10482$$

> $f1 := .021;$

$$f1 := 0.021$$

> $f2 := .021;$

$$f2 := 0.021$$

> $f3 := .036;$

$$f3 := 0.036$$

> $f4 := .021;$

$$f4 := 0.021$$

Pressure drop across each part

> $P1 := evalf\left(p \cdot Qins^2 \cdot \left(\frac{f1 \cdot l1}{A1^2 \cdot d1} + \frac{Nel1 \cdot Kel}{A1^2}\right)\right);$

$$P1 := 2.016612732$$

> $P2 := evalf\left(p \cdot Qins^2 \cdot \left(\frac{1}{Af^2} - \frac{1}{A2^2} + \frac{f2 \cdot l2}{A2^2 \cdot d2} + \frac{f3 \cdot l3}{A3^2 \cdot d3} + \frac{Nel2 \cdot Kel}{A2^2} + \frac{1}{A2^2}\left(1 - \frac{A2}{A3}\right)^2\right) + \frac{Qins \cdot p \cdot 32 \cdot v70 \cdot llf}{dlf^2 \cdot A3}\right);$

$$P2 := 2.865716997$$

> $P4 := evalf\left(p \cdot Qins^2 \cdot \left(\frac{1}{A4^2} - \frac{1}{Af^2} + \frac{f4 \cdot l4}{A4^2 \cdot d4} + \frac{Nel4 \cdot Kel}{2 \cdot A4^2} + \frac{Nred \cdot Kred}{2 \cdot A4^2}\right)\right);$

$$P4 := 2.159562354$$

Pressure drop across the system, total pressure the pump needs to supply.

> $Psystem := P1 + P2 + P4;$

$$Psystem := 7.041892083$$

Add pressure drop across filter to find total pressure drop

> $Ptotal := Psystem + 2;$

$$Ptotal := 9.041892083$$

>

Finding the pressure at the channel inlet

> $Pinlet := Ptotal - evalf\left(p \cdot Qins^2 \cdot \left(\frac{1}{A3^2} - \frac{1}{A1^2} + \frac{f1 \cdot l1}{A1^2 \cdot d1} + \frac{Nel1 \cdot Kel}{A1^2} + \frac{f2 \cdot l2}{A2^2 \cdot d2} + \frac{Nel2 \cdot Kel}{A2^2} + \frac{1}{A2^2}\left(1 - \frac{A2}{A3}\right)^2\right)\right)$

$$Pinlet := 4.165177664$$

>

Appendix H.2

Channel Reynolds number

$Re = \dfrac{QD}{\nu A}$; Q is flow rate, D is hydraulic diameter, ν is kinematic viscosity, A is the flow area

To find maximum Re ⇒ least likely to be laminar

$$Re\uparrow = \frac{Q\uparrow D}{\nu\downarrow A}$$

fixed for the design due to space limitations and availability reasons

evaluate at maximum Q and minimum ν

- min ν at 140°F; ν @ 140°F = $.511 \times 10^{-5}\ ft^2/s = .7358 \times 10^{-3}\ in^3/s$

$$Re = \frac{(231\ in^3/gal.)(16\ gal/min)(5.5\ in)}{(60\ sec/min)(.7358\times10^{-3}\ in^3/s)(5.5\ in)^2} = \boxed{14559.7}$$

Appendix H.3

Laminar Flow Guides

$Re = \dfrac{QD}{\nu A} = \dfrac{VD}{\nu}$; $V = \dfrac{Q}{A}$ is the flow velocity

$$\max V = \frac{(231\ in^3/gal)(16\ gal/min)}{(60\ sec/min)(5.75\ in)^2} = 10.713\ in/sec$$

$$2100 = \frac{10.713\ D}{(.7358\times10^{-3})}$$

$$\boxed{D_{max} = .144\ in}$$

Now Choosing a diameter of .315

$$l_e = .06\,(.315)\left(\frac{10.713\,(.314)}{(.7358\times10^{-3})}\right)$$

$= 13.84$ inches

$\boxed{\text{Appendix H.4}}$

Boundary layer analysis

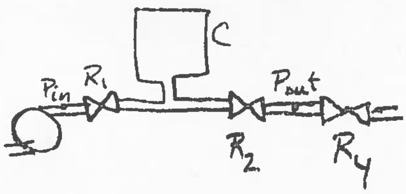
To find minimum x until turbulent boundary layer
use V_{max}, and min ν

$$Re_{x_{critical}} = 2\times10^5 = \frac{V_{max}X_{min}}{\nu_{min}} = \frac{10.713\,in/sec\; X_{min}}{(.7358\times10^{-3}\,in^2/sec)}$$

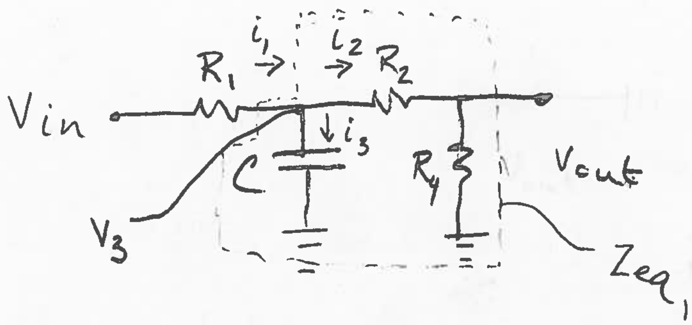
$$X_{min} = 13.74\,in$$

Appendix H.5

System Dynamic Analysis



Equivalent Circuit Analysis



$$i = \frac{1}{Z_{eq}} V$$

$$i_1 = i_2 + i_3$$

$$\frac{1}{Z_{eq_1}} = \frac{1}{R_2 + R_4} + Cs$$

$$Z_{eq_1} = \frac{1}{\frac{1}{R_2 + R_4} + Cs}$$

Definitions of C and R in fluid systems

$$C = \frac{dm_{water}}{dp} = \rho_w \frac{dV}{dp}$$

expansion tank $V = \frac{mRT}{P}$

$$\frac{dV}{dP} = -\frac{mRT}{P^2}$$

$$= \frac{-P_i V_i}{P^2}$$

$$\frac{dm_{water}}{dp} = \frac{-\rho_w P_{atm} V_{tank}}{P^2}$$

$$R = \frac{dP}{dq_m}$$

take derivative of pressure drops with respect to q_m to get R

$$Z_{eq_{tot}} = R_1 + \frac{1}{\frac{1}{R_2 + R_4} + Cs} = R_1 + Z_{eq_1}$$

$$V_{in} = i_1 Z_{eq_{tot}}$$

$$V_{in} = i_1 \left(R_1 + \frac{1}{\frac{1}{R_2 + R_4} + Cs} \right)$$

$$V_{out} = i_2 R_4$$

$$i_3 = C_s V_3$$

$$V_3 = V_{in} - i_1 R_1$$

$$i_3 = (V_{in} - i_1 R_1) C_s \quad (1)$$

$$i_1 = \frac{V_{in}}{R_1 + \cfrac{1}{\cfrac{1}{R_2+R_4} + C_s}} \quad (2)$$

$$i_2 = \frac{V_{out}}{R_4} \quad (3)$$

$$i_1 = i_2 + i_3 \quad (4)$$

Substituting (1), (2) and (3) into (4)

$$\frac{V_{in}}{R_1 + \cfrac{1}{\cfrac{1}{R_2+R_4} + C_s}} = \frac{V_{out}}{R_4} + C_s\left(V_{in} - \frac{V_{in}}{R_1 + \cfrac{1}{\cfrac{1}{R_2+R_4} + C_s}} R_1\right)$$

$$V_{out} = R_4\left(\frac{1}{R_1 + \cfrac{1}{\cfrac{1}{R_2+R_4} + C_s}} + C_s\left(\frac{R_1}{R_1 + \cfrac{1}{\cfrac{1}{R_2+R_4} + C_s}} - 1\right)\right)$$

Now going to Maple to find $H(s)$

Appendix H.5 part 2

> $restart:$

Transfer function

> $H := simplify\left(r4\left(\frac{(1+C\cdot s\cdot r1)}{r1+\frac{1}{\frac{1}{r2+r4}+C\cdot s}}-C\cdot s\right)\right);$

$$H := r4\left(\frac{1}{r1+r1\,C\,s\,r2+r1\,C\,s\,r4+r2+r4}\right)$$

> $Hj := subs(s=j\cdot w, H);$

$$Hj := r4\left(\frac{1}{r1+r1\,C\,j\,w\,r2+r1\,C\,j\,w\,r4+r2+r4}\right)$$

> $M := \frac{r4}{\text{sqrt}\left((r1+r2+r4)^2+(r1\cdot r2\cdot C\cdot w+r4\cdot r1\cdot C\cdot w)^2\right)};$

$$M := r4 \Big/ \left(r1^2+2\,r1\,r2+2\,r4\,r1+r2^2+2\,r2\,r4+r4^2 + r1^2\,r2^2\,C^2\,w^2+2\,r1^2\,r2\,C^2\,w^2\,r4+r4^2\,r1^2\,C^2\,w^2\right)^{1/2}$$

Kinematic viscosity

> $v140 := .511e{-5}\cdot 144;$

$$v140 := 0.00073584$$

> $v70 := 1.052e{-5}\cdot 144;$

$$v70 := 0.00151488$$

Flow rate, pipe diameters, pipe areas, pipe lengths, number of elbows and reducers, head loss coefficients for, Reynolds Numbers, friction factors, and corresponding resistances (1 is from pump to expansion tank, 2 is from expansion tank to channel, 3 is the free channel, lf is the laminar flow guides, 4 is from the filter to the reservoir)(all lengths are in inches, all pressures are in psi)

Flow Rate of 1gpm

> $Qins := \frac{1\cdot 231}{60};$

$$Qins := \frac{77}{20}$$

> $d1 := 1;$

$$d1 := 1$$

> $d2 := 1;$

$$d2 := 1$$

> $d3 := 5.75;$

$$d3 := 5.75$$

> $dlf := .315;$

$$dlf := 0.315$$

> $d4 := 1;$

$$d4 := 1$$

> $A1 := \frac{\mathrm{Pi} \cdot d1^2}{4};$

$$A1 := \frac{1}{4}\,\pi$$

> $A2 := \frac{d2^2 \cdot \mathrm{Pi}}{4};$

$$A2 := \frac{1}{4}\,\pi$$

> $A3 := d3^2;$

$$A3 := 33.0625$$

> $Af := 3^2;$

$$Af := 9$$

> $A4 := \frac{d4^2 \cdot \mathrm{Pi}}{4};$

$$A4 := \frac{1}{4}\,\pi$$

> $l1 := 24;$

$$l1 := 24$$

> $l2 := 8 \cdot 12;$

$$l2 := 96$$

> $l3 := 12;$

$$l3 := 12$$

> $llf := 18;$

$$llf := 18$$

> $l4 := 60;$

$$l4 := 60$$

> $Nel1 := 2;$

$$Nel1 := 2$$

> $Nel2 := 2;$

$$Nel2 := 2$$

> $Nel4 := 1;$

$$Nel4 := 1$$

> $Nred := 1;$

$$Nred := 1$$

> $Kel := 1.5;$

$$Kel := 1.5$$

> $Kred := 1.5;$

$$Kred := 1.5$$

Estimation of head loss of the filter

> $Kf := \frac{2}{.5 \cdot .0000936 \cdot \left(\frac{231}{60}\right)^2};$

$$Kf := 2883.119766$$

> $Re1 := evalf\left(\frac{Qins \cdot d1}{v70 \cdot A1}\right);$

$$\Re 1 := 3235.881554$$

> $Re2 := evalf\left(\frac{Qins \cdot d2}{v70 \cdot A2}\right);$

$$\Re 2 := 3235.881554$$

> $Re3 := evalf\left(\frac{Qins \cdot d3}{v70 \cdot A3}\right);$

$$\Re 3 := 441.9922486$$

> $Re4 := evalf\left(\frac{Qins \cdot d4}{v70 \cdot A4}\right);$

$$\Re 4 := 3235.881554$$

> $f1 := .021;$

$$f1 := 0.021$$

> $f2 := .021;$

$$f2 := 0.021$$

> $f3 := .036;$

$$f3 := 0.036$$

> $f4 := .021;$

$$f4 := 0.021$$

> $r1 := evalf\left(Qins \cdot \left(\frac{f1 \cdot l1}{A1^2 \cdot d1} + \frac{Nel1 \cdot Kel}{A1^2}\right)\right);$

$$r1 := 21.86981272$$

> $r2 := evalf\left(Qins \cdot \left(\frac{1}{Af^2} - \frac{1}{A2^2} + \frac{f2 \cdot l2}{A2^2 \cdot d2} + \frac{f3 \cdot l3}{A3^2 \cdot d3} + \frac{Nel2 \cdot Kel}{A2^2} + \frac{1}{A2^2}\left(1 - \frac{A2}{A3}\right)^2\right) + \frac{32 \cdot v70 \cdot llf}{dlf^2 \cdot A3}\right);$

$$r2 := 31.32755346$$

> $r4 := evalf\left(Qins \cdot \left(\frac{1}{A4^2} - \frac{1}{Af^2} + \frac{f4 \cdot l4}{A4^2 \cdot d4} + \frac{Nel4 \cdot Kel}{2 \cdot A4^2} + \frac{Nred \cdot Kred}{2 \cdot A4^2} + \frac{Kf}{Af^2}\right)\right);$

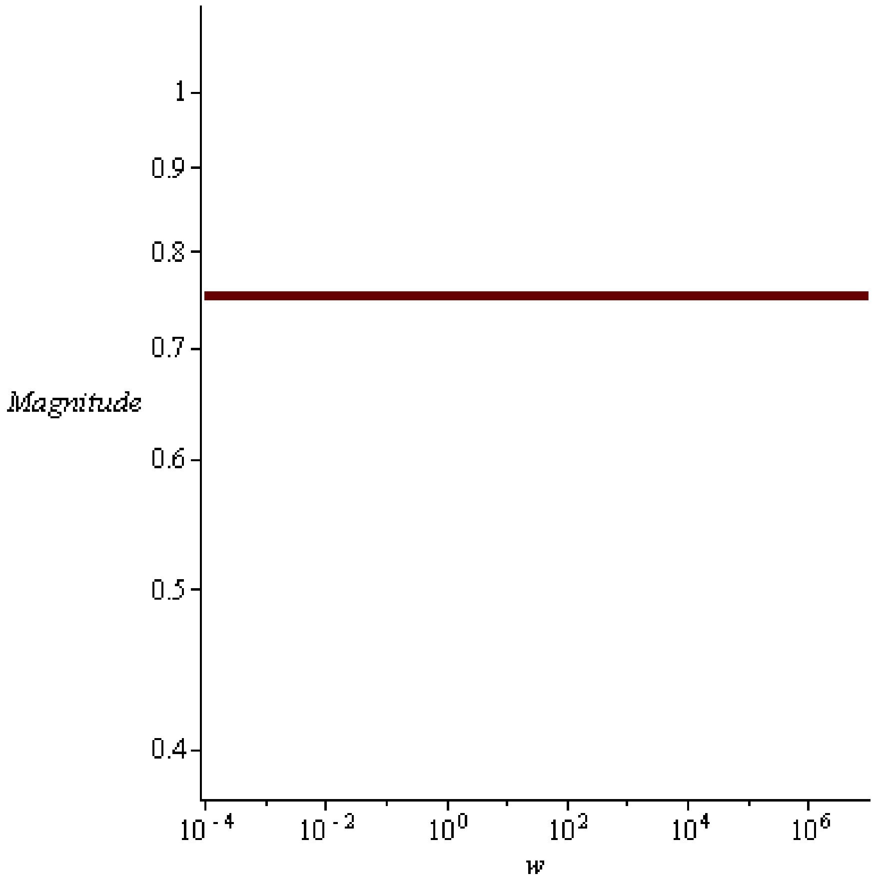
$$r4 := 160.4572505$$

Evaluating the system with zero capacitance

> $Ma := subs(C = 0, M);$

$$Ma := 0.7510123254$$

> $plot\left([Ma], w = .0001 \ldots .10000000, linestyle = [solid], thickness = 4, axis_1 = [mode = \log], axis_2 = [mode = \log], labels = [w, Magnitude]\right);$



Evaluating the system with an expansion tank size of 20in^3

> $vtank := 20;$

$$vtank := 20$$

> $patm := 14.5;$

$$patm := 14.5$$

> $pw := .0000936;$

$$pw := 0.0000936$$

> $$ptank := evalf\left(\left(\frac{Qins^2 \cdot pw}{2} \cdot \left(\frac{1}{A4^2} - \frac{1}{Af^2} + \frac{f4 \cdot l4}{A4^2 \cdot d4} + \frac{Nel4 \cdot Kel}{A4^2} + \frac{Kf}{Af^2}\right) + \frac{Qins^2 \cdot pw}{2} \cdot \left(\frac{1}{Af^2} - \frac{1}{A2^2} + \frac{f2 \cdot l2}{A2^2 \cdot d2} + \frac{f3 \cdot l3}{A3^2 \cdot d3} + \frac{Nel2 \cdot Kel}{A2^2} + \frac{1}{A2^2}\left(1 - \frac{A2}{A3}\right)^2\right) + \frac{32 \cdot v70 \cdot llf}{dlf^2 \cdot A3} \cdot Qins \cdot pw\right) + 14.5\right);$$

$$ptank := 14.53460371$$

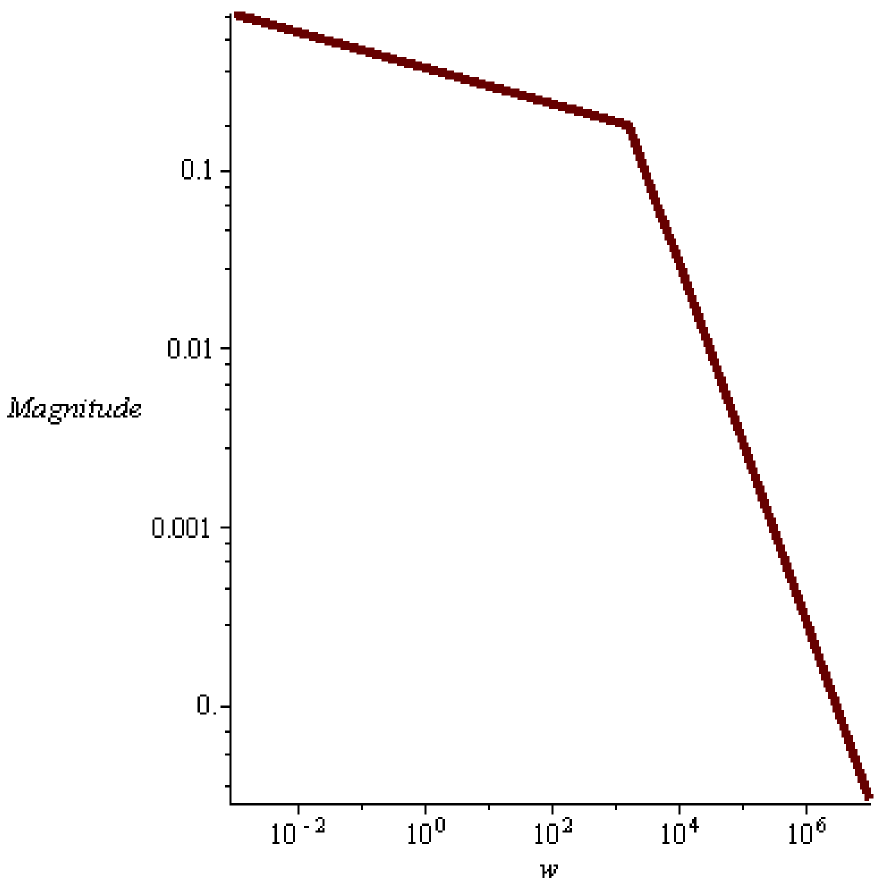
> $C := \frac{pw \cdot patm \cdot vtank}{ptank^2};$

$$C := 0.0001284894460$$

> $Ma1 := M;$

$$Ma1 := \frac{160.4572505}{\sqrt{45648.29523 + 0.2904379932\, w^2}}$$

> $plot\left([Ma1], w = .001 \,....10000000, linestyle = [solid], thickness = 4, axis_1 = [mode = \log], axis_2 = [mode = \log], labels = [\mathrm{w}, \mathrm{Magnitude}]\right);$



Evaluating the system with an expansion tank size of 2000in^3

> $vtank := 20000;$

$$vtank := 20000$$

> $patm := 14.5;$

$$patm := 14.5$$

> $pw := .0000936;$

$$pw := 0.0000936$$

> $$ptank := evalf\left(\frac{Qins^2 \cdot pw}{2} \cdot \left(\frac{1}{A4^2} - \frac{1}{Af^2} + \frac{f4 \cdot l4}{A4^2 \cdot d4} + \frac{Nel4 \cdot Kel}{A4^2} + \frac{Kf}{Af^2}\right) + \frac{Qins^2 \cdot pw}{2} \cdot \left(\frac{1}{Af^2} - \frac{1}{A2^2} + \frac{f2 \cdot l2}{A2^2 \cdot d2} + \frac{f3 \cdot l3}{A3^2 \cdot d3} + \frac{Nel2 \cdot Kel}{A2^2} + \frac{1}{A2^2}\left(1 - \frac{A2}{A3}\right)^2\right) + \frac{32 \cdot v70 \cdot llf}{dlf^2 \cdot A3} \cdot Qins \cdot pw\right);$$

$$ptank := 0.03770753045$$

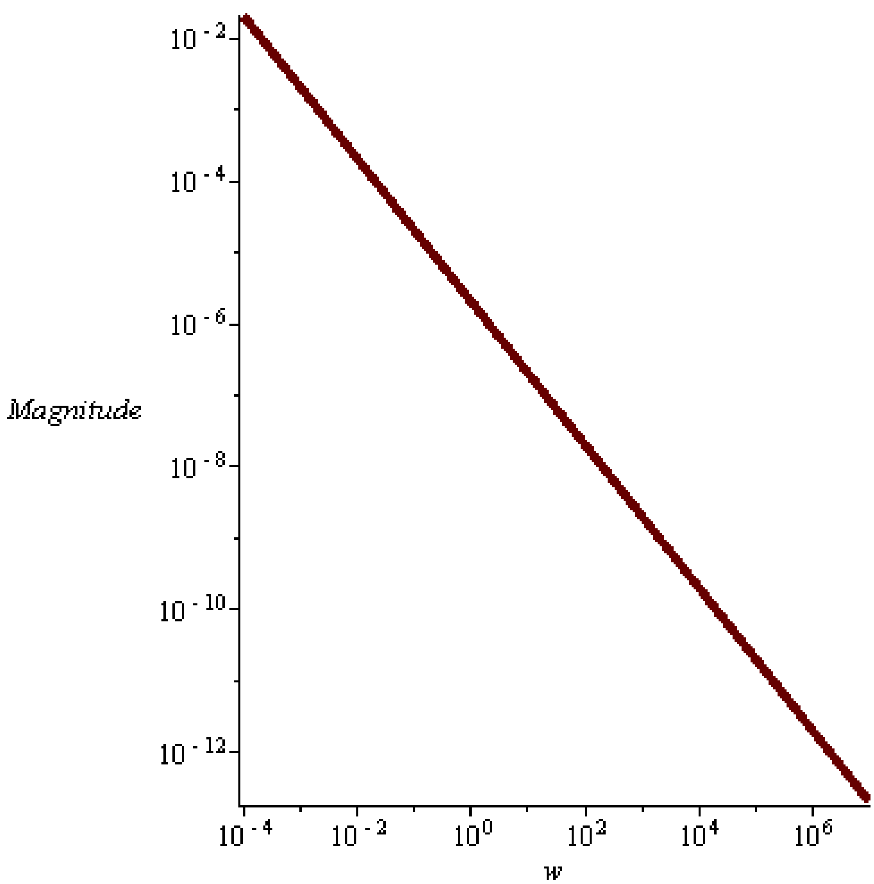
> $$C := \frac{pw \cdot patm \cdot vtank}{ptank^2};$$

$$C := 19090.51593$$

> $Ma2 := M;$

$$Ma2 := \frac{177.6834728}{\sqrt{53305.96182 + 7.614893861\ 10^{15}\ w^2}}$$

> $plot([Ma2], w = .0001 \ldots 10000000, linestyle = [solid], thickness = 4, axis_1 = [mode = \log], axis_2 = [mode = \log], labels = [w, Magnitude]);$



Assume an rpm of 3450 at full speed and 6 impeller blades and assume the pump follows affinity law Q1/Q2=N1/N2, and it has an expansion tank size of 20in^3.

> $w = evalf\left(\frac{2 \cdot \mathrm{Pi} \cdot 3450. \cdot 6}{60 \cdot 32}\right);$

$$w = 67.74059160$$

> $Ma1 := subs(w = 67.74, Ma1);$

$$Ma1 := 0.00003005868063$$

Now for a 16gpm flow r ate

> $restart:$

> $H := simplify\left(r4\left(\frac{(1 + C \cdot s \cdot r1)}{r1 + \frac{1}{\frac{1}{r2 + r4} + C \cdot s}} - C \cdot s\right)\right);$

$$H := r4\left(\frac{1}{r1 + r1\, C\, s\, r2 + r1\, C\, s\, r4 + r2 + r4}\right)$$

> $Hj := subs(s = j \cdot w, H);$

$$Hj := r4\left(\frac{1}{r1 + r1\, C\, j\, w\, r2 + r1\, C\, j\, w\, r4 + r2 + r4}\right)$$

> $M := \frac{r4}{\mathrm{sqrt}\left((r1 + r2 + r4)^2 + (r1 \cdot r2 \cdot C \cdot w + r4 \cdot r1 \cdot C \cdot w)^2\right)};$

$$M := r4 \Big/ \left(r1^2 + 2\, r1\, r2 + 2\, r4\, r1 + r2^2 + 2\, r2\, r4 + r4^2 + r1^2\, r2^2\, C^2\, w^2 + 2\, r1^2\, r2\, C^2\, w^2\, r4 + r4^2\, r1^2\, C^2\, w^2\right)^{1/2}$$

Kinematic viscosity

> $v140 := .511\mathrm{e}{-}5 \cdot 144;$

$$v140 := 0.00073584$$

> $v70 := 1.052\mathrm{e}{-}5 \cdot 144;$

$$v70 := 0.00151488$$

Flow rate, pipe diameters, pipe areas, pipe lengths, number of elbows and reducers, head loss coefficients for, Reynolds Numbers, friction factors, and corresponding resistances (1 is from pump to expansion tank, 2 is from expansion tank to channel, 3 is the free channel, lf is the laminar flow guides, 4 is from the filter to the reservoir) (all lengths are in inches, all pressures are in psi)

> $Qins := \frac{16 \cdot 231}{60};$

$$Qins := \frac{308}{5}$$

> $d1 := 1;$

$$d1 := 1$$

> $d2 := 1;$

$$d2 := 1$$

> $d3 := 5.75;$

$$d3 := 5.75$$

> $dlf := .315;$

$$dlf := 0.315$$

> $d4 := 1;$

$$d4 := 1$$

> $A1 := \frac{\text{Pi} \cdot d1^2}{4};$

$$A1 := \frac{1}{4}\,\pi$$

> $A2 := \frac{d2^2 \cdot \text{Pi}}{4};$

$$A2 := \frac{1}{4}\,\pi$$

> $A3 := d3^2;$

$$A3 := 33.0625$$

> $Af := 3^2;$

$$Af := 9$$

> $A4 := \frac{d4^2 \cdot \text{Pi}}{4};$

$$A4 := \frac{1}{4}\,\pi$$

> $l1 := 24;$

$$l1 := 24$$

> $l2 := 8 \cdot 12;$

$$l2 := 96$$

> $l3 := 12;$

$$l3 := 12$$

> $llf := 18;$

$$llf := 18$$

> $l4 := 120;$

$$l4 := 120$$

> $Nel1 := 2;$

$$Nel1 := 2$$

> $Nel2 := 2;$

$$Nel2 := 2$$

> $Nel4 := 2;$

$$Nel4 := 2$$

> $Kel := 1.5;$

$$Kel := 1.5$$

> $Kf := \frac{2}{.5 \cdot .0000936 \cdot \left(\frac{231}{60}\right)^2};$

$$Kf := 2883.119766$$

> $Re1 := evalf\left(\frac{Qins \cdot d1}{v70 \cdot A1}\right);$

$$\Re 1 := 51774.10482$$

> $Re2 := evalf\left(\frac{Qins \cdot d2}{v70 \cdot A2}\right);$

$$\Re 2 := 51774.10482$$

> $Re3 := evalf\left(\frac{Qins \cdot d3}{v70 \cdot A3}\right);$

$$\Re 3 := 7071.875977$$

> $Re4 := evalf\left(\frac{Qins \cdot d4}{v70 \cdot A4}\right);$

$$\Re 4 := 51774.10482$$

> $f1 := .021;$

$$f1 := 0.021$$

> $f2 := .021;$

$$f2 := 0.021$$

> $f3 := .036;$

$$f3 := 0.036$$

> $f4 := .021;$

$$f4 := 0.021$$

> $r1 := evalf\left(Qins \cdot \left(\frac{f1 \cdot l1}{A1^2 \cdot d1} + \frac{Nel1 \cdot Kel}{A1^2}\right)\right);$

$$r1 := 349.9170036$$

> $r2 := evalf\left(Qins \cdot \left(\frac{1}{Af^2} - \frac{1}{A2^2} + \frac{f2 \cdot l2}{A2^2 \cdot d2} + \frac{f3 \cdot l3}{A3^2 \cdot d3} + \frac{Nel2 \cdot Kel}{A2^2} + \frac{1}{A2^2}\left(1 - \frac{A2}{A3}\right)^2\right) + \frac{32 \cdot v70 \cdot llf}{dlf^2 \cdot A3}\right);$

$$r2 := 497.2512019$$

> $r4 := evalf\left(Qins \cdot \left(\frac{1}{A4^2} - \frac{1}{Af^2} + \frac{f4 \cdot l4}{A4^2 \cdot d4} + \frac{Nel4 \cdot Kel}{A4^2} + \frac{Kf}{Af^2}\right)\right);$

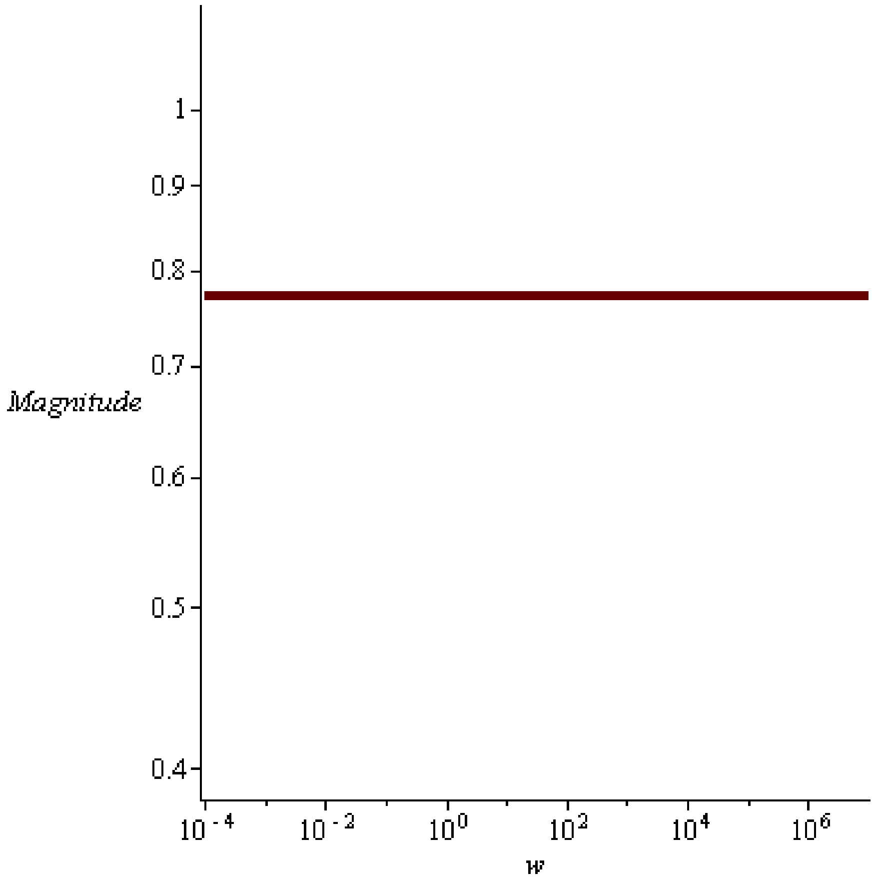
$$r4 := 2842.935565$$

Evaluating a system with zero capacitance

> $Ma := subs(C = 0, M);$

$$Ma := 0.7704215765$$

> $plot\left([Ma], w = .0001 \,....10000000, linestyle = [solid], thickness = 4, axis_1 = [mode = \log], axis_2 = [mode = \log], labels = [w, Magnitude]\right);$



Evaluating a system with an expansion tank size of 20in^3

> $vtank := 20;$

$$vtank := 20$$

> $patm := 14.5;$

$$patm := 14.5$$

> $pw := .0000936;$

$$pw := 0.0000936$$

> $$ptank := evalf\left(\left(\frac{Qins^2 \cdot pw}{2} \cdot \left(\frac{1}{A4^2} - \frac{1}{Af^2} + \frac{f4 \cdot l4}{A4^2 \cdot d4} + \frac{Nel4 \cdot Kel}{A4^2} + \frac{Kf}{Af^2}\right) + \frac{Qins^2 \cdot pw}{2} \cdot \left(\frac{1}{Af^2} - \frac{1}{A2^2} + \frac{f2 \cdot l2}{A2^2 \cdot d2} + \frac{f3 \cdot l3}{A3^2 \cdot d3} + \frac{Nel2 \cdot Kel}{A2^2} + \frac{1}{A2^2}\left(1 - \frac{A2}{A3}\right)^2\right) + \frac{32 \cdot v70 \cdot llf}{dlf^2 \cdot A3} \cdot Qins \cdot pw\right) + 14.5\right);;$$

$$ptank := 24.13012441$$

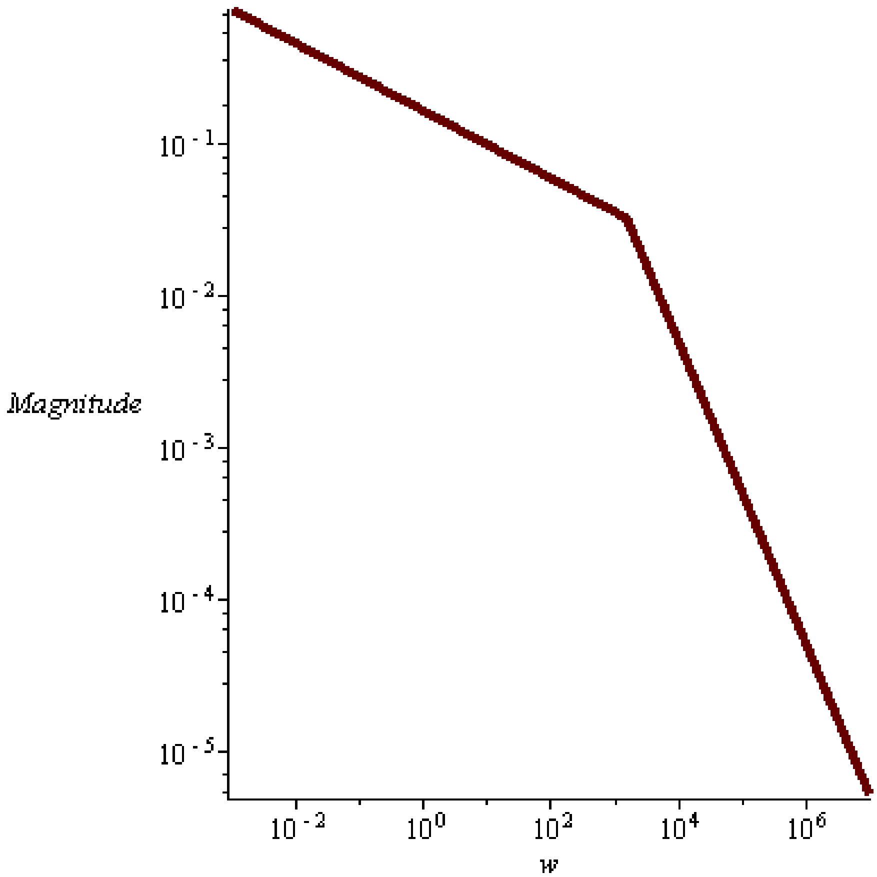
> $C := \frac{pw \cdot patm \cdot vtank}{ptank^2};$

$$C := 0.00004661811668$$

> $Ma1 := M;$

$$Ma1 := \frac{2842.935565}{\sqrt{1.361686584\,10^{7} + 2968.800708\,w^{2}}}$$

> $plot\left([Ma1], w = .001 \ldots .10000000, linestyle = [solid], thickness = 4, axis_1 = [mode = \log], axis_2 = [mode = \log], labels = [w, Magnitude]\right);$



Evaluating a system with an expansion tank size of 2000in^3

> $vtank := 20000;$

$$vtank := 20000$$

> $patm := 14.5;$

$$patm := 14.5$$

> $pw := .0000936;$

$$pw := 0.0000936$$

> $ptank := evalf\left(\left(\left(\frac{Qins^2 \cdot pw}{2} \cdot \left(\frac{1}{A4^2} - \frac{1}{Af^2} + \frac{f4 \cdot l4}{A4^2 \cdot d4} + \frac{Nel4 \cdot Kel}{A4^2} + \frac{Kf}{Af^2}\right) + \frac{Qins^2 \cdot pw}{2} \cdot \left(\frac{1}{Af^2} - \frac{1}{A2^2} + \frac{f2 \cdot l2}{A2^2 \cdot d2} + \frac{f3 \cdot l3}{A3^2 \cdot d3} + \frac{Nel2 \cdot Kel}{A2^2} + \frac{1}{A2^2}\left(1 - \frac{A2}{A3}\right)^2\right) + \frac{32 \cdot v70 \cdot llf}{dlf^2 \cdot A3} \cdot Qins \cdot pw\right) + 14.5\right)\right);$

$$ptank := 24.13012441$$

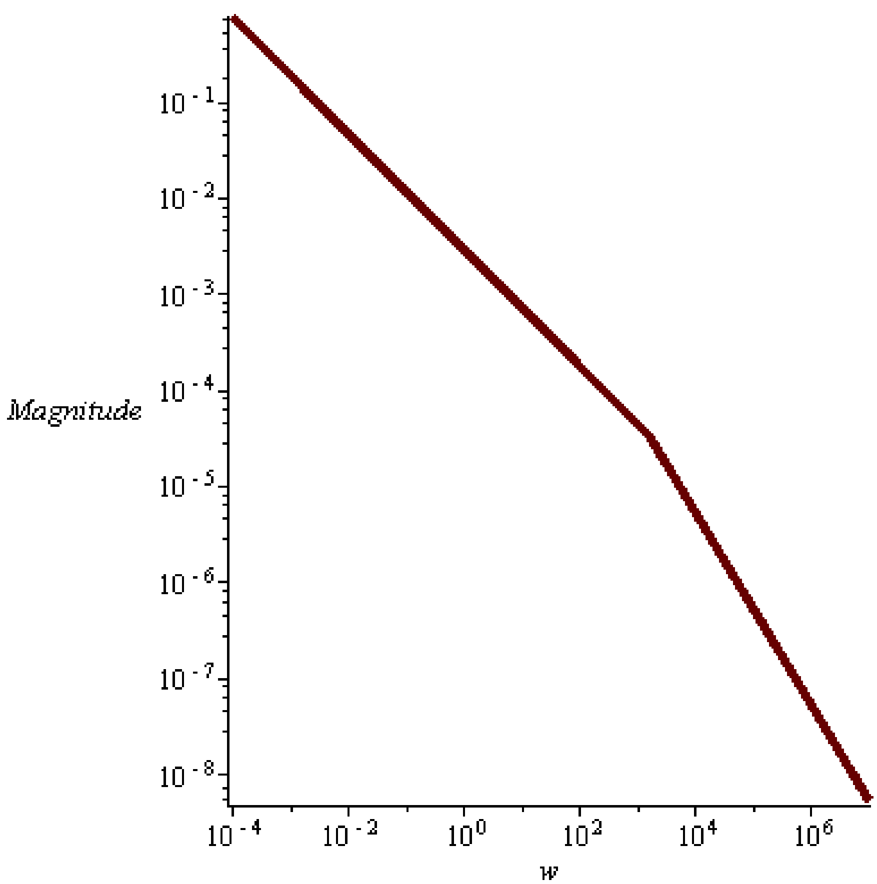
> $C := \frac{pw \cdot patm \cdot vtank}{ptank^2};$

$$C := 0.04661811668$$

> $Ma2 := M;$

$$Ma2 := \frac{2842.935565}{\sqrt{1.361686584\,10^7 + 2.968800708\,10^9\,w^2}}$$

> $plot\left([Ma2], w = .0001 \,....10000000, linestyle = [solid], thickness = 4, axis_1 = [mode = \log], axis_2 = [mode = \log], labels = [w, Magnitude]\right);$



Assume an rpm of 3450 at full speed and 6 impeller blades and assume pump follows affinity law Q1/Q2=N1/N2, 20 in^3 sized expansion tank

> $w = evalf\left(\frac{2 \cdot \mathrm{Pi} \cdot 3450. \cdot 6}{60 \cdot 2}\right);$

$$w = 1083.849466$$

> $Ma1 := subs(w = 1083.849466, Ma1);$

$$Ma1 := 0.04804645389$$

16gpm case has a higher output transfer function magnitude using affinity law assumption, iteratively finding size of expansion tank for magnitude of transfer function to be .01

> $vtank := 95;$

$$vtank := 95$$

> $patm := 14.5;$

$$patm := 14.5$$

> $pw := .0000936;$

$$pw := 0.0000936$$

>

$$ptank := evalf\left(\left(\frac{Qins^2 \cdot pw}{2} \cdot \left(\frac{1}{A4^2} - \frac{1}{Af^2} + \frac{f4 \cdot l4}{A4^2 \cdot d4} + \frac{Nel4 \cdot Kel}{A4^2} + \frac{Kf}{Af^2}\right) + \frac{Qins^2 \cdot pw}{2} \cdot \left(\frac{1}{Af^2} - \frac{1}{A2^2} + \frac{f2 \cdot l2}{A2^2 \cdot d2} + \frac{f3 \cdot l3}{A3^2 \cdot d3} + \frac{Nel2 \cdot Kel}{A2^2} + \frac{1}{A2^2}\left(1 - \frac{A2}{A3}\right)^2\right) + \frac{32 \cdot v70 \cdot llf}{dlf^2 \cdot A3} \cdot Qins \cdot pw\right) + 14.5\right);;$$

$$ptank := 24.13012441$$

> $C := \frac{pw \cdot patm \cdot vtank}{ptank^2};$

$$C := 0.0002214360543$$

> $Ma1 := M;$

$$Ma1 := \frac{2842.935565}{\sqrt{1.361686584\,10^7 + 66983.56599\,w^2}}$$

> $w = evalf\left(\frac{2 \cdot \mathrm{Pi} \cdot 3450. \cdot 6}{60 \cdot 2}\right);$

$$w = 1083.849466$$

> $Ma1 := subs(w = 1083.849466, Ma1);$

$$Ma1 := 0.01013389365$$

>

[Appendix H, 6]

Finding drain diameters

$$Q = aC\sqrt{2gh}$$

$$Q = -A\frac{dh}{dt}$$

$$\frac{-A\,dh}{dt} = aC\sqrt{2gh}$$

$$\int_{H_i}^{H_f} -\frac{A}{\sqrt{h}}\,dh = \int_0^t aC\sqrt{2g}\,dt$$

$$t = \frac{A}{aC}\left(\sqrt{H_i} - \sqrt{H_f}\right)\sqrt{\frac{2}{g}}$$

For tank

$H_f = 0$

$H_i = 24\text{ in}$

$A = \frac{\pi(20)^2}{4} = 314.59\text{ in}^2$

$C = .8$ (short tube)

$a = \frac{\pi d^2}{4}$

$g = 32.2\text{ ft/s}^2 =$

$t = 10\text{ min} = 600\text{ sec}$

$$d = \sqrt{\frac{4A}{\pi t C}\sqrt{\frac{H_i\,2}{g}}}$$

$d_{tank} = .542\text{ in} \Rightarrow$ min. drain size of tank

For channel

$H_f = 0$

$H_i = 6in$

$A = 6in \cdot 48in = 288$

$C = .8$

$$a = \frac{\pi d_{channel}^2}{4}$$

$g = 32.2 ft/s^2$

$t_{cl} = 10 min = 600 sec$

$$d_{Channel} = \sqrt{\frac{4(288)}{\pi\, 600(.8)}\sqrt{\frac{6\,(2)}{32.2\cdot 12}}} = .367in,$$ (min drain diameter for Channel

Drain of design $= 1 in$

$$t = \frac{(288)}{\frac{\pi}{4}(.8)}\sqrt{6}\sqrt{\frac{2}{32.2\cdot 12}} = t_{drain\ channel} = 128.56 sec = 2.14 min$$

Appendix H.7

Pressure drop because of change of area near filter

this pressure drop will need to be subtracted from the measured pressure drop.

$$P_1 + .5\rho\alpha_1 V_1^2 + \cancel{\rho g h_1} = P_2 + .5\rho\alpha_2 V_2^2 + \cancel{\rho g h_2} + \cancel{\frac{h}{\rho g}}$$

assume no losses because it is a slow change in flow area and pipe length is short

assume $\alpha_1 = \alpha_2 = \alpha$

$$P_1 - P_2 = \Delta P = .5\rho\alpha Q^2\left(\frac{1}{A_f^2} - \frac{1}{A_{Channel}^2}\right)$$

Appendix H.8

Analysis on bolts holding end plates on the Channel

$$F_{Bolts} = \frac{F_{total}}{N_{bolts}} = \frac{P_{end} A_{end}}{N_{bolts}} = \frac{(4.16)(5.75^2)}{12} = 11.46 \text{ lbs}$$

12 ¼-20 bolts, with an allowable clamping force of 723 lbs

$11.46 \text{ lbs} \ll 723 \text{ lbs}$

Appendix I: Design Analysis Assignment from Lecture

1. Material Selection Assignment (Functional Performance)

To characterize the performance of a particular material in application, we are going to use material index as a criteria for this evaluation. In our system, the two components we will analyze are the channel and side pipe. The channel is a major component which holds the inside chamber and laminar flow guides while the side pipe connects the pump to the end of the channel, while also adapting to the flow meter fixtures. Both materials need to withstand corrosion, pressure and high temperature, Therefore, we see the importance of these two components and the detailed analysis for each material selection is given as following.

The general procedure to choose appropriate material is described as following:
Scanning all possible materials in CES -> apply limits for each situation to filter out candidates -> ranking the candidates' performance according to material indices-> pick up the top 5 choices as required -> incorporate real life restrictions (Eg. Capability to get the material, vender availability, etc.) for final choice

Component # 1 – Channel
The channel itself must carry the design loads and pressure without failing and survives in water laden and moderate thermal environments during operation. According to Ashby [1], we found 2 material indices that apply to this situation. The channel, with a rectangular hollowed cross section, can be treated as a beam, which is supported at both ends (flanges) on the table. We want to minimize its weight which is an ergonomic issue Dow was concerned about. Cost also matters, but not as much as weight. Therefore, we put minimizing weight as our first priority here for material index. We identified the function, objective and the constraints for channel.

Function: Beam
Objective: Minimize the mass
Constraints: (a) Length specified
(b) Support all inside water without deflecting too much
(c) Support all inside water and pressure without failing by yield or fracture

In summary, there are two models we need to consider:

1. Beam, minimum weight, stiffness prescribed, $M = E^{1/2} / \rho$
2. Beam, minimum weight, strength prescribed, $M = \sigma_y^{2/3} / \rho$

Input limit in CES material selector for channel material

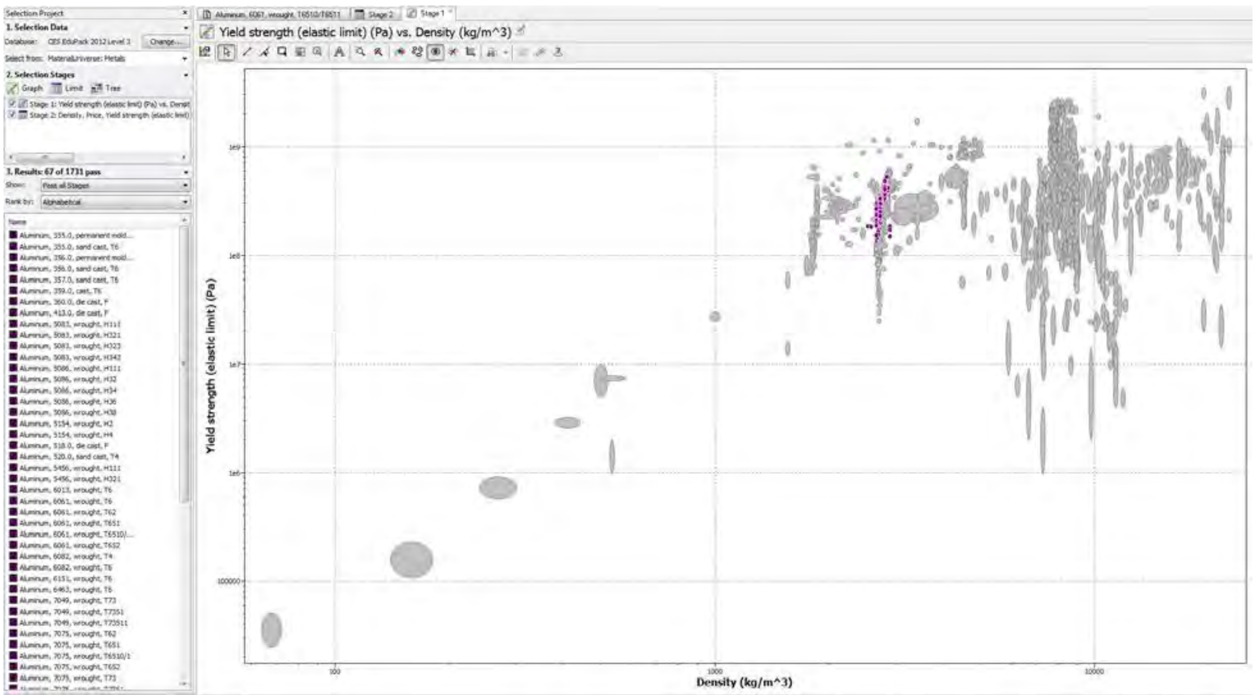
a) Price: maximum 350 USD/in/lbf.s^2
Reason: we are limited in our budget of 400 USD.
b) Yield strength (elastic): minimum 40 psi
Reason: the maximum pressure output from the pump is 19.7 psi, we would like to have a safety factor of 2 so the minimum value of yield strength for this material has been set to 40 psi.
c) Operating temperature: minimum of maximum T = 175^{o}F, maximum of minimum T = 30^{o}F
Reason: our system must be able to handle hot water which is 140^{o}F. As the prior limit, we can not apply the value that strictly meet the limit but need to leave some flexibility.
d) Capability with water (fresh): excellent
Reason: the system needs to contain both clean and dirty water. The CES did not really have a specific category for dirty water but more about chemicals. When Arizona dust is added in, the solution will not be acid or basic, therefore, we cannot really put any limit in CES for dirty water.

After setting up the limit, we are going to use the material index to pick the top five choices.

1. Minimum weight, strength prescribed, $M = \sigma_y^{2/3} / \rho$

We plotted yield strength versus density and the candidates passed the first run are shown in purple while the gray ones did not meet the initial criteria. (Fig. 1)

Fig.1 Candidates after apply $M = \sigma_y^{2/3} / \rho$ (represented by the purple bubbles while the rest of gray bubbles did not pass the limits)



Using a gradient line to filter out more candidates, we use a slope of 1.2 and place the line in the graph, drag it until we have about 20 candidates for further selection. The reason for 1.2 is due to the term $\sigma_y^{2/3}$, the slope is not 1 (if the graph is σ_y vs. ρ, then the slope is 1) and we used our judgment to make the best estimation here. (Fig. 2)

We arranged the top choices by performance index and optimize the choices here. Therefore, the top five selections as appearing in the lower left corner in Fig. 3 are

1. Aluminum 7249, wrought, T76511
2. Aluminum 7475, wrought, T651
3. Aluminum 7075, wrought, T6510/1
4. Aluminum 7475, wrought, T61
5. Aluminum 7475, wrought T7651

Fig.2 Candidates after apply a gradient line with slope of 1.2 (represented by the purple bubbles while the rest of gray bubbles did not pass the limits)

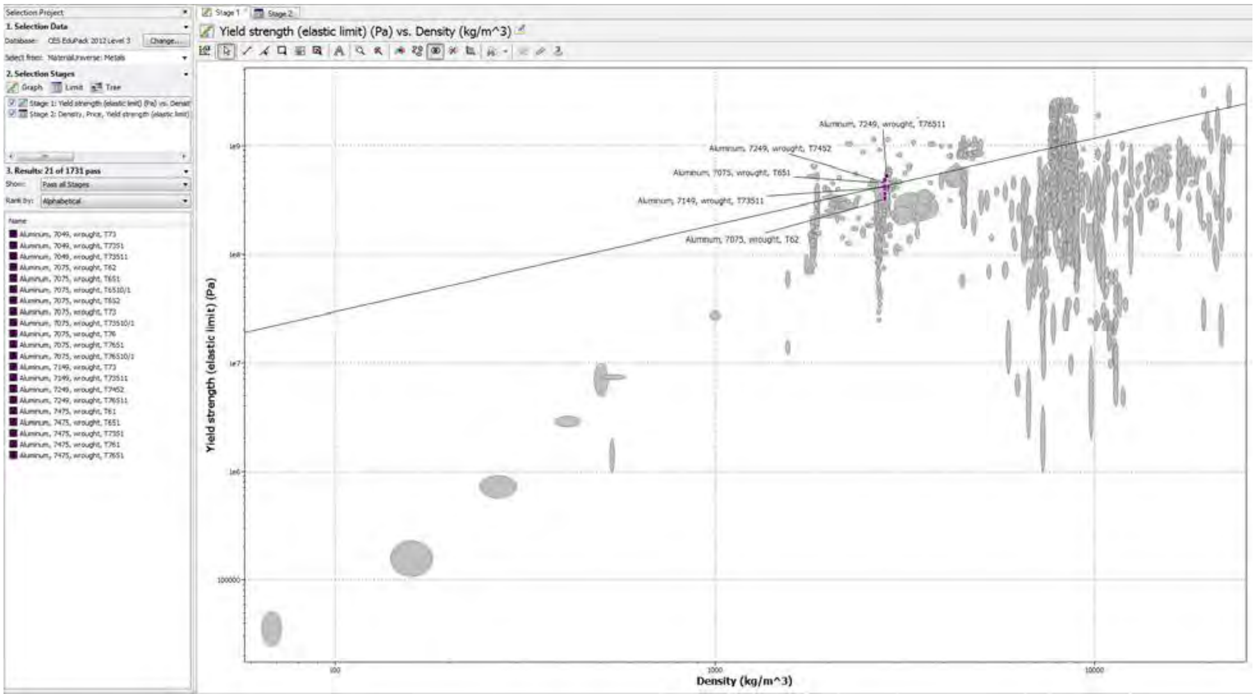
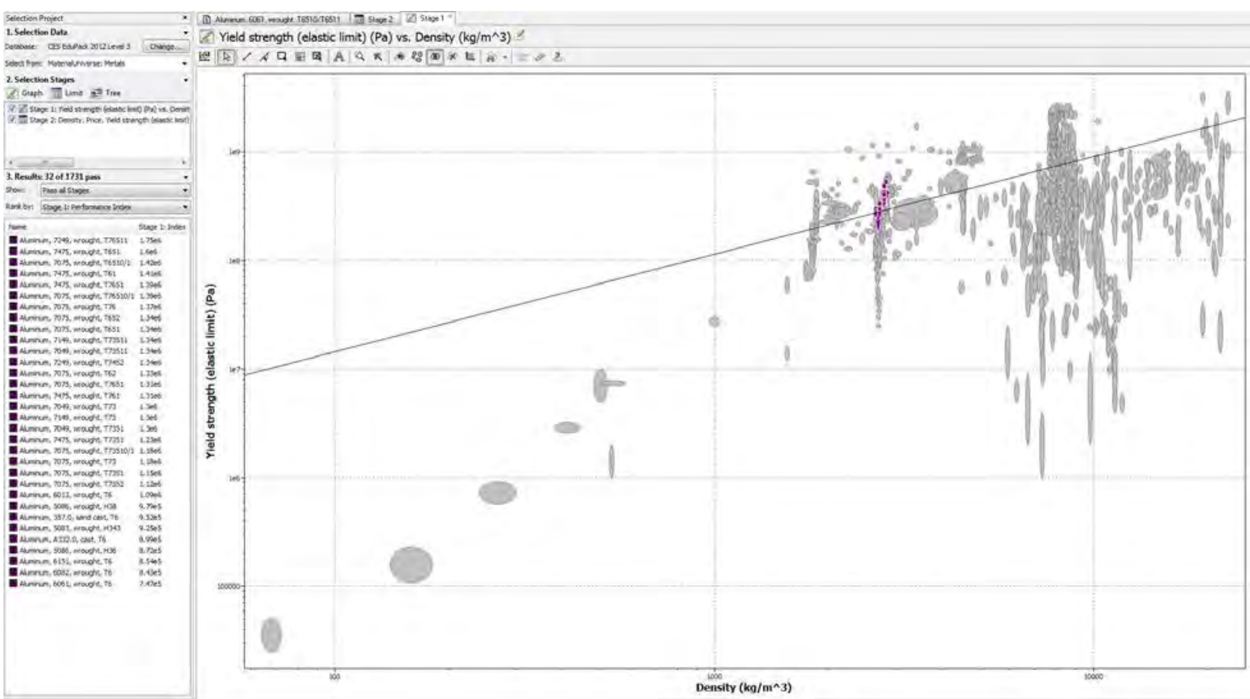


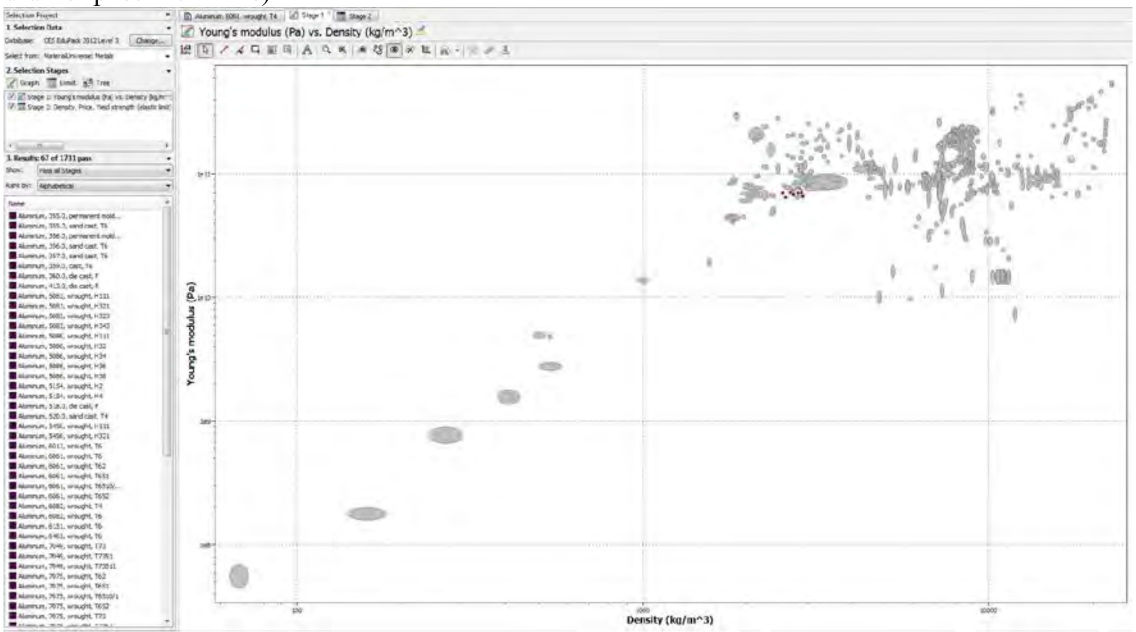
Fig.3 Top five candidates are ranked according to performance index shown in lower left



2. Beam, minimum weight, stiffness prescribed, $M = E^{1/2} / \rho$ (with the same limit as above)

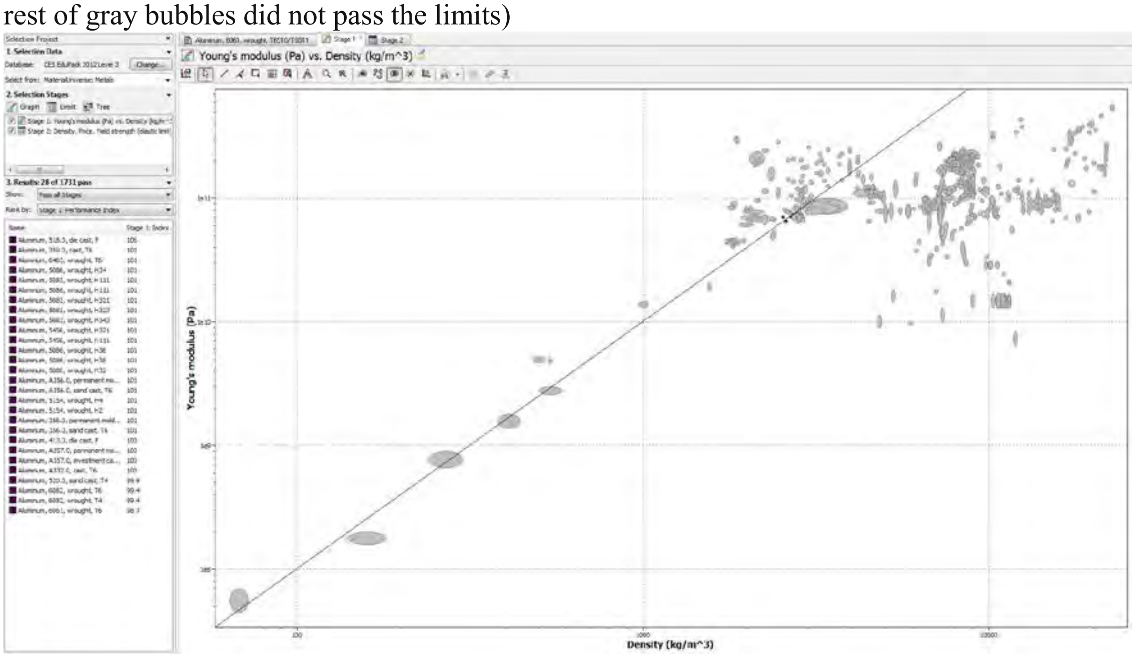
We plotted Young's modulus versus density and the candidates passed the first run are shown in purple while the gray ones did not meet the initial criteria. (Fig. 4)

Fig.4 Candidates after apply $M = E^{1/2} / \rho$ (represented by the purple bubbles while the rest of gray bubbles did not pass the limits)



Using a gradient line to filter out more candidates, we use a slope of 2.5 and place the line in the graph, drag it until we have about 20 candidates for further selection. Again, we chose the value of 2.5 is due to the term $E^{1/2}$ based on engineering judgment.

Fig.5 Candidates after apply a gradient line with slope of 2.5 (represented by the purple bubbles while the rest of gray bubbles did not pass the limits)



We arranged the top choices by performance index and optimize the choices here. Therefore, the top five selections are appeared in the lower left corner in Fig. 5 are:

1. Aluminum 518, die cast, F
2. Aluminum 359, cast, T6
3. Aluminum 6463, wrought, T6
4. Aluminum 5086, wrought, H34
5. Aluminum 5083, wrought, H111

Based on the results from CES, we looked into the practical situation by browsing Mcmasterr Carr for aluminum stock and tubes that will be used in our design. Most of the aluminums are multipurpose aluminum (Alloy 6061). Some other available alloy choices available are 2024, 3003, 6063 but not the top ones which we selected based on CES (for instance, 5000 series). This could be due to the limit we put in does not fall exactly within a particular metal property range. However, alloy 6061 appears in both filtered results. If we looked furthermore into the index ranking, this alloy is really close to the top choices. Since alloy 6061 has a combination of good strength, corrosion resistance and machinability [2], it is the most widely used aluminum and it fits in our project well. Therefore, we constructed our channel in our device with aluminum 6061with its profile shown in Fig. 6 and 7, which meets all system requirements.

Fig.6 Material property of aluminum 6061 (continued)

General Properties				
Density	2.5e-4	-	2.55e-4	lbf.s^2/in/in^3
Price	* 513	-	566	USD.in/lbf.s^2
Composition overview				
Composition (summary)				
Al/1Mg/.6SiCuCr				
Base	Al (Aluminum)			
Composition detail (metals, ceramics and glasses)				
Al (aluminum)	97	-	99	%
Cr (chromium)	0	-	0.6	%
Cu (copper)	0	-	0.6	%
Mg (magnesium)	1			%
Si (silicon)	0	-	0.6	%
Mechanical properties				
Young's modulus	9.86e6	-	1.07e7	psi
Flexural modulus	* 9.86e6	-	1.07e7	psi
Shear modulus	3.63e6	-	3.92e6	psi
Bulk modulus	9.43e6	-	1.04e7	psi
Poisson's ratio	0.325	-	0.335	
Shape factor	27			
Yield strength (elastic limit)	2.8e4	-	4.21e4	psi
Tensile strength	3.5e4	-	4.64e4	psi
Compressive strength	* 3e4	-	4.21e4	psi
Flexural strength (modulus of rupture)	2.8e4	-	4.21e4	psi
Elongation	0.12	-	0.17	strain
Hardness - Vickers	1.35e5	-	1.49e5	psi
Hardness - Brinell	1.38e4	-	1.52e4	psi
Fatigue strength at 10^7 cycles	1.31e4	-	1.45e4	psi
Fatigue strength model (stress range)	8.18e3	-	1.27e4	psi
Parameters: Stress Ratio = 0, Number of Cycles = 1e7				
Fracture toughness	* 3e4	-	3.19e4	psi.in^0.5
Mechanical loss coefficient (tan delta)	* 1e-4	-	0.002	
Thermal properties				
Melting point	1.08e3	-	1.2e3	°F
Maximum service temperature	230	-	338	°F
Minimum service temperature	-459			°F
Thermal conductivity	19	-	21.1	lbf/s.°F
Specific heat capacity	7.56e5	-	7.87e5	lbf.in.in/lbf.s^2.°F
Thermal expansion coefficient	1.26e-5	-	1.33e-5	strain/°F
Latent heat of fusion	5.95e8	-	6.09e8	lbf.in.in/lbf.s^2
Electrical properties				
Electrical resistivity	1.54e-6	-	1.61e-6	ohm.in
Galvanic potential	* -0.79	-	-0.71	V

Fig.7 Material property of aluminum 6061 (continued)

Optical properties	
Transparency	Opaque
Durability: flammability	
Flammability	Non-flammable
Durability: fluids and sunlight	
Water (fresh)	Excellent
Water (salt)	Acceptable
Weak acids	Excellent
Strong acids	Excellent
Weak alkalis	Acceptable
Strong alkalis	Unacceptable
Organic solvents	Excellent
UV radiation (sunlight)	Excellent
Oxidation at 500C	Unacceptable

Component # 2 – Side pipe
The side pipe itself should meet all conditions specified for the channel, especially for withstanding the pressure from the pump. The pipe can be treated as a beam, which is supported at both ends on the table. It also needs to support a flow meter which will be attached to the middle of itself. We are not really concerned about the deflection of the pipe due the support of the table. We identified the function, objective and the constraints for pipe.

Function: Beam
Objective: Minimize the mass
Constraints: (a) Length specified
(c) Support all inside water and pressure without failing by yield or fracture

In summary, the model we need to consider is: Beam, minimum weight, strength prescribed, $M = \sigma_y^{2/3} / \rho$

The input limit is the same as the channel selection, we reiterate here,

a) Price: maximum 350 USD/in/lbf.s^2
b) Yield strength (elastic): minimum 40 psi
c) Operating temperature: minimum of maximum T = 175°F, maximum of minimum T = 30°F
d) Capability with water (fresh): excellent

Therefore, we start the CES with plotting yield strength vs. density (Fig. 8). The candidates passed applied limitations are shown in highlighted area in Fig. 9. By ranking according to performance index with a gradient line of slope =1.2, the top 5 choices are

1. PVC (rigid, lead stabilized)
2. Polyester cast (rigid)
3. PF (casting resin)
4. PE-HD (general purpose)
5. PE-HD (low-medium molecular weight)

The choices are also shown in the lower left side in Fig. 10.

Fig.8 Initial plot of yield strength versus density (no limitation applied)

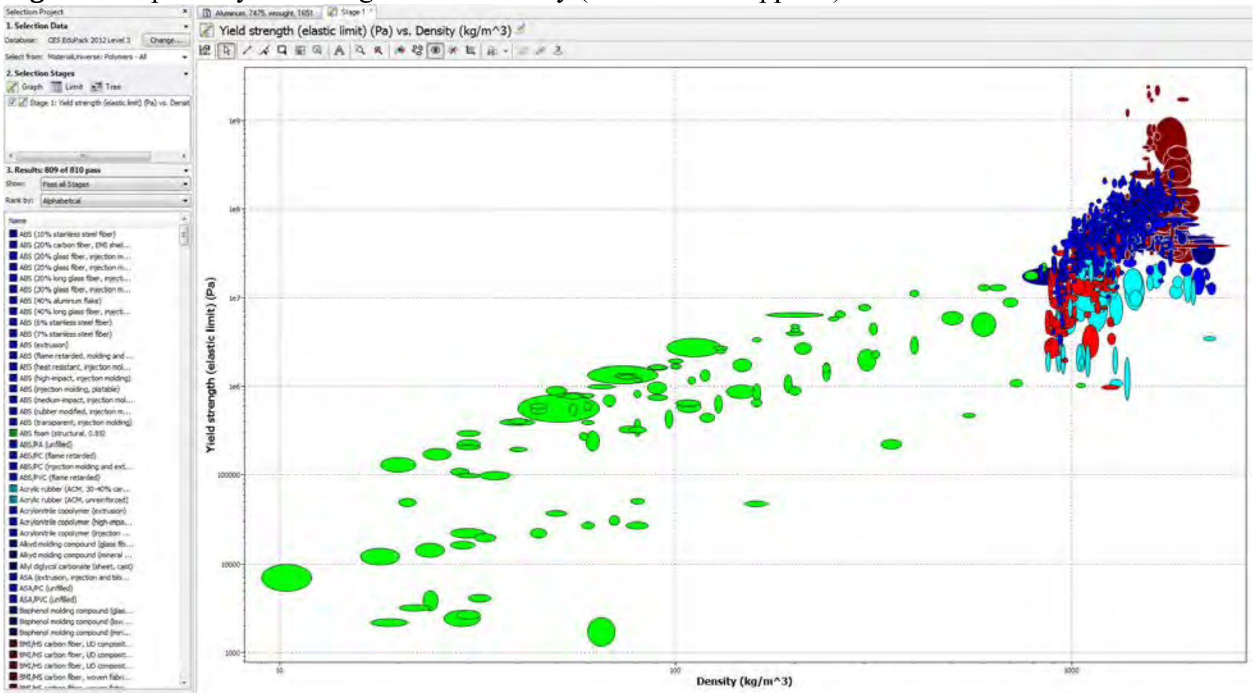


Fig.9 Candidates after apply $M = E^{1/2} / \rho$ (represented by the purple bubbles while the rest of gray bubbles did not pass the limits)

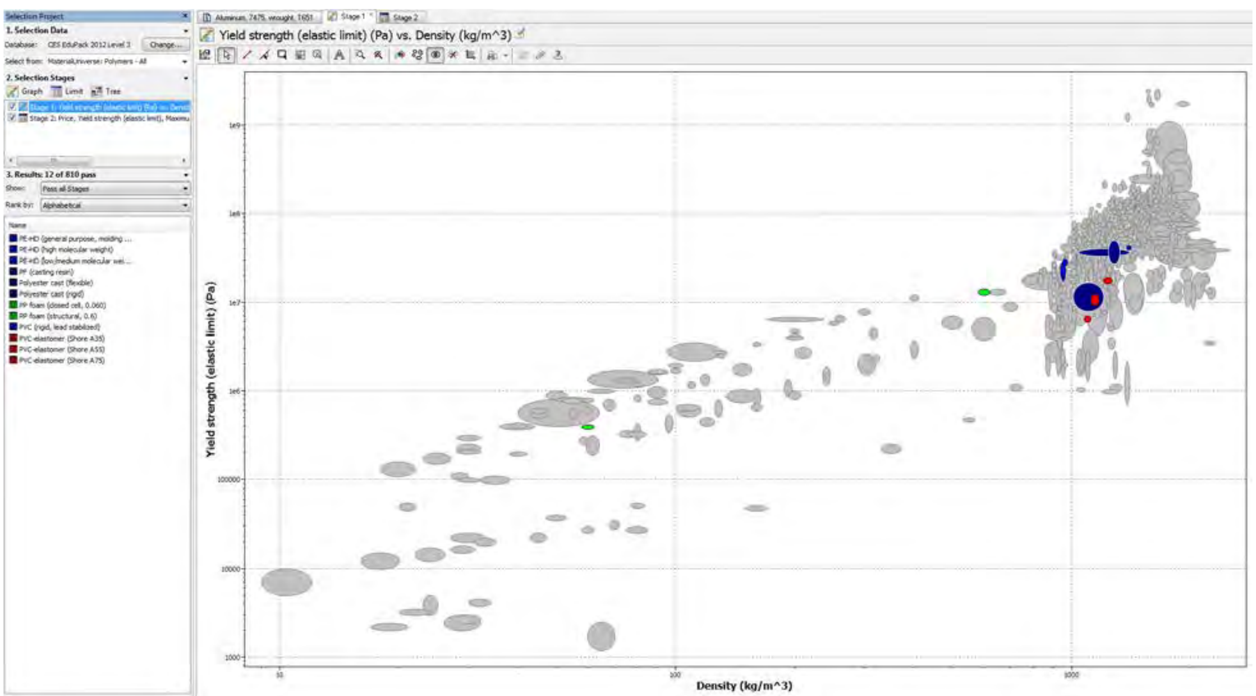
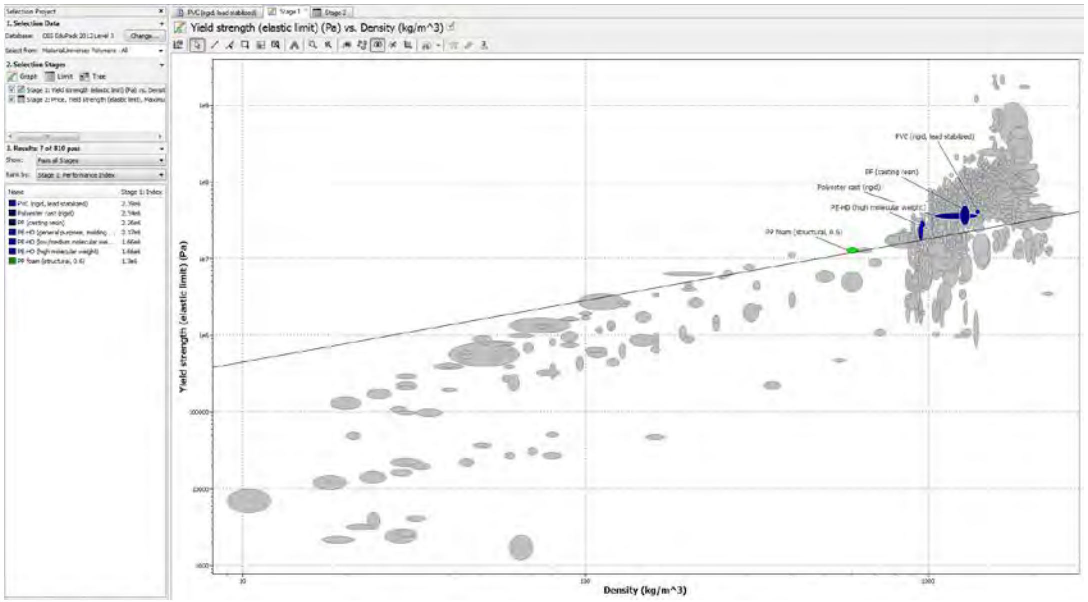


Fig.10 Candidates after apply a gradient line with slope of 1.2 (represented by the purple bubbles while the rest of gray bubbles did not pass the limits)



After selection, we looked into the availability of PVC online and found it is a commonly used pipe material which fits our system requirements. The detailed profile for PVC is shown in Fig.11and12. We do not necessarily need to follow the exact details of what the program suggested to us, eg lead stabilized, but find this is a really useful tool to guide us though the material selection and figured out best choice.

Fig.11 Material property of PVC (continued)

General Properties

Density	1.29e-4	-	1.31e-4	lbf.s^2/in/in^3
Price	* 231	-	254	USD.in/lbf.s^2

Composition overview

Composition (summary)

Compound of PVC, (CH2CHCl)n, with lead-based stabilizer

Base	Polymer
Polymer class	Thermoplastic : amorphous
Polymer type	PVC
Polymer type full name	Polyvinyl chloride, rigid, unplasticized
Filler type	Unfilled

Composition detail (polymers and natural materials)

Polymer	100	%

Mechanical properties

Young's modulus	3.32e5	-	3.48e5	psi
Compressive modulus	* 3.32e5	-	3.48e5	psi
Flexural modulus	3.61e5	-	3.79e5	psi
Shear modulus	* 1.19e5	-	1.24e5	psi
Bulk modulus	* 5.5e5	-	5.78e5	psi
Poisson's ratio	* 0.392	-	0.407	
Shape factor	5.7			
Yield strength (elastic limit)	5.71e3	-	6.29e3	psi
Tensile strength	* 7.14e3	-	7.87e3	psi
Compressive strength	* 6.86e3	-	7.56e3	psi
Flexural strength (modulus of rupture)	9.53e3	-	1.05e4	psi
Elongation	0.14	-	0.161	strain
Hardness - Vickers	* 1.68e4	-	1.85e4	psi
Hardness - Rockwell M	* 76	-	84	
Hardness - Rockwell R	* 105	-	120	
Fatigue strength at 10^7 cycles	* 2.63e3	-	3.42e3	psi
Fracture toughness	* 1.33e3	-	3.85e3	psi.in^0.5
Mechanical loss coefficient (tan delta)	* 0.0167	-	0.0175	

Impact properties

Impact strength, notched 23 °C	21.7	-	29.7	in.lbf/in^2
Impact strength, notched -30 °C	* 5.71	-	11.4	in.lbf/in^2
Impact strength, unnotched 23 °C	3.37e3	-	3.43e3	in.lbf/in^2

Thermal properties

Glass temperature	176	-	190	°F
Heat deflection temperature 0.45MPa	* 172	-	235	°F
Heat deflection temperature 1.8MPa	127	-	187	°F
Maximum service temperature	* 158	-	183	°F
Minimum service temperature	14	-	32	°F
Thermal conductivity	* 0.0344	-	0.0357	lbf/s.°F
Specific heat capacity	8.61e5	-	9.47e5	lbf.in.in/lbf.s^2.°F
Thermal expansion coefficient	6.55e-5	-	6.81e-5	strain/°F

Fig.12 Material property of PVC

Optical properties	
Refractive index	1.53 - 1.54
Transparency	Transparent
Absorption, permeability	
Water absorption @ 24 hrs	* 0.04 - 0.4 %
Permeability (O2)	4.26e-12 - 8.5e-12 in^4/s.lbf
Durability: flammability	
Flammability	Self-extinguishing
Durability: fluids and sunlight	
Water (fresh)	Excellent
Water (salt)	Excellent
Weak acids	Excellent
Strong acids	Excellent
Weak alkalis	Excellent
Strong alkalis	Excellent
Organic solvents	Limited use
UV radiation (sunlight)	Good
Oxidation at 500C	Unacceptable

2. Material Selection Assignment (Environmental Performance)

By adding material to CAD model we used approximately 10.19 lb of aluminum 6061 and 0.68lb of PVC. For comparison purpose in SimaPro, we will compare stainless steel to aluminum as stainless steel is also a widely used metal. For piping material, we will use PVC to HDPE which is also common to see in application. As the length in both components are pre- calculated, in this comparison, the volume will be fixed but the mass will be different due to density. The detailed analysis is shown in Table.1. We will input these masses into SimaPro for analysis.

Table.1 Masses for materials in comparison

Material	Aluminum	Stainless steel	PVC	HDPE
Density(lb/in^3)	0.1	0.28	0.047	0.0344
Volume (in^3)	104.45	104.45	14.4094	14.4094
Mass (lb)	10.19	29.43	0.6772	0.4957

1. Comparing aluminum alloy Al MG 2, at plant/RER S and stainless steel hot rolled coil

By comparing 10.19 lbs. of aluminum and 29. 43lbs. of stainless steel into SimaPro, we are going to determine the mass of emissions, compare damage categories, normalized score and single score in "points".

We calculated the total mass of air emissions, water emissions, use of raw materials and solid waste for each material. The raw data is shown in Table 2 and the comparison graphic obtained after data processing is shown in Fig. 13. (We only consider items with mass units and discard other categories that has non-mass units according to instruction)

From the data, we can observe that aluminum has more impact on soil and water than steel does but steel has way more influence on waste, air and raw than aluminum does. This conclusion can be drawn from the dramatic drop between the bars in Fig.13.

By carefully looking into the disaggregated damage categories, aluminum has more impact 6 out 10 categories than the stainless steel does. The impact of aluminum alloy which is shown in red dominates green bars. Therefore, aluminum has more influence on disaggregated damage than stainless steels does.

Table. 2 Value of individual emission of aluminum and stainless steel

unit (oz)	Aluminum	Steel
soil	0.272957492	0
waste	0	726.2963298
water	67.40369039	2.747615177
air	569.032243	1607.71698
raw	429.2873766	9275.868186

Fig.13 Graphic of individual emission comparison between the two materials

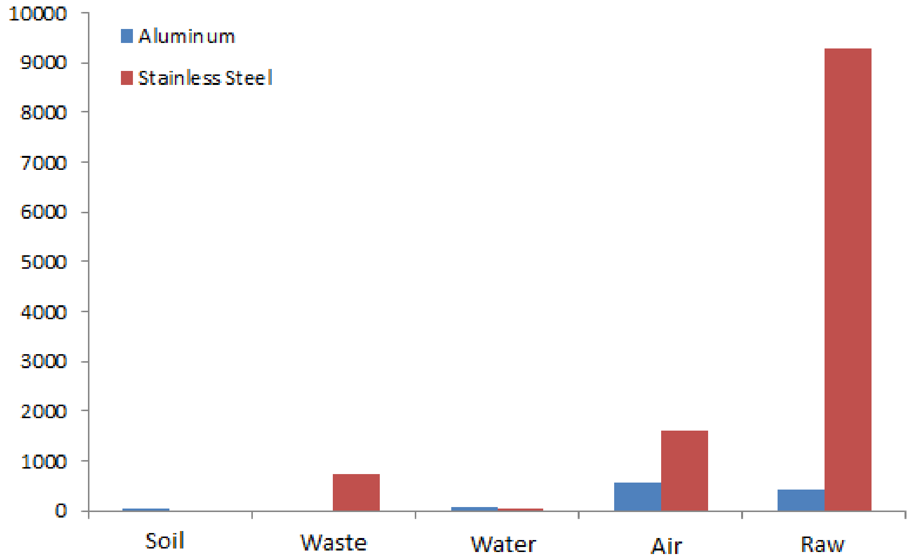
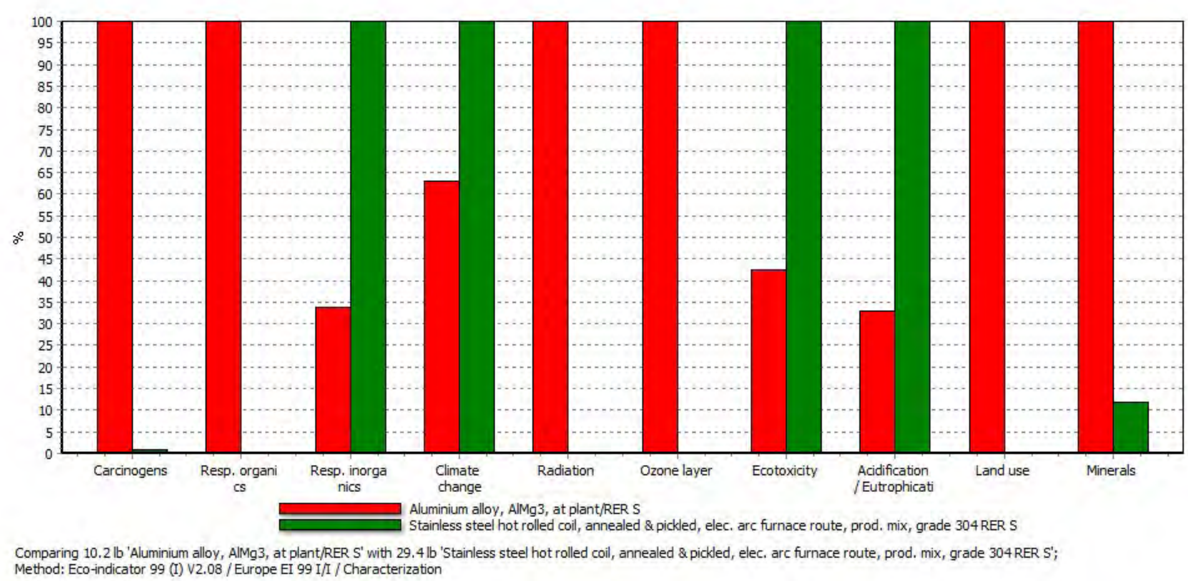


Fig.14 Relative impacts in disaggregated damage categories



While we compare both materials normalized score in human health, ecosystem quality and resources, human health and resources seem to be mostly important on the EI 99 point values as values in both categories exceeds the number in ecosystem quality a lot (Fig. 15)

Fig. 15 Normalized score in human health, eco-toxicity and resource categories

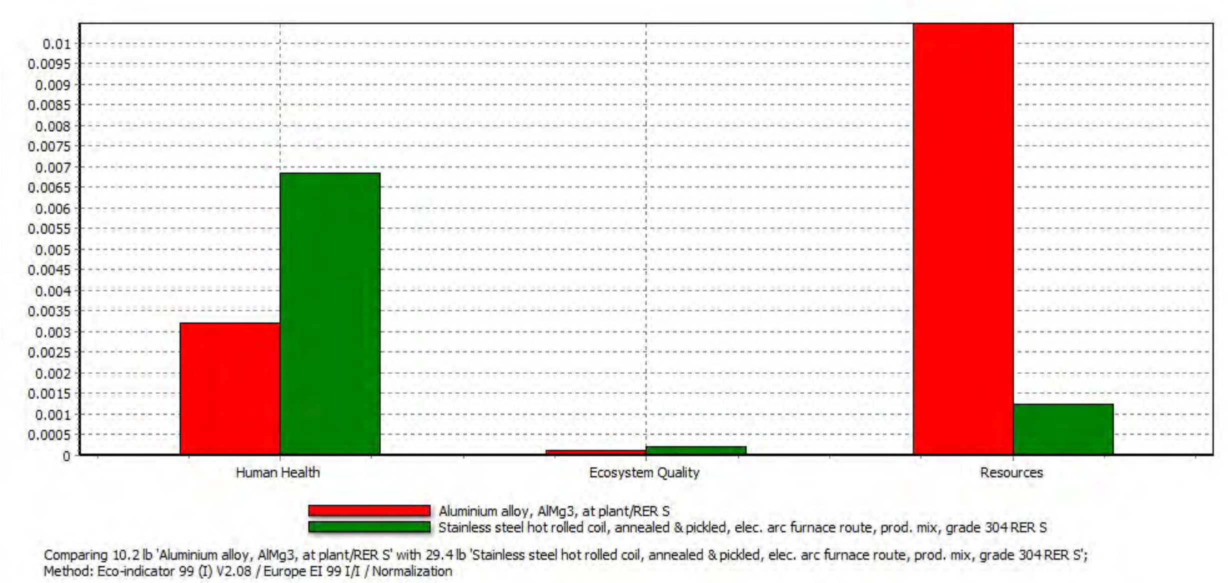
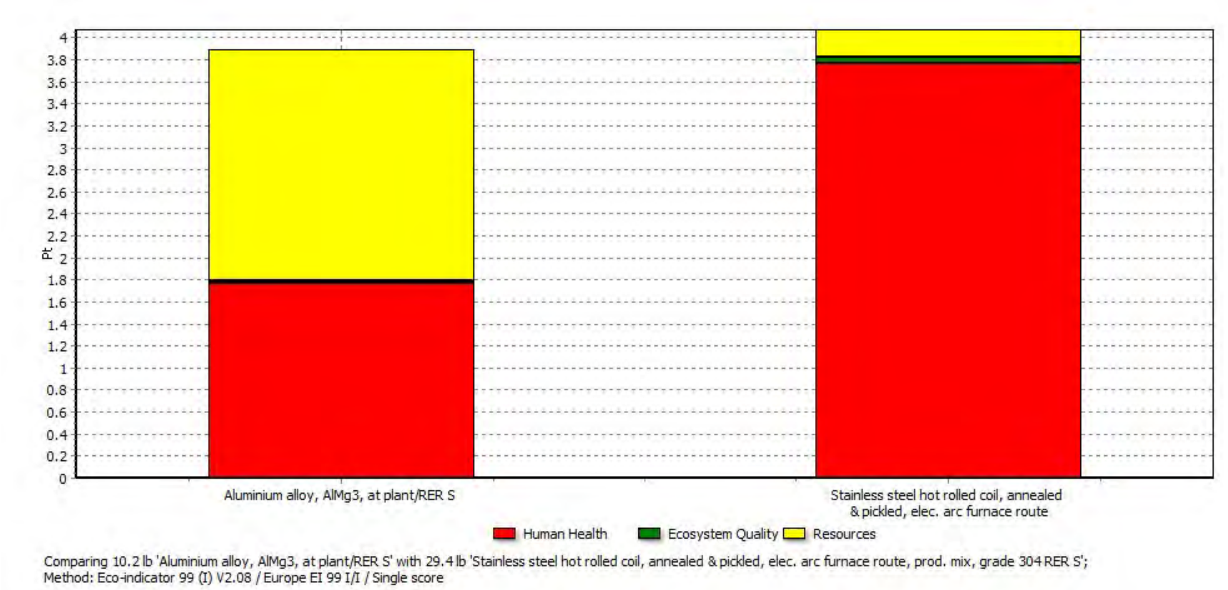


Fig. 16 Single score comparison in "points"



The higher value of indicator implies larger eco-burden and vice versa. When we comparing individual score by stacking the bars in Fig.15, we observed that in Fig. 16, stainless steel has relatively high impact in the overall system than aluminum does, where the difference is about 5%. When the life cycle of the whole product is taken into consideration, more factors need to be involved, such as easiness of recycle and reuse. Since, both materials are being widely used and promising life-cycle assessment has been achieved, the consideration of the full life cycle makes both materials equally important.

For our application, we will not considering using stainless steel due to its large density which is the major concern. Since the channel requires listing, under the same volume, making the system with stainless steel will have 3 times the weight of that of aluminum. Not only it does not met the ergonomic factor but also for the difficulty in machining due to the stainless steel's hardness. The issue may also rise in welding since we need to connect the channel with all other pieces.

Looking back to other materials in CES, we found the candidates are still aluminum but with different alloy series numbers. We will still use alloy 6061 due to the vendor availability and common use.

2. Comparing PVC pipe E and HDPE pipes E

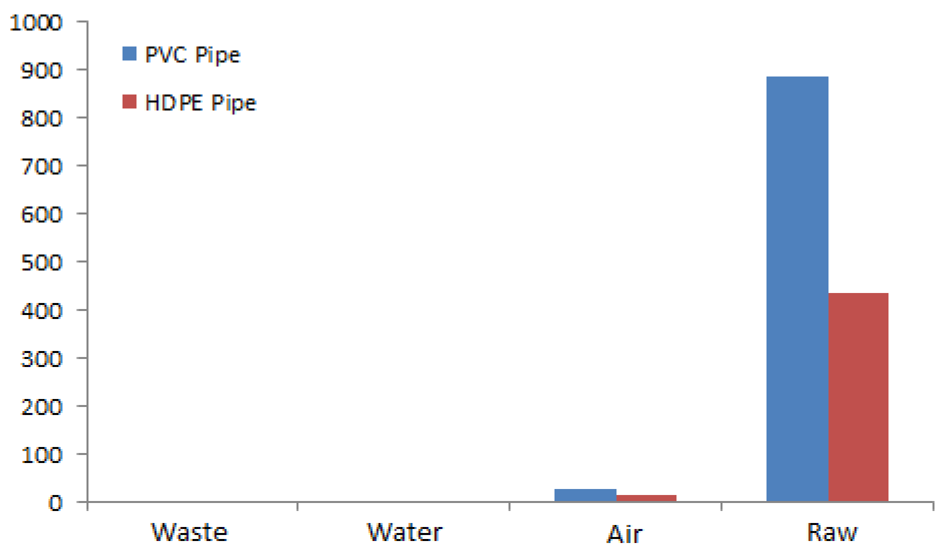
By comparing 0.67 lb of PVC and 0.50 HDPE into SimaPro, we are going to determine the mass of emissions, compare damage categories, normalized score and single score in "points".

We calculated the total mass of air emissions, water emissions, use of raw materials and solid waste for each material. The raw data is shown in Table 3 and the comparison graphic obtained after data processing is shown in Fig. 17. (We only consider items with mass units and discard other categories that have non-mass units according to instruction). From the data, we can observe that PVC has almost twice impact on air and raw than that of HDPE (Fig.17).

Table. 3 Value of individual emission of aluminum and stainless steel

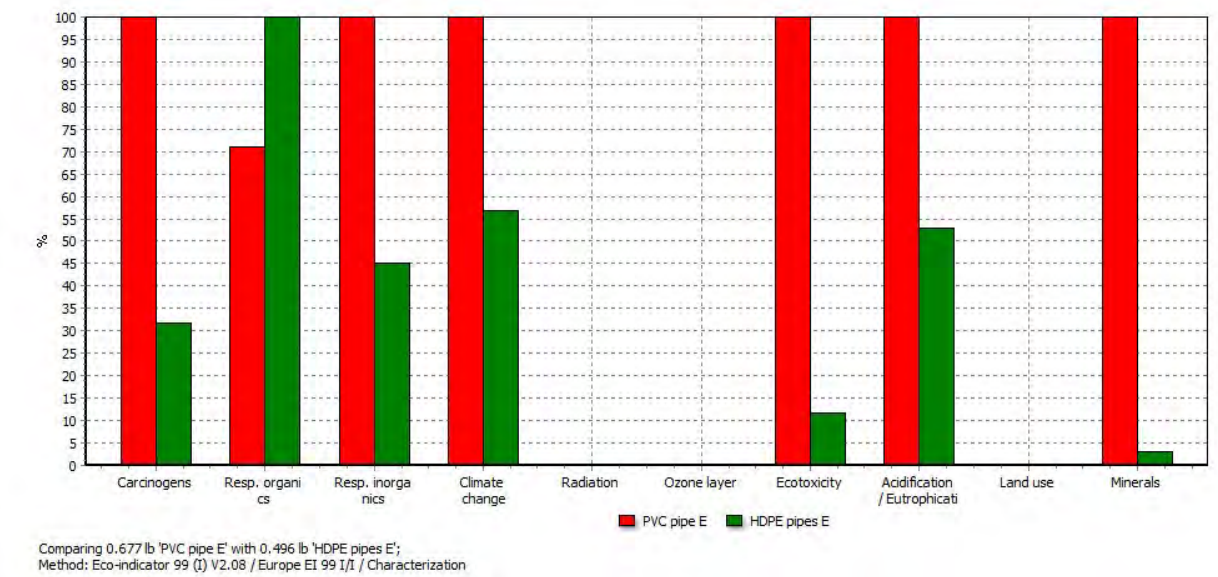
unit(oz)	PVC pipe	HDPE pipe
waste	1.156569744	0.41275965
water	1.284309712	0.012918607
air	27.82144217	15.12280223
raw	886.3670183	435.3017645

Fig. 17 Graphic of individual emission comparison between the two materials



By carefully looking into the disaggregated damage categories, the only category that HDPE exceeds PVC is resp. organics. It is obvious that the red bars dominate green bars in general (Fig. 18). Therefore, PVC has more influence on disaggregated damage than HDPE.

Fig. 18 Relative impacts in disaggregated damage categories



From the normalized score for both materials in Fig. 19, it is quite obvious that PVC has more environmental impact than HDPE in every aspect. This trend is even more convincing in Fig. 20 where the single score of PVC is larger which implies a heavier eco-burden than HDPE does.

Fig. 19 Normalized score in human health, eco-toxicity and resource categories

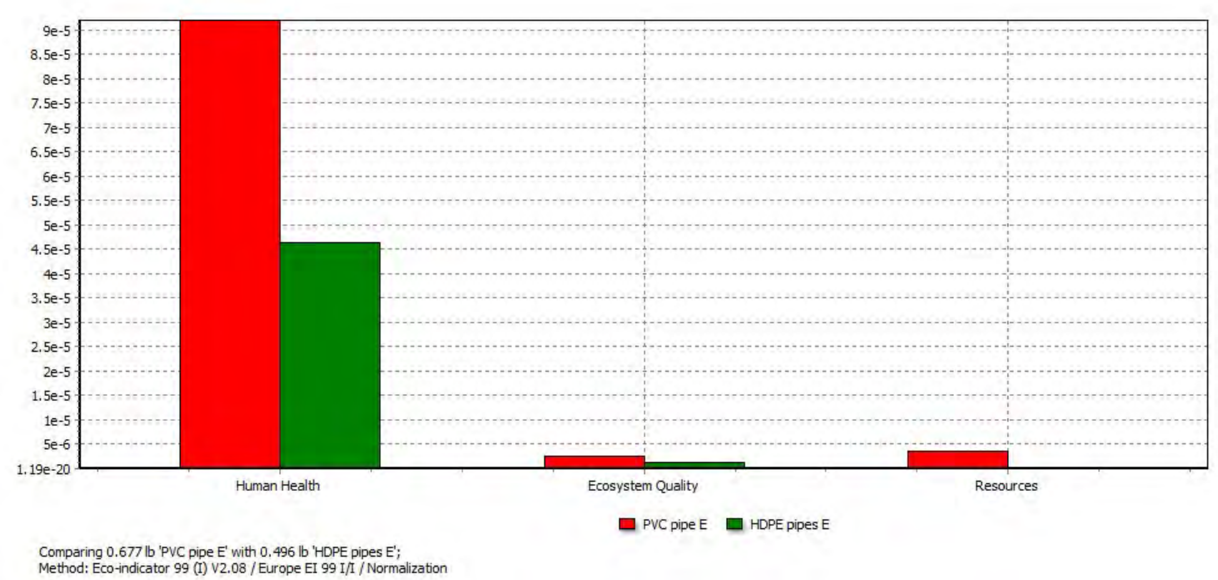
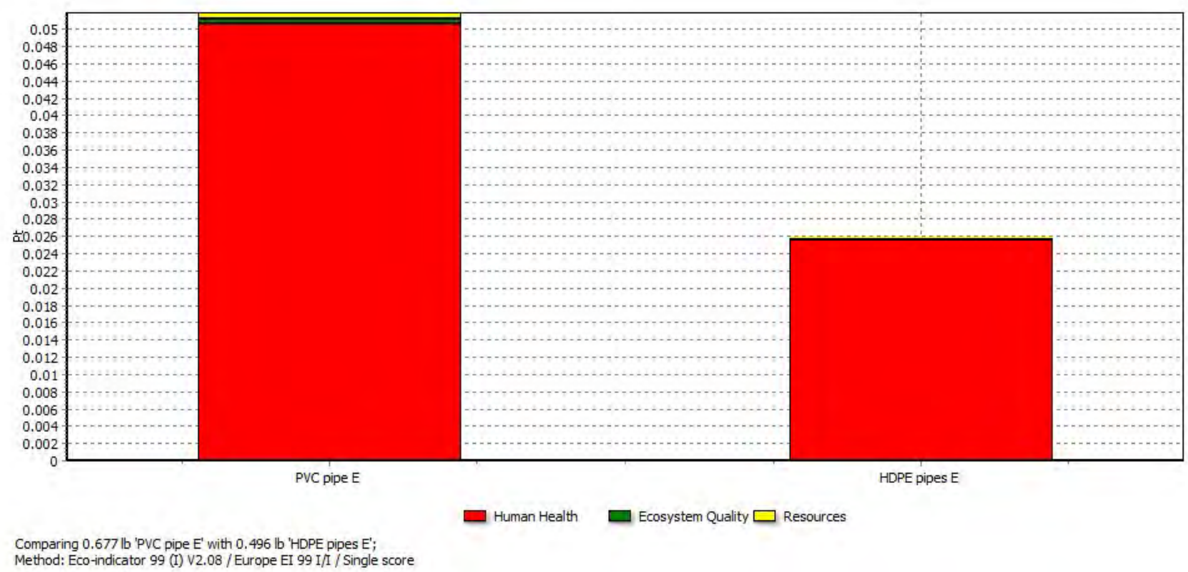


Fig. 20 Single score comparison in "points"



Again, when the life cycle of the whole product is considered, the PVC will still have a bigger impact since it has higher Eco indicator points in nearly every category. However, even though the HDPE pipe seems excel PVC pipe in most areas, we will still use PVC pipe into our system. The reason is that this pipe needs to connect the flow meter. The method of joining for PVC is push on while for HDPE, the way for join two pieces together is by heat fusion. We have considered the situation that we need to flow meter to be removable in the long run for either fixture or cleaning. Therefore, push on will be a better methods as heat fusion may damage the joint.

3. Manufacturing Process Selection Assignment

a) The device we designed will be beneficial to evaluate the performance of filter media to help relieve environmental concerns and benefit society. Therefore, a good amount of products will be reasonable. On the other hand, not a huge mass production (eg. Million or billions) is necessary Dow is our client and they required this special designed device for their particular use. By considering all these factors, we proposed this device will most likely to be used in different labs in Dow only and therefore, the real world production volume is 10 batches based on our engineering and real life judgment.

b) In our system, we used aluminum for all metal parts due to its relatively low cost, easiness in machining and welding and low density. We used it for channel (hollowed square tube), drain connection (tube), chamber (sheets), etc. Therefore, an efficient and low cost mass production way is needed. Same thing happened to PVC pipes, we used a large number of pipes for connection. As it is an important material in plumbing and water applications, effective and low cost way for mass production is required. Therefore, we used the CES manufacturing process selector to figure out the best way to manufacturing both aluminum and PVC in mass production (with our proposed batch size of 10 units for both)

Procedure: change database to Edu Level 2 -> Processes-Shaping -> Shape: Hollow 3-D -> apply limits -> Tree limitations -> Material selection (in our case, either aluminum or thermoplastic) -> rank choices

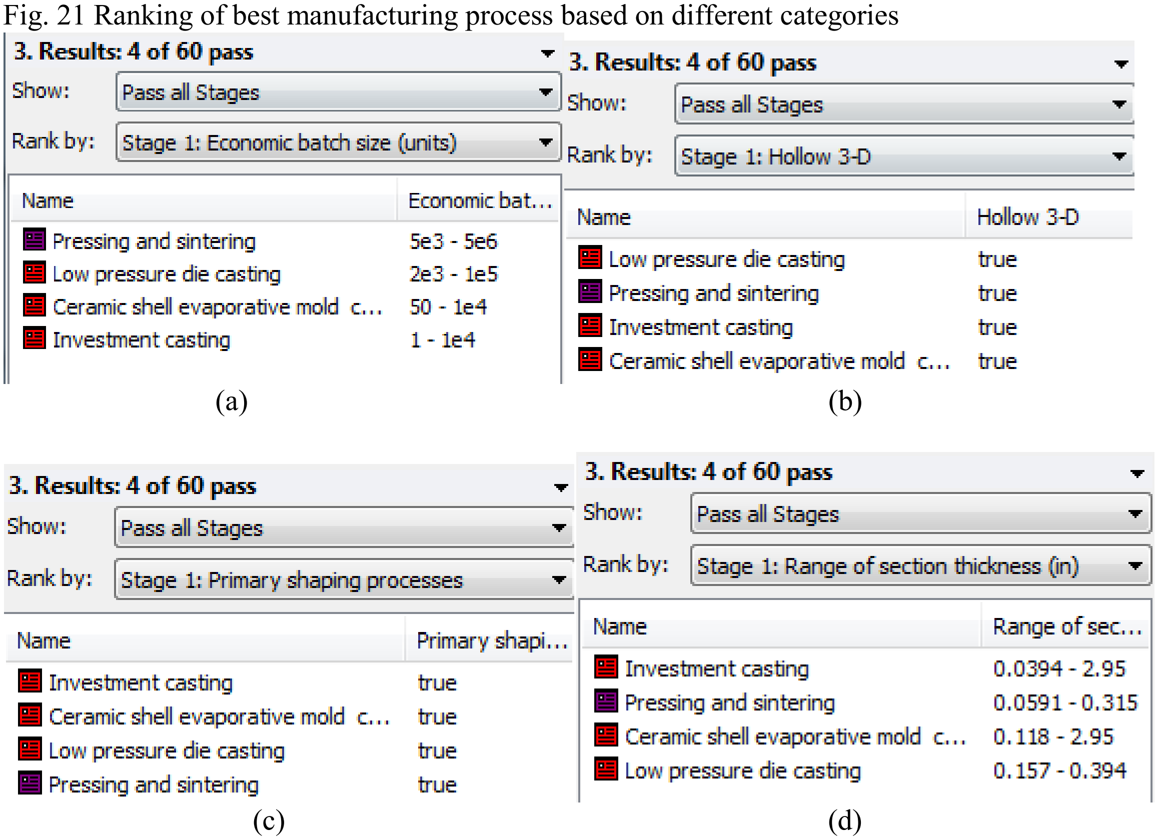
Aluminum
Following the procedure above, with the following limits applied, we ranked the best manufacturing process on economic batch size, range of section thickness and surface roughness respectively, as shown in Table 4. There are 4 out of 60 candidates passed all applied limitations with the detailed images from the software directly (Fig. 21)

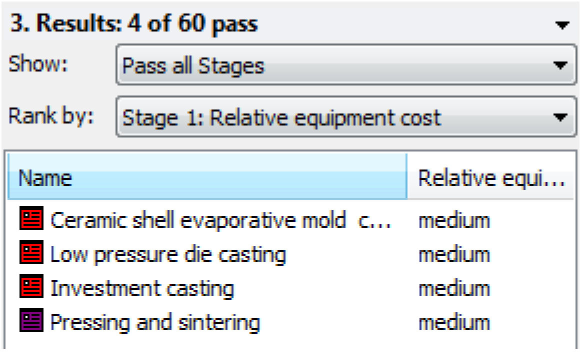
The limits applied to aluminum are
Shape: Hollow 3-D
Physical attributes: Range of section thickness: minimum = 0.05 in, maximum = 0.25 in
Surface roughness (A= very smooth): A and B
Process characteristics: Primary shaping processes (check mark)
Economic attributes: Economic batch size: minimum = 10 units
Relative tooling cost: medium or low
Relative equipment cost: medium or low

Table.4 Rank of best manufacturing process according to various criteria

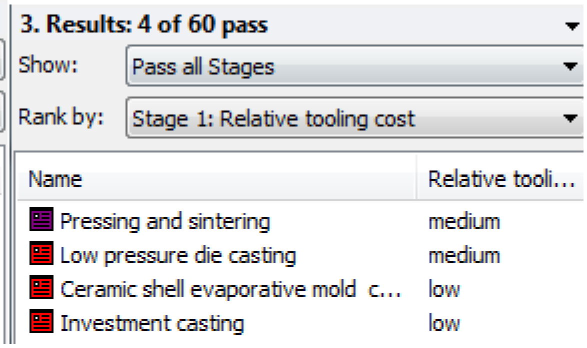
Ranking	Economic Batch Size	Range of section thickness	Surface roughness
1	Pressing and sintering	Investment casting	Investment casting
2	Low pressure die casting	Pressing and sintering	Low pressure die casting (Tie)
3	Ceramic shell evaporative mold casting	Ceramic shell evaporative mold casting	Pressing and sintering(Tie)
4	Investment casting	Low pressure die casting	Ceramic shell evaporative mold casting(Tie)

Fig. 21 Ranking of best manufacturing process based on different categories

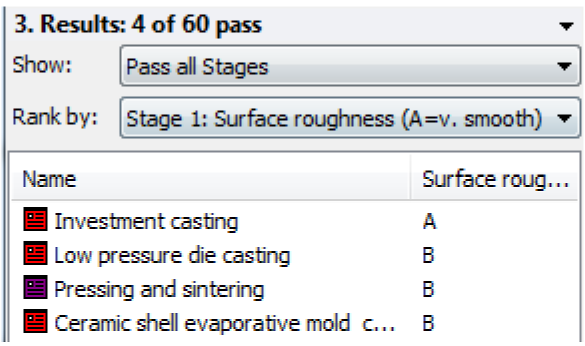




(e)



(f)



(g)

If we cared about labor intensity, after adding medium or low criteria, the investment casting is gone which excels both in range of section thickness and surface roughness. While considering all possible factors above, since we only produce 10 units, the relative cost should be reduced as much as possible as expensive investment would not be beneficial after these 10 products. In this case, we did not consider the labor intensity as a priority. Above all, we believe investment casting is the best manufacturing process for its excellence in primary shaping, section thickness and relatively low equipment and tooling cost, together with a smooth surface ending.

PVC

Following the same procedure of the manufacturing process selection as aluminum, we applied the following limits to thermoplastic (PVC)

Shape: Hollow 3-D
Physical attributes: Range of section thickness: minimum = 0.05 in, maximum = 0.25 in
Surface roughness (A= very smooth): A and B
Process characteristics: Primary shaping processes (check mark)
Economic attributes: Economic batch size: minimum = 10 units
There are 4 out of 60 candidates passed all limitations. Here are results from different rankings (Table 5)

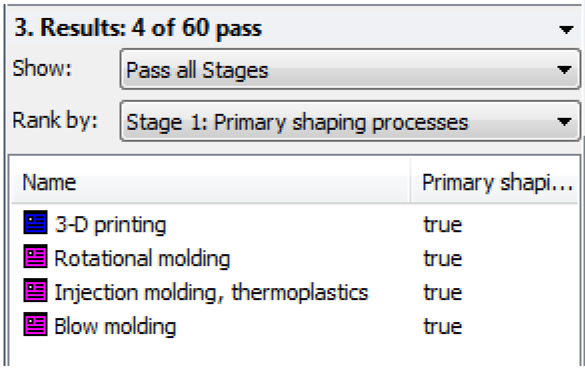
Table.5 Rank of best manufacturing process according to various criteria

Ranking	Economic Batch Size	Range of section thickness	Surface roughness
1	Blow molding	Blow molding	Blow molding (Tie)
2	Injection molding	Injection molding	Injection molding (Tie)
3	Rotational molding	3-D printing	Rotational molding (Tie)

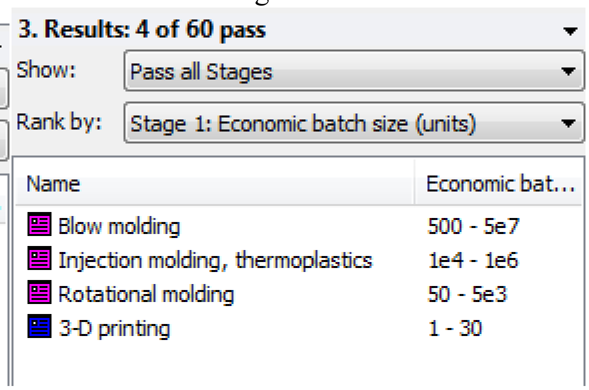
4	3-D printing	Rotational molding	3-D printing

The detailed ranking for each subcatogory is listed in Fig. 22

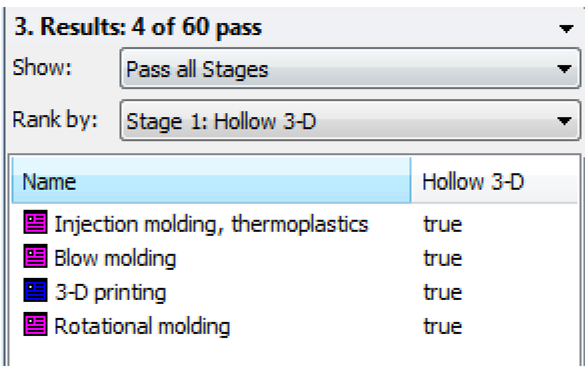
Fig. 22 Ranking of best manufacturing process based on different categories



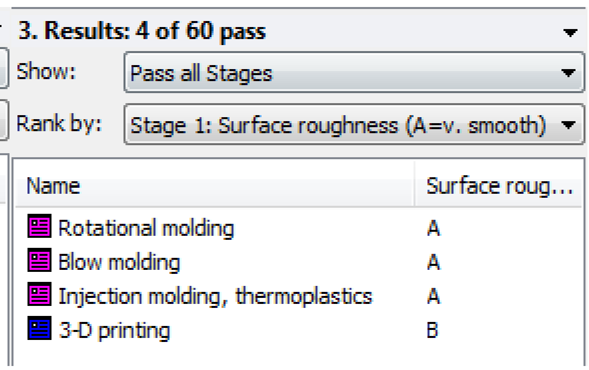
(a)



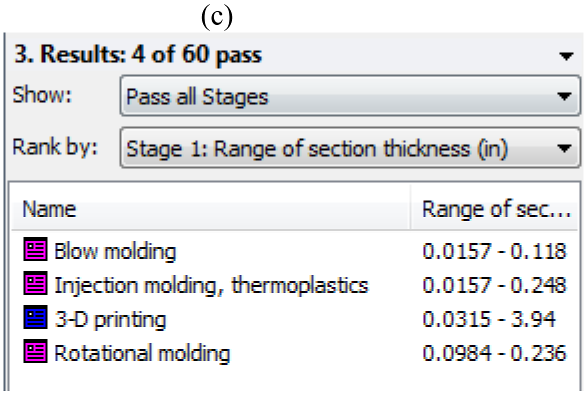
(b)



(c)



(d)



(e)

It is obvious that blow molding ranks the top one is every subcategory. Furthermore, if we add extra limits, make the cost of relative tooling, relative equipment and labor intensity either medium or low, the only winner is blow molding. Therefore, we are confident to say that the best manufacturing process for PVC piping production with a batch size of 10 units is blow molding.

References

[1] Ashby (online material) Chapter 5, *Materials selection – the basics*

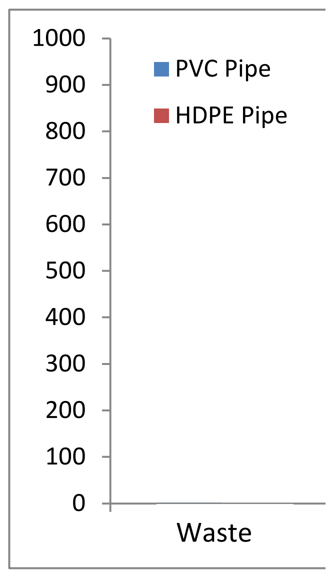
[2] www.mcmastercarr.com

SimaPro 7.	Inventory	Date:	########	Time:	5:02 PM
Project	test5		

Calculation	Compare
Results:	Inventory
Product 1:	0.6772 lb PVC pipe E (of project Industry data 2.0)
Product 2:	0.4657 lb HDPE pipes E (of project Industry data 2.0)
Method:	Eco-indicator 99 (I) V2.08 / Europe EI 99 I/I
Indicator:	Inventory
Unit:	?
Default uni	Yes
Exclude inf	No
Exclude lor	No
Sorted on i	Main category
Sort order:	Descending

No	Substance	Compartm	Unit	PVC pipe E	HDPE pipes E
1	Wood wast	Waste	oz	0.010099	0.00662
2	Waste, uns	Waste	oz	0.017063	0.010751
3	Waste, soli	Waste	oz	-0.24438	-0.11645
4	Waste, ind	Waste	oz	-0.04152	-0.01721
5	Waste to re	Waste	oz	0.007114	0.0336
6	Waste retu	Waste	oz	0.664014	0.234453
7	Waste in ir	Waste	oz	0.045204	0.006611
8	Slags and	Waste	oz	0.349409	0.150921
9	Plastic was	Waste	oz	0.052732	0.036268
10	Packaging	Waste	oz	5.36E-10	1.3E-09
11	Packaging	Waste	oz	9.9E-11	3.88E-11
12	Packaging	Waste	oz	0.010075	0.006928
13	Mineral wa	Waste	oz	0.09899	0.009872
14	Metal wast	Waste	oz	0.001303	0.000896
15	Constructic	Waste	oz	0.000983	9.03E-08
16	Compost	Waste	oz	1.87E-06	3.73E-06
17	Coal tailing	Waste	oz	0.041854	0.000531
18	Chemical v	Waste	oz	0.04115	0.018817
19	Chemical v	Waste	oz	0.102476	0.030149
				1.15657	0.41276
20	Zinc, ion	Water	oz	8.31E-07	9.99E-07
21	TOC, Total	Water	oz	0.000123	8.31E-05
22	Tin, ion	Water	oz	1.04E-07	5.62E-10
23	Suspendec	Water	oz	0.071417	0.002448
24	Sulfur	Water	oz	1.06E-06	6.24E-08
25	Sulfate	Water	oz	0.036107	0.006206
26	Strontium	Water	oz	5.9E-07	7.96E-11
27	Solved soli	Water	oz	0.220833	0.000161
28	Sodium, io	Water	oz	0.289251	0.000579
29	Silicon	Water	oz	2.64E-19	2.26E-19
30	Potassium,	Water	oz	0.000354	5.06E-06
31	Phosphoru	Water	oz	0.000344	3.55E-06
32	Phenol	Water	oz	5.71E-06	1.4E-05
33	Organic su	Water	oz	0.001707	5.1E-07
34	Nitrogen, t	Water	oz	0.000158	1.14E-05
35	Nitrate	Water	oz	6.74E-05	1.74E-05

unit(oz)	PVC pipe
waste	1.156569744
water	1.284309712
air	27.82144217
raw	886.3670183

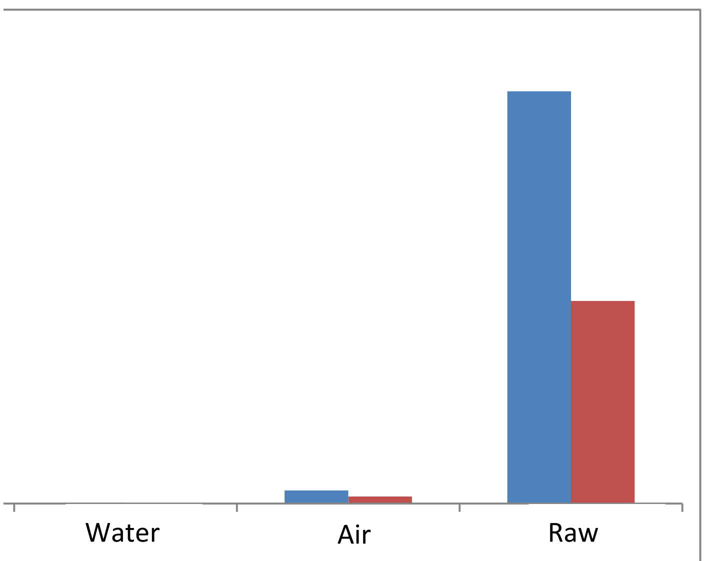


36	Nickel, ion	Water	oz	1.15E-05	2.82E-09
37	Metallic ior	Water	oz	0.000438	5.57E-05
38	Mercury	Water	oz	2.37E-07	1.64E-09
39	Manganese	Water	oz	4.81E-10	1.35E-09
40	Magnesiun	Water	oz	5.69E-06	8E-09
41	Lead	Water	oz	8.17E-08	1.54E-08
42	Iron, ion	Water	oz	5.41E-06	3.62E-07
43	Hydrocarbo	Water	oz	3.53E-05	3.38E-05
44	Fluoride	Water	oz	8.19E-08	5.03E-08
45	Ethane, ch	Water	oz	0.000104	3.39E-10
46	Ethane, 1,1	Water	oz	2.2E-05	1.85E-11
47	DOC, Diss	Water	oz	0.00021	7.57E-05
48	Dioxin, 2,3,	Water	oz	7.15E-08	7.34E-09
49	Detergent,	Water	oz	9.26E-05	4.69E-05
50	Cyanide	Water	oz	1.64E-09	1.12E-09
51	Copper, ior	Water	oz	1.73E-05	1.17E-06
52	COD, Cher	Water	oz	0.145143	0.001535
53	Chromium	Water	oz	3.32E-11	1.67E-11
54	Chlorine	Water	oz	3.44E-05	8.04E-09
55	Chlorinatec	Water	oz	6.78E-06	4.35E-08
56	Chloride	Water	oz	0.5013	0.001176
57	Chlorate	Water	oz	0.00261	7.5E-07
58	Carbonate	Water	oz	0.008383	0.000217
59	Calcium, io	Water	oz	0.003757	2.16E-05
60	Cadmium,	Water	oz	1.1E-10	1.18E-10
61	Bromate	Water	oz	4.5E-06	4.17E-09
62	BOD5, Biol	Water	oz	0.001387	0.000169
63	Benzene	Water	oz	7.15E-13	2.96E-14
64	Arsenic, ior	Water	oz	2.85E-09	1.49E-09
65	AOX, Adso	Water	oz	1.48E-05	3.16E-11
66	Ammonium	Water	oz	0.000199	3.02E-05
67	Aluminium	Water	oz	2.36E-06	4.18E-06
68	Acids, uns	Water	oz	0.000158	2.18E-05
				1.28431	0.012919
69	Zinc	Air	oz	1.35E-07	1.33E-08
70	Xylene	Air	oz	1.72E-09	1.18E-09
71	Toluene	Air	oz	2.66E-09	1.82E-09
72	Sulfuric aci	Air	oz	3.84E-13	1.38E-14
73	Sulfur dioxi	Air	oz	0.105194	0.046415
74	Styrene	Air	oz	8.39E-13	4.84E-13
75	Silver	Air	oz	5.74E-09	5.14E-17
76	Selenium c	Air	oz	1.19E-10	1.78E-18
77	Propene	Air	oz	8.74E-06	9E-06
78	Particulates	Air	oz	0.014688	0.005923
79	PAH, polyc	Air	oz	1.38E-08	9.47E-09
80	Oxygen	Air	oz	1.54E-05	3.03E-17
81	Organic su	Air	oz	0.000744	0.000448
82	NMVOC, n	Air	oz	0.000432	0.001129
83	Nitrogen o	Air	oz	0.064763	0.033471
84	Nickel	Air	oz	2.01E-06	9.46E-09
85	Methane, c	Air	oz	3.39E-06	4.32E-13
86	Methane	Air	oz	0.312973	0.149467
87	Metals, uns	Air	oz	3.92E-05	2.15E-05
88	Mercury	Air	oz	3.45E-06	2.95E-08

89	Mercaptan:	Air	oz	2.49E-07	1.78E-07
90	Lead	Air	oz	1.3E-06	1.36E-08
91	Hydrogen s	Air	oz	1.31E-06	8.95E-07
92	Hydrogen f	Air	oz	5.13E-05	2.3E-05
93	Hydrogen c	Air	oz	4.28E-18	3.67E-18
94	Hydrogen c	Air	oz	0.001977	0.000711
95	Hydrogen	Air	oz	0.047589	0.000501
96	Hydrocarbo	Air	oz	0.024319	0.03427
97	Hydrocarbo	Air	oz	0.000112	7.66E-09
98	Hydrocarbo	Air	oz	0.000218	0.000645
99	Fluorine	Air	oz	4.52E-08	7.42E-10
100	Ethylene o:	Air	oz	1.62E-09	1.11E-09
101	Ethene	Air	oz	0.000157	1.22E-05
102	Ethane, ch	Air	oz	0.000849	1.86E-08
103	Ethane, 1,2	Air	oz	0.000524	1.12E-09
104	Dioxin, 2,3,	Air	oz	3.17E-09	3.22E-31
105	Dinitrogen	Air	oz	5.17E-11	3E-11
106	Copper	Air	oz	3.35E-07	1.97E-11
107	Chromium	Air	oz	1.46E-06	9.41E-09
108	Chlorine	Air	oz	0.001353	1.04E-09
109	Chlorinated	Air	oz	0.000161	9.97E-06
110	Carbon mo	Air	oz	0.033138	0.095876
111	Carbon dis	Air	oz	2.67E-08	1.11E-10
112	Carbon dio	Air	oz	27.21199	14.75387
113	Cadmium	Air	oz	1.36E-08	8.42E-10
114	Benzene, e	Air	oz	1.04E-09	7.11E-10
115	Benzene	Air	oz	4.85E-09	3.32E-09
116	Asbestos	Air	oz	5.19E-10	2.63E-14
117	Arsenic	Air	oz	4.36E-08	9.24E-10
118	Antimony	Air	oz	3.12E-11	1.68E-10
119	Ammonia	Air	oz	0.000131	6E-09
120	Aldehydes,	Air	oz	4.5E-09	1.84E-10
				27.82144	15.1228
121	Zinc, in gro	Raw	oz	6.77E-06	0.000117
122	Water, pro	Raw	oz	6.809274	0.712551
123	Water, pro	Raw	oz	58.1081	3.827161
124	Water, pro	Raw	oz	9.091493	7.268498
125	Water, pro	Raw	oz	2.074074	0.983186
126	Water, pro	Raw	oz	26.13559	13.90394
127	Water, coo	Raw	oz	2.353623	0.001168
128	Water, coo	Raw	oz	319.7035	319.4106
129	Water, coo	Raw	oz	382.9377	0.493903
130	Water, coo	Raw	oz	61.23623	84.13151
131	Water, coo	Raw	oz	0.013619	1.201134
132	Unspecified	Raw	oz	1.42E-08	9.75E-09
133	Talc, in gro	Raw	oz	2.31E-25	9.42E-26
134	Sulfur, in g	Raw	oz	-0.00449	0.000415
135	Sulfur, bon	Raw	oz	8.44E-07	1.73E-06
136	Sodium nit	Raw	oz	1.54E-10	3.34E-09
137	Sodium chl	Raw	oz	11.05516	0.002721
138	Shale, in g	Raw	oz	7.86E-05	7.02E-05
139	Sand, unsp	Raw	oz	0.006045	0.000629
140	Sand, quar	Raw	oz	1.07E-20	9.42E-29
141	Rutile, in g	Raw	oz	1.75E-08	1.2E-08

142	Potassium	Raw	oz	0.011247	1.09E-07
143	Phosphoru	Raw	oz	2.42E-05	2.62E-08
144	Oxygen, in	Raw	oz	0.848624	0.000228
145	Olivine, in (	Raw	oz	0.000164	0.000111
146	Nitrogen, ir	Raw	oz	0.828004	1.266555
147	Nickel, in g	Raw	oz	4.57E-07	2.23E-09
148	Mercury, in	Raw	oz	2.99E-05	5.34E-09
149	Magnesiun	Raw	oz	5.12E-11	1.11E-09
150	Limestone,	Raw	oz	0.278573	0.003311
151	Lead, in gr	Raw	oz	3.08E-05	1.87E-05
152	Iron, in gro	Raw	oz	0.017509	0.011856
153	Gravel, in (	Raw	oz	6.46E-05	4.37E-05
154	Granite, in	Raw	oz	2.25E-12	1.68E-13
155	Fluorspar,	Raw	oz	2.34E-05	3.16E-06
156	Ferromang	Raw	oz	1.59E-05	1.08E-05
157	Feldspar, ir	Raw	oz	5.38E-16	4.61E-16
174	Dolomite, ir	Raw	oz	0.000214	0.000145
175	Copper, in	Raw	oz	0.001049	2.55E-08
176	Clay, unsp	Raw	oz	1.99E-05	4.1E-09
177	Clay, bentc	Raw	oz	0.000284	0.000256
178	Chromium,	Raw	oz	2.97E-05	2.04E-05
179	Calcium su	Raw	oz	2.78E-05	2.48E-05
180	Calcite, in (	Raw	oz	3.01E-30	2.74E-32
181	Biomass	Raw	oz	0.187492	0.138838
182	Bauxite, in	Raw	oz	0.000105	8.1E-05
183	Baryte, in (	Raw	oz	0.00224	1.56E-06
184	Animal ma	Raw	oz	2.53E-10	3.34E-09
185	Air	Raw	oz	4.671272	1.942603
				886.367	435.3018

HDPE pipe
0.41275965
0.012918607
15.12280223
435.3017645

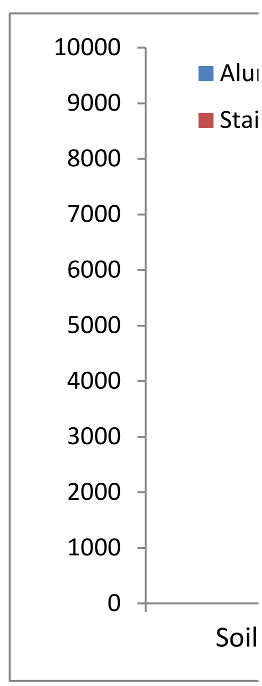


SimaPro 7. Inventory Date: ######## Time: 5:00 PM
Project test4

Calculation Compare
Results: Inventory
Product 1: 10.19 lb Aluminium alloy, AlMg3, at plant/RER S (of project Ecoinvent system processes)
Product 2: 29.43 lb Stainless steel hot rolled coil, annealed & pickled, elec. arc furnace route, prod. m
Method: Eco-indicator 99 (I) V2.08 / Europe EI 99 I/I
Indicator: Inventory
Unit: ?
Default uni Yes
E0clude inf No
E0clude lor No
Sorted on i Main category
Sort order: Descending

No	Substance	Compartm	Unit	Aluminium	Stainless steel hot rolled coil, annealed & pi
1	Zinc	Soil	oz	0.000129	0
2	Vanadium	Soil	oz	6.23E-07	0
3	Titanium	Soil	oz	2.18E-05	0
4	Tin	Soil	oz	9.69E-07	0
5	Thiram	Soil	oz	8.7E-10	0
6	Teflubenzu	Soil	oz	7.35E-09	0
7	Tebutam	Soil	oz	1.17E-08	0
8	Sulfuric aci	Soil	oz	1.15E-11	0
9	Sulfur	Soil	oz	0.001824	0
10	Strontium	Soil	oz	1.55E-05	0
11	Sodium	Soil	oz	0.003115	0
12	Silicon	Soil	oz	0.002896	0
13	Potassium	Soil	oz	0.001399	0
14	Pirimicarb	Soil	oz	2.42E-09	0
15	Phosphoru	Soil	oz	0.000232	0
16	Orbencarb	Soil	oz	5.95E-07	0
17	Oils, unspe	Soil	oz	0.190958	0
18	Oils, bioger	Soil	oz	0.000189	0
19	Nickel	Soil	oz	2.37E-06	0
20	Napropami	Soil	oz	4.93E-09	0
21	Molybdenu	Soil	oz	2.89E-07	0
22	Metribuzin	Soil	oz	1.1E-07	0
23	Metolachlo	Soil	oz	2.8E-06	0
24	Metaldehyc	Soil	oz	2.78E-09	0
25	Mercury	Soil	oz	7.02E-08	0
26	Manganes	Soil	oz	0.00039	0
27	Mancozeb	Soil	oz	3.13E-06	0
28	Magnesiun	Soil	oz	0.002013	0
29	Linuron	Soil	oz	3.87E-07	0
30	Lead	Soil	oz	5.43E-06	0
31	Iron	Soil	oz	0.017061	0
33	Glyphosate	Soil	oz	4.64E-06	0
34	Fluoride	Soil	oz	0.000515	0
35	Fenpiclonil	Soil	oz	9.66E-08	0
36	Cypermeth	Soil	oz	3.83E-08	0
37	Copper	Soil	oz	0.000422	0
38	Cobalt	Soil	oz	6.74E-07	0

unit (oz)
soil
waste
water
air
raw



39	Chromium	Soil	oz	0.000648	0
40	Chromium	Soil	oz	1.38E-05	0
41	Chlorothalc	Soil	oz	2.41E-06	0
42	Chloride	Soil	oz	0.021211	0
43	Carbon	Soil	oz	0.013299	0
44	Carbofurar	Soil	oz	2.69E-07	0
45	Carbetamic	Soil	oz	1.15E-08	0
46	Calcium	Soil	oz	0.013087	0
47	Cadmium	Soil	oz	3.13E-07	0
48	Boron	Soil	oz	0.00013	0
49	Bentazone	Soil	oz	2.56E-08	0
50	Benomyl	Soil	oz	4.9E-10	0
51	Barium	Soil	oz	0.000771	0
52	Atrazine	Soil	oz	6.01E-11	0
53	Arsenic	Soil	oz	8.19E-07	0
54	Antimony	Soil	oz	1.73E-10	0
55	Aluminium	Soil	oz	0.002591	0
56	Aldrin	Soil	oz	2.29E-10	0
57	Aclonifen	Soil	oz	5.02E-08	0
58	2,4-D	Soil	oz	7.69E-08	0
				0.272957	0
59	Waste, uns	Waste	oz	0	611.9605
60	Steel waste	Waste	oz	0	114.3359
				0	726.2963
62	Zinc, ion	Water	oz	0.091521	0
64	Zinc	Water	oz	0	0.000523
65	0ylene	Water	oz	0.000296	0
66	VOC, volat	Water	oz	0.001057	0
67	Vanadium,	Water	oz	0.020921	0
68	Urea	Water	oz	3.69E-10	0
73	Tungsten	Water	oz	0.001835	0
74	Trimethylar	Water	oz	5.77E-12	0
75	Triethylene	Water	oz	3.13E-05	0
76	Tributyltin (	Water	oz	1.62E-05	0
77	Toluene, 2-	Water	oz	4.04E-10	0
78	Toluene	Water	oz	0.00036	0
79	TOC, Total	Water	oz	0.50464	0
80	Titanium, ic	Water	oz	0.540237	0
81	Tin, ion	Water	oz	0.001277	0
82	Tin	Water	oz	0	7.58E-05
87	Thallium	Water	oz	0.000141	0
91	t-Butylamin	Water	oz	9.39E-10	0
92	t-Butyl met	Water	oz	5.82E-06	0
93	Suspendec	Water	oz	0.089894	0
94	Sulfur	Water	oz	0.000509	0.433681
95	Sulfite	Water	oz	0.000599	0
96	Sulfide	Water	oz	2.05E-05	0
97	Sulfate	Water	oz	26.41411	0
100	Strontium	Water	oz	0.100853	0
101	Solved soli	Water	oz	0.442284	0
102	Solids, inor	Water	oz	0.258922	0
103	Sodium, ioi	Water	oz	6.276034	0
104	Sodium for	Water	oz	2.54E-07	0

106	Silver, ion	Water	oz	8.36E-05	0
108	Silicon	Water	oz	8.508847	0
109	Selenium	Water	oz	0.001869	0
110	Scandium	Water	oz	0.000989	0
112	Rubidium	Water	oz	2.9E-05	0
119	Propylene (	Water	oz	3.39E-06	0
120	Propylamin	Water	oz	1.28E-10	0
121	Propionic a	Water	oz	8.87E-11	0
122	Propene	Water	oz	1.73E-05	0
123	Propanal	Water	oz	3.19E-10	0
124	Potassium,	Water	oz	2.095156	0
127	Phosphoru	Water	oz	3.73E-05	0
128	Phosphate	Water	oz	1.049113	0.001393
129	Phenol	Water	oz	0.000279	0
130	Particulate:	Water	oz	0	0.110563
131	PAH, polyc	Water	oz	8.22E-05	0
132	Oils, unspe	Water	oz	0.185458	0
133	o-0ylene	Water	oz	2.23E-08	0
134	Nitrogen, o	Water	oz	0.003282	0
135	Nitrogen	Water	oz	0.00326	0.048085
136	Nitrobenze	Water	oz	2.56E-09	0
137	Nitrite	Water	oz	0.000831	0
138	Nitrate	Water	oz	0.307432	0.094396
140	Nickel, ion	Water	oz	0.022748	0
141	Nickel	Water	oz	0	0.001592
143	Molybdenu	Water	oz	0.002407	0.000782
144	Methyl forn	Water	oz	3.33E-11	0
145	Methyl ami	Water	oz	1.29E-10	0
146	Methyl acry	Water	oz	1.97E-07	0
147	Methyl ace	Water	oz	3.26E-12	0
148	Methanol	Water	oz	3.86E-05	0
149	Methane, c	Water	oz	3.9E-05	0
150	Mercury	Water	oz	6.52E-05	0
152	Manganese	Water	oz	0.318206	0.001333
153	Magnesium	Water	oz	3.53142	0
154	m-0ylene	Water	oz	3.11E-08	0
155	Lithium, ior	Water	oz	0.001087	0
157	Lead	Water	oz	0.001779	0.000243
159	Lactic acid	Water	oz	2.51E-10	0
160	Isopropylar	Water	oz	7.66E-10	0
161	Iron, ion	Water	oz	1.141612	0
163	Iron	Water	oz	0	0.061853
166	Iodide	Water	oz	0.000302	0
167	Hypochlorit	Water	oz	0.000207	0
168	Hydro0ide	Water	oz	7.01E-07	0
169	Hydrogen s	Water	oz	0.000401	0
170	Hydrogen p	Water	oz	9.93E-07	0
172	Hydrocarbo	Water	oz	0.000391	0.010265
173	Hydrocarbo	Water	oz	0.001556	0
174	Hydrocarbo	Water	oz	3.47E-05	0
175	Hydrocarbo	Water	oz	0.000376	0
177	Glutaraldeh	Water	oz	2.24E-06	0
178	Formic acid	Water	oz	1.17E-10	0
179	Formate	Water	oz	1.21E-07	0
180	Formamide	Water	oz	4.03E-10	0

181	Formaldeh	Water	oz	2.37E-06	0
182	Fluosilicic a	Water	oz	0.001871	0
183	Fluoride	Water	oz	0.302068	0.032585
184	Ethylene o(	Water	oz	1.33E-08	0
185	Ethylene di	Water	oz	6.72E-09	0
186	Ethylamine	Water	oz	2.62E-09	0
187	Ethyl aceta	Water	oz	5.48E-10	0
188	Ethene, ch	Water	oz	1.72E-07	0
189	Ethene	Water	oz	1.28E-05	0
190	Ethanol	Water	oz	1.49E-07	0
191	Ethane, 1,2	Water	oz	4.93E-07	0
192	DOC, Diss	Water	oz	0.504265	0
193	Dipropylam	Water	oz	3.21E-10	0
194	Dimethylan	Water	oz	4.69E-10	0
195	Diethylamii	Water	oz	5.11E-10	0
196	Dichromate	Water	oz	1.69E-05	0
197	Cyanide	Water	oz	0.000368	0
198	Cumene	Water	oz	3.86E-05	0
199	Copper, ior	Water	oz	0.01343	0
200	Copper	Water	oz	0	5.74E-05
201	COD, Cher	Water	oz	1.413183	0.212568
205	Cobalt	Water	oz	0.008169	0
206	Chromium,	Water	oz	1.9E-05	0
207	Chromium	Water	oz	0.013615	0.000108
209	Chromium	Water	oz	0	0.000434
210	Chlorosulfc	Water	oz	1.02E-10	0
211	Chloroform	Water	oz	1.27E-09	0
212	Chloroacet	Water	oz	1.28E-11	0
213	Chloroacet	Water	oz	5.9E-07	0
214	Chlorine	Water	oz	0.000129	0
215	Chlorinatec	Water	oz	1.6E-06	0
216	Chloride	Water	oz	3.38724	1.674725
217	Chlorate	Water	oz	0.004063	0
218	Chloramine	Water	oz	2.94E-09	0
222	Cesium	Water	oz	2.9E-06	0
225	Carbo0ylic	Water	oz	0.012495	0
226	Carbonate	Water	oz	0.000148	0
227	Carbon dis	Water	oz	1.55E-08	0
228	Calcium, ic	Water	oz	7.06355	0
229	Cadmium,	Water	oz	0.00144	0
230	Cadmium	Water	oz	0	1.03E-05
231	Butyrolacto	Water	oz	1.3E-10	0
232	Butyl aceta	Water	oz	7.59E-08	0
233	Butene	Water	oz	3.44E-08	0
234	Bromine	Water	oz	0.002494	0
235	Bromide	Water	oz	9.67E-07	0
236	Bromate	Water	oz	0.00053	0
237	Boron	Water	oz	0.060653	0
238	Borate	Water	oz	1.71E-08	0
239	BOD5, Biol	Water	oz	0.859838	0
240	Beryllium	Water	oz	0.000591	0
241	Benzene, e	Water	oz	6.96E-05	0
242	Benzene, c	Water	oz	5.4E-07	0
243	Benzene, 1	Water	oz	2.68E-08	0
244	Benzene	Water	oz	0.000231	0

246	Barium	Water	oz	0.012179	0
247	Barite	Water	oz	0.018112	0
248	Arsenic, ioı	Water	oz	0.004385	0
249	AO0, Adso	Water	oz	5.89E-06	0
253	Antimony	Water	oz	0.000817	0
254	Aniline	Water	oz	1.14E-09	0
255	Ammoniun	Water	oz	0.014767	0
256	Ammonia	Water	oz	0	0.028488
257	Aluminium	Water	oz	1.777877	0.005556
259	Acrylate, io	Water	oz	2.11E-08	0
260	Acidity, uns	Water	oz	2.08E-06	0.0283
261	Acetyl chlo	Water	oz	1.73E-10	0
262	Acetonitrile	Water	oz	2.8E-11	0
263	Acetone	Water	oz	1.31E-08	0
264	Acetic acid	Water	oz	3.4E-06	0
265	Acetaldehy	Water	oz	1.18E-07	0
266	Acenaphth	Water	oz	1.13E-09	0
267	Acenaphth	Water	oz	1.8E-08	0
268	4-Methyl-2-	Water	oz	4.24E-09	0
269	2-Propanol	Water	oz	1.77E-09	0
270	2-Methyl-2-	Water	oz	3.69E-14	0
271	2-Methyl-1-	Water	oz	3.99E-10	0
272	2-Aminopro	Water	oz	9.61E-12	0
273	1,4-Butane	Water	oz	9.54E-11	0
274	1-Propanol	Water	oz	3.34E-10	0
275	1-Pentene	Water	oz	1.66E-10	0
276	1-Pentanol	Water	oz	2.2E-10	0
277	1-Butanol	Water	oz	5.84E-08	0
				67.40369	2.747615
279	Zirconium	Air	oz	2.02E-07	0
281	Zinc	Air	oz	0.008967	0
282	0ylene	Air	oz	0.002487	0
290	Water	Air	oz	0.068503	0
291	Vanadium	Air	oz	0.000537	0
296	Uranium	Air	oz	1.64E-07	0
297	Tungsten	Air	oz	1.28E-06	0
298	Trimethylaı	Air	oz	2.41E-12	0
299	Toluene, 2-	Air	oz	1.96E-10	0
300	Toluene	Air	oz	0.001071	0
301	Titanium	Air	oz	0.000233	0
302	Tin	Air	oz	3.34E-05	0
307	Thorium	Air	oz	1.34E-07	0
308	Thallium	Air	oz	1.57E-07	0
309	Terpenes	Air	oz	1.91E-07	0
310	t-Butylamin	Air	oz	3.91E-10	0
311	t-Butyl met	Air	oz	1.73E-07	0
312	Sulfuric aci	Air	oz	1.88E-08	0
313	Sulfur trio0	Air	oz	5.16E-09	0
314	Sulfur he0a	Air	oz	0.014508	0
315	Sulfur dio0	Air	oz	1.972214	5.831573
316	Sulfate	Air	oz	0.007474	0
317	Styrene	Air	oz	5.59E-07	0
318	Strontium	Air	oz	6.82E-05	0
319	Sodium hy	Air	oz	8.94E-08	0

320	Sodium for	Air	oz	1.06E-07	0
321	Sodium dic	Air	oz	4.55E-06	0
322	Sodium chl	Air	oz	2.39E-07	0
323	Sodium	Air	oz	0.000557	0
325	Silver	Air	oz	4.8E-07	0
326	Silicon tetra	Air	oz	1.45E-08	0
327	Silicon	Air	oz	0.020725	0
328	Selenium	Air	oz	5.1E-05	0
329	Scandium	Air	oz	1.14E-05	0
337	Propylene (	Air	oz	1.41E-06	0
338	Propylamin	Air	oz	5.31E-11	0
339	Propionic a	Air	oz	3.44E-05	0
340	Propene	Air	oz	0.000218	0
341	Propane	Air	oz	0.006513	0
342	Propanal	Air	oz	5.02E-08	0
344	Potassium	Air	oz	0.003553	0
345	Polychlorin	Air	oz	6.37E-08	0
349	Platinum	Air	oz	2.74E-11	0
350	Phosphoru	Air	oz	7.44E-05	0
351	Phosphine	Air	oz	7.69E-12	0
352	Phenol, pe	Air	oz	4.83E-07	0
353	Phenol, 2,4	Air	oz	2.78E-11	0
354	Phenol	Air	oz	6.66E-06	0
355	Pentane	Air	oz	0.006239	0
356	Particulates	Air	oz	0.272453	2.092772
357	Particulates	Air	oz	0.55045	0
358	Particulates	Air	oz	0.234223	0
359	PAH, polyc	Air	oz	0.002838	0
360	Ozone	Air	oz	0.003411	0
362	NMVOC, n	Air	oz	0.1383	0
363	Nitrogen o(	Air	oz	1.088406	3.540656
364	Nitrobenze	Air	oz	6.39E-10	0
365	Nitrate	Air	oz	3.84E-05	0
367	Nickel	Air	oz	0.00071	0.013985
368	Monoethar	Air	oz	1.55E-06	0
369	Molybdenu	Air	oz	1.16E-05	0.002938
370	Methyl lact	Air	oz	1.15E-10	0
371	Methyl forn	Air	oz	8.35E-11	0
372	Methyl ethy	Air	oz	1.61E-05	0
373	Methyl bora	Air	oz	3.42E-11	0
374	Methyl ami	Air	oz	5.36E-11	0
375	Methyl acry	Air	oz	1.01E-08	0
376	Methyl ace	Air	oz	1.36E-12	0
377	Methanol	Air	oz	0.00023	0
378	Methanesu	Air	oz	3.38E-11	0
379	Methane, t	Air	oz	1.21E-09	0
380	Methane, t	Air	oz	6.18E-12	0
381	Methane, t	Air	oz	0.008005	0
382	Methane, t	Air	oz	4.25E-07	0
383	Methane, n	Air	oz	6.22E-08	0
384	Methane, f	Air	oz	1.033944	0
385	Methane, c	Air	oz	3.8E-12	0
386	Methane, c	Air	oz	1.2E-08	0
387	Methane, c	Air	oz	4.39E-08	0
388	Methane, c	Air	oz	1.04E-05	0

389	Methane, b	Air	oz	1.76E-06	0
390	Methane, b	Air	oz	2.9E-06	0
391	Methane, b	Air	oz	1.63E-13	0
392	Methane, b	Air	oz	0.119773	0
393	Mercury	Air	oz	3.3E-05	0
395	Manganese	Air	oz	0.00021	0
396	Magnesium	Air	oz	0.000621	0
397	m-0ylene	Air	oz	1.42E-05	0
399	Lead	Air	oz	0.001327	0
401	Lactic acid	Air	oz	1.05E-10	0
407	Isopropylar	Air	oz	3.19E-10	0
408	Isoprene	Air	oz	2.02E-08	0
409	Isocyanic a	Air	oz	2.78E-06	0
410	Iron	Air	oz	0.003835	0
415	Iodine	Air	oz	0.000145	0
416	Hydrogen s	Air	oz	0.003046	0
417	Hydrogen p	Air	oz	2.4E-08	0
418	Hydrogen f	Air	oz	0.025245	0
419	Hydrogen c	Air	oz	0.033507	0
421	Hydrogen	Air	oz	0.001597	0
422	Hydrocarbo	Air	oz	0.002911	0
423	Hydrocarbo	Air	oz	0.000543	0
424	Hydrocarbo	Air	oz	0.000918	0
425	Hydrocarbo	Air	oz	0.002348	0
426	Hydrocarbo	Air	oz	4.06E-07	0
427	He0ane	Air	oz	0.001998	0
428	Heptane	Air	oz	0.000635	0
429	Helium	Air	oz	0.00016	0
431	Furan	Air	oz	4.35E-07	0
432	Formic acid	Air	oz	1.55E-06	0
433	Formamide	Air	oz	1.68E-10	0
434	Formaldehy	Air	oz	0.001084	0
435	Fluosilicic a	Air	oz	0.001039	0
436	Fluorine	Air	oz	0.000223	0
437	Ethyne	Air	oz	3.79E-05	0
438	Ethylene o	Air	oz	1.76E-07	0
439	Ethylene di	Air	oz	2.8E-09	0
440	Ethylamine	Air	oz	1.09E-09	0
441	Ethyl cellul	Air	oz	3.23E-08	0
442	Ethyl aceta	Air	oz	1.61E-05	0
443	Ethene, tet	Air	oz	5.16E-09	0
444	Ethene, ch	Air	oz	1.28E-05	0
445	Ethene	Air	oz	0.006761	0
446	Ethanol	Air	oz	0.000173	0
447	Ethane, he	Air	oz	0.000889	0
448	Ethane, 1,2	Air	oz	3.21E-06	0
449	Ethane, 1,2	Air	oz	1.86E-05	0
450	Ethane, 1,1	Air	oz	4.22E-10	0
451	Ethane, 1,1	Air	oz	1.82E-05	0
452	Ethane, 1,1	Air	oz	2.34E-09	0
453	Ethane, 1,1	Air	oz	4.21E-08	0
454	Ethane	Air	oz	0.030166	0
455	Dipropylam	Air	oz	1.34E-10	0
456	Dio0in, 2,3	Air	oz	4.05E-10	1.05E-09
457	Dinitrogen	Air	oz	0.014759	0

458	Dimethyl m	Air	oz	4.19E-11	0
459	Diethylamii	Air	oz	2.13E-10	0
460	Cyanoaceti	Air	oz	3.34E-11	0
461	Cyanide	Air	oz	3.05E-05	0
462	Cumene	Air	oz	1.61E-05	0
463	Copper	Air	oz	0.001221	0
466	Cobalt	Air	oz	2.24E-05	0
467	Chromium	Air	oz	1.64E-05	2.8E-05
469	Chromium	Air	oz	0.000561	0.053518
470	Chlorosulfc	Air	oz	4.08E-11	0
471	Chlorosilar	Air	oz	1.45E-08	0
472	Chloroform	Air	oz	9.36E-08	0
473	Chloroacet	Air	oz	7.46E-09	0
474	Chlorine	Air	oz	0.000196	0
475	Chloramine	Air	oz	3.29E-10	0
479	Carbon mc	Air	oz	3.225582	4.63998
480	Carbon mc	Air	oz	0.510836	0
481	Carbon dis	Air	oz	0.009075	0
482	Carbon dio	Air	oz	0.008804	1591.542
483	Carbon dio	Air	oz	528.2448	0
484	Carbon dio	Air	oz	31.24457	0
486	Calcium	Air	oz	0.001846	0
487	Cadmium	Air	oz	9.1E-05	0
488	Butyrolacto	Air	oz	5.41E-11	0
489	Butene	Air	oz	6.35E-05	0
490	Butane	Air	oz	0.004922	0
491	Butadiene	Air	oz	1.75E-10	0
492	Bromine	Air	oz	0.000305	0
493	Boron triflu	Air	oz	1.42E-15	0
494	Boron	Air	oz	0.002387	0
495	Beryllium	Air	oz	5.89E-07	0
496	Benzo(a)py	Air	oz	8.81E-05	0
497	Benzene, p	Air	oz	5.96E-09	0
498	Benzene, h	Air	oz	3.96E-08	0
499	Benzene, e	Air	oz	6.72E-05	0
500	Benzene, 1	Air	oz	2.55E-10	0
501	Benzene, 1	Air	oz	5.06E-12	0
502	Benzene	Air	oz	0.001833	0
503	Benzaldehy	Air	oz	4.88E-08	0
504	Benzal chlc	Air	oz	7.15E-13	0
506	Barium	Air	oz	7.09E-05	0
507	Arsine	Air	oz	1.04E-13	0
508	Arsenic	Air	oz	0.000318	0
512	Antimony	Air	oz	3.34E-05	0
513	Anthranilic	Air	oz	4.27E-12	0
514	Aniline	Air	oz	4.74E-10	0
515	Ammonium	Air	oz	7.99E-07	0
516	Ammonia	Air	oz	0.023915	0
517	Aluminium	Air	oz	0.048478	0
518	Aldehydes,	Air	oz	4.58E-06	0
521	Acrylic acic	Air	oz	8.9E-09	0
522	Acrolein	Air	oz	1.4E-07	0
523	Acetonitrile	Air	oz	2.29E-07	0
524	Acetone	Air	oz	9.59E-05	0
525	Acetic acid	Air	oz	0.000653	0

526	Acetaldehy	Air	oz	0.000114	0
527	Acenaphth	Air	oz	6.28E-10	0
528	2-Propanol	Air	oz	3.44E-06	0
529	2-Nitroben:	Air	oz	5.86E-12	0
530	2-Methyl-1-	Air	oz	1.66E-10	0
531	2-Butene, 2	Air	oz	1.54E-14	0
532	2-Aminopr(	Air	oz	3.85E-12	0
533	1,4-Butane	Air	oz	2.38E-10	0
534	1-Propanol	Air	oz	2.29E-09	0
535	1-Pentene	Air	oz	6.93E-11	0
536	1-Pentanol	Air	oz	9.18E-11	0
537	1-Butanol	Air	oz	1.03E-11	0
				569.0322	1607.717
538	Zirconium,	Raw	oz	7.61E-07	0
539	Zinc, 9.0%	Raw	oz	4.415776	0
546	Water, uns	Raw	oz	0	8939.925
557	Vermiculite	Raw	oz	0.00025	0
558	Uranium, ir	Raw	oz	0.003808	0
559	Ule0ite, in (	Raw	oz	3.2E-05	0
613	TiO2, 95%	Raw	oz	2.05E-08	0
614	TiO2, 54%	Raw	oz	0.020173	0
615	Tin, 79% ir	Raw	oz	0.000147	0
616	Tellurium, (	Raw	oz	7.85E-08	0
617	Tantalum, ;	Raw	oz	5.74E-07	0
618	Talc, in grc	Raw	oz	0.000422	0
619	Sylvite, 25	Raw	oz	0.000471	0
620	Sulfur, in g	Raw	oz	0.000131	0
621	Stibnite, in	Raw	oz	1.48E-09	0
622	Sodium sul	Raw	oz	0.003695	0
623	Sodium niti	Raw	oz	4.17E-10	0
624	Sodium chl	Raw	oz	4.490285	0
625	Silver, Ag 9	Raw	oz	7.14E-08	0
626	Silver, Ag 4	Raw	oz	1.08E-07	0
627	Silver, Ag 4	Raw	oz	1.1E-07	0
628	Silver, Ag 2	Raw	oz	4.83E-08	0
629	Silver, 3.2p	Raw	oz	5.24E-07	0
630	Silver, 0.0C	Raw	oz	7.34E-07	0
631	Shale, in gi	Raw	oz	3.1E-06	0
632	Sand, unsp	Raw	oz	0.000376	0
633	Rhenium, i	Raw	oz	1.6E-09	0
634	Rh, Rh 2.4	Raw	oz	4.25E-09	0
635	Rh, Rh 2.0	Raw	oz	1.36E-09	0
636	Pt, Pt 4.8E-	Raw	oz	1.3E-08	0
637	Pt, Pt 2.5E-	Raw	oz	3.63E-09	0
638	Phosphoru	Raw	oz	0.001919	0
639	Phosphoru	Raw	oz	0.000948	0
640	Peat, in grc	Raw	oz	2.336853	0
641	Pd, Pd 7.3I	Raw	oz	1.4E-07	0
642	Pd, Pd 2.0I	Raw	oz	5.82E-08	0
643	Olivine, in (	Raw	oz	4.49E-07	0
644	Oil, crude,	Raw	oz	47.46258	0
666	Nickel, in g	Raw	oz	0	0.122462
667	Nickel, 1.9	Raw	oz	0.124179	0
668	Nickel, 1.1:	Raw	oz	0.000122	0

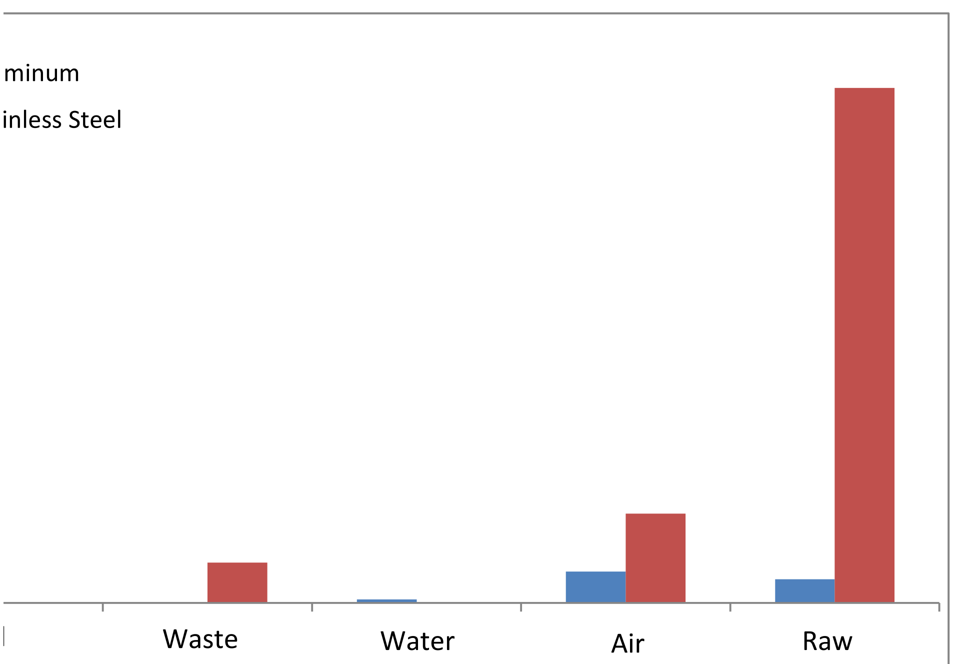
669	Molybdenu	Raw	oz	0	0.000759
670	Molybdenu	Raw	oz	0.000186	0
671	Molybdenu	Raw	oz	0.004437	0
672	Molybdenu	Raw	oz	9.22E-05	0
673	Molybdenu	Raw	oz	0.001211	0
674	Molybdenu	Raw	oz	0.008494	0
675	Metamorph	Raw	oz	0.265087	105.1985
676	Manganes	Raw	oz	0	1.039119
677	Manganes	Raw	oz	1.938872	0
678	Magnesium	Raw	oz	3.739486	0
679	Magnesite,	Raw	oz	0.056058	0
680	Lithium, 0.:	Raw	oz	4.86E-09	0
681	Lead, 5.0%	Raw	oz	0.011261	0
682	Kieserite, 2	Raw	oz	1.15E-05	0
683	Kaolinite, 2	Raw	oz	0.002725	0
684	Iron, 46% i	Raw	oz	3.911819	101.6849
685	Iodine, 0.0:	Raw	oz	2.59E-07	0
686	Indium, 0.0	Raw	oz	5.81E-07	0
687	Gypsum, ir	Raw	oz	0.004033	0
688	Gravel, in (	Raw	oz	79.68418	0
689	Granite, in	Raw	oz	3.9E-10	0
690	Gold, Au 9.	Raw	oz	6.59E-09	0
691	Gold, Au 7.	Raw	oz	1.1E-07	0
692	Gold, Au 6.	Raw	oz	9.75E-08	0
693	Gold, Au 4.	Raw	oz	6.3E-08	0
694	Gold, Au 4.	Raw	oz	2.63E-08	0
695	Gold, Au 2.	Raw	oz	1.06E-07	0
696	Gold, Au 1.	Raw	oz	6.95E-08	0
697	Gold, Au 1.	Raw	oz	5.8E-08	0
698	Gold, Au 1.	Raw	oz	3.16E-08	0
701	Gallium, 0.	Raw	oz	3.24E-10	0
702	Fluorspar,	Raw	oz	0.124802	0
703	Fluorine, 4.	Raw	oz	0.000217	0
704	Fluorine, 4.	Raw	oz	0.00048	0
705	Feldspar, ir	Raw	oz	3.1E-07	0
715	Dolomite, ir	Raw	oz	0.025741	22.64655
716	Diatomite,	Raw	oz	1.42E-08	0
717	Copper, 2.:	Raw	oz	0.457083	0
718	Copper, 1.4	Raw	oz	0.092193	0
719	Copper, 1.:	Raw	oz	0.347552	0
720	Copper, 0.9	Raw	oz	0.062661	0
721	Colemanite	Raw	oz	0.001161	0
722	Cobalt, in (	Raw	oz	4.75E-07	0
723	Coal, hard,	Raw	oz	113.3389	0
724	Coal, brow	Raw	oz	66.16817	0
725	Clay, unsp	Raw	oz	4.039969	0
726	Clay, bento	Raw	oz	0.079806	0
727	Cinnabar, i	Raw	oz	9.28E-06	0
728	Chrysotile,	Raw	oz	0.0001	0
729	Chromium,	Raw	oz	0	7.253645
730	Chromium,	Raw	oz	0.750098	0
731	Carbon, in	Raw	oz	0.00034	0
732	Carbon dio	Raw	oz	33.09387	0
733	Calcite, in (	Raw	oz	24.87991	97.99748
734	Cadmium,	Raw	oz	3.56E-05	0

735	Bromine, 0	Raw	oz	1.12E-06	0
736	Bora0, in g	Raw	oz	2.32E-06	0
737	Basalt, in g	Raw	oz	0.029002	0
738	Barite, 15%	Raw	oz	0.286902	0
739	Anhydrite, i	Raw	oz	1.1E-06	0
740	Aluminium,	Raw	oz	37.01824	0
				429.2874	9275.868

ni0, grade 304 RER S (of project ELCD)

ckled, elec. arc furnace route, prod. mi0, grade 304 RER S

Aluminum	Steel
0.272957492	0
0	726.2963298
67.40369039	2.747615177
569.032243	1607.71698
429.2873766	9275.868186



Great Plains Industries, Inc.
5252 E. 36th St. N.
Wichita, KS 67220
Tel: 888-996-3837
Fax: 316-686-6746
Email: meters@gplains.com

Item # TM075-N, TM Series Water Meter 3/4 in.

TM Series Water Meter 3/4 in.

3/4" PVC water meter with NPT fittings and local electronic LCD computer that reads Gallons, Litres and Cubic Feet.FindADistributor();

SPECIFICATIONS

Design Type	Turbine
Fitting Size	3/4 Inch
Fitting Type	NPT (Female)
Housing Material	PVC
Flow Range	2 to 20 GPM 7.6 to 76 LPM
Accuracy	±3.0 %
Accuracy (% of Reading - Turbine with Computer)	±3.0 %
Operating Temperature Range	+32 to 140 ºF 0 to 60 ºC
Reads	Gallons Litres
Pressure Rating at 73ºF	225 psi 15.3 bar
Display Options	Rate of Flow, Batch and Cumulative Totals. Field Calibration available.
Battery Life	5 Years
Typical K-Factor	1100
Electronic Choice	09 - 2 Totals (1 Resettable/ 1 Cumulative), Factory Calibration in Gallons and Litres, 2 User Calibrations and Flowrate

Wetted Material Housing	PVC
Wetted Material Bearings	Ceramic
Wetted Material Shaft	Tungsten Carbide
Wetted Material Rotor	PVDF
Wetted Material Rings	316 Stainless Steel
Applications	OEM Water Treatment Equipment / Skids Small Waste Water Treatment Equipment Sub-Metering of Facility Water Usage Water Based Cooling Systems
Popularity	**Most Popular**
Approval	CE
Approvals	CE
Warranty	1 Year
Powered By	Lithium battery
Max Cumulative	6 Digit
Use with	Water and Mild Chemicals
Max Batch	6 Digit
Display Type	LCD
Operating Temperature Ranges	+32 to 140 ºF 0 to 60 ºC
Flowrate	2 to 20 gpm 7.6 to 76 lpm
Construction	Schedule 80 PVC
Unique Feature	Sturdy Construction with easy access to internal parts

Model FP2000

Configurable Pressure Transducer

DESCRIPTION

The FP2000 series is a configurable differential pressure transducer which allows the customer to select the configuration which best fits the needs of the application. Choose from multiple accuracies, outputs, pressure ports, electrical terminations, and pressure ranges.

The FP2000 is available with gage, absolute, barometric, or vacuum reference and, best of all, they delivery in two weeks or less.

FEATURES

- mV/V, 0 Vdc to 5 Vdc, 0 Vdc to 10 Vdc, 4 mA to 20 mA
- Gage, absolute, barometric, vacuum
- Differential (wet/wet, wet/dry)
- Intrinsically safe option[5]
- CE available[6]

FP2000 pressure sensors are custom built from stocked components, and most are shipped in 10 business days or less. Please see http://measurementsensors.honeywell.com for updated listings

Model FP2000

PERFORMANCE SPECIFICATIONS

Characteristic	Measure
Accuracy [1]	See accuracy table
Output (selectable)	mV/V (see accuracy table), 0 Vdc to 5 Vdc, 0 Vdc to 10 Vdc, or 4 mA to 20 mA (two wire)
Resolution	Infinite

ENVIRONMENTAL SPECIFICATIONS

Characteristic	Measure
Temperature, operating	-40 °C to 116 °C [-40 °F to 240 °F]
Temperature, compensated	4 °C to 60 °C [40 °F to 140 °F] [2]
Temperature, error band [2]	
0.10 % accuracy	±0.5 % full scale
0.25 % accuracy	±1.0 % full scale

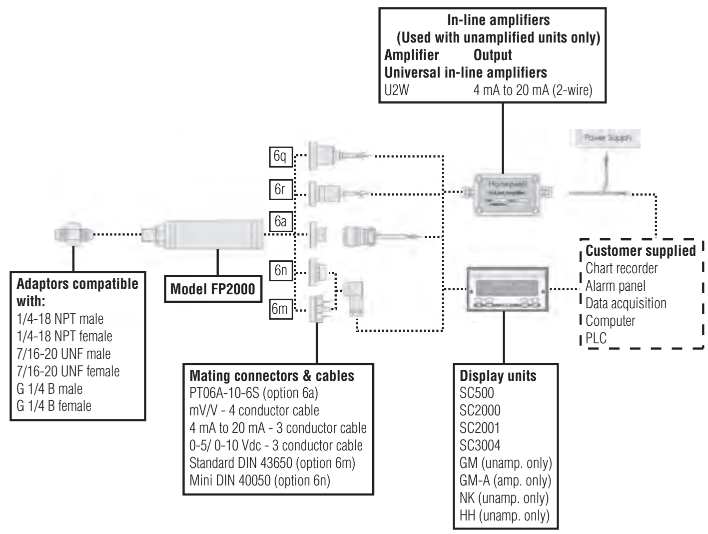
ELECTRICAL SPECIFICATIONS

Characteristic	Measure
Excitation (calibration)	
Amplified	
(4 mA to 20 mA; 0 Vdc to 5 Vdc)	9 Vdc to 28 Vdc
Amplified	
(0 Vdc to 10 Vdc)	15 Vdc to 28 Vdc
Unamplified (mV/V)	10 Vdc

MECHANICAL SPECIFICATIONS

Characteristic	Measure
Media 3	Gas, liquid
Overload - safe	
positive (+) direction	4X full scale or 3000 psi, whichever is less
negative (-) direction	4X full scale or 250 psi, whichever is less
Overload - burst	
positive (+) direction	3000 psi
negative (-) direction	500 psi
Pressure port	200 % over capacity
Wetted parts material	Ha C276 & 316L stainless steel

TYPICAL SYSTEM DIAGRAM



PRESSURE RANGES AND RANGE CODES

	psi	Range code	torr	Range code	mBar	Range code	kPa	Range code	Bar	Range code	in Hg	Range code	mm Hg	Range code	in H_2O	Range code
Gage/ Absolute	0.5*	AN	15**	HA	35**	JA	2**	KA	0.035**	MA	1**	UB	15**	VA	5**	WB
	1*	AP	50**	HB	70**	JB	7**	KB	0.1**	MB	2**	UD	50**	VB	10**	WA
	2*	AR	135**	HC	175**	JC	15**	KC	0.2	MC	5	UF	135	VC	20**	WC
	2.5*	AS	250	HD	350	JD	35	KD	0.5	MD	10	UA	250	VD	30**	WE
	5	AT	750	HE	700	JE	70	KE	1	ME	15	UC	750	VE	50**	WG
	10	AV	1500	HF	750	JF	100	KF	2	MF	20	UE	1500	VF	100	WI
	15	BJ			1000	JG	200	KG	3.5	NA	30	UG			120	WK
	25	BL			3500	JH	300	KH	5	MG	50	UI			150	WM
	30	BM			7000	JI	700	KJ	7	NB	60	UK			200	WP
	50	BN			10000	JK	1000	KL	10	MH	80	UM			300	WR
	75	BP					1500	KM	20	MI	100	UP			500	WS
	100	BR					1700	KN	30	MJ	200	UH				
	150	CJ					2000	KP	35	NC	300	UJ				
	200	CL					3000	KQ	50	MK	500	UL				
	250	CN					5000	KR	70	ND	1000	UN				
	300	CP					7000	KS	100	ML	0-32	US				
	400	CQ					10000	KT	135	NE	16-32	UQ				
	500	CR					15000	KU	350	NG	26-32	UR				
	600	CS					20000	KV	500	MM						
	750	CT					35000	KW	700	NH						
	1000	CV					50000	KY								
	1500	DJ					70000	KZ								
	2000	DL														
	2500	DM														
	3000	DN														
	5000	DR														
	6000	DS														
	7500	DT														
	10000	DV														
Barometric (Order code FPB)											0-30	UG				
											16-32	UQ				
											26-32	UR				
Vacuum (Order code FPV)	1	AP	50	HB	35	JA	7	KB	0.035	MA	10	UA	15	VA	10	WA
	5	AT	135	HC	70	JB	15	KC	0.1	MB	20	UE	50	VB	20	WC
	10	AV	250	HD	175	JC	35	KD	0.2	MC	30	UG	135	VC	30	WE
	15	BJ	750	HE	350	JD	100	KF	0.5	MD			250	VD	50	WG
					700	JE			1	ME			750	VE	100	WI
					750	JF										
					1000	JG										
Differential (Order codes FDD, FDW)	0.5	AN	15	HA	35	JA	2	KA	0.035	MA	1	UB	15	VA	5	WB
	1	AP	50	HB	70	JB	7	KB	0.1	MB	2	UD	50	VB	10	WA
	2	AR	135	HC	175	JC	15	KC	0.2	MC	5	UF	135	VC	20	WC
	2.5	AS	250	HD	350	JD	35	KD	0.5	MD	10	UA	250	VD	30	WE
	5	AT	750	HE	700	JE	70	KE	1	ME	15	UC	750	VE	50	WG
	10	AV	1500	HF	750	JF	100	KF	2	MF	20	UE	1500	VF	100	WI
	15	BJ			1000	JG	200	KG	3.5	NA	30	UG			120	WK
	25	BL			3500	JH	300	KH	5	MG	50	UI			150	WM
	30	BM			7000	JI	700	KJ	7	NB	60	UK			200	WP
	50	BN			10000	JK	1000	KL	10	MH	80	UM			300	WR
	75	BP					1500	KM	20	MI	100	UP			500	WS
	100	BR					1700	KN	30	MJ	200	UH				
	150	CJ					2000	KP	35	NC	300	UJ				
	200	CL					3000	KQ	50	MK	500	UL				
	250	CN					5000	KR	70	ND	1000	UN				
	300	CP					7000	KS			0-32	US				
	400	CQ					10000	KT			16-32	UQ				
	500	CR					15000	KU			26-32	UR				
	600	CS					20000	KV								
	750	CT					35000	KW								
	1000	CV					50000	KY								

* 0.5 psi to 2.5 psi ranges are not available for absolute pressure

** Not available in absolute

Model FP2000

INTERNAL AMPLIFIERS

Amplifier specifications	Unamplified output: Option 2u	Voltage output: Option 2d	Voltage output: Option 2g	Current two-wire: Option 2p
Output signal	See accuracy table	0 Vdc to 5 Vdc	0 Vdc to 10 Vdc	4 mA to 20 mA
Input power (voltage)	10 Vdc	9 Vdc to 28 Vdc	15 Vdc to 28 Vdc	9 Vdc to 32 Vdc
Input power (current)	2 mA @ 10 Vdc	10 mA	15 mA	4 mA to 24 mA
Frequency response	Natural frequency	300 Hz	300 Hz	300 Hz
Power supply rejection	N/A	60 dB	60 dB	60 dB
Operating temperature	-40 °C to 116 °C [-40 °F to 240 °F]	-29 °C to 85 °C [-20 °F to 185 °F]	-29 °C to 85 °C [-20 °F to 185 °F]	-29 °C to 85 °C [-20 °F to 185 °F]
Reverse voltage protection	N/A	Yes	Yes	Yes
Short circuit protection	N/A	Momentary	Momentary	Yes

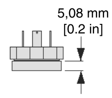
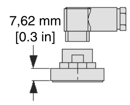
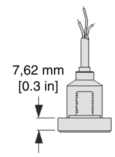
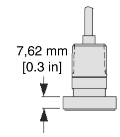
Amplifier specifications	Voltage output: Option 2e	Voltage output: Option 2f	Intrinsically safe amp: Option 2n (2N)***	Current two-wire: Option 2y
Output signal	0 Vdc to 5 Vdc	0 Vdc to 10 Vdc	4 mA to 20 mA	4 mA to 20 mA
Input power (voltage)	9 Vdc to 28 Vdc	15 Vdc to 28 Vdc	9 Vdc to 28 Vdc	9 Vdc to 32 Vdc
Input power (current)	10 mA	15 mA	4 mA to 24 mA	4 mA to 24 mA
Frequency response	2000 Hz	2000 Hz	2000 Hz	2000 Hz
Power supply rejection	60 dB	60 dB	60 dB	60 dB
Operating temperature	-29 °C to 85 °C [-20 °F to 185 °F]	-29 °C to 85 °C [-20 °F to 185 °F]`	-29 °C to 85 °C [-20 °F to 185 °F]	-29 °C to 85 °C [-20 °F to 185 °F]
Reverse voltage protection	Yes	Yes	Yes	Yes
Short circuit protection	Momentary	Momentary	Yes	Yes

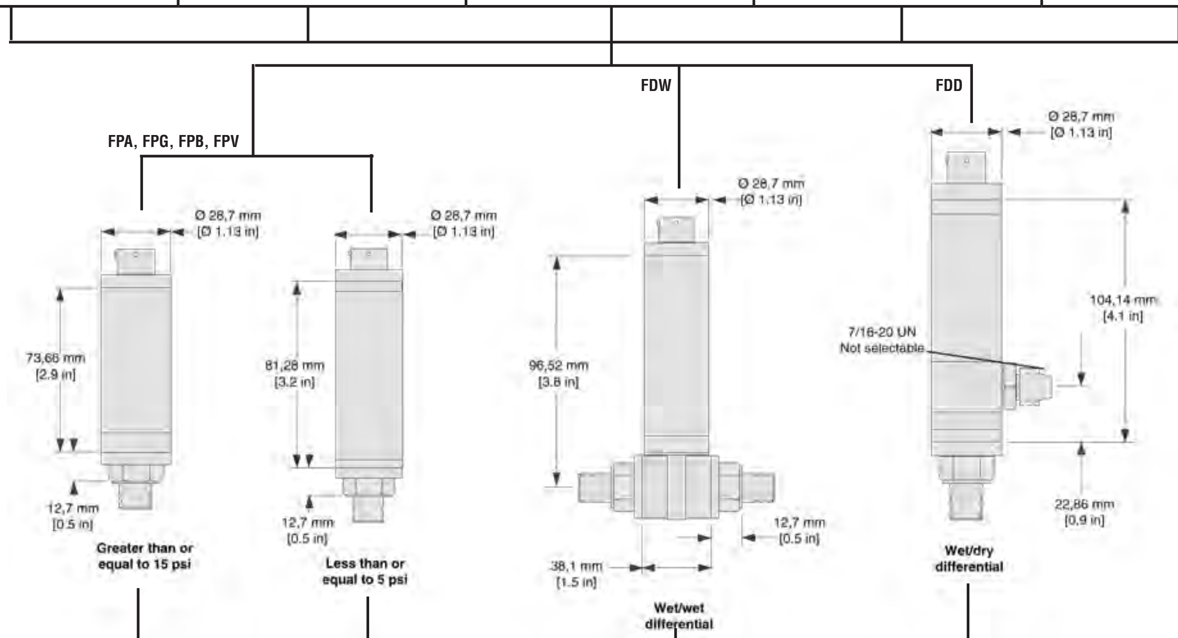
ACCURACY

Non-amplifed output @ 10 Vdc excitation	Gage and absolute	Vacuum	Barometric	Differential
0.10 % accuracy	50 mV[4]	25 mV	40 mV	50 mV[4]
0.25 % accuracy	100 mV	50 mV	80 mV	100 mV

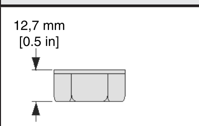
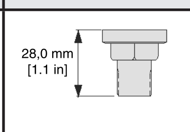
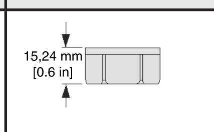
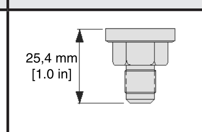
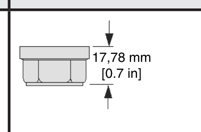
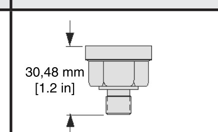
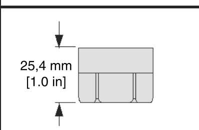
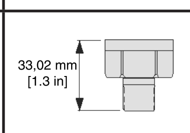
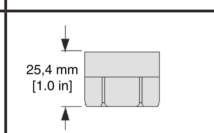
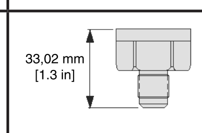
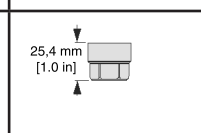
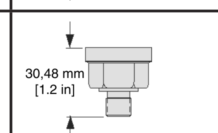
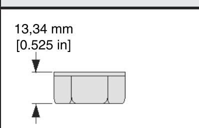
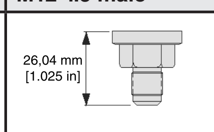
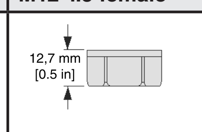
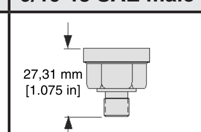
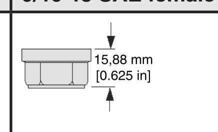
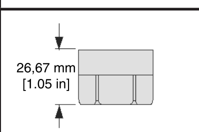
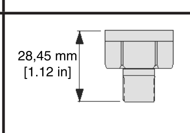
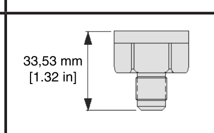
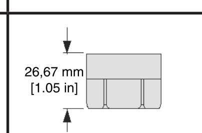
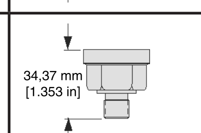
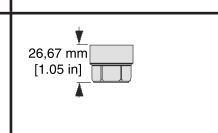
MOUNTING DIMENSIONS

Electrical termination

Code 6a: 6-pin, vented, Bendix style	Code 6m: 4-pin, vented, standard DIN (43650)	Code 6n: 4-pin, vented, mini DIN	Code 6q: 4-conductor, vented, integral cable, 1,52 m [5 ft]	Code 6r: 4-conductor, vented, integral cable, conduit fitting 1,52 m [5 ft]
				



Pressure ports

	Code 5a 1/4-18 NPT female	Code 5b 1/4-18 NPT male	Code 5c 7/16-20 UNF female	Code 5d 7/16-20 UNF male	Code 5f G 1/4 B female	Code 5g G 1/4 B male
Less than 1000 psi						
Greater than 1500 psi						
	Code 5h 1/8-27 NPT female	**Code 5i 1/8-27 NPT male**	**Code 5p M12-1.5 male**	**Code 5q M12-1.5 female**	**Code 5r 9/16-18 SAE male**	**Code 5s 9/16-18 SAE female**
Less than 1000 psi						
Greater than 1500 psi						

Model FP2000

WIRING CODES

	Unamplified output: Option 2u	Voltage output: Option 2d/2e	Voltage output: Option 2g/2f	Current two-wire: Option 2p/2y	Intrinsically safe amp: Option 2n (2N)***
Bendix PTIH-10-6P (Option 6a)					
No shunt cal	A (+) Excitation B (+) Excitation C (-) Excitation D (-) Excitation E (-) Output F (+) Output	A (+) Supply B (-) Supply return C (-) Output 0 Vdc to 5 Vdc D (+) Output E No connection F No connection	A (+) Supply B (-) Supply return C (-) Output 0 Vdc to 10 Vdc D (+) Output Vdc E No connection F No connection	A (+) Supply B No connection C No connection D (+) Output 4 mA to 20 mA E No connection F No connection	A (+) Supply B No connection C No connection D (+) Output 4 mA to 20 mA E Case ground F No connection
With shunt cal (option 3d)	A (+) Excitation B (-) Excitation C (+) Output D (-) Output E No connection F Shunt Cal	A (+) Supply B (-) Supply return C (-) Output 0 Vdc to 5 Vdc D (+) Output E No connection F Shunt cal	A (+) Supply B (-) Supply return C (-) Output 0 Vdc to 10 Vdc D (+) Output E No connection F Shunt cal	A (+) Supply B No connection C No connection D (+) Output 4 mA to 20 mA E No connection F Shunt cal	A (+) Supply B No connection C No connection D (+) Output 4 mA to 20 mA E No connection F Shunt cal
Std. DIN 43650 (Option 6m)					
No shunt cal	1 (+) Excitation 2 (+) Output 3 (-) Output 4 (-) Excitation	1 (+) Supply 2 (+) Output 3 Supply/ output com. GND No connect. to case	1 (+) Supply 2 (+) Output 3 Supply/ output com. GND No connect. to case	1 (+) Supply 2 (+) Output 4 mA to 20 mA 3 No connection GND No connection	1 (+) Supply 2 (+) Output 3 Case ground GND No connection
With shunt cal (option 3d)	Not Applicable	1 (+) Supply 2 (+) Output 3 Supply/output com. GND Shunt cal	1 (+) Supply 2 (+) Output 3 Supply/output com. GND Shunt cal	1 (+) Supply 2 (+) Output 4 mA to 20 mA 3 No connection GND Shunt cal	1 (+) Supply 2 (+) Output 3 Case ground GND Shunt cal
Mini DIN 40050 (Option 6n)					
No shunt cal	1 (+) Excitation 2 (+) Output 3 (-) Output 4 (-) Excitation	1 (+) Supply 2 (+) Output 3 Supply/output com. GND No connect. to case	1 (+) Supply 2 (+) Output 3 Supply/output com. GND No connect. to case	1 (+) Supply 2 (+) Output 4 mA to 20 mA 3 No connection GND No connection to case	1 (+) Supply 2 (+) Output 3 Case ground GND No connection
With shunt cal (option 3d)	Not Applicable	1 (+) Supply 2 (+) Output 3 Supply/output com. GND Shunt cal	1 (+) Supply 2 (+) Output 3 Supply/output com. GND Shunt cal	1 (+) Supply 2 (+) Output 4 mA to 20 mA 3 No connection GND Shunt cal	1 (+) Supply 2 (+) Output 3 Case ground GND Shunt cal
1.83 m [5 ft] integral cable (Option 6q)					
No shunt cal	R (+) Excitation Bl (-) Excitation G (-) Output W (+) Output	R (+) Supply Bl (-) Supply return G (-) Output W (+) Output 0 Vdc to 5 Vdc	R (+) Supply Bl (-) Supply return G (-) Output W (+) Output 0 Vdc to 10 Vdc	R (+) Supply Bl (+) Output 4 mA to 20 mA	R (+) Supply Bl (+) Output 4 mA to 20 mA W Case ground
With shunt cal (option 3d)	Not Applicable	R (+) Supply Bl (-) Supply return G Shunt cal W (+) Output 0 Vdc to 5 Vdc	R (+) Supply Bl (-) Supply return G Shunt cal W (+) Output 0 Vdc to 10 Vdc	R (+) Supply Bl (+) Output 4 mA to 20 mA G Shunt cal	R (+) Supply Bl (+) Output 4 mA to 20 mA W Case ground G Shunt cal
Conduit fitting (Option 6r)					
No shunt cal	R (+) Excitation Bl (-) Excitation G (-) Output W (+) Output	R (+) Supply Bl (-) Supply return G (-) Output W (+) Output 0 Vdc to 5 Vdc	R (+) Supply Bl (-) Supply return G (-) Output W (+) Output 0 Vdc to 10 Vdc	R (+) Supply Bl (+) Output 4 mA to 20 mA	R (+) Supply Bl (+) Output 4 mA to 20 mA W Case ground
With shunt cal (option 3d)	Not Applicable	R (+) Supply Bl (-) Supply return G Shunt cal W (+) Output 0 Vdc to 5 Vdc	R (+) Supply Bl (-) Supply return G Shunt cal W (+) Output 0 Vdc to 10 Vdc	R (+) Supply Bl (+) Output 4 mA to 20 mA G Shunt cal	R (+) Supply Bl (+) Output 4 mA to 20 mA W Case ground G Shunt cal

Note: For wiring codes, R=red; Bl = black; W = white; G = green. Color specifies cable and letter or number specifies connection

*** See Honeywell's Web site (http://measurementsensors.honeywell.com) for most up-to-date information regarding Intrinsically Safe approvals ref. #008-0547-00.

How to order

The FP2000 Order Code is an easy way for you to order exactly what you want the factory to build. Simply make one selection in each of the six required categories. Choose adders and accessories only if you require them. By visiting our Web site at **www.honeywell.com/sensing** you can view complete technical specifications for the FP2000, or click to our on-line shopping site and actually place your order.

Step 1

Transducer type

	Type Code
☐ Pressure - gage	FPG
☐ Pressure - absolute	FPA
☐ Differential - wet/wet	FDW
☐ Pressure - barometric	FPB
☐ Differential - wet/dry	FDD
☐ Pressure - vacuum	FPV

Unit type

☐ psi	☐ bar
☐ torr	☐ in Hg
☐ mBar	☐ mm Hg
☐ kPa	☐ in H_2O

Step 2

Pressure range

Gage, absolute, and differential

	Range code		Range code
☐ 0.5 psi	AN	☐ 250 psi	CN
☐ 1 psi	AP	☐ 300 psi	CP
☐ 2 psi	AR	☐ 400 psi	CQ
☐ 2.5 psi	AS	☐ 500 psi	CR
☐ 5 psi	AT	☐ 600 psi	CS
☐ 10 psi	AV	☐ 750 psi	CT
☐ 15 psi	BJ	☐ 1000 psi	CV
☐ 25 psi	BL	☐ 1500 psi	DJ
☐ 30 psi	BM	☐ 2000 psi	DL
☐ 50 psi	BN	☐ 2500 psi	DM
☐ 75 psi	BP	☐ 3000 psi	DN
☐ 100 psi	BR	☐ 5000 psi	DR
☐ 150 psi	CJ	☐ 6000 psi	DS
☐ 200 psi	CL	☐ 7500 psi	DT
		☐ 10000 psi	DV

Barometric		Vacuum	
☐ 16-32 in Hga	UQ	☐ 1 psi	AP
☐ 26-32 in Hga	UR	☐ 5 psi	AT
☐ 0-30 in Hga	UG	☐ 10 psi	AV
		☐ 15 psi	BJ

Accuracy

	Accuracy code
☐ 0.10 %	1
☐ 0.25 %	2

Step 3

Output

	Basic output code	If adding 9d or 9f (<5000 psi)	If adding 1y, 3d, 9e or 14c
☐ mV/V	2u	NA	2u
☐ 5 Vdc	2d	NA	2e
☐ 10 Vdc	2g	NA	2f
☐ 4 mA to 20 mA	2p	2n(2N)	2y

NOTE: If any ADDERS are required, the output code must be revised. See step 4.

Pressure Port

	Port code
☐ 1/4-18 NPT female	5a
☐ 1/4-18 NPT male	5b
☐ 7/16-20 UNF female	5c
☐ 7/16-20 UNF male	5d
☐ G 1/4 B female	5f
☐ G 1/4 B male	5g
☐ 1/8-27 NPT female	5h
☐ 1/8-27 NPT male	5i
☐ M12 x 1.5 male	5p
☐ M12 x 1.5 female	5q
☐ 9/16-18 UNF SAE male	5r
☐ 9/16-18 UNF SAE female	5s

Electrical connector

	Connector code
☐ Bendix PTIH-10-6P	6a
☐ DIN 43650	6m
☐ Mini DIN (40050)	6n
☐ Integral polyurethane 5 ft cable	6q
☐ 1/2 x 14 NPT conduit 5 ft cable exit	6r

Step 4

Adders

	Adder code
☐ Enhanced thermals Gage: 0 °F to 180 °F Absolute: 0 °F to 180 °F Differential: 0 °F to 180 °F Barometric: 30 °F to 170 °F Vacuum: 10 °F to 170 °F	1y
☐ Shunt cal	3d
☐ IS rating	9d
☐ CE rating	9e
☐ IS and CE rating	9f
☐ Zero and span adjustments	14c
☐ mV/V	2u
☐ 5 Vdc	2e
☐ 10 Vdc	2f
☐ 4 mA to 20 mA (CE only)	2y
☐ 4 mA to 20 mA (IS only	2n (2N)
☐ 4 mA to 20 mA (IS and CE)	2n (2N)

NOTE: If you choose any adder output from step 4, you must revise your output code selection using this output code chart. IS outputs available only on ranges up to 5000 psi.

Accessories

Mating connectors only

	Acc. code
☐ Mini DIN	AA161
☐ Bendix	AA111

Mating conn. with 15 ft. cable for Bendix connector (6A)

	Without shunt	With shunt (3d)
☐ mV/V	AA113	AA513
☐ 4 mA to 20 mA	AA116	AA516
☐ 0 to 5/0 to 10 Vdc	AA117	AA517

Step 5

Example order code **FDW 1 CN 2y 5b 6a 1y AA116**

Selection	Description	Code
Transducer type	Differential wet/wet	FDW
Accuracy	0.10 %	1
Pressure range	250 psi	CN
Output	4 mA to 20 mA	2y
Pressure port	1/4-18 NPT male	5b
Electrical output connections	Bendix PTIH-10-6P	6a
Adders	Enhanced temperature range	1y
Accessories	Mating connector with cable	AA116

There must be a code in each of the six basic code boxes. If there are no adders or accessories chosen, leave the boxes blank.

Description	Basic code					Adder code (see step 4)				
Order code	Type	Accuracy	Range	Output	Pressure	Elect. conn.	Extended	Shunt cal.	IS/CE rated	Pots
Accessory code										

Zero and span adjustments are located on the side. See drawing for details. No zero and span adjustments are available on mV/V output option.

NOTES

1. Accuracies stated are expected for best-fit straight line for all errors, including linearity, hysteresis, and non-repeatability through zero.
2. For low pressure ranges, temperature effects may vary.
3. The wet/wet differential pressure transducer has two separate, welded Hastelloy diaphragms. In wet/dry unit, the wet port (high port) has all-welded stainless steel and Hastelloy construction. The dry port (low port) has no isolation diaphragm.
4. For low gage and differential pressure ranges at 0.10 % accuracy, non-amplified output @ 10 Vdc excitation = 100 mV.
5. Range up to and include 5000 psi.
6. Not available with 6m.

Warranty. Honeywell warrants goods of its manufacture as being free of defective materials and faulty workmanship. Honeywell's standard product warranty applies unless agreed to otherwise by Honeywell in writing; please refer to your order acknowledgement or consult your local sales office for specific warranty details. If warranted goods are returned to Honeywell during the period of coverage, Honeywell will repair or replace, at its option, without charge those items it finds defective. **The foregoing is buyer's sole remedy and is in lieu of all warranties, expressed or implied, including those of merchantability and fitness for a particular purpose. In no event shall Honeywell be liable for consequential, special, or indirect damages.**

While we provide application assistance personally, through our literature and the Honeywell web site, it is up to the customer to determine the suitability of the product in the application.

Specifications may change without notice. The information we supply is believed to be accurate and reliable as of this printing. However, we assume no responsibility for its use.

WARNING

PERSONAL INJURY

- DO NOT USE these products as safety or emergency stop devices or in any other application where failure of the product could result in personal injury.

Failure to comply with these instructions could result in death or serious injury.

WARNING

MISUSE OF DOCUMENTATION

- The information presented in this datasheet is for reference only. DO NOT USE this document as product installation information.
- Complete installation, operation and maintenance information is provided in the instructions supplied with each product.

Failure to comply with these instructions could result in death or serious injury.

Find out more

Honeywell serves its customers through a worldwide network of sales offices, representatives and distributors. For application assistance, current specifications, pricing or name of the nearest Authorized Distributor, contact your local sales office.

To learn more about Honeywell's test and measurement products, call **+1-614-850-5000**, visit **http://measurementsensors.honeywell.com,** or e-mail inquiries to **info.tm@honeywell.com**

Sensing and Control
Honeywell
1985 Douglas Drive North
Golden Valley, MN 55422
www.honeywell.com

008835-2-EN IL50 GLO
December 2011

Honeywell

Straight Centrifugal Pumps

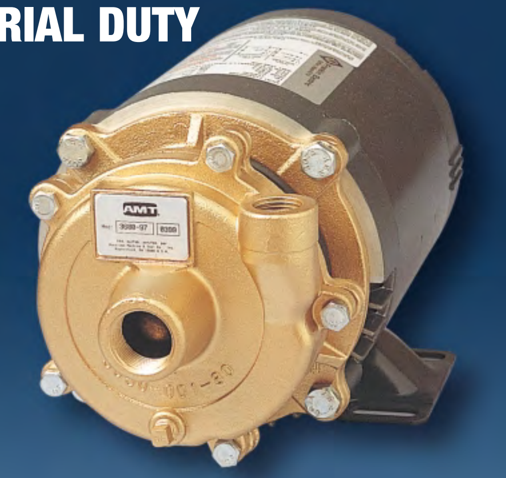
- ***Available in : 300 Series Investment Cast Stainless Steel, Cast Bronze** and **Cast Iron with Stainless Steel** Impeller Construction*
- ***Viton® Mechanical Seal and O-Ring with Stainless Steel and Bronze Models***
- ***Buna-N Mechanical Seal and O-Ring with Cast Iron Models***
- ***Optional Silicon Carbide Mechanical Seals Available***
- ***Discharge Port Rotates in 90° Increments***
- ***Maximum Working Pressure 75 PSI***
- ***Max. Temperature 200°F***
- ***Max. Flow 90 GPM***
- ***Max. Head 65 Ft. (28 PSI)***
- ***Self-cleaning, Semi-open Impellers***
- ***Available with Open Drip Proof (ODP) or Totally Enclosed Fan Cooled(TEFC) 56J Motors***
- ***1/3 HP to 2 HP Single and Three Phase, 3450 RPM Motors***

This line of AMT Straight Centrifugal pumps is designed for continuous-duty low pressure OEM, Industrial/Commercial and General Service applications including circulation, chemical processing, liquid transfer and cooling. These durable and compact pumps are available in a variety of construction and seal materials to meet your specification. The line also features a wide selection of single and three phase ODP or TEFC motors, up to 2 horsepower. All models feature Type 6 mechanical seals and O-rings. Pull-from-the-rear design for easy service without disturbing any piping. Self-cleaning impellers to prevent clogging and minimize maintenance.

AMT Centrifugal pumps are reliable, cost effective and low maintenance. Many are readily available **"Off-the Shelf"** for fast 24 hour shipment. For use with non-flammable liquids compatible with pump component materials.

Viton® is a registered trademark of E.I. DuPont

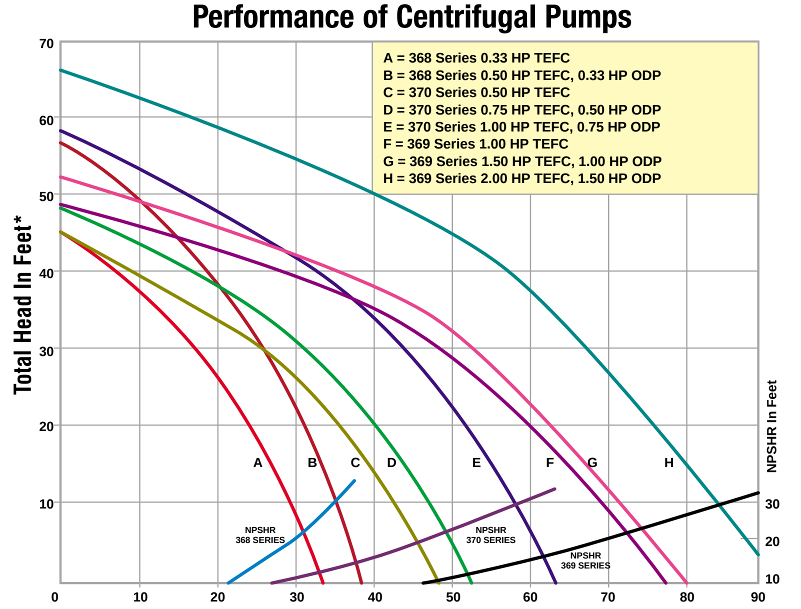
INDUSTRIAL DUTY



Bronze Centrifugal Pump

Stainless Steel Centrifugal Pump

Performance of Centrifugal Pumps



* Convert to PSI, divide by 2.31 Liquid-Water specific gravity 1.0

Straight Centrifugal Pumps

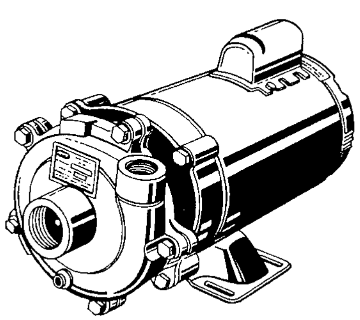
Pump Dimensional & Specification Data

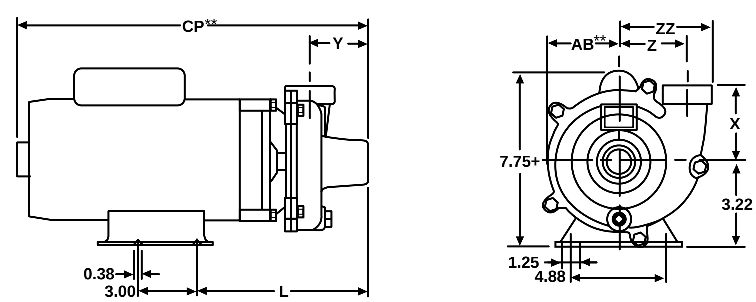
MODEL ‡	CURVE	HP	PH	ENG	VOLTAGES 60 HZ +	FULL LOAD AMPS	SUC*	DIS*	AB**	CP**	L	X	Y	Z	ZZ	SHIPPING WT. XCI ‡ (-95)	XB ‡ (-97)	XSS ‡ (-98)
3680	B	1/3	1	ODP	115/230	8 / 4	3/4"	1/2"	2.4	11.8	6.3	1.9	1.4	1.9	2.9	26 lbs.	27 lbs.	26 lbs.
368A	A	1/3	1	TEFC	115/230	7 / 4	3/4"	1/2"	2.4	13.4	6.3	1.9	1.4	1.9	2.9	31 lbs.	32 lbs.	31 lbs.
368B	B	1/2	1	TEFC	115/230	9 / 5	3/4"	1/2"	2.4	13.3	6.3	1.9	1.4	1.9	2.9	33 lbs.	34 lbs.	33 lbs.
3701	D	1/2	1	ODP	115/230	10 / 5	1"	3/4"	3.0	11.9	6.3	2.4	1.4	2.1	3.3	31 lbs.	32 lbs.	31 lbs.
370B	C	1/2	1	TEFC	115/230	9 / 5	1"	3/4"	3.0	13.3	6.3	2.4	1.4	2.1	3.3	33 lbs.	34 lbs.	33 lbs.
3703	D	1/2	3	ODP	230/460	3 / 2	1"	3/4"	3.0	12.4	6.3	2.4	1.4	2.1	3.3	31 lbs.	32 lbs.	31 lbs.
368C	B	1/2	3	TEFC	230/460	3 / 2	3/4"	1/2"	2.4	13.1	6.3	1.9	1.4	1.9	2.9	31 lbs.	32 lbs.	31 lbs.
370F	C	1/2	3	TEFC	230/460	3 / 2	1"	3/4"	3.0	13.2	6.3	2.4	1.4	2.1	3.3	34 lbs.	35 lbs.	34 lbs.
3700	E	3/4	1	ODP	115/230	13 / 7	1"	3/4"	3.0	12.4	6.3	2.4	1.4	2.1	3.3	34 lbs.	35 lbs.	34 lbs.
370A	D	3/4	1	TEFC	115/230	9 / 5	1"	3/4"	3.0	13.8	6.3	2.4	1.4	2.1	3.3	37 lbs.	38 lbs.	37 lbs.
3702	E	3/4	3	ODP	230/460	4 / 2	1"	3/4"	3.0	12.6	6.3	2.4	1.4	2.1	3.3	32 lbs.	33 lbs.	32 lbs.
370C	D	3/4	3	TEFC	230/460	3 / 2	1"	3/4"	3.0	13.2	6.3	2.4	1.4	2.1	3.3	35 lbs.	36 lbs.	35 lbs.
370E	E	1	1	TEFC	115/230	12 / 6	1"	3/4"	3.0	15.1	6.3	2.4	1.3	2.1	3.3	39 lbs.	40 lbs.	39 lbs.
370D	E	1	3	TEFC	230/460	4 / 2	1"	3/4"	3.0	14.2	6.3	2.4	1.3	2.1	3.3	36 lbs.	37 lbs.	36 lbs.
3691	G	1	1	ODP	115/230	17 / 9	1-1/4"	1"	3.0	12.9	6.3	2.5	1.3	2.0	3.4	36 lbs.	N/A.	36 lbs.
369C	F	1	1	TEFC	115/230	12 / 6	1-1/4"	1"	3.0	14.2	6.3	2.5	1.3	2.0	3.4	40 lbs.	N/A.	40 lbs.
3693	G	1	3	ODP	230/460	5 / 3	1-1/4"	1"	3.0	13.0	6.3	2.5	1.3	2.0	3.4	35 lbs.	N/A.	35 lbs.
369F	F	1	3	TEFC	230/460	4 / 2	1-1/4"	1"	3.0	13.8	6.3	2.5	1.3	2.0	3.4	39 lbs.	N/A.	39 lbs.
3690	H	1-1/2	1	ODP	115/230	22 / 11	1-1/4"	1"	3.0	13.3	6.3	2.5	1.3	2.0	3.4	40 lbs.	N/A.	40 lbs.
369A	G	1-1/2	1	TEFC	115/230	18 / 9	1-1/4"	1"	3.0	15.1	6.3	2.5	1.3	2.0	3.4	48 lbs.	N/A.	48 lbs.
3692	H	1-1/2	3	ODP	230/460	7 / 4	1-1/4"	1"	3.0	13.5	6.3	2.5	1.3	2.0	3.4	38 lbs.	N/A.	38 lbs.
369B	G	1-1/2	3	TEFC	230/460	5 / 3	1-1/4"	1"	3.0	14.2	6.3	2.5	1.3	2.0	3.4	40 lbs.	N/A.	40 lbs.
369D	H	2	1	TEFC	115/230	22 / 11	1-1/4"	1"	3.0	15.4	6.3	2.5	1.3	2.0	3.4	52 lbs.	N/A.	52 lbs.
369E	H	2	3	TEFC	230/460	6 / 3	1-1/4"	1"	3.0	14.3	6.3	2.5	1.3	2.0	3.4	50 lbs.	N/A.	50 lbs.

(*) Standard NPT (female) pipe thread.
(**) This dimension may vary due to motor manufacturer's specifications.
(+) 3-Phase motors can also operate on 50 Hz. (This will change Full Load Amps, Service Factor and RPM)
NOTE: Dimensions have a tolerance of ±1/8".
NOTE: Electric supply for ALL motors must be within ±10% of nameplate voltage rating(Ex. 230V ±10%= 207 to 253)

‡ *When Ordering Add the Correct-9x Suffix to Model Number Indicating Material Selection (ex: 3680-95)*

XCI (-95)=Cast Iron Construction with SS Impeller and Buna-N Seals, Max. Temperature 180˚F
XB (-97)=Cast Bronze Construction with Viton® Seals, Max. Temperature 200˚F
XSS (-98)=Stainless Steel Construction with Viton® Seals, Max. Temperature 200˚F





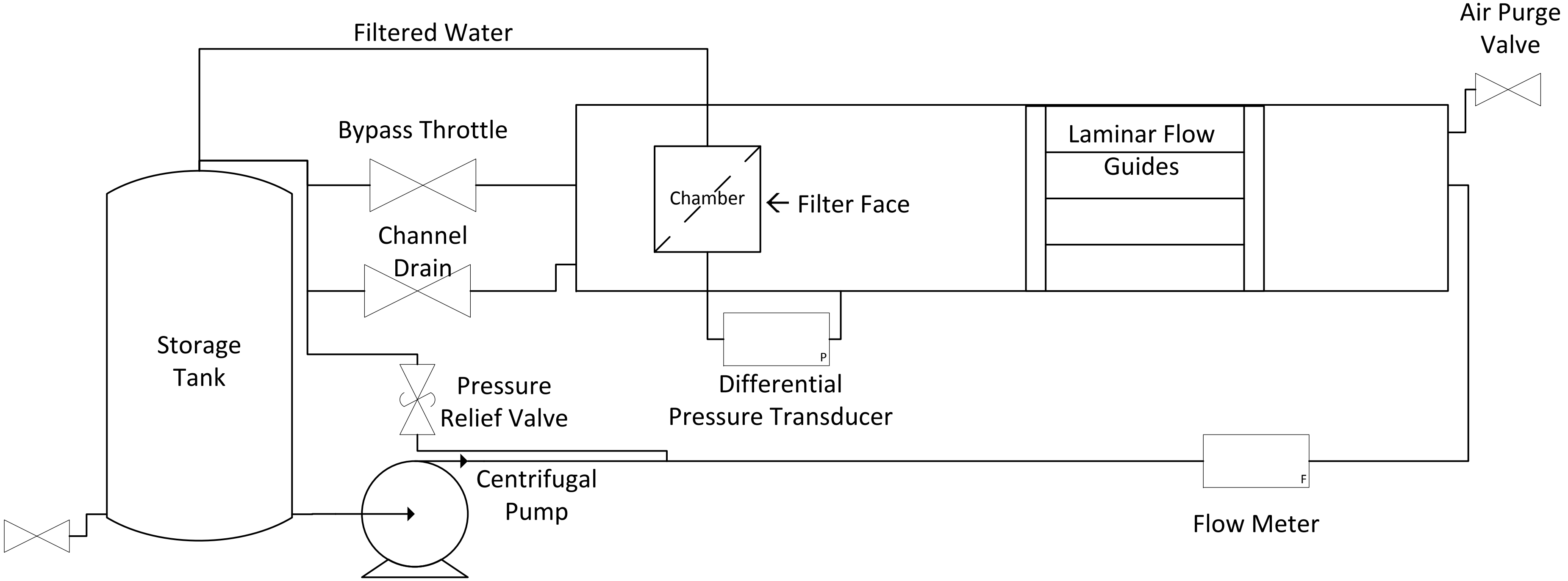
Standard Features

- Stainless Steel, Bronze & Cast Iron Construction
- Buna-N or Viton® Mechanical Seals and O-Rings Depending on Model
- Stainless Steel Hardware
- NEMA 56J ODP & TEFC Single and Three Phase Motors
- Stainless Steel Motor Shaft
- NEMA Base Mounted Motor
- Self-cleaning Impeller
- Discharge Rotates in 90˚ Increments
- Maximum Working Pressure to 75 PSI
- Max. Temperature 200˚F(Viton®), 180˚F (Buna-N)
- Front Drain Plug
- **"Off-the-Shelf"** Availability for Many Models

ots OFF THE SHELF PUMPS

Viton® is a registered trademark of E.I. DuPont

See price book pages 30 & 31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Air Purge
Valve
Bypass Throttle
Laminar Flow
Guides
Chamber
Filter Face
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Drain
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Relief Valve
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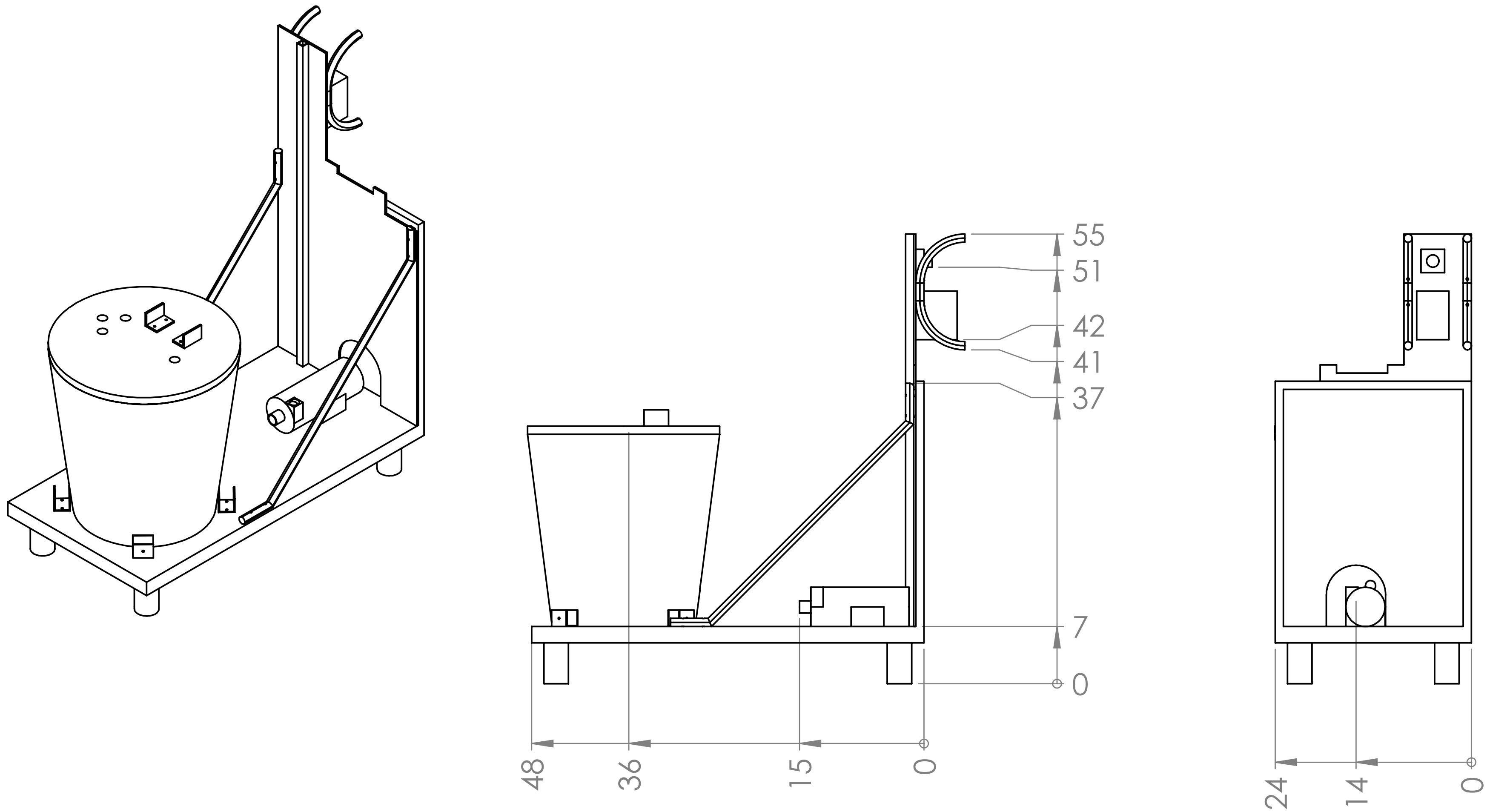
Centrifugal
Pump
F
Flow Meter



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			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

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SIZE	DWG. NO.	REV
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SCALE: 1:20	WEIGHT:	SHEET 1 OF 1

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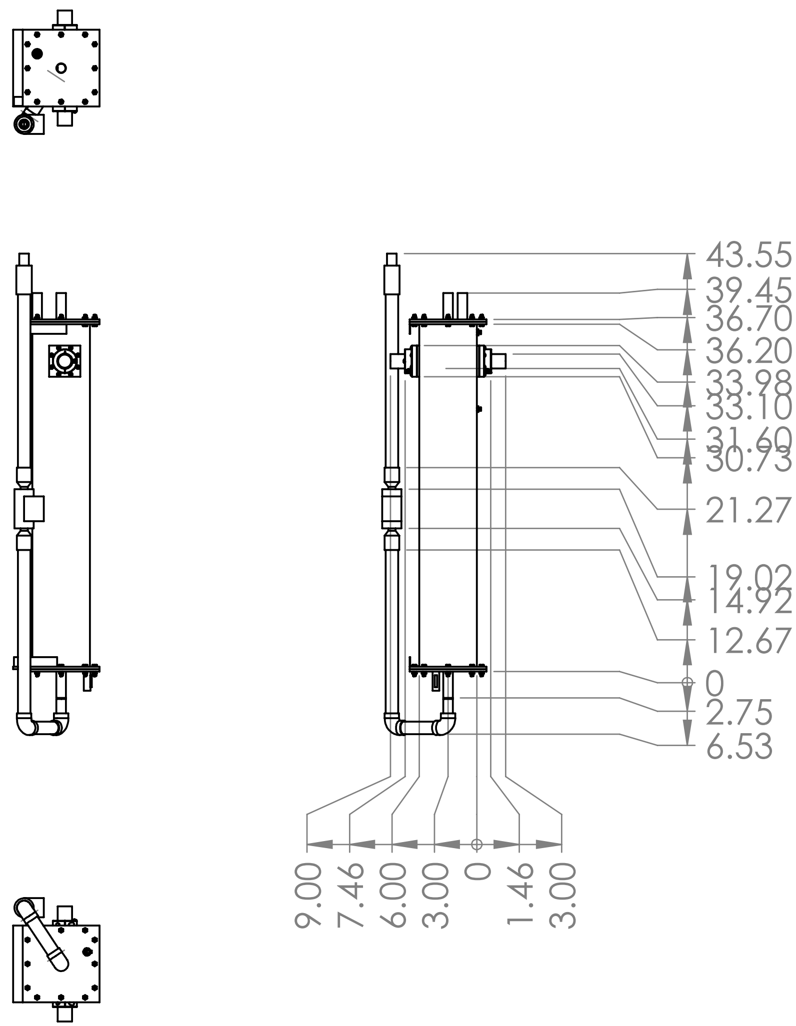

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			CHECKED			TITLE: CHANNEL LAYOUT
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL	COMMENTS:			SIZE A DWG. NO. REV
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APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:20 WEIGHT: SHEET 1 OF 1

PROPRIETARY AND CONFIDENTIAL

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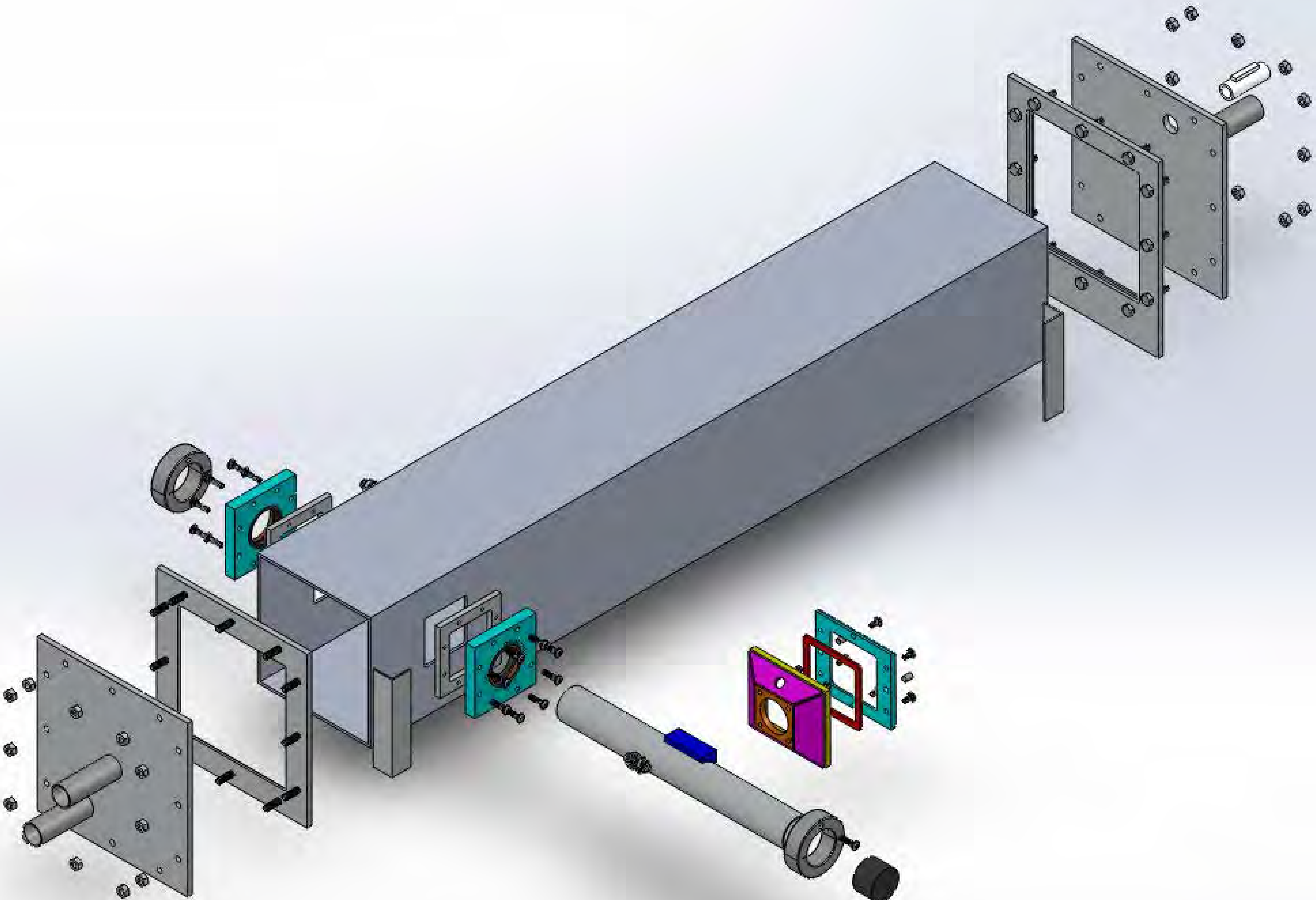
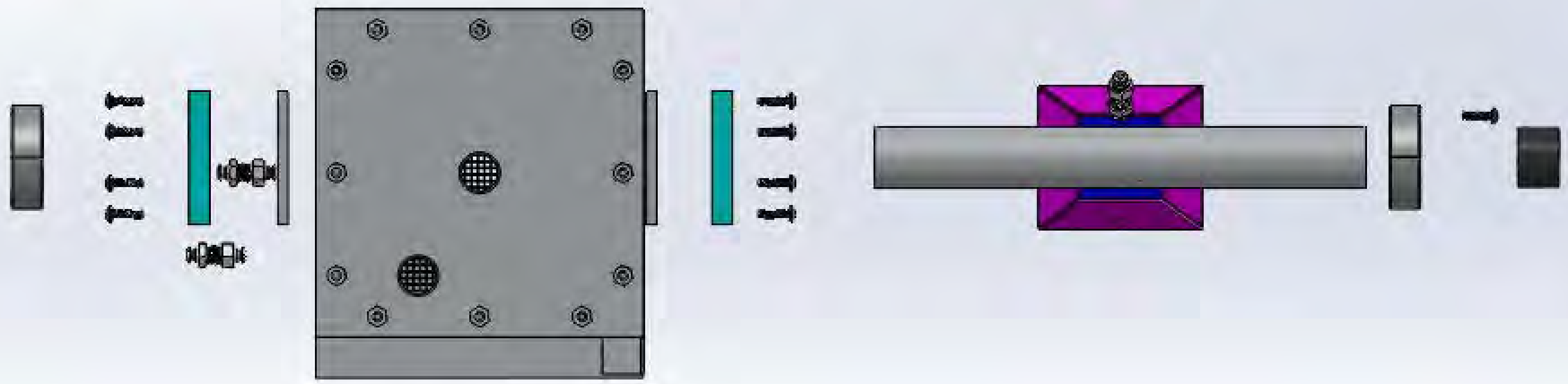
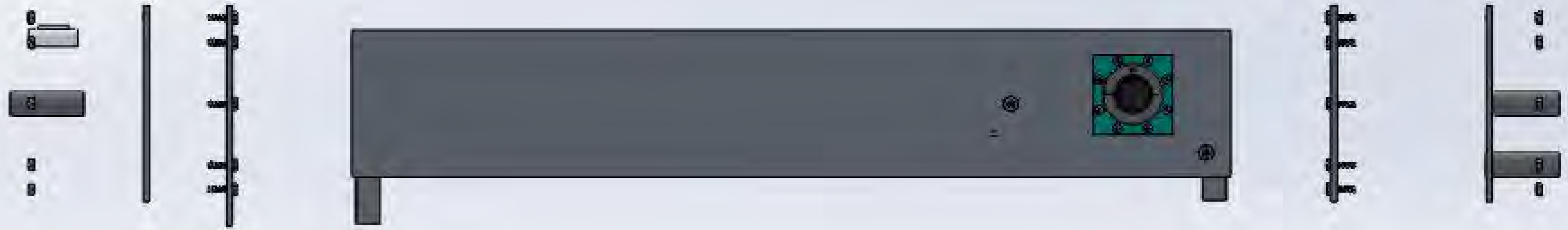
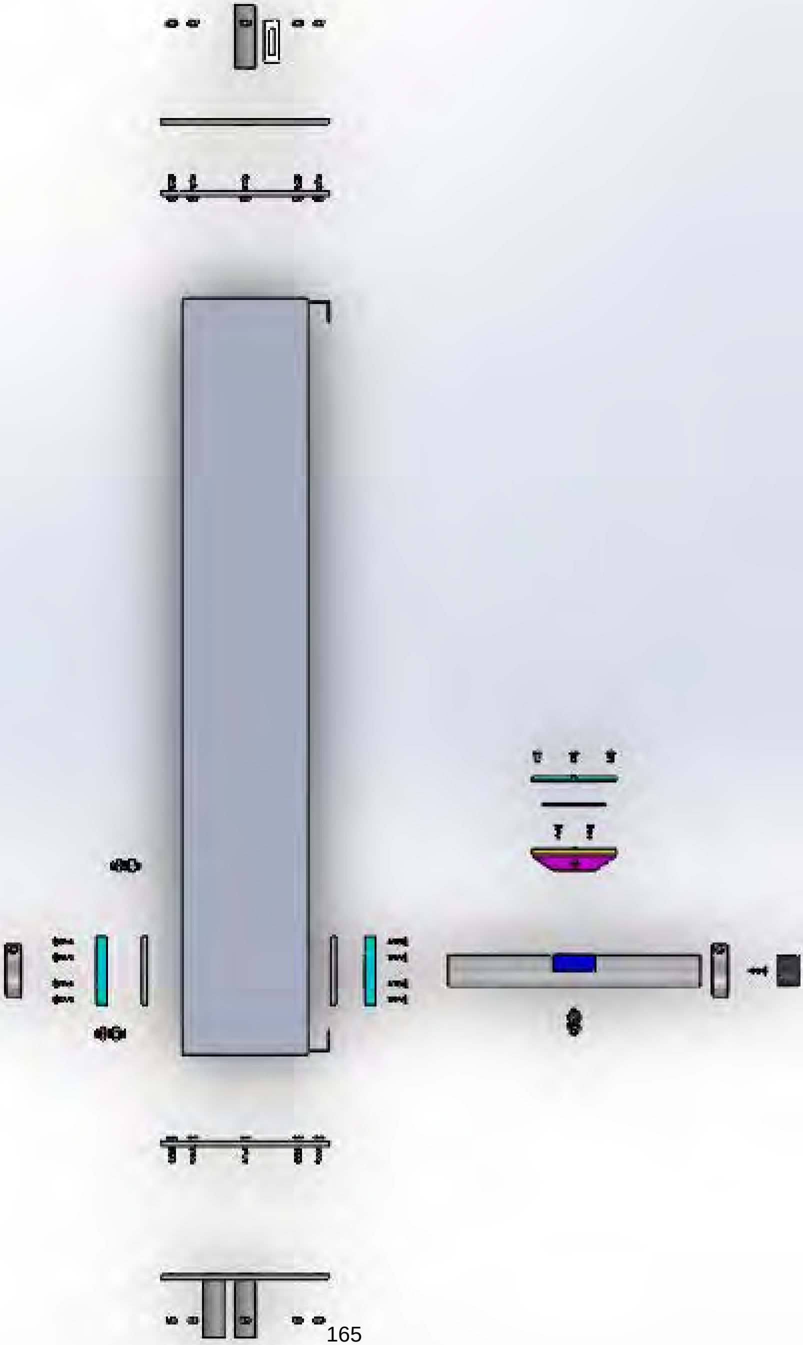
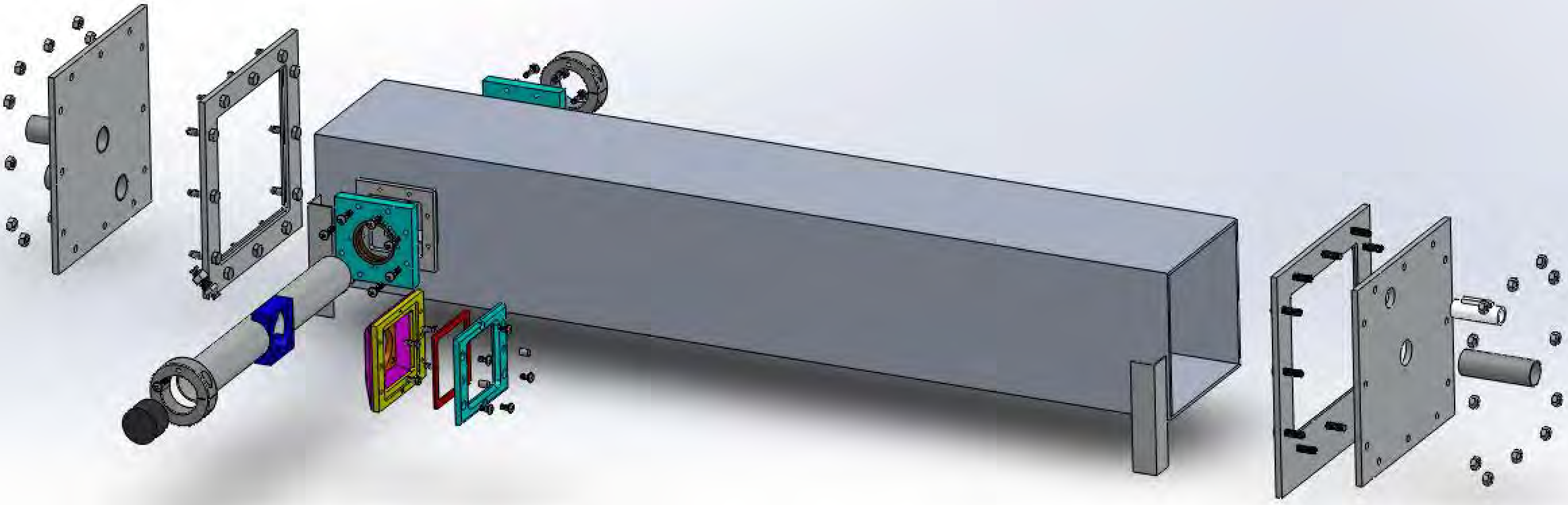
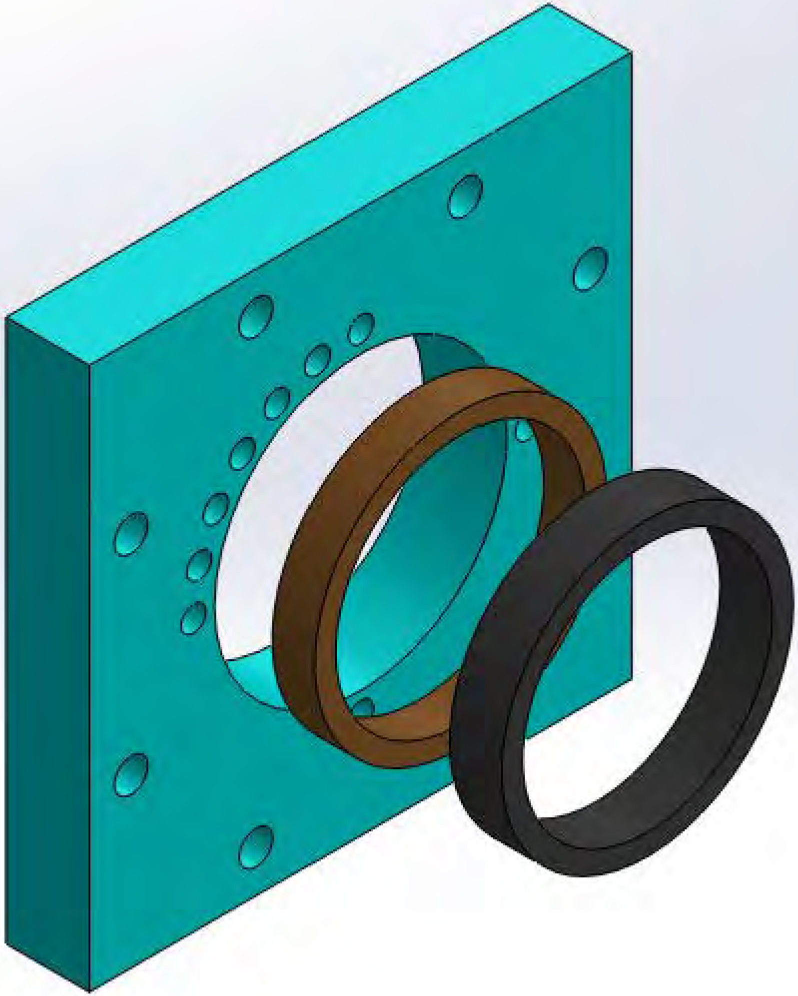


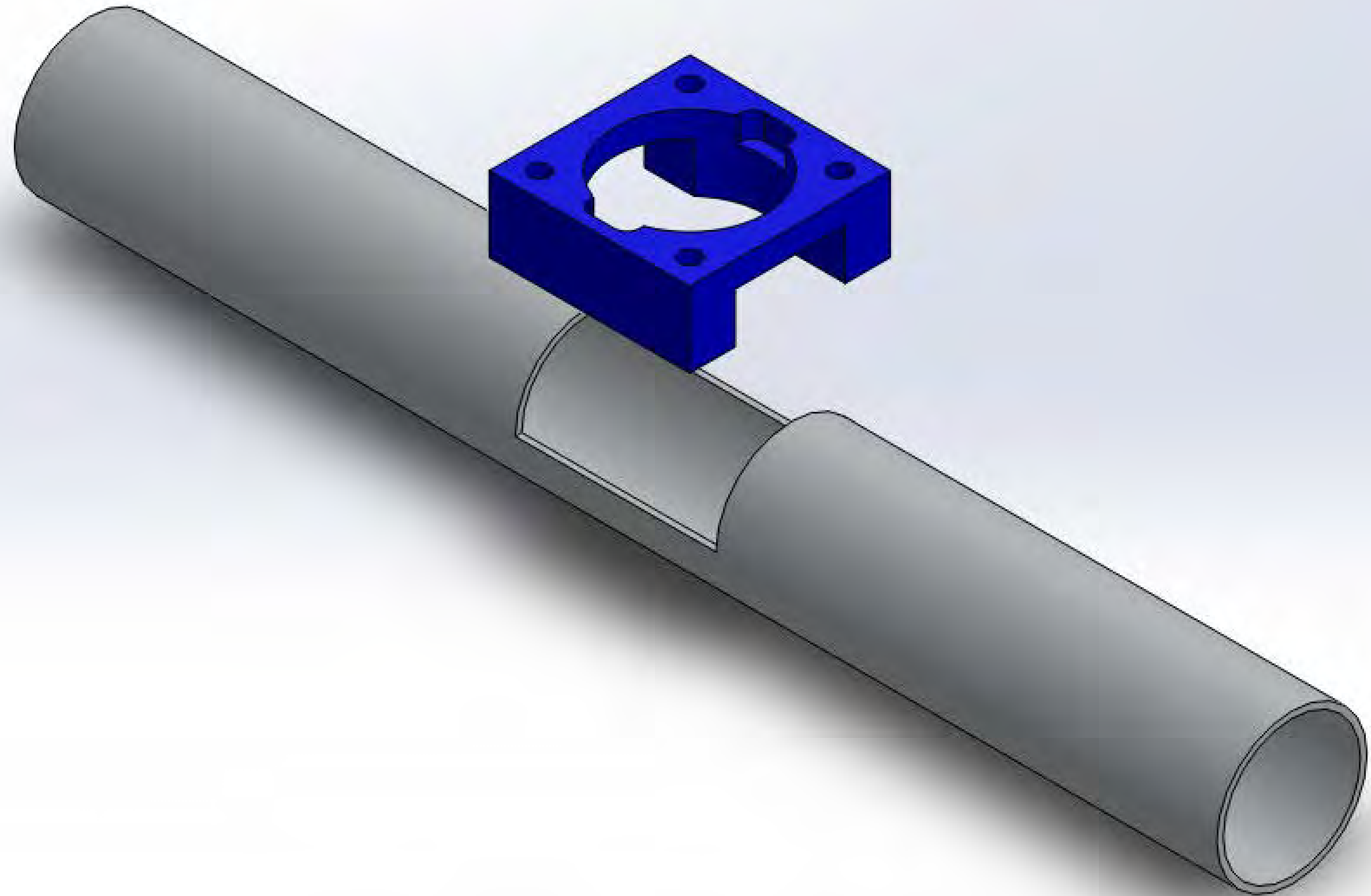


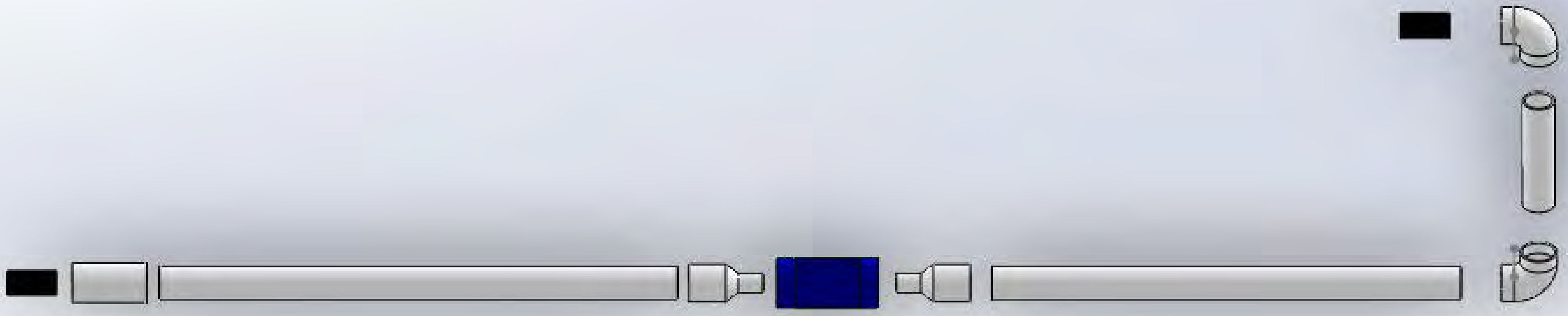


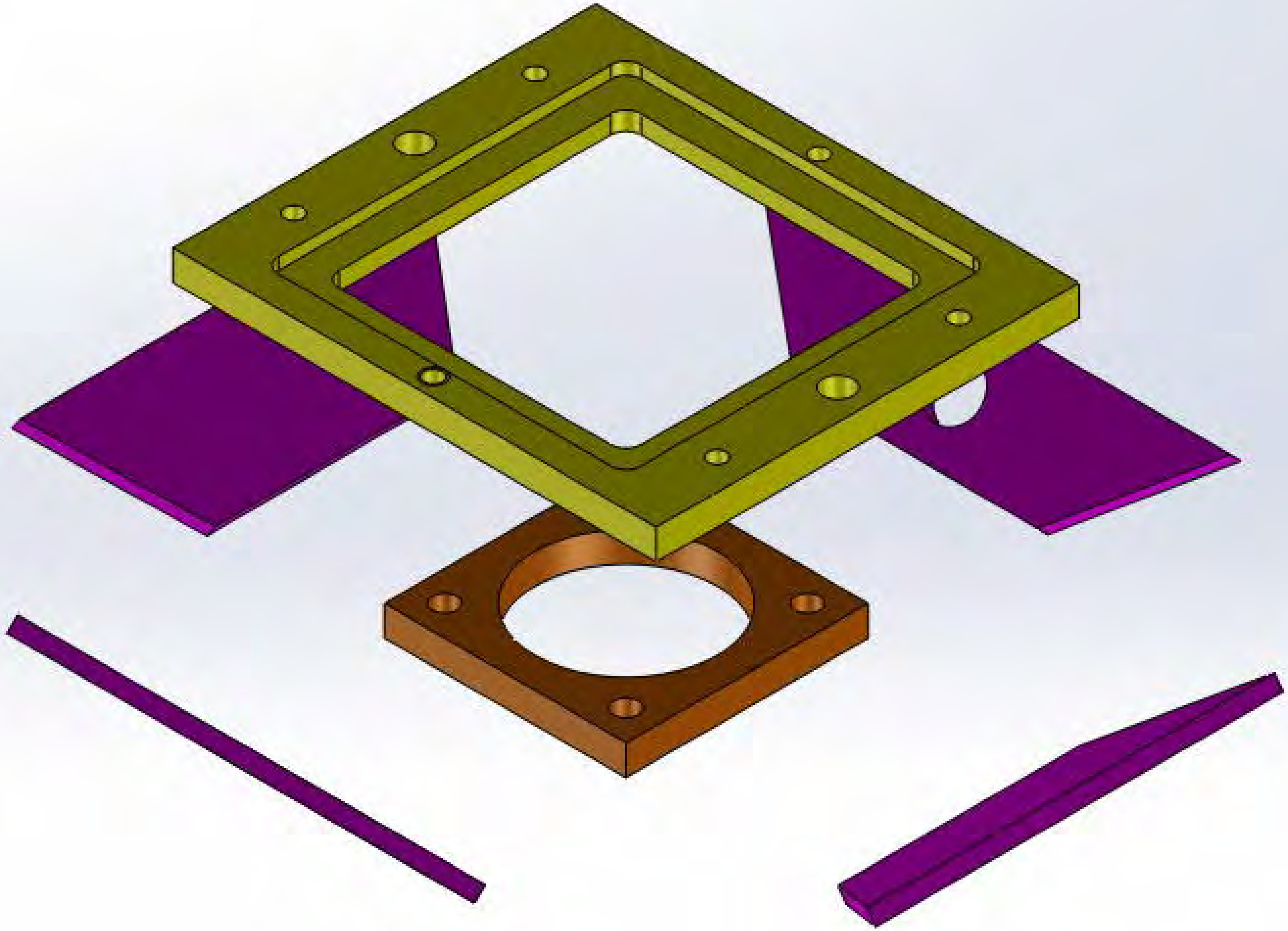


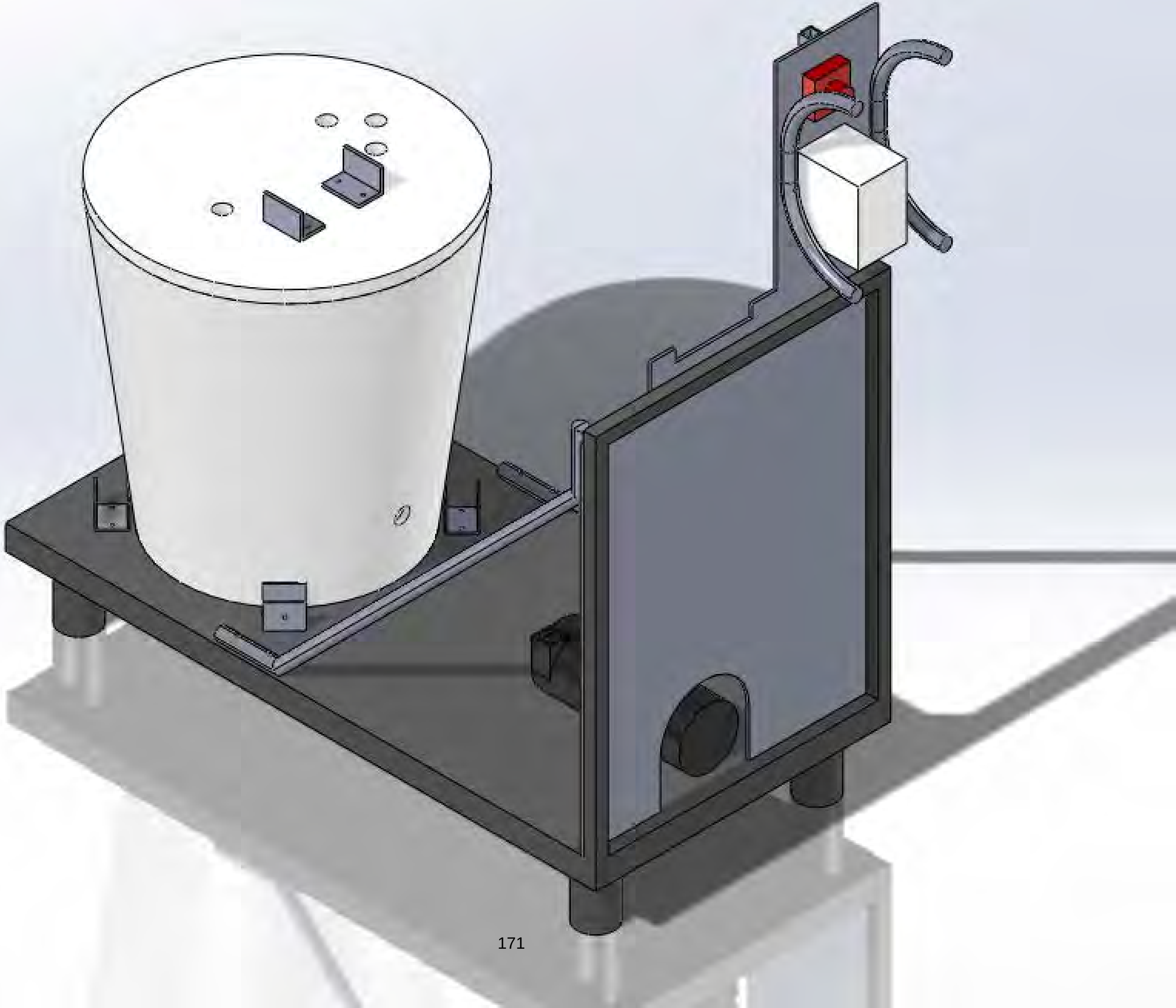


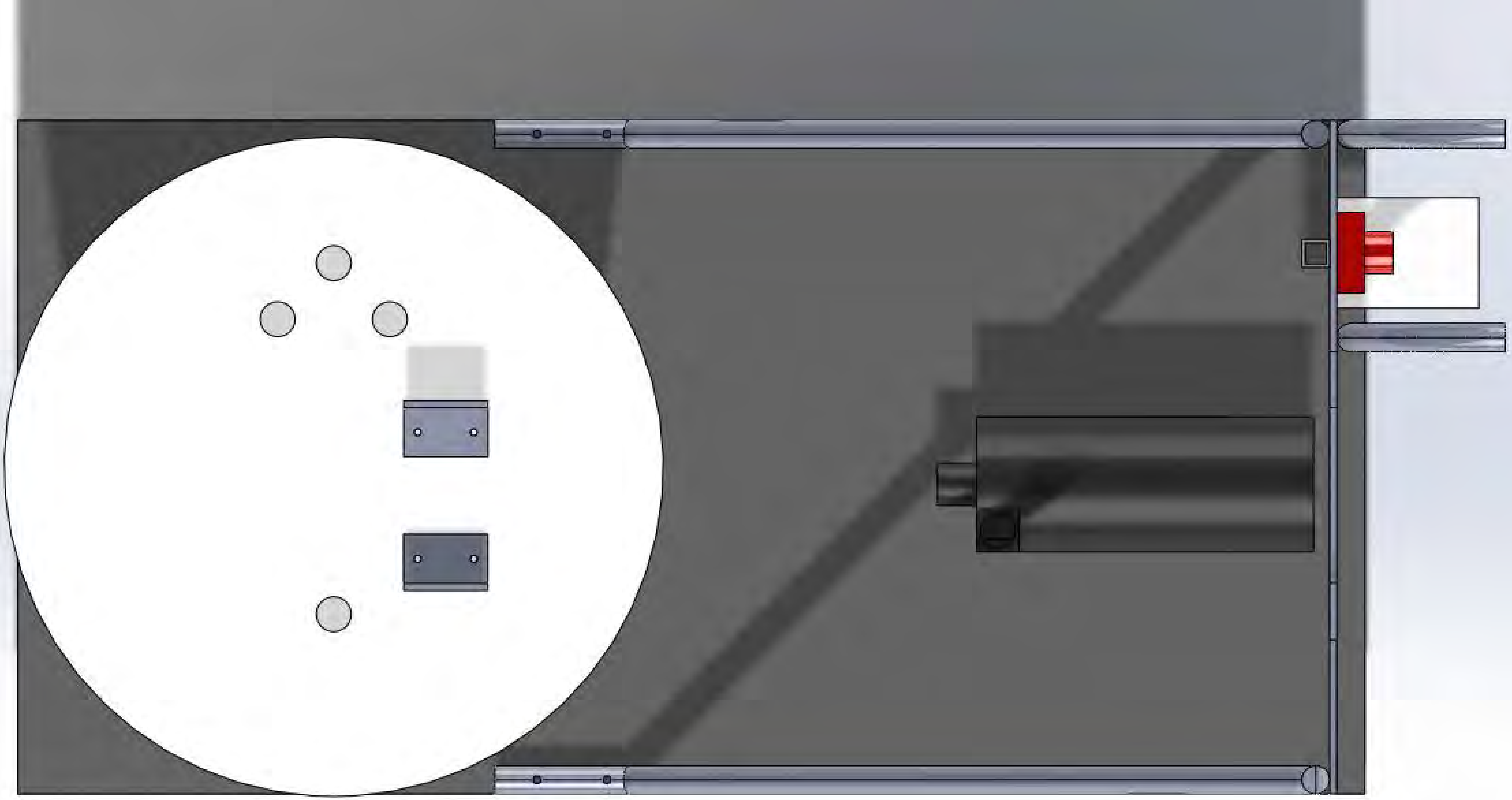












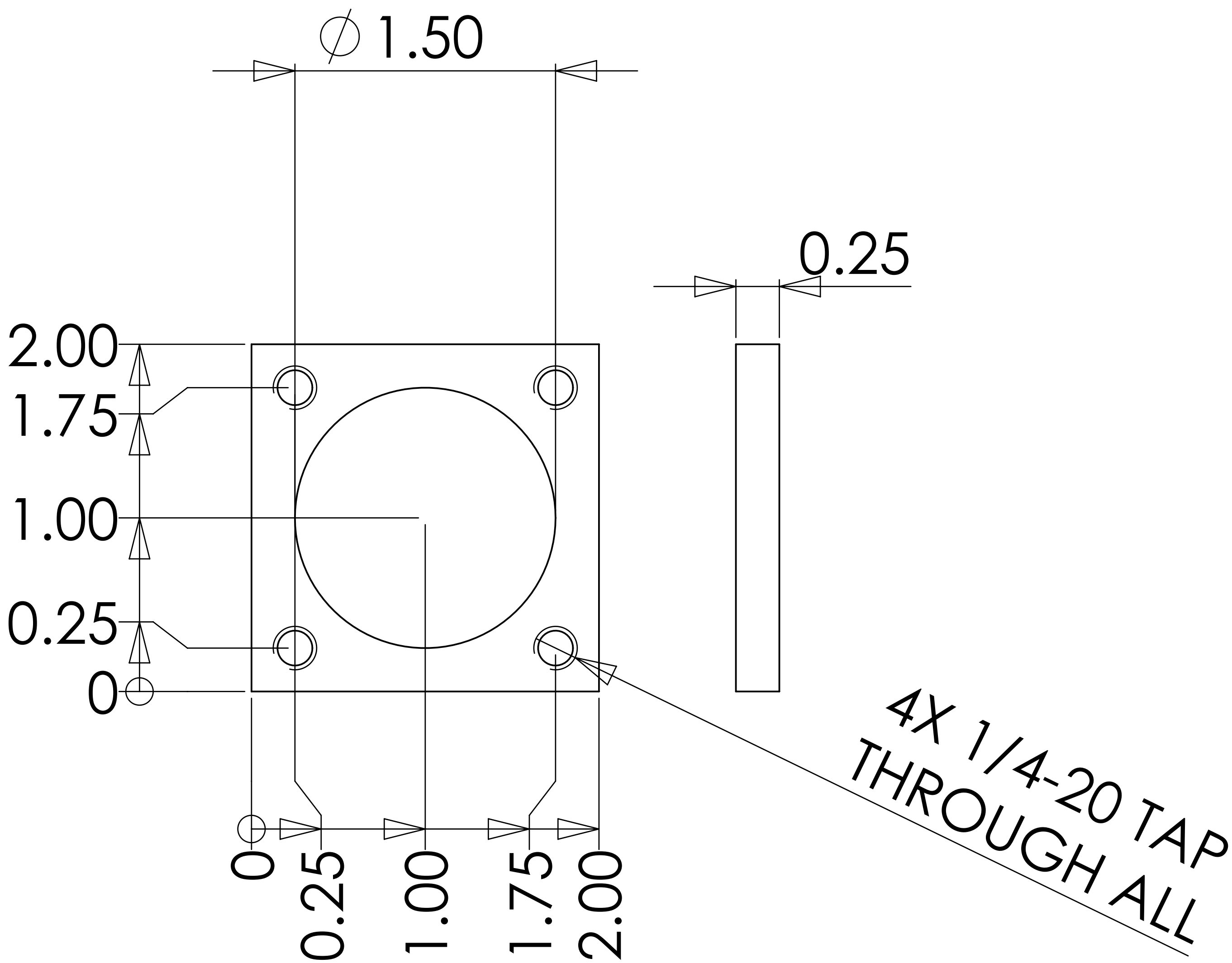
PART	QTY	STOCK, IF FABRICATED	VENDOR	PART #	SAME STOCK AS:	MAT'L	SUBSYSTEM	UNIT COST	ADJ UNIT COST	COST TO TEAM
1.25" Hose Clamp	14	-	Home Depot	78575171253	-	SS	Multiple	$1.05	$1.05	$14.70
Hose (1/2", (ft)	1	-	Home Depot	705743	-	PVC	Channel	$0.36	$0.36	$0.36
1/2" NPT Close Nipple	1	-	Home Depot	32888991231	-	Steel	Channel	$0.96	$0.96	$0.96
1/8" Tubing (ft)	3	-	McMaster-Carr	5233K51	-	Vinyl	Multiple	$0.14	$3.50	$10.50
3/4" Conduit Retaining Clips	3	-	Home Depot	811458	-	Steel	Cart	$1.25	$0.42	$1.25
3/4" Hose Clamp	1	-	Home Depot	100561	-	SS	Channel	$0.85	$0.85	$0.85
3/4" NPT Close Nipple	1	-	Home Depot	64307	-	Steel	Cart	$1.35	$1.35	$1.35
3/8" Wire Retaining Clips	4	-	Home Depot	541729	-	Plastic	Cart	$1.28	$0.32	$1.28
Amplifier Circuit for Sensor	1		Built in Hose	471 Op Amp	-	Electronics	Channel	<1	$0.00	$0.00
Ball Valve (1" FNPT)	3	-	Home Depot	32888071353	-	PVC	Multiple	$4.92	$4.92	$14.76
Ball Valve (1/2" FNPT)	1	-	Home Depot	87940000361	-	PVC	Channel	$1.93	$1.93	$1.93
Barbed Adapter (1"Hose x 1" NPT)	11	-	Home Depot	25528105099	-	PVC	Multiple	$0.54	$0.54	$5.94
Barbed Adapter (3/4" Hose x 3/4" MNPT)	1	-	Home Depot	37117	-	PVC	Cart	$0.95	$0.95	$0.95
Bolt (Hex Head, 1" x 1/4-20)	24	-	McMaster-Carr	90201A113	-	Steel	Channel	$0.39	$0.00	$0.00
Bolt (Hex Head, 2" x 1/4-20)	16	-	McMaster-Carr	90201A119	-	Steel	Cart	$0.46	$0.00	$0.00
Bolt (Hex Head, 2" x 5/16-18)	6	-	McMaster-Carr	90201A230	-	Steel	Cart	$0.79	$0.79	$4.75
Bolt (Hex Head, 3" x 1/4-20)	4	-	McMaster-Carr	91257A554	-	Steel	Cart	$0.41	$0.41	$1.65
Bolted Retaining Ring	1	1/4" x 18" x 48" 6061 Aluminum Sheet	Alro	Drop*	a	6061 Al	Chamber	$0.00	$0.00	$0.00
Cart	1	-	McMaster-Carr	9925T32	-	Steel	Cart	$59.99	$0.00	$0.00
Chamber Back Piece	1	See "a" Stock	-	-	a	6061 Al	Chamber	$0.00	$0.00	$0.00
Chamber Front Piece	1	See "a" Stock	-	-	a	6061 Al	Chamber	$0.00	$0.00	$0.00
Chamber Gasket	1	0.125" x 6" x 6" Neoprene Sheet	McMaster-Carr	6455K53	-	Neoprene	Chamber	$9.76	$9.76	$9.76
Chamber Long Sides	2	1/8" x 2" x 12" 6061 Aluminum	Alro	Drop*	c	6061 Al	Chamber	$0.00	$0.00	$0.00
Chamber Short Sides	2	See "c" Stock	-	-	c	6061 Al	Chamber	$0.00	$0.00	$0.00
Channel	1	6" x 6" x 36" Square Aluminum Tube, 0.125" Wall	Alro	Drop*	-	6061 Al	Channel	$57.50	$57.50	$57.50
Channel End Flange	1	See "a" Stock	-	-	a	6061 Al	Channel	$0.00	$0.00	$0.00
Channel End Gasket	2	See "b" Stock	-	-	b	Neoprene	Channel	$0.00	$0.00	$0.00
Channel Front Flange	1	See "a" Stock	-	-	a	6061 Al	Channel	$0.00	$0.00	$0.00
Channel Holder Angle	2	2" x 2" Aluminum Angle, 1/4" Wall	Alro	Drop*	-	6061 Al	Cart	$0.00	$0.00	$0.00
Channel Holder Riser	4	2" x 1" Aluminum Rect. Tube, 0.125" Wall	Alro	Drop*	-	6061 Al	Cart	$0.00	$0.00	$0.00
Channel Tapped Ring	2	See "a" Stock	-	-	a	6061 Al	Channel	$0.00	$0.00	$0.00
Dowel Pins (1/4" x 1/2")	2	-	McMaster-Carr	97395A475	-	Steel	Chamber	$9.92	$0.00	$0.00
Epoxy	1	-	Home Depot	757442	-	Solvent	Channel	$5.47	$0.00	$0.00
E-Stop Button	1	-	McMaster-Carr	6785K22	-	Plastic/Copper	Cart	$44.60	$0.00	$0.00
Extension Cord (14ga, 25')	1	-	Home Depot	685238	-	Copper/Rubber	Cart	$29.95	$29.95	$0.00

Flow Meter	1	-	Great Plains Industries?	TM075-N	-	Plastic	Channel	$305.00	$0.00	$0.00
Hose (1" ID, Braided Reinforcement, ft)	20	-	Home Depot	705308	-	PVC	Multiple	$1.28	$1.28	$25.60
Hose (3/4" ID, ft)	4	-	Home Depot	714565	-	PVC	Cart	$1.88	$1.88	$7.53
Laminar Flow Guides	15	Corrugated Acrylic Sheet, 96" x 48" x 1/4"	ıgatedplastics.net	48964	-	Acrylic	Channel	$14.00	$0.93	$0.00
Laminar Flow Guides Downstream Support	2	See "a" Stock	-	-	a	6061 Al	Channel	$0.00	$0.00	$0.00
Laminar Flow Guides Upstream Support Center	1	See "e" stock	-	-	-	6061 Al	Channel			$0.00
Lock Collar	2	-	McMaster-Carr	9410T130	-	Steel	Chamber	$11.08	$11.08	$22.16
Machine Screw (1" x 8-32)	2	-	McMaster-Carr	91735A199		Steel	Channel	$0.22	$0.22	$0.43
Machine Screw (3/4" x 10-24)	18	-	McMaster-Carr	91735A245		Steel	Channel	$0.22	$0.22	$4.04
Machine Screws (2" x 8-32)	5	-	McMaster-Carr	91735A210		Steel	Cart	$0.53	$0.53	$2.66
Machine Screws (3/8" x 10-24)	6	-	McMaster-Carr	91735A240		Steel	Chamber	$0.15	$0.15	$0.92
Nuts (1/4" x 5/16-18)	4	-	McMaster-Carr	93827A211		Steel	Cart	$0.06	$0.00	$0.00
Nuts (1/8 x 8-32)	7	-	McMaster-Carr	90480A009		Steel	Multiple	$0.01	$0.01	$0.10
Nuts (3/16 x 1/4-20)	55	-	McMaster-Carr	90473A029		Steel	Multiple	$0.03	$0.03	$0.00
Pipe	1	-	McMaster-Carr	9056K793	-	6061 Al	Chamber	$14.77	$14.77	$14.77
Pipe Adapter Block	1	12" x 12" x 1/2" 6061 Aluminum Plate	Alro	Drop*	e	6061 Al	Chamber	$0.00	$0.00	$0.00
Pipe Hangers	2	-	McMaster-Carr	30075T4		Plastic	Channel	$1.46	$1.46	$2.92
Pipe Nipple	3	1" OD x 0.015 wall 6061 Aluminum Tube	McMaster-Carr	9056K753	-	6061 Al	Channel	$10.40	$10.40	$31.20
Pipe Plug	1	-	McMaster-Carr	2439K43		Plastic/Rubber	Chamber	$7.24	$7.24	$7.24
Pipe Threaded Insert	1	1" Aluminum Rod Stock	Alro	Drop*		6061 Al	Chamber	$0.00	$0.00	$0.00
Plastic Sheet	1					Plastic	Cart			$0.00
Plug (1" MNPT)	1	-	Home Depot	612758		PVC	Chamber	$0.95	$0.95	$0.95
Plywood Board	1	1/2" x sheet Plywood	Home Depot	Lumber		Wood	Cart	$18.00	$18.00	$18.00
Pressure Relief Valve	1	-	McMaster-Carr	9763K12		Brass	Cart	$53.61	$53.61	$0.00
Pressure Sensor	1	-	Sensocon			Steel	Channel			$0.00
Pressure Taps	3	-	McMaster-Carr	51025K211		Brass	Multiple	$12.05	$12.05	$36.15
Pump	1	-	Corrosion Fluids, Inc	AMT-370F-95		Steel/Copper	Cart	$415.00	$0.00	$0.00
PVC Elbow (1" x 90)	2	-	Home Depot	187194		PVC	Channel	$0.57	$0.57	$1.14
PVC Long Pipe	1	1" x 10' PVC Pipe	Home Depot	193755	d	PVC	Channel	$3.38	$3.38	$3.38
PVC Primer and Adhesive	1	-	Home Depot	462620		Solvent	Channel	$6.97	$0.00	$0.00
PVC Short Pipe	1	See "d" Stock	Home Depot	-	d	PVC	Channel	$0.00	$0.00	$0.00
PVC Very Short Pipe	1	See "d" Stock	-	-	d	PVC	Channel	$0.00	$0.00	$0.00
Rope (ft)	8	-	Home Depot	292192		Poly	Cart	$0.10	$0.10	$0.83
Self Tapping Screws (34" x 8-32)	16	-	McMaster-Carr			Steel	Cart			$0.00
Shaft Bushing	2		McMaster-Carr	6391K315		Bronze	Channel	$4.02	$2.01	$4.02
Shaft Seal	2	-	McMaster-Carr	9514K154		Neoprene	Channel	$4.75	$4.75	$9.50
Shaft Seal Holder	2	See "e" stock	-	-	e	6061 Al	Channel	$0.00	$0.00	$0.00
Shaft Seal Holder Gasket	2	See "b" Stock	-	-	b	Neoprene	Channel	$0.00	$0.00	$0.00
Shroud Supports	2	3/4" Galvanized Conduit	Home Depot	203194	f	Steel	Cart	$3.98	$1.99	$3.98
Side Braces	1	See "f" Stock	-	-	f	Steel	Cart	$0.00	$0.00	$0.00
Side Pipe Brackets	2	1" x 1" x 1/8" Aluminum Angle	Alro	Drop*	-	6061 Al	Channel	$0.00	$0.00	$0.00

Tank	1	-	Dow Chemical	DAP Pack	-	Plastic	Cart	Unkn	$0.00	$0.00
Tank Bracket	4	2" x 2" x 1/8" wall 6061 Aluminum "U" Channel	Alro	Drop*	-	6061 Al	Cart	$0.00	$0.00	$0.00
Tee (1" FNPT)	1	-	Home Depot	187925	-	PVC	Chamber	$0.86	$0.86	$0.86
Tee (1" FNPT)	1	-	Home Depot	181943	-	Steel	Cart	$4.56	$4.56	$4.56
Teflon Tape (ft)	10	-	Home Depot	178438	-	PFTE	Multiple	$0.49	$0.02	$0.00
Threaded Adapter (1" F Socket x 1" FNPT)	1	-	Home Depot	12871625671	-	PVC	Channel	$0.77	$0.77	$0.77
Threaded Adapter Elbow (1/2" MNPT x 1/2")	1	-	Home Depot	651453	-	PVC	Channel	$0.52	$0.52	$0.52
Threaded Reducer (1" F Socket x 3/4" MNPT)	2	-	Home Depot	Unkn	-	PVC	Channel	Unkn	$0.00	$0.00
Threaded Reducer (1" MNPT x 3/4" FNPT)	2	-	Home Depot	Unkn	-	Steel	Cart	Unkn	$0.00	$0.00
VFD	1	-	Automation Direct GS2-10P5	GS2-10P5	-	Plastic/Copper	Cart	$166.00	$0.00	$0.00
Washers (Flat, 1/16 x 8-32)	11	-	McMaster-Carr	96659A103		Steel	Multiple	$0.04	$0.04	$0.00
Washers (Flat, 1/4 x 3/4)	55	-	McMaster-Carr	91081A129		Steel	Multiple	$0.03	$0.03	$0.00
Wire (12ga, 4 conductor,ft)	5	-	Home Depot	Unkn		Rubber/Copper	Cart	$1.73	$1.73	$0.00
Wire Knockout Clip	3	-	Home Depot	839647		Steel	Cart	$1.49	$0.00	$0.00
Wire Nuts	3	-	Home Depot	621095		Plastic/Steel	Cart	$0.05	$0.00	$0.00
Lumped cost of all Alro usable Drops	1	-	Alro	-	-	Aluminum	Multiple	$60.44	$60.44	$60.44
										$393.17

Part	Qty	Stock
Side Pipe Bracket	2	1" x 1" x 1/16" wall Aluminum angle

Step	Description	Machine	Fixturing	Tooling	Speed	Feed
1	Cut to length on the bandsaw	Bandsaw	Vice			



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DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
6061 ALUMINUM

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

CHAMBER BACK PLATE

SIZE	DWG. NO.	REV
A	Chamber_Back_Plate	

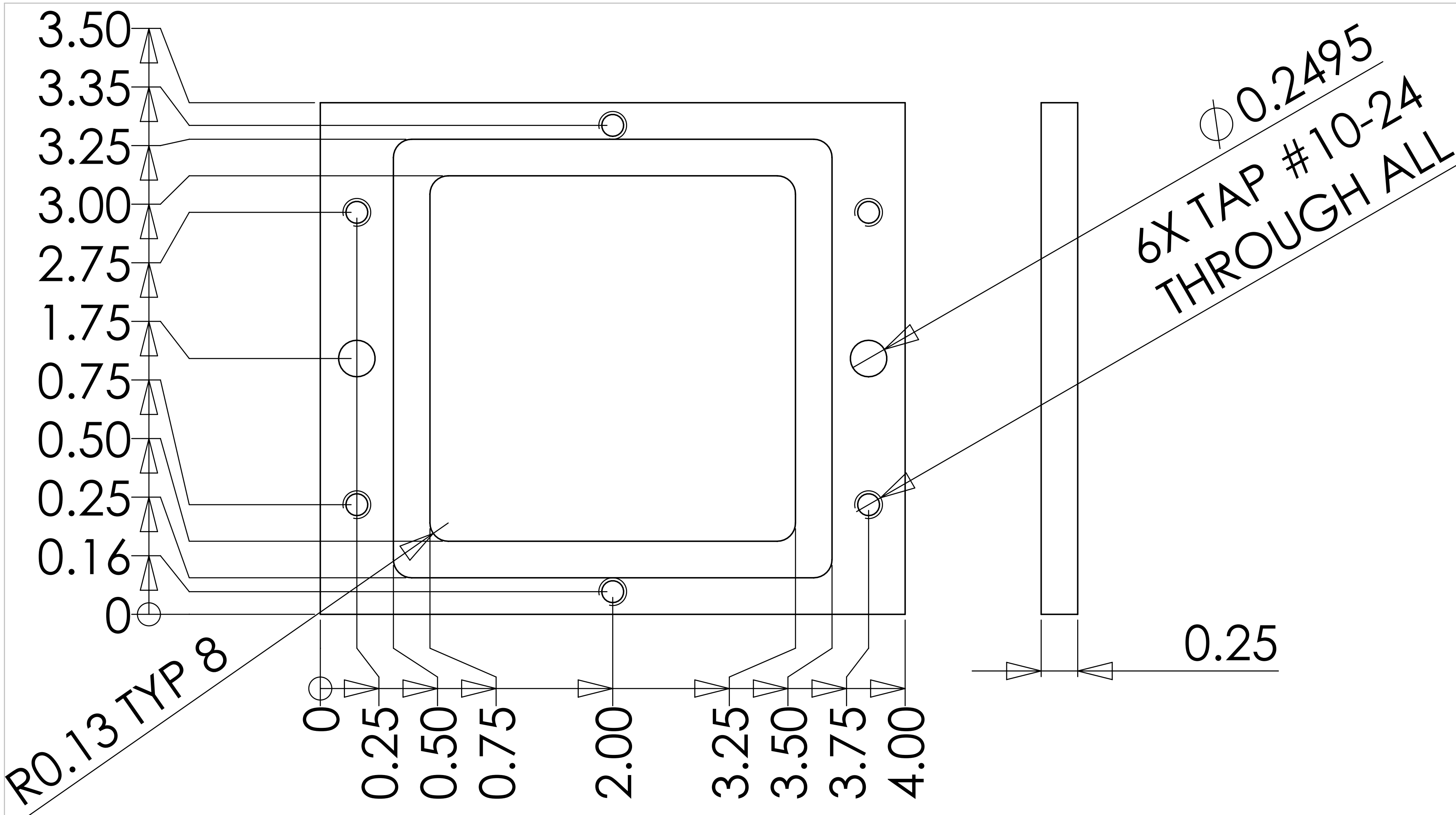
SCALE: 1:1 WEIGHT: SHEET 1 OF 1

NEXT ASSY	USED ON
APPLICATION	

5 4 3 2 1

Part	Qty	Stock
Chamber Back Plate	1	1/4" Aluminum Sheet

Step	Description	Machine	Fixturing	Tooling	Speed
1	Mount stock to mill table with mill clamps and sacrificial wood	Mill	Mill Clamps, Plywood		
2	Center drill all holes	Mill	Drill Chuck	Center Drill	
4	Drill the tapped holes to finish	Mill	Drill Chuck	#25 Drill Bit	
5	Tap the tapped holes	Mill	Drill Chuck, live center	1/4-20 tap, tap handle	
6	Drill the center hole to undersized (as high as drill bits will allow)	Mill	Drill Chuck	Drill bits (up to 1.375")	
7	Use an adjustable boring head to finish the center hole	Mill	Collet	Adjustable Boring Head	
8	Mill the outside edges	Mill	Collet	1/2" HSS 2-flute Endmill	



NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
6061 ALUMINUM

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

CHAMBER FRONT PLATE

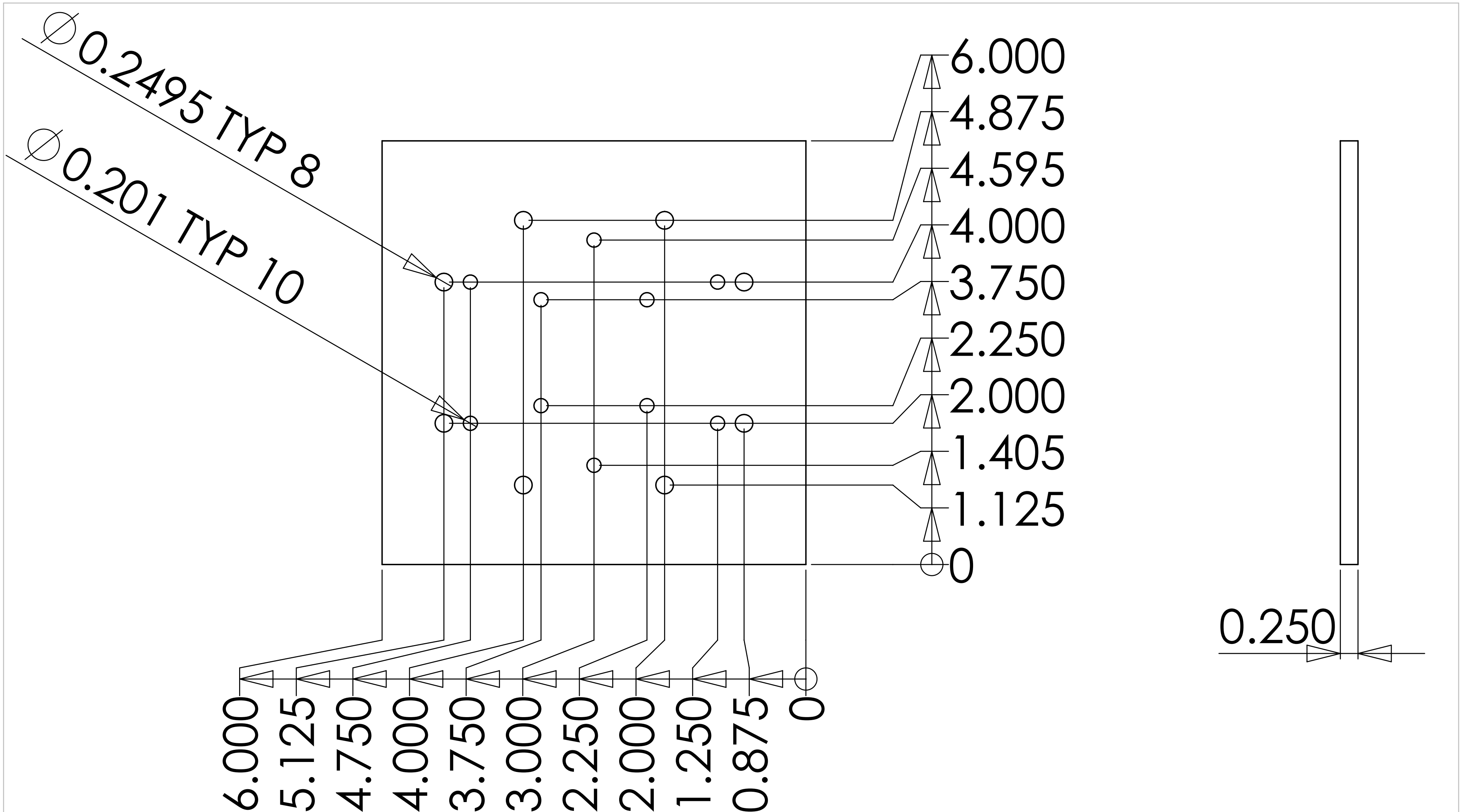
SIZE A DWG. NO. Chamber_Front_Plate_3in REV

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

5 4 3 2 1

Part	Qty	Stock
Chamber Front Plate	1	1/4" Aluminum Sheet

Step	Description	Machine	Fixturing	Tooling	Speed
1	Mount stock to mill table with mill clamps and sacrificial wood	Mill	Mill Clamps, Plywood		
2	Center drill all holes	Mill	Drill Chuck	Center Drill	
3	Drill the reamed holes to undersize	Mill	Drill Chuck	D Drill	
4	Drill the tapped holes to finish	Mill	Drill Chuck	#25 Drill Bit	
5	Ream the reamed holes to finish	Mill	Drill Chuck	.2495 Ream	
6	Cut out the inside pocket	Mill	Collet	1/4" HSS 2-flute Endmill	
7	Mill the inside shoulder	Mill	Collet	1/4" HSS 2-flute Endmill	
8	Mill the outside edges	Mill	Collet	1/2" HSS 2-flute endmill	



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
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			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL 6061 ALUMINUM	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

TITLE: CHAMBER JIG BASE

SIZE	DWG. NO.	REV
A	Chamber_Jig_Base	
SCALE: 1:2	WEIGHT:	SHEET 1 OF 1

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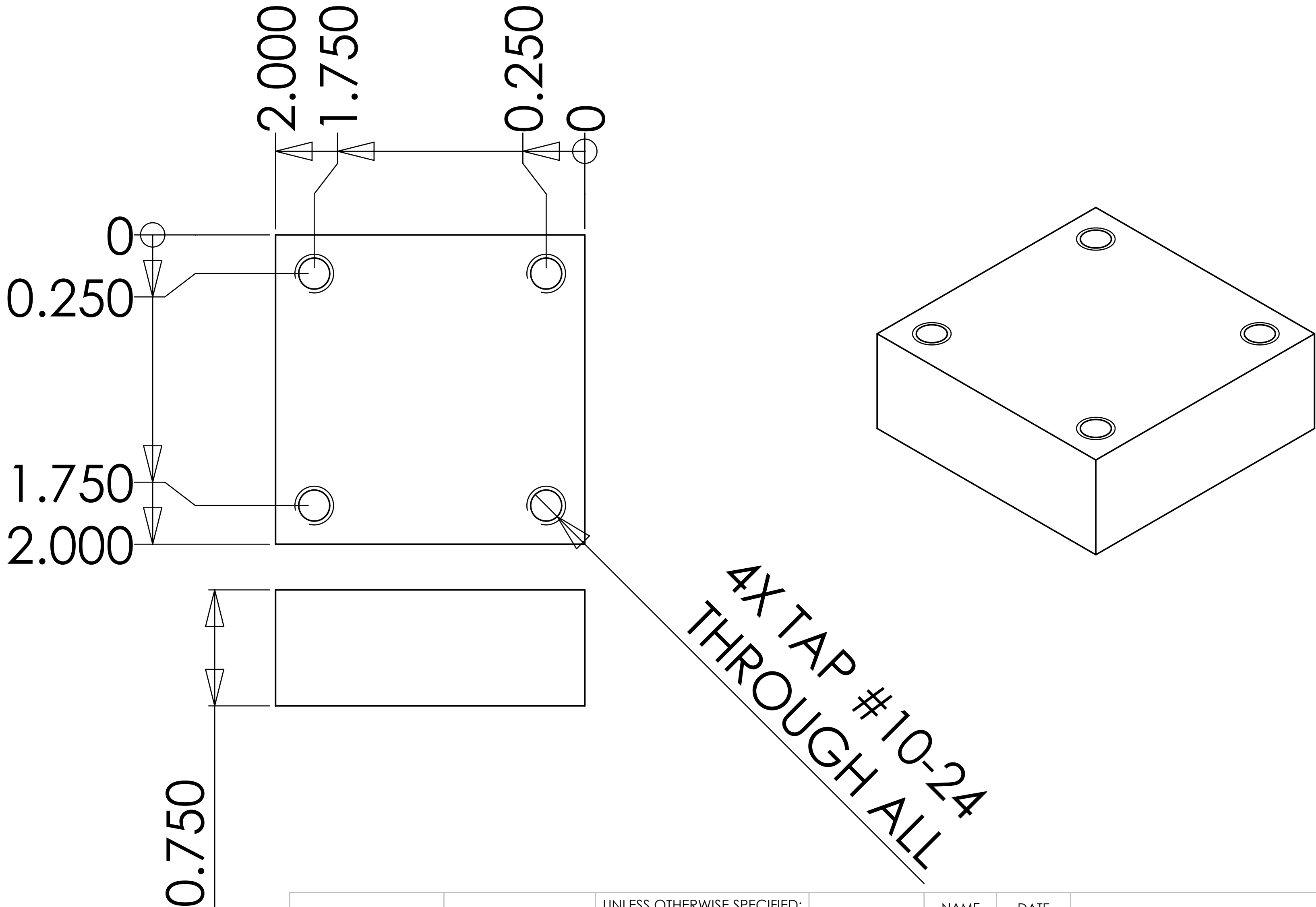
5 4 3 2 1

Part	Qty	Stock
Chamber Jig Base	1	1/4" 6061 Aluminum Plate

Step	Description	Machine	Fixturing	Tooling	Speed	Feed
1	Mount stock to mill bed with mill clamps and sacrificial base	Mill	Mill clamps, plywood			
2	Center drill all holes	Mill				
3	Drill all drilled holes to finish	Mill	Drill Chuck	#7 Drill		
4	Drill all reamed holes to undersize	Mill	Drill Chuck	D Drill		
5	Ream the reamed holes to	Mill	Drill Chuck	.2495 Reamer		
6	Mill the outside edges	Mill	Collet	1/2" HSS 2-flute endmill		



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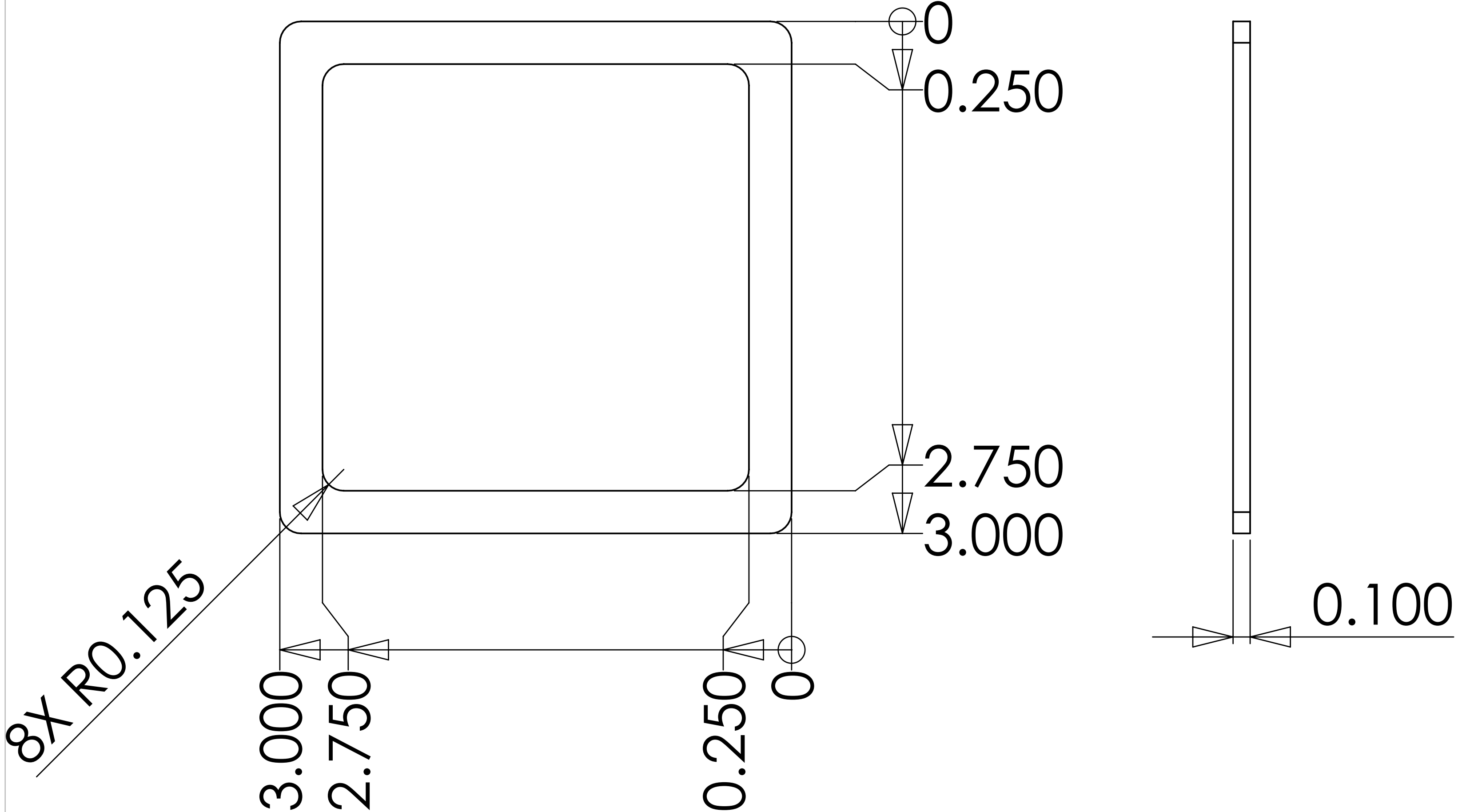
			CHECKED			TITLE: CHAMBER JIG CENTER
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL 6061 ALUMINUM	COMMENTS:			SIZE A / DWG. NO. Chamber_Jig_Center / REV
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:1 / WEIGHT: / SHEET 1 OF 1

5 4 3 2 1

	Part	Qty	Stock			
	Chamber Jig Center	1	3/4" 6061 Aluminum			

Step	Description	Machine	Fixturing	Tooling	Speed	Feed
1	Rough cut to size on the band saw	Bandsaw				
2	Mount in mill vice with finshed edge down	Mill	Mill Vice			
3	Finish exposed top edge	Mill	Collet	1/2" HSS 2 flute endmill		
4	Flip piece, mount in mill vice on parallels	Mill	Mill vice, Parallels			
5	Finish edge first non-clamped edge	Mill	Collet	1/2" HSS 2 flute endmill		
6	Flip around in vice, set datum with edge finder	Mill	Mill vice, Parallels, colle	Edge Finder		
7	Finish final non-clamped edge	Mill	Collet	1/2" HSS 2 flute endmill		
8	Center drill Holes	Mill	Drill Chuck	Center Drill		
9	Drill the holes	Mill	Drill Chuck	#25 Drill		
10	Tap the holes	Mill	Drill Chuck	#10-24 Tap, Tap handle		
11	File Edges	By Hand	-	File		



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			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL 0.10" NEOPRENE RUBBER SHEET	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

TITLE:

CHAMBER MAIN GASKET

SIZE	DWG. NO.	REV
A	Chamber_Main_Gasket	

SCALE: 1:1 WEIGHT: SHEET 1 OF 1

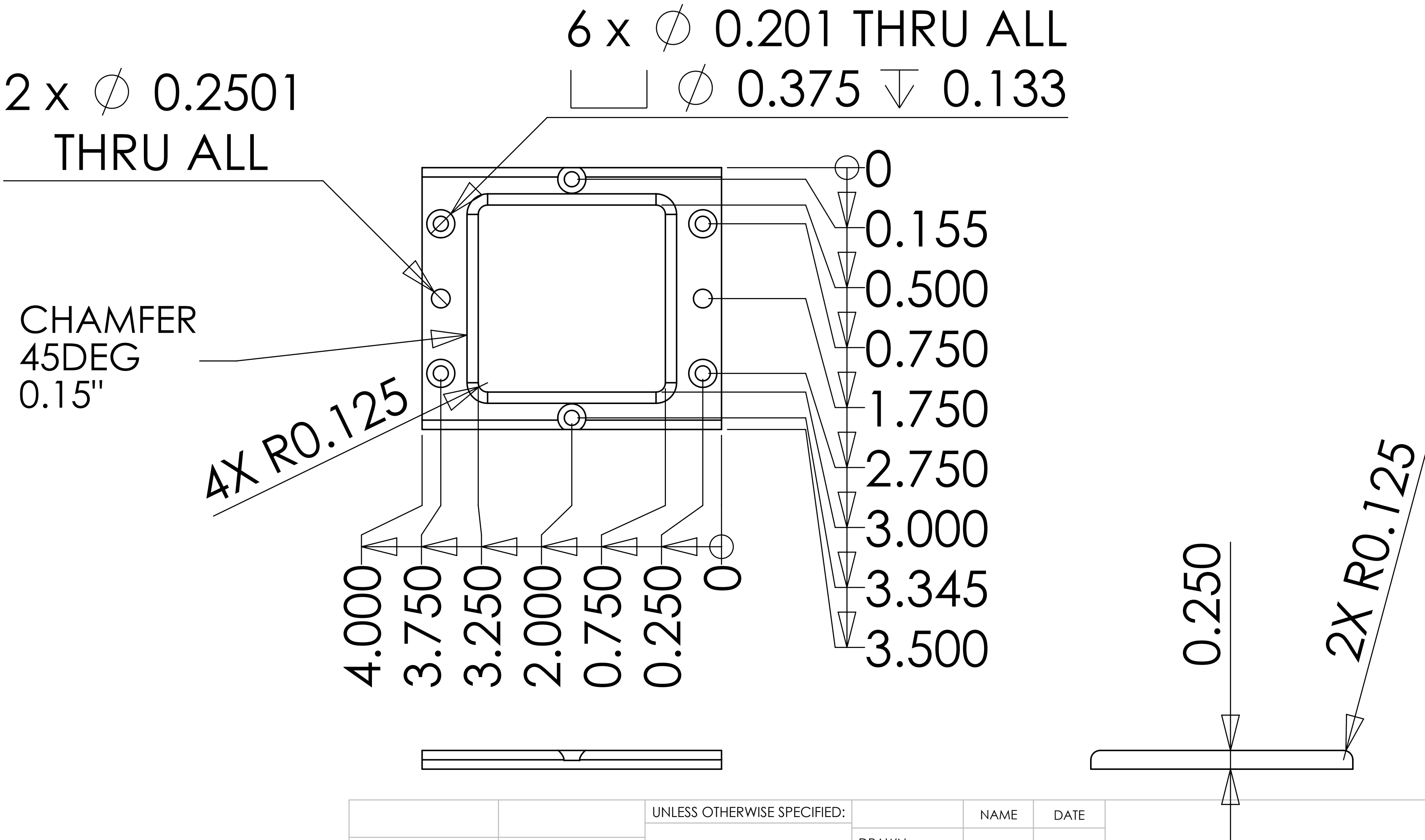
5 4 3 2 1

	Part	Qty
	Chamber Main Gasket	1

Step	Description	Machine
1	Position stock on bed of Laser Cutter	Laser Cutter
2	Cut design from DXF using Laser Cutter	Laser Cutter

Stock
1/16" Neoprene Rubber Sheet

Fixturing	Tooling	Speed	Feed
-	-	-	-
-	-	Determined by lase	-



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			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL 6061 ALUMINUM	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

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TITLE:

CHAMBER RETAINING RING

SIZE	DWG. NO.	REV
A	Chamber_Retaining_Ring	

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

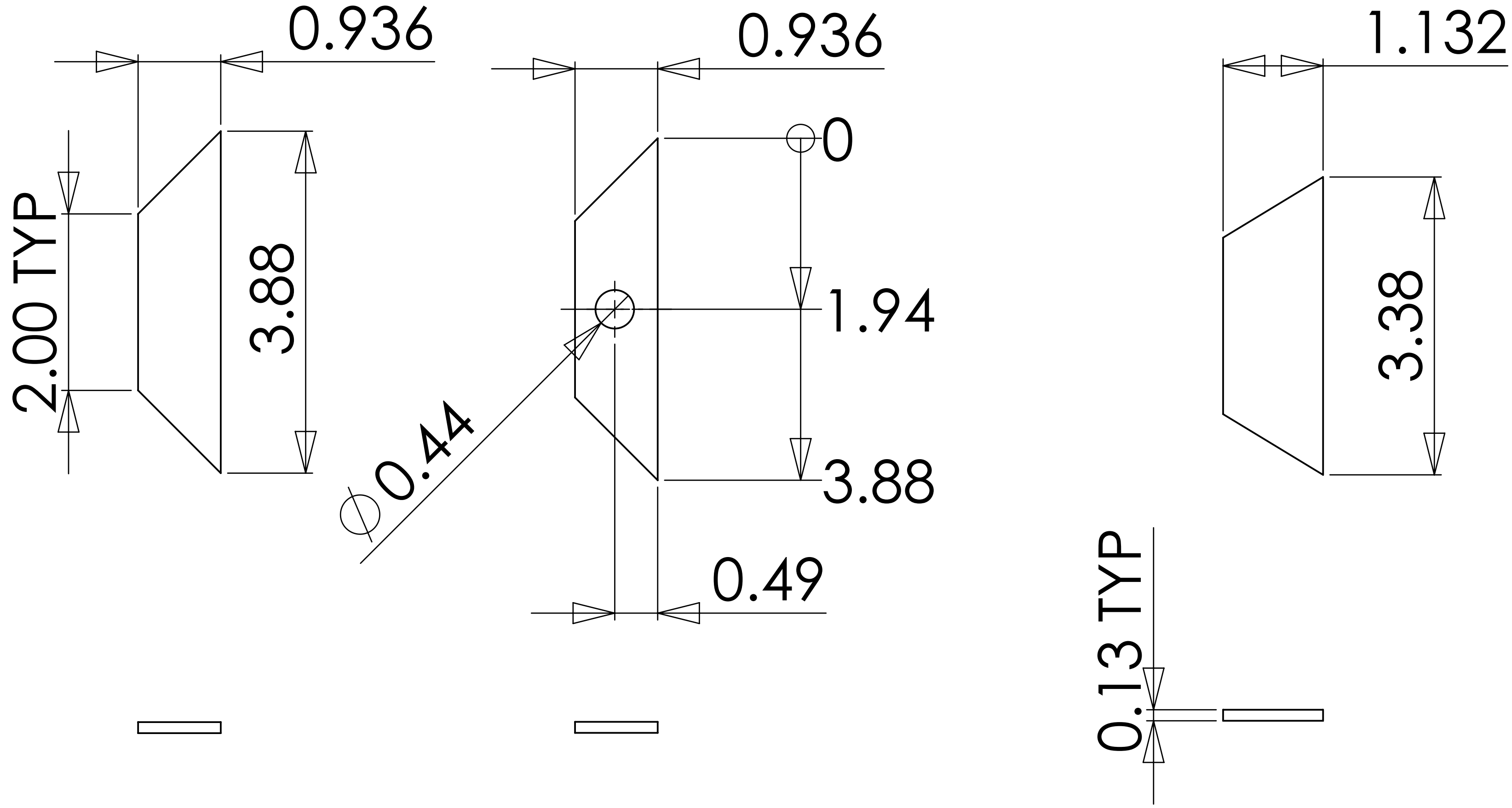
5 4 3 2 1

	Part	Qty	
	Chamber Retaining Ring		1

Step	Description	Machine
1	Mount stock to mill table with mill clamps and sacrificial w	Mill
2	Center drill all holes	Mill
3	Drill the reamed holes to undersize	Mill
4	Drill the counterbored holes to finish	Mill
5	Counterbore the counterbored holes	Mill
6	Ream the reamed holes to finish	Mill
7	Cut out the inside pocket	Mill
8	Fillet the inside pocket	Mill
9	Mill the outside edges	Mill
10	Chamfer the two long outside edges	Mill

Stock
1/4" Aluminum Sheet

Fixturing	Tooling	Speed	Feed
Mill Clamps, Plywood			
Drill Chuck	Center Drill		
Drill Chuck	D Drill		
Drill Chuck	#7 Drill Bit		
Drill Chuck	3/8" Counterbore		
Drill Chuck	.2501 Ream		
Collet	1/4" HSS 2-flute Endmill		
Collet	45-degree fillet cutter		
Collet	1/2" HSS 2-flute endmill		
Collet	1/4" radius cutter		



CHAMBER SIDE LONG
MAKE 1

CHAMBER SIDE LONG WITH HOLE
MAKE 1

CHAMBER SIDE SHORT
MAKE 2

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TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
1/8" 6061 ALUMINUM

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

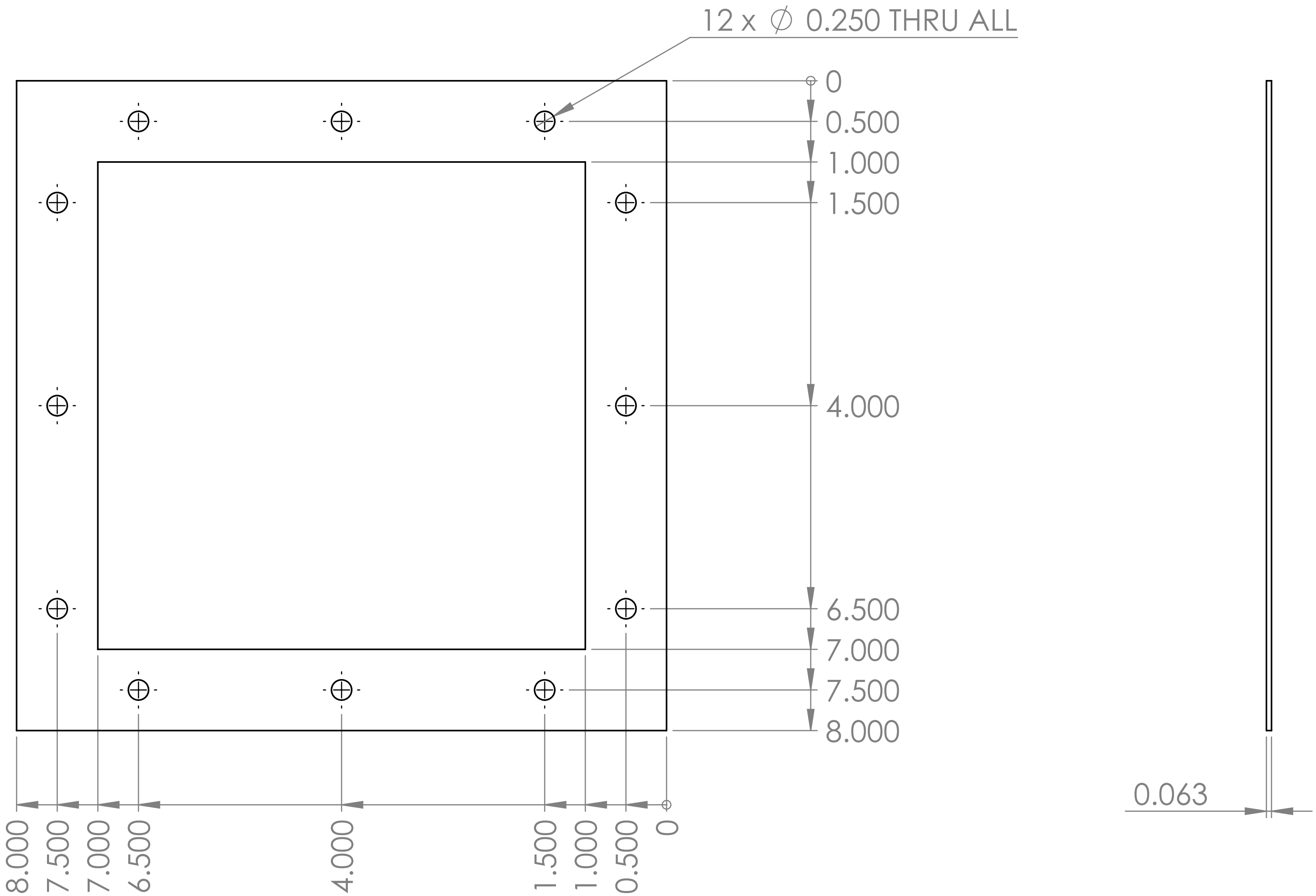
TITLE:
CHAMBER SIDES

SIZE	DWG. NO.	REV
A	Chamber_Sides	

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

Part	Qty	Stock
Chamber Sides	4 (various)	1/8" x 2" x length 6061 Aluminum Plate

Step	Description	Machine	Fixturing	Tooling	Speed	Feed
1	Cut pieces to length on bandsaw	Bandsaw	By Hand			
2	Mount the two long side pieces together in the mill vice with the longest length running along the jaws	Mill	Mill Vice, possibly parallels			
3	Mill down the height to finished spec	Mill	Collet	1/4" HSS 2-flute endmill		
4	Repeat steps 2 and 3 for the short side pieces					
5	File edges	By Hand		File		
6	Mark locations of angled (trapezoid) edges with a scratch awl and a pair of calipers	By Hand		Scratch awl, calipers		
7	Cut the marks from step 6 on the bandsaw	Bandsaw	By Hand	Bandsaw		
8	Mark the location of the hole in the one long side piece	By Hand		Calipers, scratch awl		
9	Drill the hole on the drill press	Drill Press	Vice	7/16" drill bit		
10	File and deburr all	By Hand	By Hand	File, deburrer		



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			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL 1/16" NEOPRENE SHEET	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

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MAKE 2

TITLE:

INLET GASKET
OUTLET GASKET

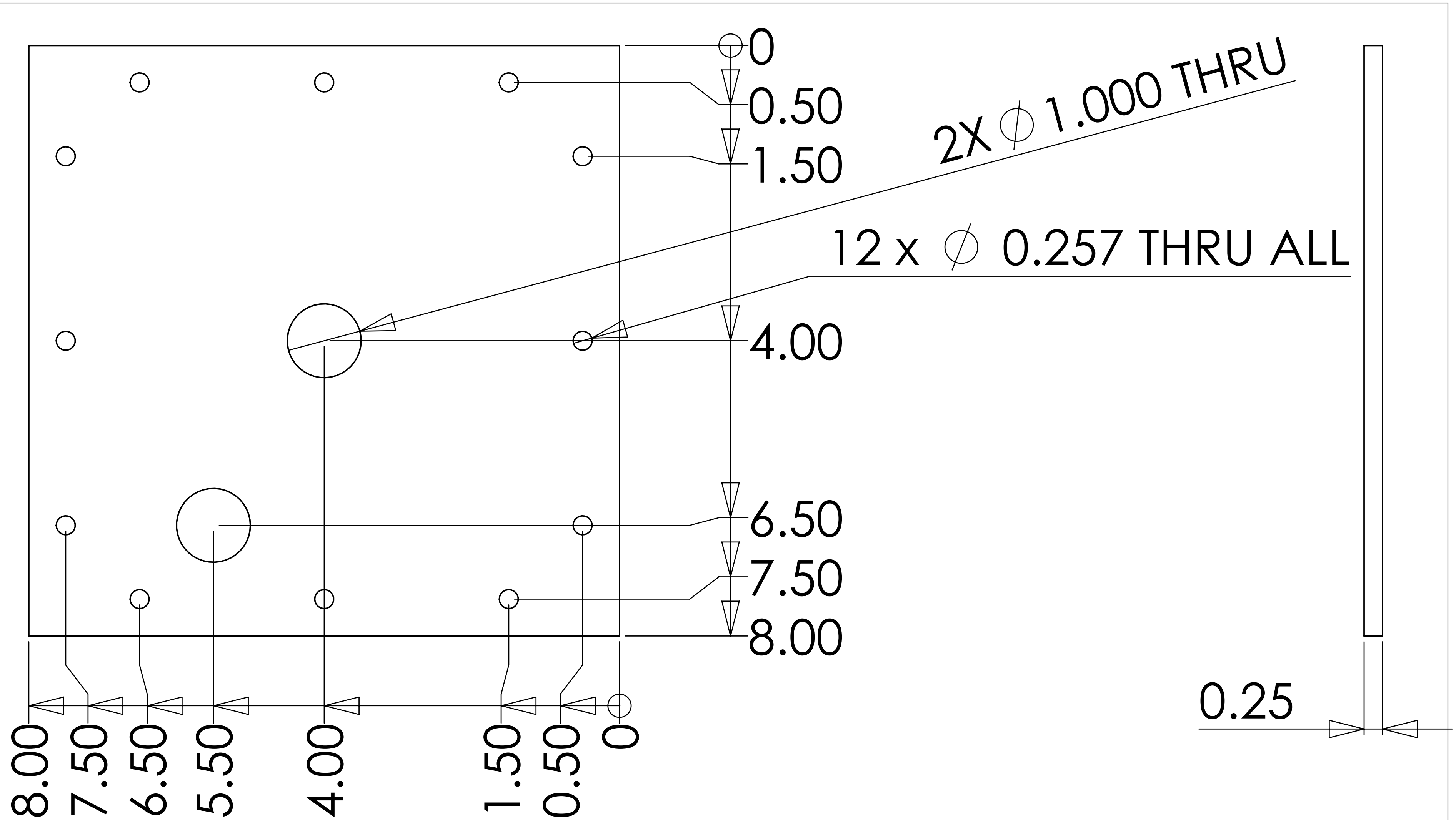
SIZE A DWG. NO. Channel_Cap_Gasket REV

SCALE: 1:1 WEIGHT: SHEET 1 OF 1

5 4 3 2 1

Part	Qty	Stock
Inlet Gasket / Outlet Gasket	2	1/16" Neoprene Rubber Sheet

Step	Description	Machine	Fixturing	Tooling	Speed	Feed
1	Position stock on bed of Laser Cutter	Laser Cutter	-	-	-	-
2	Cut design from DXF using Laser Cutter	Laser Cutter	-	-	Determined by laser cutter postprocessor	-



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DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN			
	CHECKED			TITLE: CHANNEL FRONT PLATE
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL 1/4" 6061 ALUMINUM PLATE	COMMENTS:			SIZE A DWG. NO. Channel_Endcap REV
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:2 WEIGHT: SHEET 1 OF 1

NEXT ASSY	USED ON
APPLICATION	

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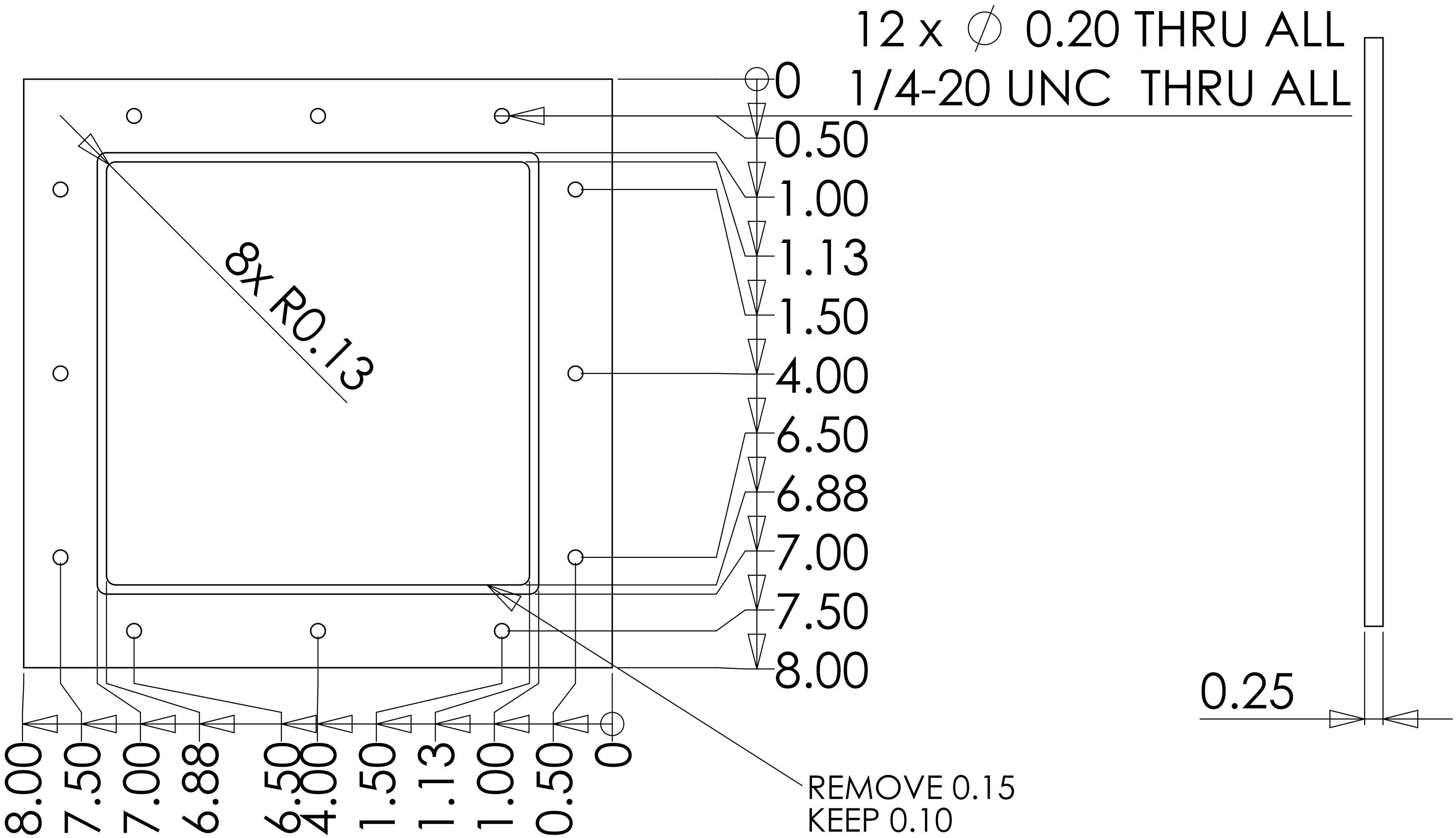
5 4 3 2 1

Part	Qty	Stock
Outlet Channel Cap	1	1/4" 6061 Aluminum Plate

Step	Description	Machine	Fixturing	Tooling	Speed	Feed
1	Mount stock to mill table with mill clamps and sacrificial wood base	Mill	Mill Clamps, Plywood			
2	Center drill holes	Mill	Drill Chuck	Center Drill		
3	Drill small through holes to finish	Mill	Drill Chuck	F Drill		
4	Drill large holes undersize	Mill	Drill Chuck	7/8" drill bit		
6	Tap the tapped hole	Mill	Drill Chuck, Live Center	1/2-28 NPT Tap, Tap handle		
7	Ream 1" holes to finish	Mill	Collet	1" reamer		
8	Mill outside edges	Mill	Collet	1/2" HSS 2-flute Endmill		



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APPLICATION	

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TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

OUTLET CHANNEL FLANGE

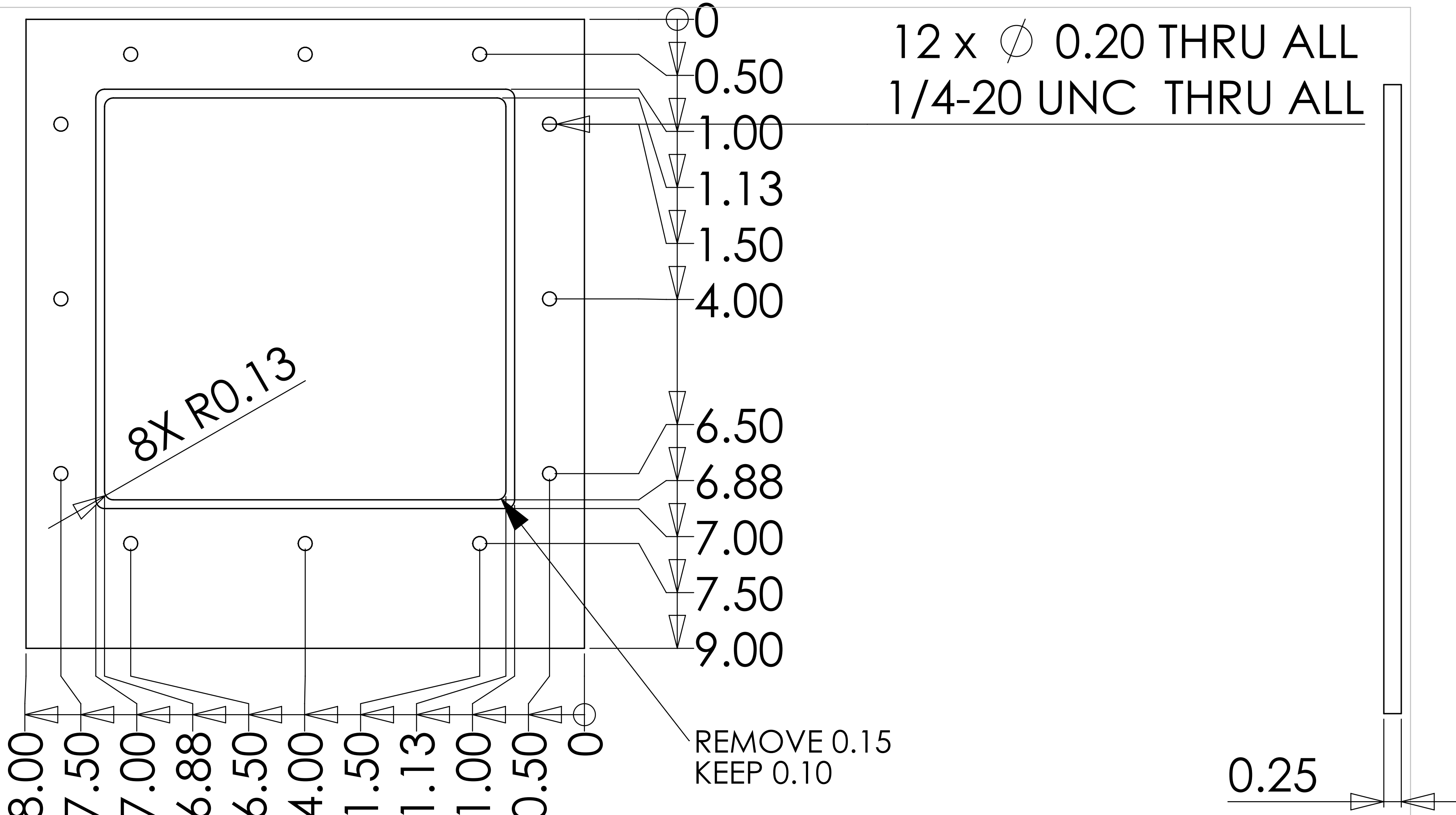
SIZE	DWG. NO.	REV
A	Channel_Flange_End	

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

5 4 3 2 1

Part	Qty	Stock
Outlet Channel Flange	1	1/4" Aluminum Plate

Step	Description	Machine	Fixturing	Tooling	Speed	Feed
1	Mount stock to mill bed with mill clamps and sacrificial wood	Mill	Mill clamps, plywood			
2	Center drill holes	Mill	Drill Chuck	Center Drill		
3	Drill holes to finish	Mill	Drill Chuck	#25 Drill Bit		
4	Tap holes	Mill	Drill Chuck	#10-24 Drill bit, Live Center		
5	Mill out penetration	Mill	Collet	1/2" HSS 2-flute endmill		
6	Mill out shoulder	Mill	Collet	1/4" HSS 2-flute endmill		
7	Mill outside edges	Mill	Collet	1/2" HSS 2-flute endmill		



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ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
1/4" 6061 ALUMINUM PLATE

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:
INLET CHANNEL FLANGE

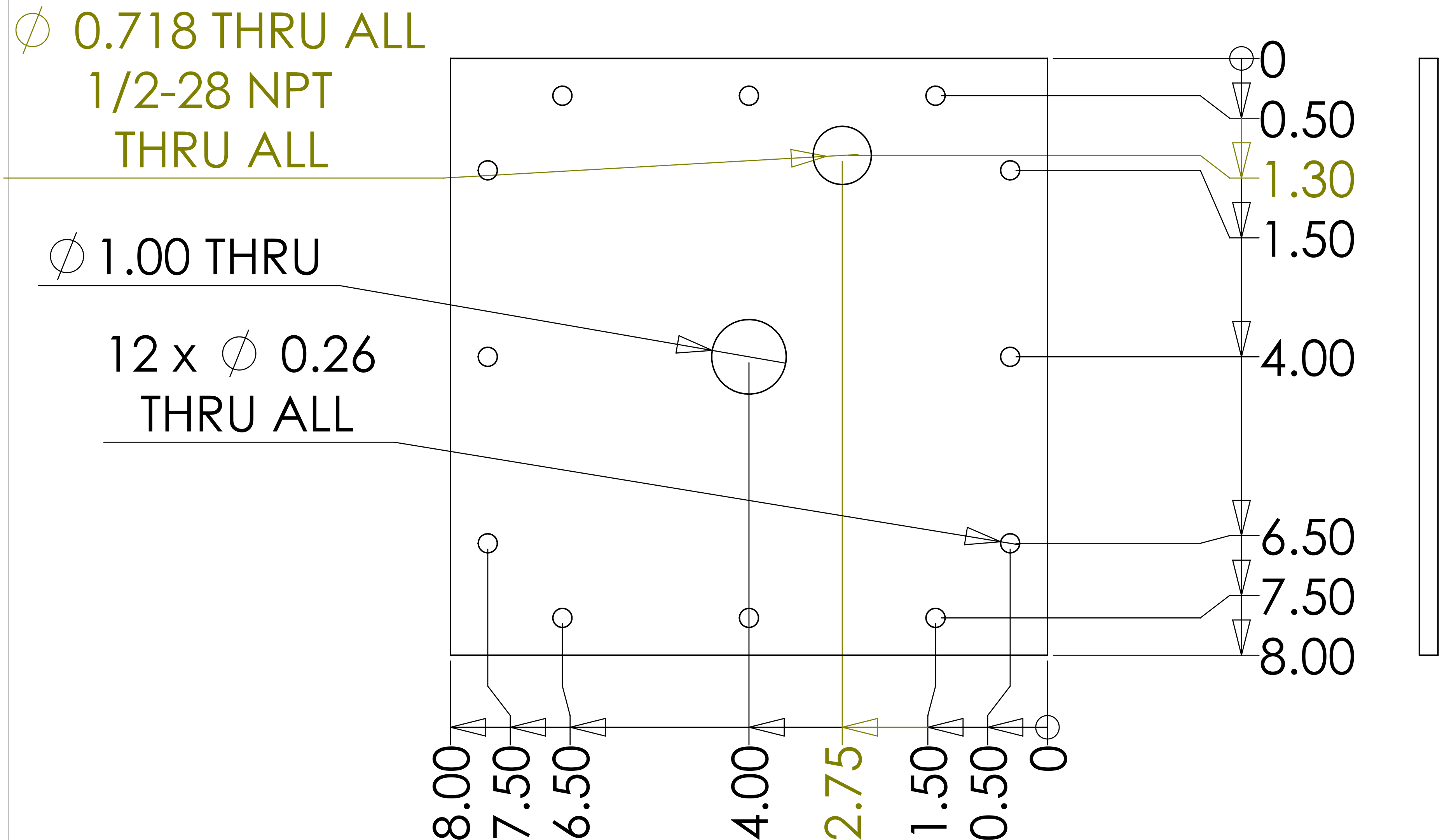
SIZE	DWG. NO.	REV
A	Channel_Flange_Front	

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

5 4 3 2 1

Part	Qty	Stock
Inlet Channel Flange	1	1/4" Aluminum Plate

Step	Description	Machine	Fixturing	Tooling	Speed	Feed
1	Mount stock to mill bed with mill clamps and sacrificial wood	Mill	Mill clamps, plywood			
2	Center drill holes	Mill	Drill Chuck	Center Drill		
3	Drill holes to finish	Mill	Drill Chuck	#25 Drill Bit		
4	Tap holes	Mill	Drill Chuck	#10-24 Drill bit, Live Center		
5	Mill out penetration	Mill	Collet	1/2" HSS 2-flute endmill		
6	Mill out shoulder	Mill	Collet	1/4" HSS 2-flute endmill		
7	Mill outside edges	Mill	Collet	1/2" HSS 2-flute endmill		



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APPLICATION	

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TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
1/4" 6061 ALUMINUM

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:
INLET CHANNEL CAP

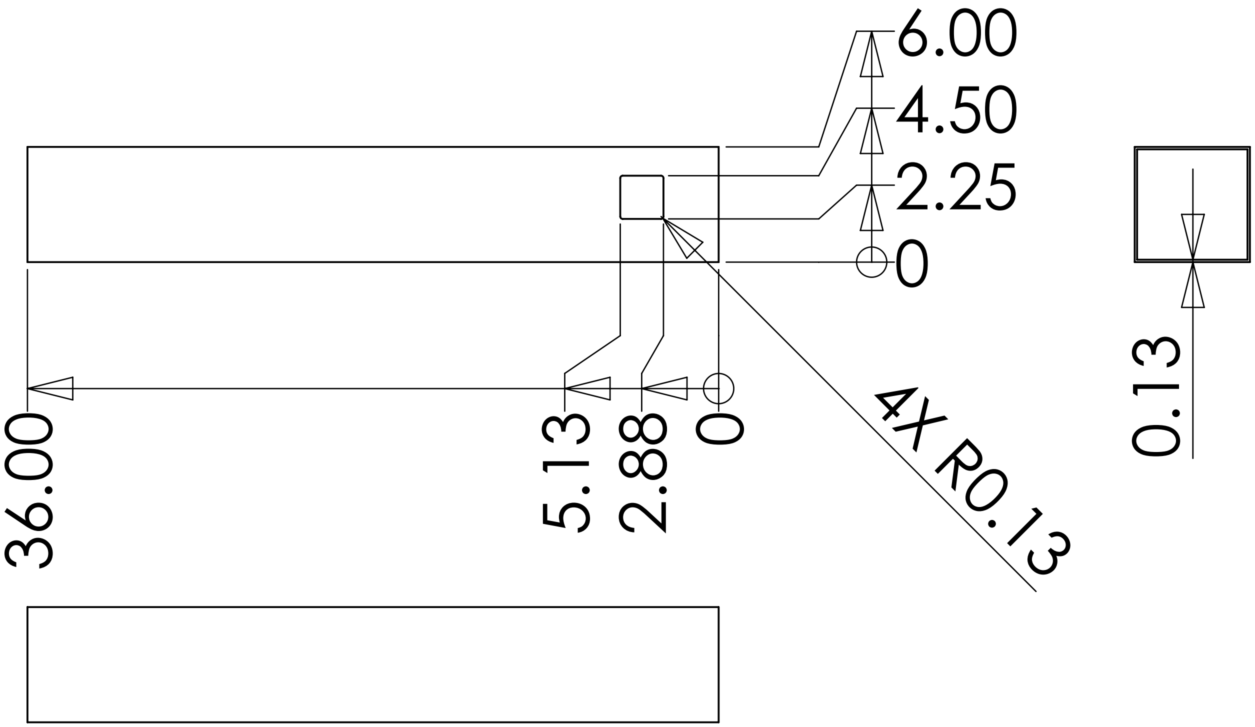
SIZE	DWG. NO.	REV
A	Channel_Frontcap	

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

5 4 3 2 1

Part	Qty	Stock
Inlet Channel Cap		1/4" 6061 Aluminum Plate

Step	Description	Machine	Fixturing	Tooling	Speed	Feed
1	Mount stock to mill table with mill clamps and sacrificial wood base	Mill	Mill Clamps, Plywood			
2	Center drill holes	Mill	Drill Chuck	Center Drill		
3	Drill small through holes to finish	Mill	Drill Chuck	F Drill		
4	Drill large hole undersize	Mill	Drill Chuck	7/8" drill bit		
5	Drill tapped hole to finish	Mill	Drill Chuck	23/32" drill bit		
6	Tap the tapped hole	Mill	Drill Chuck, Live Center	1/2-28 NPT Tap, Tap handle		
7	Ream 1" hole to finish	Mill	Collet	1" reamer		
8	Mill outside edges	Mill	Collet	1/2" HSS 2-flute Endmill		



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			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL 6"X6"X1/8" WALL 6063 ALUMINUM TUBING	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

TITLE:

CHANNEL

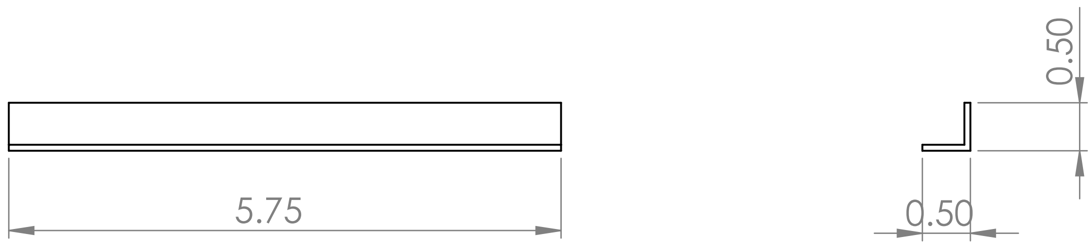
SIZE	DWG. NO.	REV
A	Channel_Monopiece	

SCALE: 1:10 WEIGHT: SHEET 1 OF 1

5 4 3 2 1

Part	Qty	Stock
Channel	1	6" x 6" x 0.125" wall 6061 Aluminum extrusion

Step	Description	Machine	Fixturing	Tooling	Speed	Feed
1	Cut to length on horizontal bandsaw	Horizontal Bandsaw	Bandsaw Vice			
2	Mount in Mill Vice. If vice too small, use mill clamps and secure to mill table	Mill	Mill Vice, Mill Clamps	-		
3	Find datum with edgefinder	Mill	Collet	Edgefinder		
4	Mill out opening in one side	Mill	Collet	1/4" HSS 2-flute Endmill		
5	Flip over and repeat steps 2-4	Mill				
6						
7						
8						
9						
10						
11						
12						



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
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			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL 6061 ALUMINUM	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
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TITLE:

LAMINAR FLOW GUIDE BRACKET

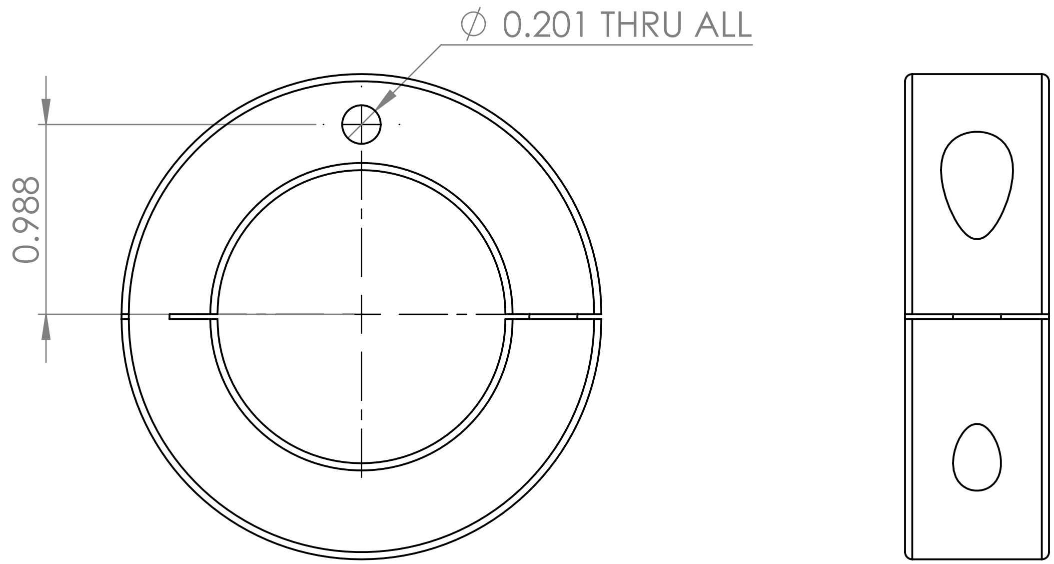
SIZE	DWG. NO.	REV
A	Flow_Guide_Bracket	

SCALE: 1:2	WEIGHT:	SHEET 1 OF 1

5 4 3 2 1

Part	Qty	Stock
Laminar Flow guide Bracket	2	1"x1"x1/16" 6061 Angle

Step	Description	Machine	Fixturing	Tooling	Speed	Feed
1	Cut to length on bandsaw	Bandsaw	Vice	-		
2	Mount in Mill vice	Mill	Mill Vice	-		
3	Set datum with edge finder	Mill	Collet	Edgefinder		
4	Trip one leg to correct width	Mill	Collet	1/4" HSS 2-flute endmill		
5	Flip around in vice, repeat steps 4 and 5	Mill	-	-		



ALL DIMENSIONS UNCHANGED FROM
STOCK PIECE UNLESS OTHERWISE NOTED

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			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL MCMASTER PART 9410T130	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

TITLE:
ANGLE ADJUSTMENT LOCK COLLAR

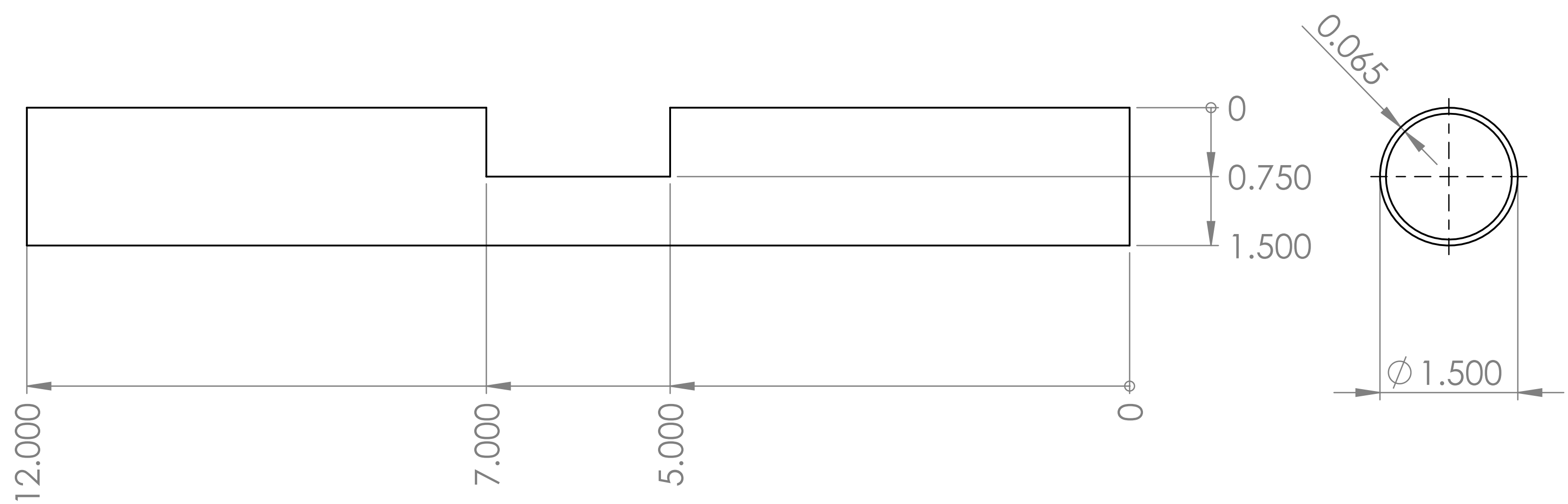
SIZE	DWG. NO.	REV
A	Lock_Collar_9410T130_MOD	

SCALE: 1:1	WEIGHT:	SHEET 1 OF 1

5 4 3 2 1

Part	Qty	Stock
Angle Adjustment Lock Collar	1	McMaster 9410T130

Step	Description	Machine	Fixturing	Tooling	Speed	Feed
1	Place 1.5" carrier in middle of stock, tighten down		Short Piece of 1.5" pipe	-		
2	Mount stock in mill vice	Mill	Mill Vice	-		
3	Set datum with edge finder	Mill	Collet	Edge Finder		
4	Center drill hole	Mill	Drill Chuck	Center Drill		
5	Drill hole	Mill	Drill Chuck	#25 drill bit		



NEXT ASSY	USED ON	
APPLICATION		

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TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
6061 ALUMINUM TUBE

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

PIPE

SIZE	DWG. NO.	REV
A	Pipe	
SCALE: 1:1	WEIGHT:	SHEET 1 OF 1

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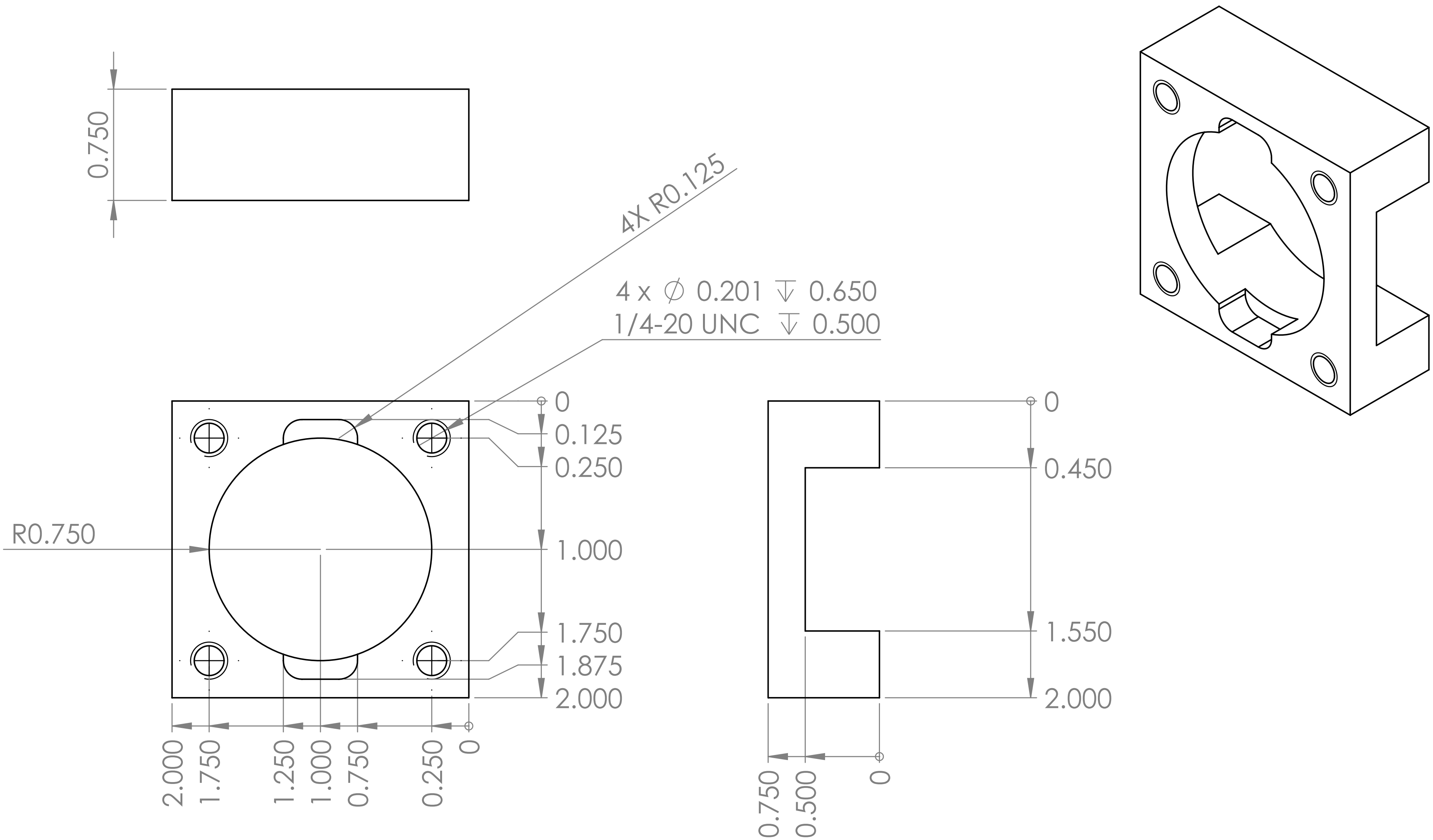
5 4 3 2 1

Part	Qty	Stock
Pipe	1	1.5" OD 6061 Aluminum Tube x .065 wall

Step	Description	Machine	Fixturing	Tooling	Speed	Feed
1	Mount in mill vice with block	Mill	Mill Vice, Notched Block	-	-	-
2	Set datum	Mill	Collet	Edge Finder		
3	Trip end to length with endmill	Mill	Collet	1/2" HSS 2-flute endmill		
4	Mill out opening	Mill	Collet	1/2" HSS 2-flute endmill		



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		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN		
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL 6061 ALUMINUM	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

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TITLE:

PIPE ADAPTER BLOCK

SIZE	DWG. NO.	REV
A	Pipe_Adapter_Block	

SCALE: 1:1	WEIGHT:	SHEET 1 OF 1

5 4 3 2 1

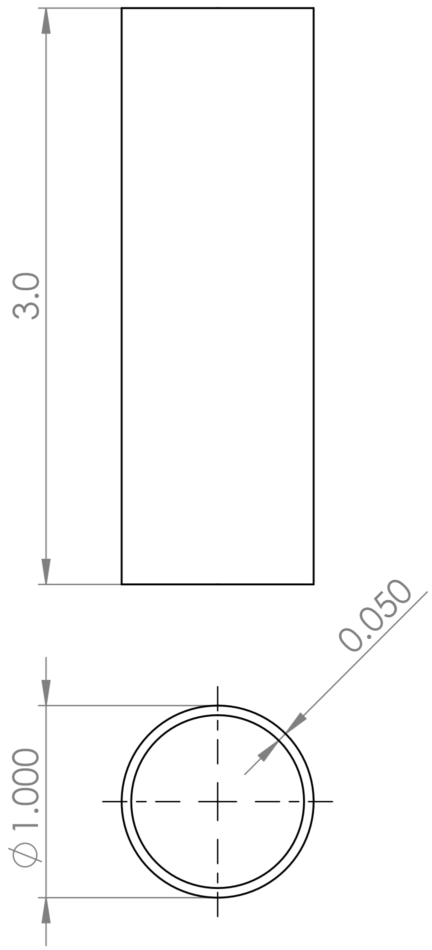
	Part	Qty	Stock		
	Pipe Adapter Block	1	3/4" 6061 Alunimum Plate		

Step	Description	Machine	Fixturing	Tooling	Speed
1	Rough cut to size on the band saw	Bandsaw			
2	Mount in mill vice with finshed edge down	Mill	Mill Vice		
3	Finish exposed top edge	Mill	Collet	1/2" HSS 2 flute endmill	
4	Flip piece, mount in mill vice on parallels	Mill	Mill vice, Parallels		
5	Finish edge first non-clamped edge	Mill	Collet	1/2" HSS 2 flute endmill	
6	Flip around in vice, set datum with edge finder	Mill	Mill vice, Parallels, colle	Edge Finder	
7	Finish final non-clamped edge	Mill	Collet	1/2" HSS 2 flute endmill	
8	Drill out large center hole as much as possible	Mill	Collet / Drill Chuck	Drill bits up to 1"	
9	When drills run out, change to boring head.	Mill	Collet	Adjustable Boring Head	
10	Mill out small pockets	Mill	Collet	1/4" HSS 2 flute endmill	
11	Center Drill the tapped Holes	Mill	Drill Chuck	Center Drill	
12	Drill the tapped Holes	Mill	Drill Chuck	#25 drill bit	
13	Tap the tapped holes	Mill	Drill Chuck, Live Center	#10-24 tap, tap handle	
14	Flip piece over, re-find datum	Mill	Mill Vice, Parallels	Edge Finder	
15	Mill out channel	Mill	Collet	1/4" HSS 2 flute endmill	
16	File/Deburr	By Hand		Deburrer, File	

Feed

Part	Qty	Stock
Corrugated Plastic Panel	34	Corrugated Plastic Sheet

Step	Description	Machine	Fixturing	Tooling	Speed	Feed
1	Cut to size with a straighedge and a utility knife	By hand	Table, Straightedge	Utility Knife		



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APPLICATION	

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TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
6061 ALUMINUM TUBE

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

CAP NIPPLE

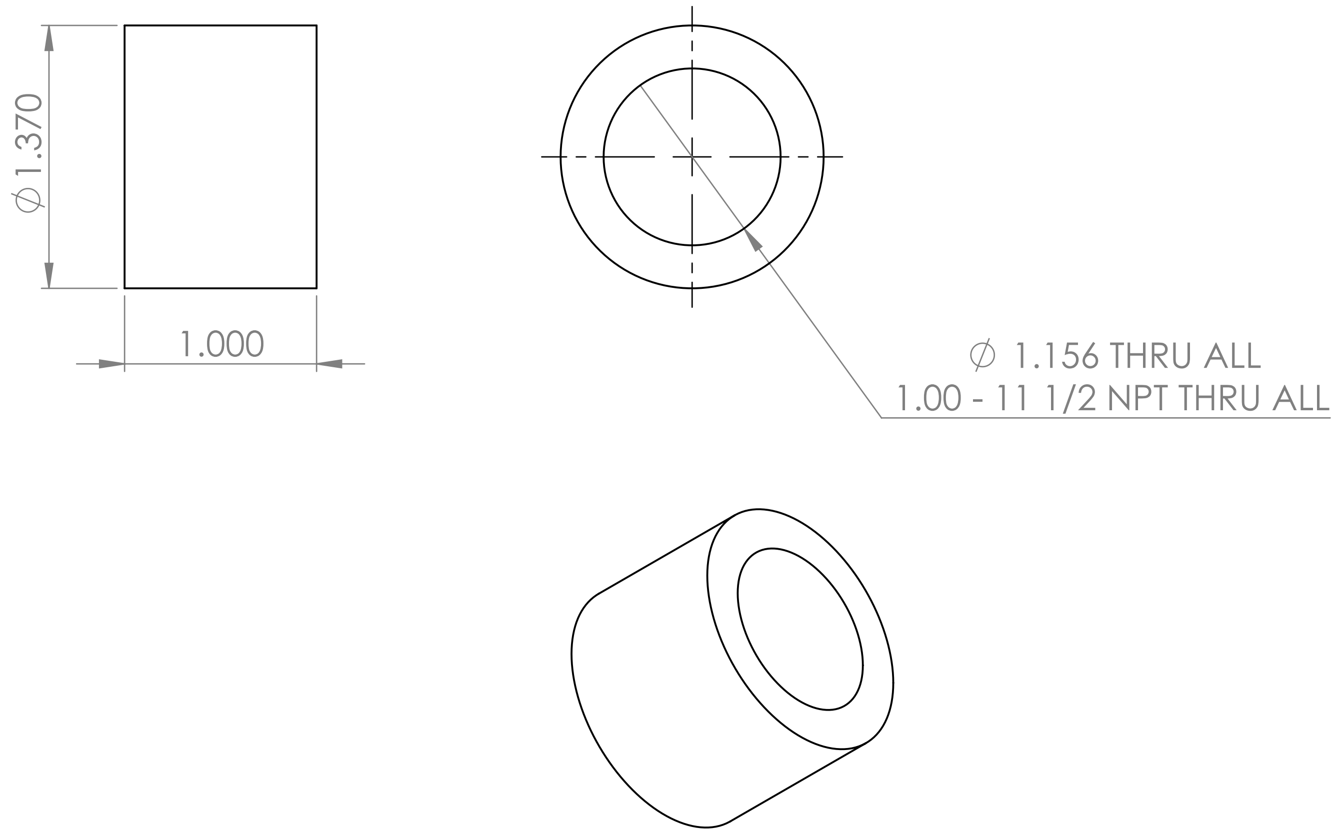
SIZE	DWG. NO.	REV
A	Pipe_Stub_3x1	

SCALE: 1:1	WEIGHT:	SHEET 1 OF 1

5 4 3 2 1

Part	Qty	Stock
Cap Nipple	2	1" OD Aluminum Tubing x 0.050 wall

Step	Description	Machine	Fixturing	Tooling	Speed	Feed
1	Mount in Lathe Chuck	Lathe	Lathe Chuck	-	-	-
2	Cut off to 3" long	Lathe	Tool Post	Cutoff Tool		



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INTERPRET GEOMETRIC TOLERANCING PER:	COMMENTS:	
MATERIAL 6061 ALUMINUM ROD		
FINISH		
DO NOT SCALE DRAWING		

NEXT ASSY	USED ON
APPLICATION	

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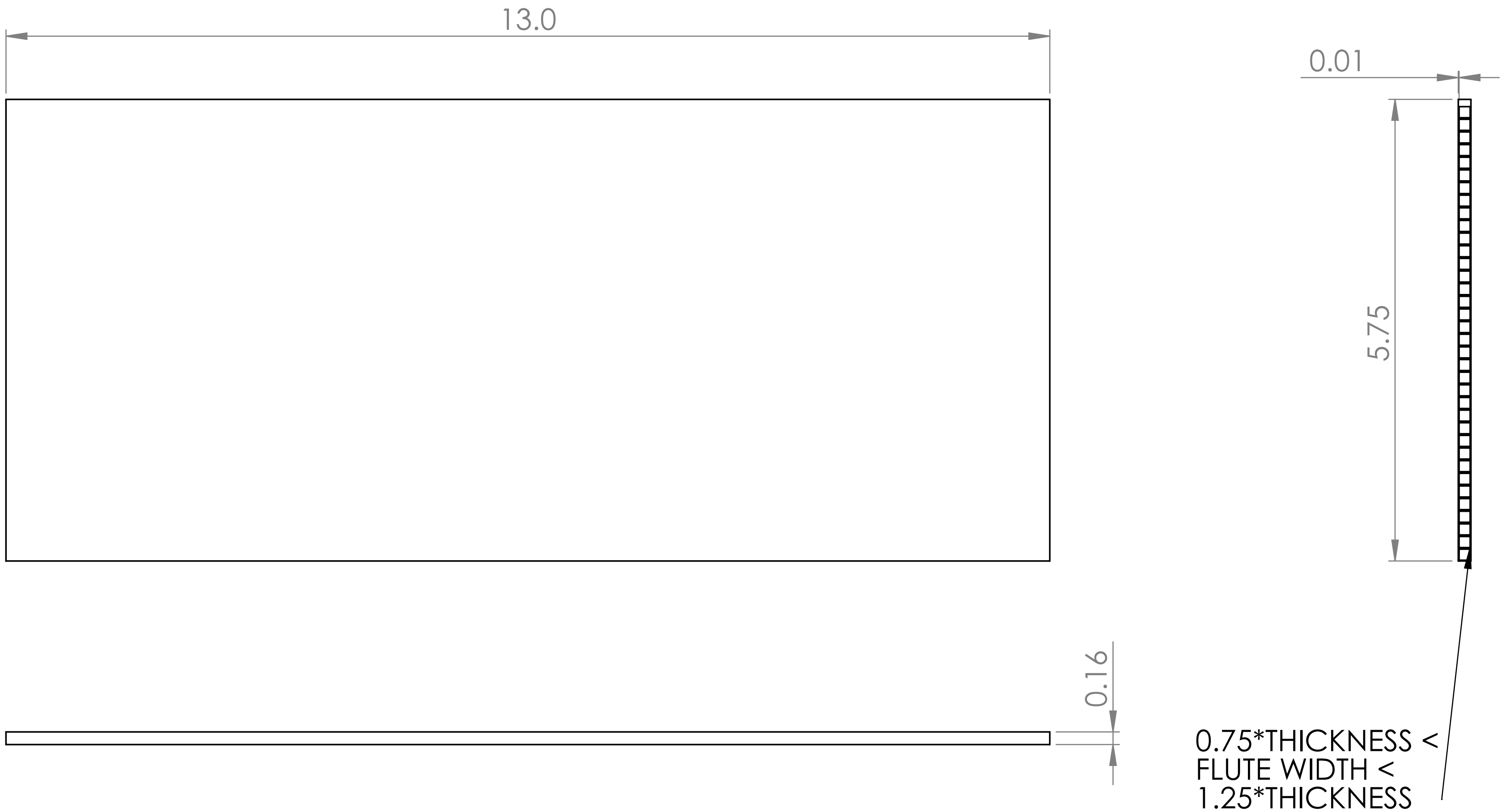
TITLE: PIPE TAPPED PLUG

SIZE	DWG. NO.	REV
A	Pipe_Tapped_Plug	
SCALE: 1:1	WEIGHT:	SHEET 1 OF 1

5 4 3 2 1

Part	Qty	Stock
Pipe Tapped Plug	1	1.5" 6061 Aluminum Rod

Step	Description	Machine	Fixturing	Tooling	Speed	Feed
1	Mount stock in lathe	Lathe	Chuck	-	-	-
2	Turn diameter down to 1.315"	Lathe	Tool Post	Facing Tool		
3	Face the end	Lathe	Tool Post	Facing Tool		
4	Center drill the end	Lathe	Drill Chuck	Center Drill		
5	Use drill bits of increasing size to make 1.156" hole	Lathe	Drill Chuck	Various up to 1.15"		
6	If drill bits of that size are not available, move up to a boring bar after 1"	Lathe	Tool Post	Boring Bar		
7	Tap the hole	Lathe	Drill Chuck, Live Center	1.00 - 11 1/2 NPT Tap, Tap Handle		
8	Cut part to length	Lathe	tool Post	Cutoff Tool		



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TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
CORRUGATED PLASTIC SHEET

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

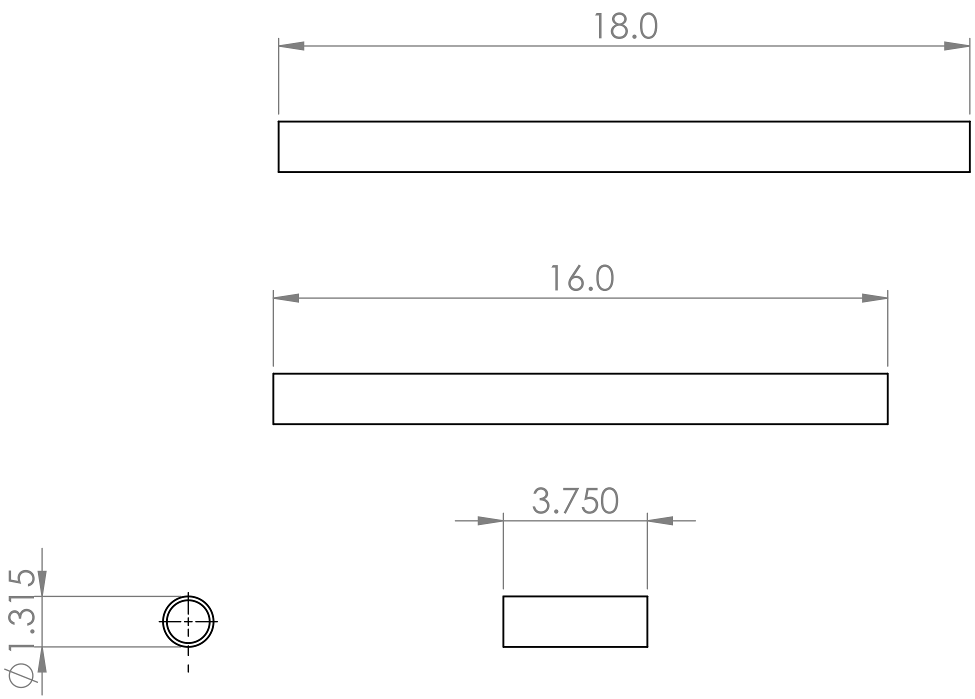
TITLE:

CORRUGATED PLASTIC PANEL

SIZE	DWG. NO.	REV
A	Plastic_Corr_Sheet	

SCALE: 1:5 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



LONG PIECE - MAKE 1

SHORT PIECE - MAKE 1

VERY SHORT PIECE - MAKE 1

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APPLICATION	

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TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
1" PVC PIPE

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

PVC PIPE PIECES

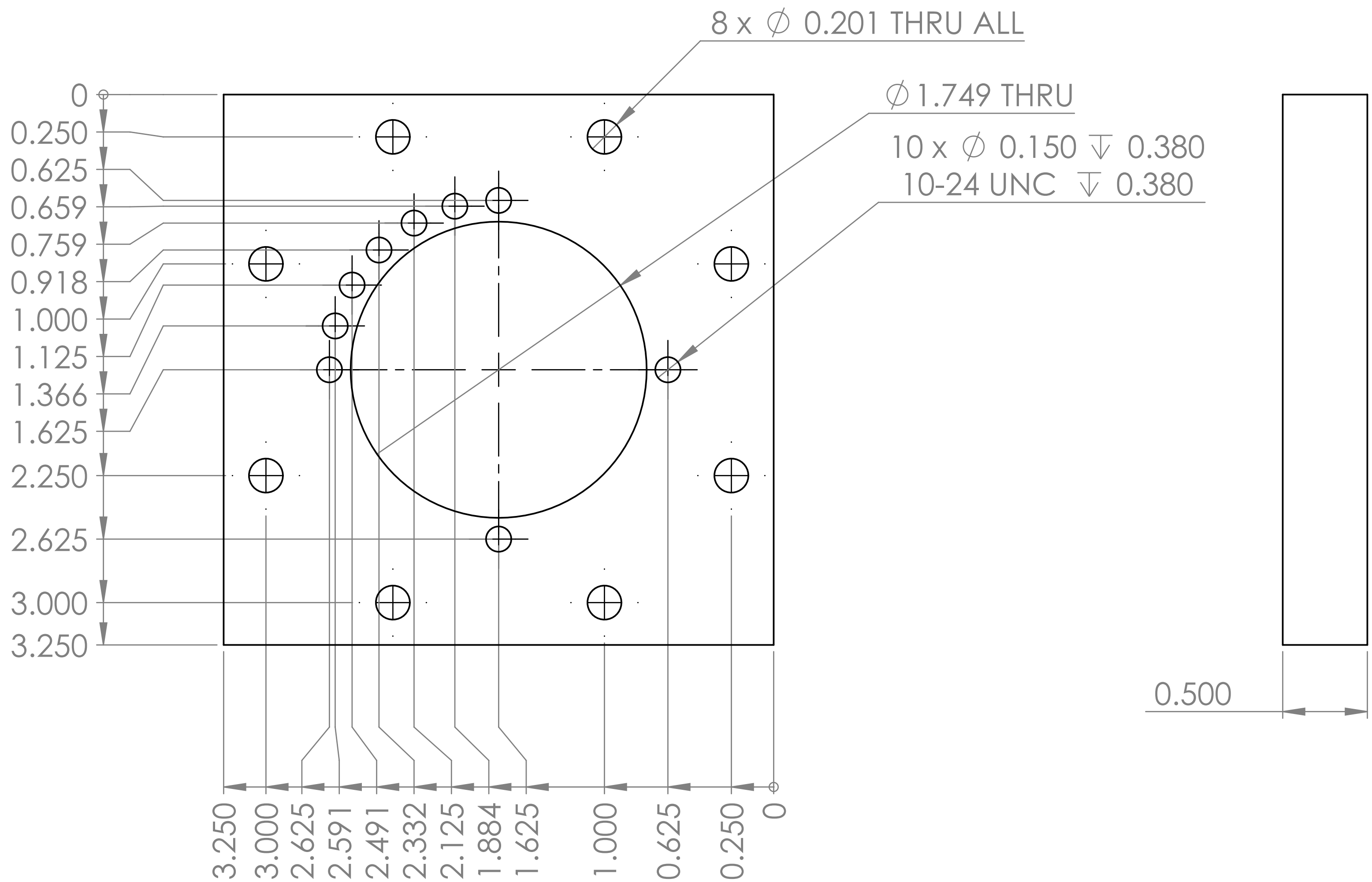
SIZE	DWG. NO.	REV
A	PVC_Pipe_Long	

SCALE: 1:5	WEIGHT:	SHEET 1 OF 1

5 4 3 2 1

Part	Qty	Stock
PVC Pipes (all Sizes)	4, of various lengths	1" x 10' PVC Pipe

	Process	Machine	Fixturing	Tooling	Speeds	Feeds
1	Cut to length on the bandsaw	Bandsaw	Vice	-		
2	Deburr	By Hand	-	Deburring tool	-	-



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TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
6061 ALUMINUM

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

MAKE 2

TITLE:

SHAFT SEAL HOLDER

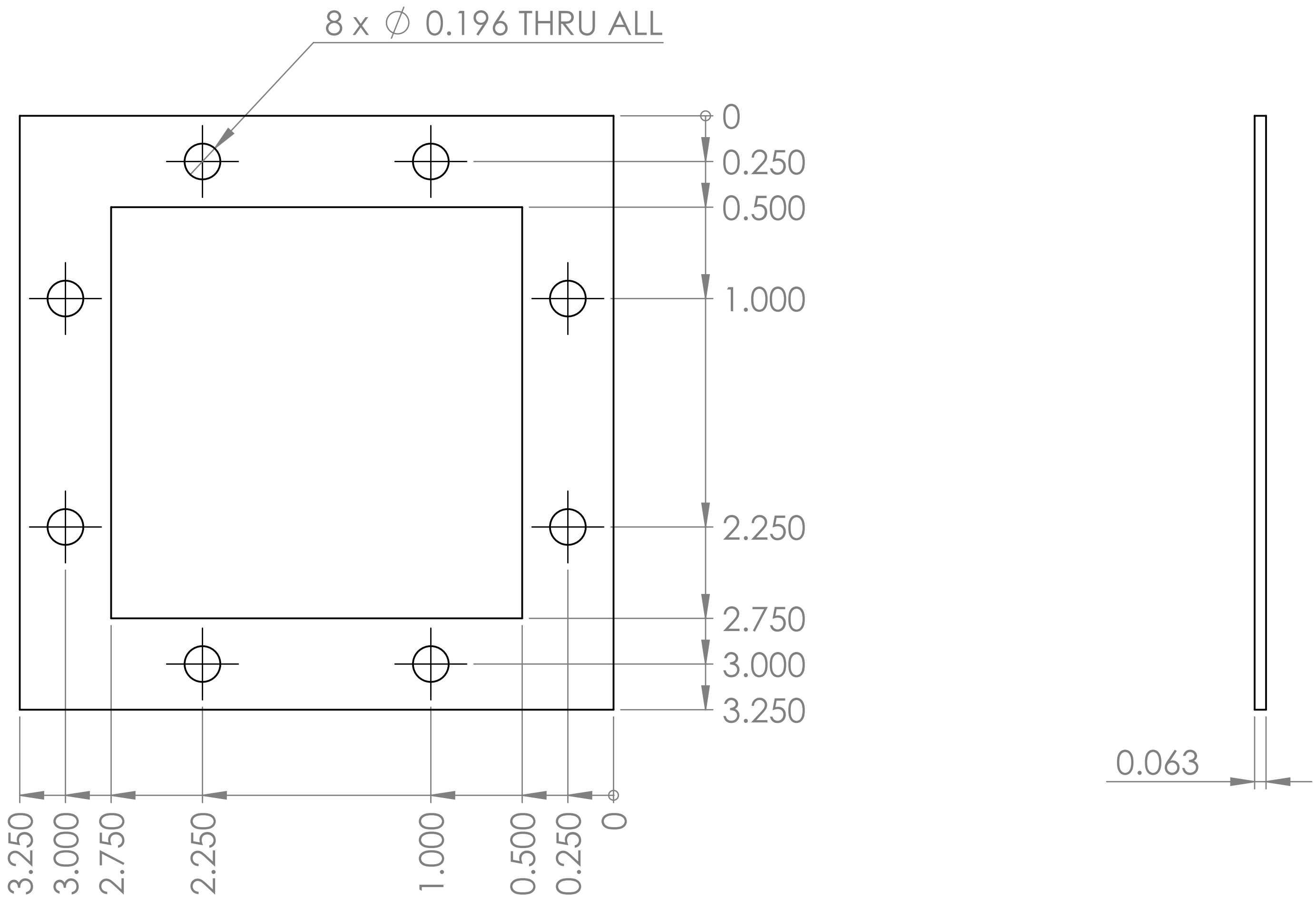
SIZE	DWG. NO.	REV
A	Shaft_Seal_Holder	

SCALE: 1	WEIGHT:	SHEET 1 OF 1

5 4 3 2 1

Part	Qty	Stock
Shaft Seal Holder	2	1/2" 6061 Aluminum Plate

Step	Description	Machine	Fixturing	Tooling	Speed	Feed
1	Rough out piece on the Bandsaw	Bandsaw	-			
2	Mount piece to mill table with mill clamps and sacrificial wood	Mill	Mill Clamps, Plywood	-	-	-
3	Rough drill center opening	Mill	Collet	Morse Drill		
4	Center Drill all non-bored Holes	Mill	Drill Chuck	Center Drill		
5	Drill outside holes through	Mill	Drill Chuck	#7 Drill bit		
6	Drill inside holes to specified depth	Mill	Drill Chuck	#25 Drill Bit		
7	Tap inside holes	Mill	Drill Chuck, Live Center	#10-24 tap, tap handle		
8	Bore out large opening	Mill	Collet	Adjustable Boring Head		
9	Cut outside edges	Mill	Collet	1/4" HSS two-flute endmill		



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	MAKE 2
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN			TITLE: SHAFT SEAL GASKET
			CHECKED			
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL 1/16" NEOPRENE SHEET	COMMENTS:			SIZE A DWG. NO. Shaft_Seal_Holder_Gasket REV
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:1 WEIGHT: SHEET 1 OF 1

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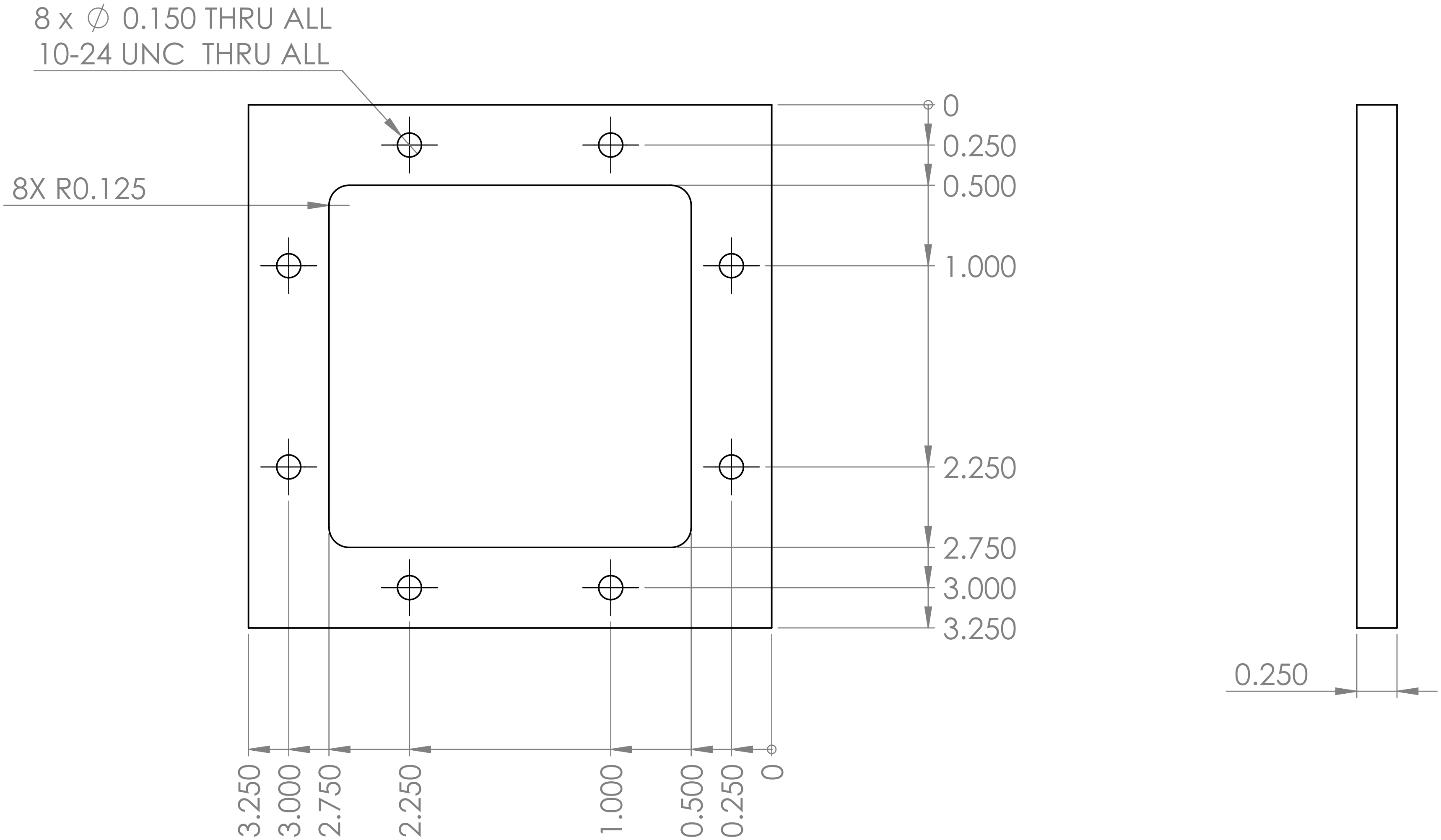
5 4 3 2 1

Part	Qty	Stock
Shaft Seal Gasket	2	1/16" Neoprene Rubber Sheet

Step	Description	Machine	Fixturing	Tooling	Speed	Feed
1	Position stock on bed of Laser Cutter	Laser Cutter	-	-	-	-
2	Cut design from DXF using Laser Cutter	Laser Cutter	-	-	Determined by laser cutter postprocessor	-



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN		
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL 6061 ALUMINUM	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

PROPRIETARY AND CONFIDENTIAL

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MAKE 2

TITLE:

SHAFT SEAL TAPPED RING

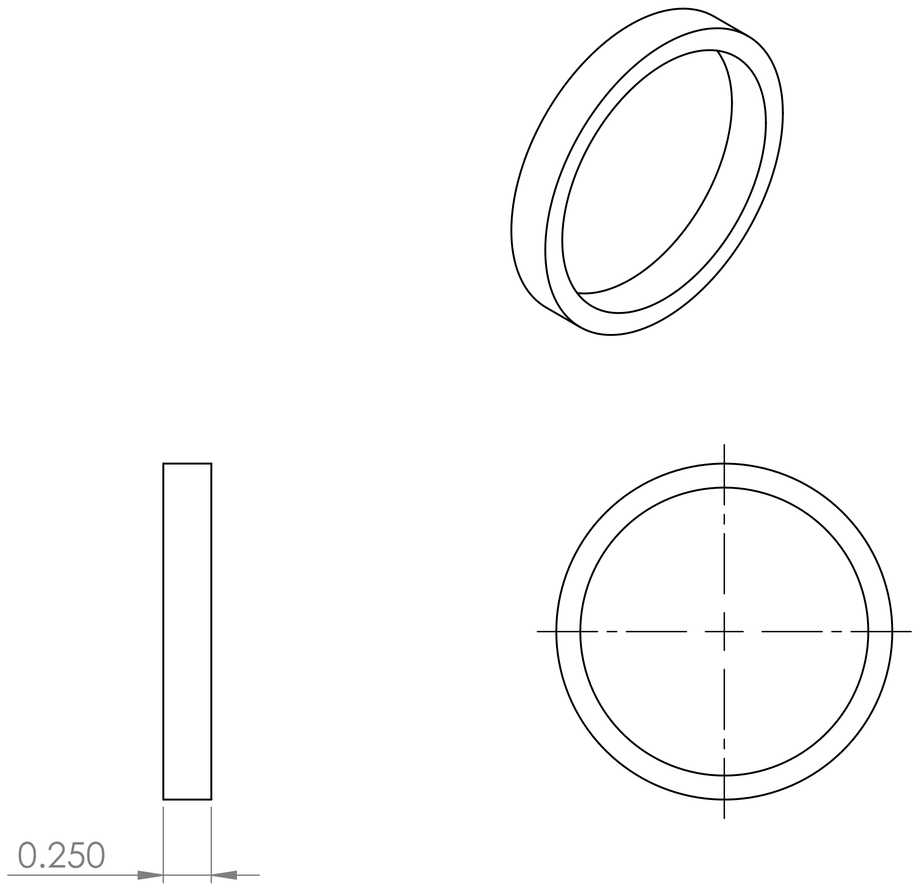
SIZE A DWG. NO. Shaft_Seal_Tapped_Ring REV

SCALE: 1:1 WEIGHT: SHEET 1 OF 1

5 4 3 2 1

Part	Qty	Stock
Shaft Seal Tapped Ring	2	1/4" 6061 Aluminum Plate

Step	Description	Machine	Fixturing	Tooling	Speed	Feed
1	Rough stock to size on the Bandsaw	Bandsaw	-	-		
2	Attach piece to mill table with mill clamps and a sacrificial wood baseplate	Mill	Mill Clamps, Plywood	-	-	-
3	Mill out center opening	Mill	1/4" Collet	1/4" HSS 2-Flute Endmill		
	Center Drill Holes	Mill	Drill Chuck	Center Drill		
4	Drill Holes	Mill	Drill Chuck	#25 Drill bit		
5	Tap Holes	Mill	Drill Chuck, Live Center	#10-24 Tap, Tap Handle	Slowly	-
6	Machine outside edge	Mill	1/4" Collet	1/4" HSS 2-Flute Endmill		



DIMENSIONS ARE UNCHANGED FROM STOCK UNLESS OTHERWISE NOTED

MAKE 2

TITLE:

SHAFT BUSHING

		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN		
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL MCMASTER 6391K315	COMMENTS:		
NEXT ASSY	USED ON	FINISH OILITE BUSHING			
APPLICATION		DO NOT SCALE DRAWING			

PROPRIETARY AND CONFIDENTIAL

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SIZE	DWG. NO.	REV
A	Shaft_Sleeve_Bushing	

SCALE: 1:1 WEIGHT: SHEET 1 OF 1

5 4 3 2 1

Part	Qty	Stock
Shaft Bushing	2	McMaster 6391K315

Step	Description	Machine	Fixturing	Tooling	Speed	Feed
1	Mount stock in lathe chuck.	Lathe	Lathe Chuck	-	-	-
2	Use Dial Indicator to ensure mounting is straight	Lathe	Toolpost, Magnets	Dial Indicator	-	-
3	Use cutoff tool to cut 0.25" length off of stock	Lathe	Toolpost	1/8" Cutoff Tool		
4	Deburr cut	By Hand	-	Deburrer	-	-

---------- Forwarded message ----------
From: **[Redacted]**
Date: Wed, Nov 28, 2012 at 4:19 PM
Subject: electrical inspection
To: [Redacted]
Cc: [Redacted]

Hi [Redacted Professor],

Just a quick note to let you know that I brought an electrician ([Redacted]) with me today to inspect the ME450 project in room 1089 GG Brown. [Redacted electrician] inspected the wiring and asked [Redacted teammate] a few questions about the apparatus, and then gave [Redacted teammate] the OK to proceed with testing.

Thanks,
[Redacted Guy from Plant]

User Guide for Filter Media Test Unit

SAFETY

- No user shall operate the Filter Media Test Unit without having read these instructions and chapters 1 and 2 of the VFD's user guide.
- The Filter Media Test Unit will only be operated indoors.
- The VFD will pull a maximum of 9A, 120VAC 1Ø. Ensure the outlet to which it is connected is rated for this load and is protected by *at least* passive means (eg: fuse, circuit breaker).
- Users will tie back long hair and refrain from wearing flowing clothing around the pump to avoid entanglement.
- Users shall be familiar with the location of all device features, including the Emergency Stop, before operating
- The unit shall not be operated without at least one person present. Two persons present is preferred for initial setup.

Setup (Typical)

1. Position cart alongside table with the VFD facing where the user will sit, and with the right-hand side of the cart (VFD side) against the edge of the table.
2. Remove the channel from the cart. Place the channel on the table such that the downstream end of the channel points towards the cart.
3. Verify that the chamber is installed and that all seals and endcaps are tightened.
4. Route all loose drain hoses into the tank through the holes on the tank lid.
5. Close the drain valve and open the air purge valve.
6. Connect circuitry for the pressure sensor to the appropriate power supply and DAQ.
7. Plug in the VFD cord and pull the Emergency Stop out (unlocked).
8. Verify that the tank is full of water and the pump will not aspirate.
9. Set the desired speed on the VFD and press run. The pump will ramp up to speed and begin filling the channel.
10. As the channel fills, keep one hand on the air purge valve. As the water level nears the top of the channel, close the valve most of the way. Close the valve fully when water starts rising into the tube connected to the air purge valve (indicating that the channel is full).
11. Remove the tube from one side of the pressure transducer, then stick the tube back in loosely (not far enough to lock in). Wait until water starts to trickle out of the transducer, then shove the tube fully in to lock it. Repeat with the other tube entering the transducer. Wipe the transducer dry with a rag.

Operation (Typical)

1. Set desired filter angle by removing the screw in the lock collar, turning the pipe to the desired angle, and replacing the screw. There are seven holes behind the lock collar in to which the screw can seat – they are spaced every 15 degrees starting at vertical.
2. Set desired amount of bypass by adjusting the bypass valve.
3. Allow sensor readings to even out, and then collect readings.
4. Repeat steps 1, 2, and 3 as desired for data collection. The VFD may be adjusted while running without ramping down to a stop and back up again.

Cleanup (Typical)

1. Press stop button on VFD. The controller will ramp down to 0Hz. Once fully ramped down, press the Emergency Stop button.
2. Coil the VFD cord around the cart handle.
3. Open the drain valve, bypass valve, and air purge valve.
4. Allow the system to drain out. When placed on a low table, it may be required to lift the channel into the air and tilt it towards downstream to achieve this.
5. Remove the downstream ends of the drain hose and the bypass hose from the tank. Wipe ends dry with a rag.
6. Set the channel on the holding slot in the cart, with the upstream end positioned next to the VFD.

Water Change

1. Follow normal procedures for draining the channel
2. Roll cart to a floor drain
3. Position tank drain hose over/in floor drain
4. Open tank drain valve
5. Once system has drained, close the tank drain valve
6. Stick a hose into an opening on top of the tank, and fill until the water level is 2-3” below the top of the tank.

Filter Change

1. Ensure the channel is drained (see ‘Cleanup’) and positioned on a tabletop.
2. Remove the 12 nuts from the endcap (a socket wrench or nut driver is recommended).
3. Remove the end cap from the flange studs. Set aside.
4. Remove the angle adjustment screw from the lock collar. Turn the chamber/pipe 180 degrees clockwise from the usual normal flow position, and replace the screw.
5. Using a #1 Phillips-head screwdriver, remove the machine screws from the chamber retaining ring.
6. Remove the chamber retaining ring and the old filter media.
7. Wipe the gasket and all exposed mating surfaces of the chamber clean with a rag.
8. Place the new filter media (trimmed to size) on the gasket.
9. Place the retaining ring over the filter media, aligning it using the dowel pins. This step is difficult, as the filter media will want to fall off when unsupported. One recommendation is to wet the gasket – this often causes the media to stick to it.
10. Replace the machine screws, tightening snugly in a star-pattern (like a car tire). Note that in the chamber provided, there are two screws slightly shorter than the rest. These screws are for the top and bottom holes.
11. Replace the endcap, and secure it to the studs with nuts. Tighten the nuts securely in place (~5lb-ft).

Chamber Change (Retooling)

1. Follow steps 1-5 of the filter change procedures.
2. Using a slotted screwdriver, remove the four screws holding the chamber to the pipe.

3. Screw the new chamber onto the pipe.
4. Follow filter change steps 8-11, as appropriate for the new chamber.

Appendix S: Engineering Changes since DR3

Although our design for the full assembly as submitted in Design Review 3 was as detailed as we were capable of providing at the time, a variety of changes needed to be made along the way. These changes, which were made to either improve the design functionality or ease manufacturing, were documented and approved in a series of six Engineering Change Requests (ECRs). These ECRs are included at the end of this appendix.

In summary, ECR 1 changed how the endcaps are attached to the channel flanges. We decided to screw steel studs through the tapped holes of the flanges instead of screwing the endcaps directly in to minimize the stress placed on the tapped aluminum threads. ECR 2 changed our cart selection to a new style to improve the user experience and ease manufacturing, while ECR 3 sped up manufacturing time and decreased component lead time by allowing the team to interchange fastener types as long as they maintained the same length and threading as originally specified.

As assembly progressed, several other minor problems popped up, which were addressed through ECR 4 (adjusting the lengths of the PVC pipes that run along the side of the channel to account for the pipe clips being unexpectedly tall) and ECR 5 (which simplified the method used to hold the laminar flow guides in place). As the final components arrived, the team needed to formalize the assembly of the cart unit, which had been only vaguely specified in DR3 and was based off of the cart that had been changed in ECR 2. An omnibus ECR 6 clarified all of these points.

After scheduled construction was completed, our device was evaluated by Professor Krauss before testing began. He advised several additions be made to address issues of safety. These changes, plus a change to the sensor caused by procurement problems, were addressed in ECR 7.

ENGINEERING CHANGE REQUEST #7
ME450 TEAM 10
1 December 2012

Nature of Request: This change request is to add several last-minute details to the cart. Many of these details are at the request of Prof. Gordon Krauss in the interest of safety.

Details of Request:

- The plywood piece that holds the VFD and E-Stop button is somewhat unstable. To increase its stiffness, two braces made of bent electrical conduit will be attached to the non-VFD side of the plywood and run down to the cart deck. Connections at both the plywood and the cart deck will be made with ¼-20 bolts. Drawings of these braces and their installation are attached.
- To help make the VFD splashproof, two bent pieces of conduit will be attached on either side of the VFD, as shown in attached drawings. These pieces will be bolted though the plywood with ¼-20 bolts. A 6" wide strip of plastic sheet will then be wrapped around the top and sides of the metal pieces and secured with self-tapping 8-32 screws.
- Due to manufacturing issues with the original pressure transducer, we substitute in a Sensocon 251-01 wet-wet differential pressure transducer. Its plumbing into the channel remains unchanged, though its connection to the DAQ is now routed through a resistor and a voltage-following Op-Amp to deal with the fact that this sensor has a current output. A schematic of this setup is attached.

Reason for Request: To increase system safety, stability, and functionality.

Impacted Systems/Components: Pressure Transducer, Cart, Plywood

Request Made By: [Redacted], 1 December 2012

Approved by:

ENGINEERING CHANGE REQUEST #6
ME450 TEAM 10
27 November 2012

Nature of Request: This change request is to clarify the attachment of the pump, tank, and electronics to the cart. The existing plans do not specify any of this, except that both the pump and tank are sitting on the cart. Those plans allow the assemblers to have discretion over certain details of the assembly; this ECR covers parts that we would like to add to aid in the assembly.

Details of Request:

- The tank is positioned on the cart with its center 17” from the leading (non-handled) edge and 10.5” from the left edge (as viewed from the handle). The tank is held in position by four brackets (drawing attached) which are positioned in 90-degree increments around the base of the cart. The brackets are to be positioned tight to the tank, at 45-degree angles to the edges of the cart, and bolted through the cart with ¼”-20 bolts.
- As currently specified, there are two 1” barbed x 1” NPT adapters tapped through the sides of the tank. One of these adapters should be centered 1.2” above the floor level of the tank, and that the other adapter be centered 4.5” above the floor level of the tank and rotated 90-degrees clockwise from the first hole (as viewed from above).
- The barbed adapter positioned 4.5” off the ground level will be fed to the pump, and its length should be oriented parallel to the long edge of the cart.
- The pump is positioned such that the length is parallel to the long edge of the cart, the motor end of the pump is 1.5” from the handle, and the unit is positioned laterally such that the inlet of the pump is in line with the outlet barb of the tank. The pump is bolted to the cart deck with four 5/16”-18 bolts.
- A piece of plywood is bolted to the cart handle to provide a mounting place for the electronics (drawing attached). Three holes are drilled with even spacing in each cart handle, and the plywood is attached to the handle using ¼”-20 bolts fed through these holes and corresponding holes drilled in the plywood to match.
- A 48” long piece of 1”x1”x0.125” aluminum square tubing shall be bolted to the pump side of the plywood for stiffening purposes. The tubing shall be secured to the plywood using ¼”-20 bolts in five locations – three being the existing holes that allow for connection of the plywood to the handle, and two drilled at the discretion of the assemblers in the upper 24” of the tube. These holes must be centered on the tube and not interfere with the installation of any of the electronics.
- The emergency stop button shall be mounted on the side of the plywood not facing the pump. Its lowest edge shall be 43.5” from the bottom of the plywood, it shall be centered over the stiffening tube, and secured with machine screws through the plywood as specified by the manufacturer.

- The VFD shall be mounted on the side of the plywood not facing the pump. Its lowest edge shall be 35” from the bottom of the plywood, it shall be centered over the stiffening tube, and secured with machine screws through the plywood as specified by the manufacturer.
- The plywood has a notch cut in it to allow one end of the channel to be supported securely by the cart during transport. To support the other end, two angle brackets (drawing attached) shall be attached to the lid of the tank in such a way that they are aligned with the notch in the plywood. These brackets will be secured through the lid with ¼”-20 bolts. If the channel hits the lid of the tank in this installation, lengths of 2”x1” aluminum tube may be added under the brackets to elevate them.

Reason for Request: To clarify the vague specifications for the cart as currently described.

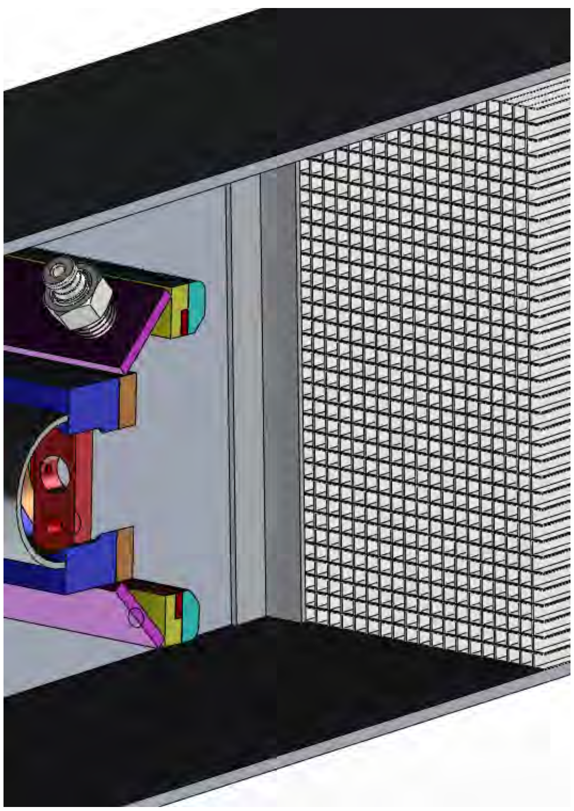
Impacted Systems/Components: Cart, Tank, Pump, VFD

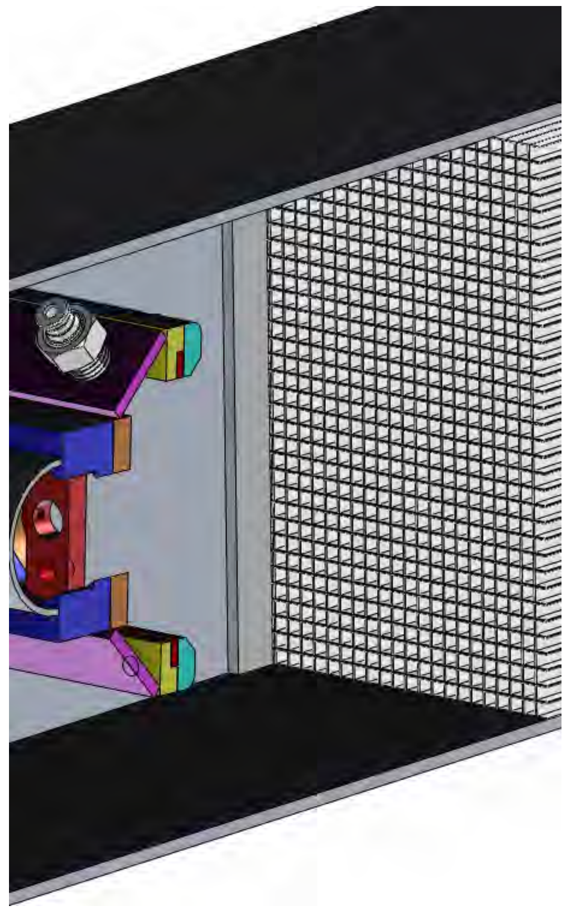
Request Made By: [Redacted], 27 November 2012

Approved by:

ENGINEERING CHANGE REQUEST #5
ME450 TEAM 10
19 November 2012

Nature of Request: The laminar flow guide brackets, which were formerly specified as 1/16” angle aluminum (0.5” leg) are now changed to 1/8” aluminum plate, ½” leg. Both remain as long as the ID of the channel. To formalize a point that was not clearly defined in the original report, these brackets will be secured to the inside of the channel using two-part epoxy.





Reason for Request: The laminar flow guides are much stiffer than we expected, meaning that we need less material to support them in place. The smaller the brackets are, the less turbulence they will introduce into the stream.

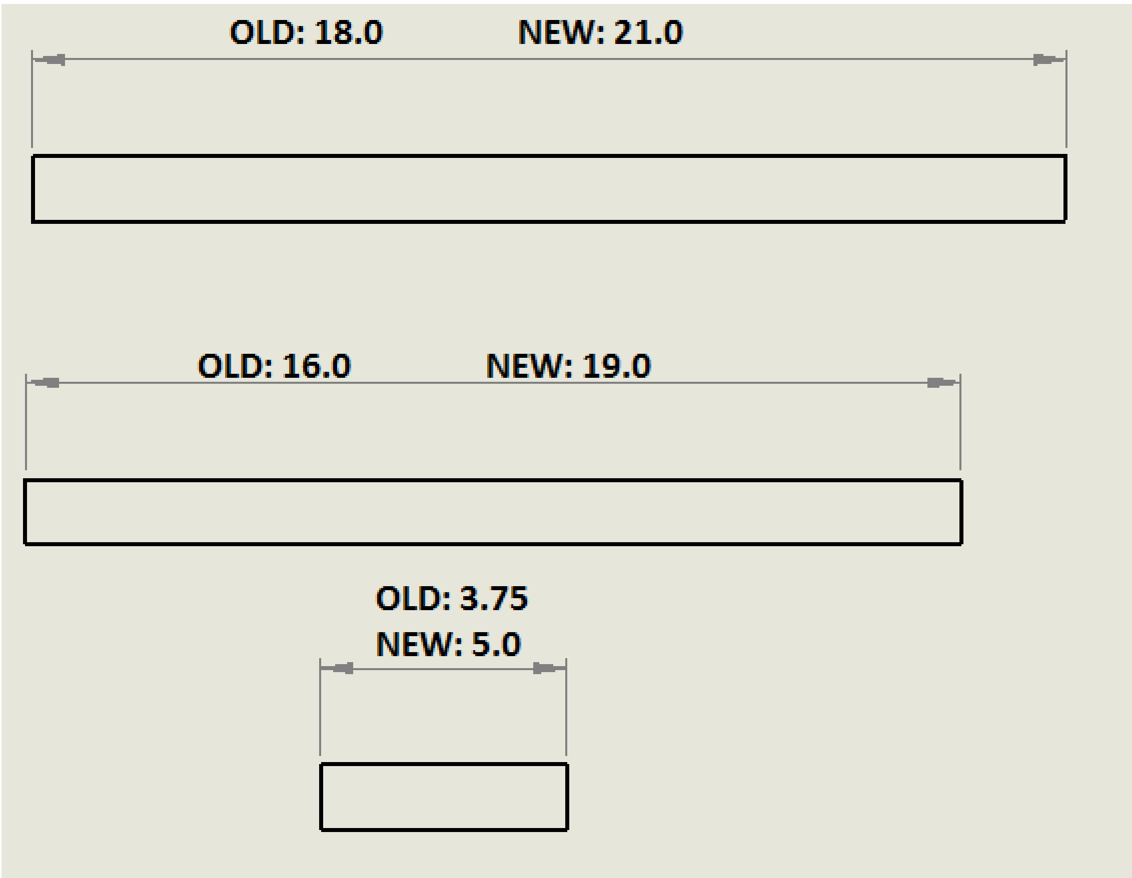
Impacted Systems/Components: Laminar Flow Guides, Laminar Flow Guide Brackets, Channel

Request Made By: [Redacted], 19 November 2012

Approved by:

ENGINEERING CHANGE REQUEST #4
ME 450 TEAM 10
19 NOVEMBER 2012

Description of Change: The lengths of the PVC pipes on the side (supply) pipe are being lengthened to the specifications shown below.



Reason for Change: The clips purchased to mount the PVC pipe assembly to the side of the channel were thicker than expected. The extension of the shortest piece is required to make everything lie against the side of the channel as intended. Additionally, the interface between the PVC and the channel at the end turned out longer than expected due to the stiffness of the hose. The extension of the two longer pieces is required to make the pipe extend all the way past the end of the channel as intended.

Affected Systems: Side pipe assembly

Requested by: [Redacted] 19 November 2012

Approved by:

ENGINEERING CHANGE REQUEST #3
ME450 TEAM 10
19 November 2012

Nature of Request: Currently, all bolts and screws on the assembly have a specified head type and size. We request that all current specifications for fastener heads be changed to allow for any of the following styles at the discretion of the team: Phillips, slotted, hex head, hex socket cap. We further request that all sizes of fastener heads (excepting the screws securing the chamber retaining ring to the chamber) be left to the discretion of the team. The lengths and materials of all fasteners would remain as originally specified, and the heads of all fasteners on a single joint (eg: all bolts on the channel flange) would be required to have the same head shape and size.

Reason for Request: Fasteners are easy to come by in the shared assembly shop and from second-hand sources. Using such bolts and screws reduces our incurred costs and minimizes our lead time while not interfering with the strength or functionality of the final product. Unfortunately, these bolts and screws have rarely had the head sizes specified in our original plans.

Impacted Systems: Channel, Channel Flange, Channel Tapped Rings, Chamber, Pipe Adapter Block

Change Requested by: [Redacted], 19 November 2012

Change Approved by:

ENGINEERING CHANGE REQUEST #2
ME450 F12 TEAM 10 – 11/15/2012

OLD: Harbor Freight 5770

NEW: McMaster 9925T52

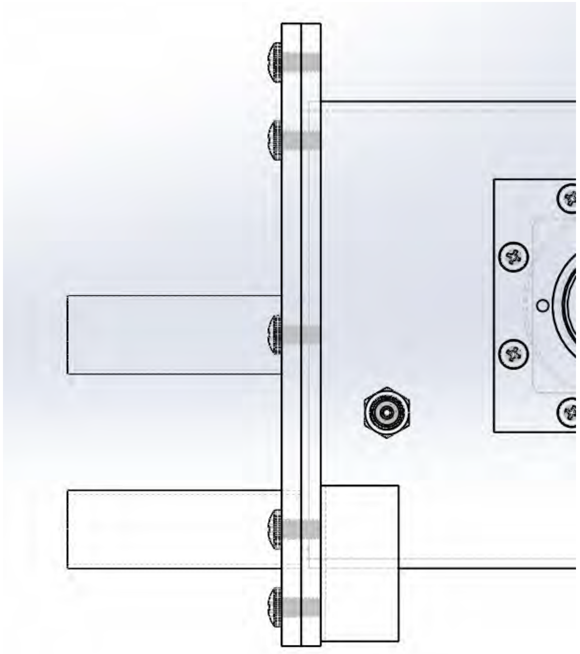
Reason for Change: The new cart, although more expensive, will be more user friendly, more reusable, and require less modification.

Change Requested by: [Redacted], 11/15/12

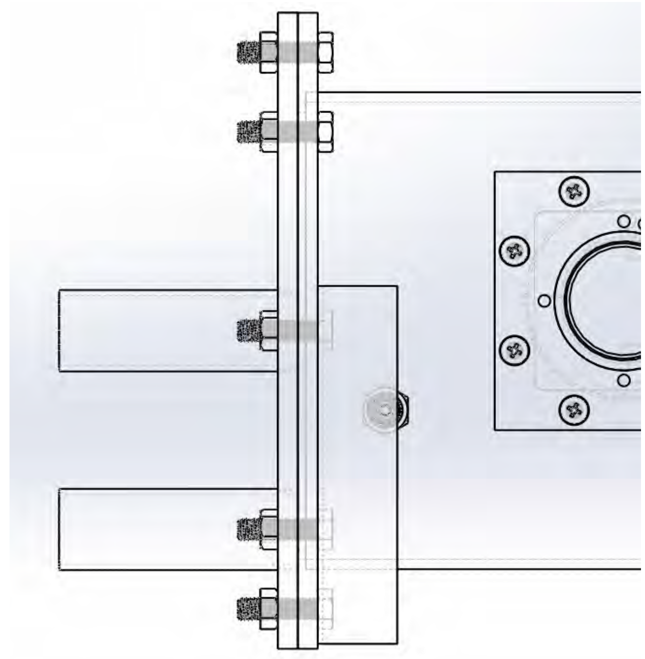
Approved by:

ENGINEERING CHANGE REQUEST #1
ME450 F12 TEAM 10 – 11/15/2012

OLD



NEW



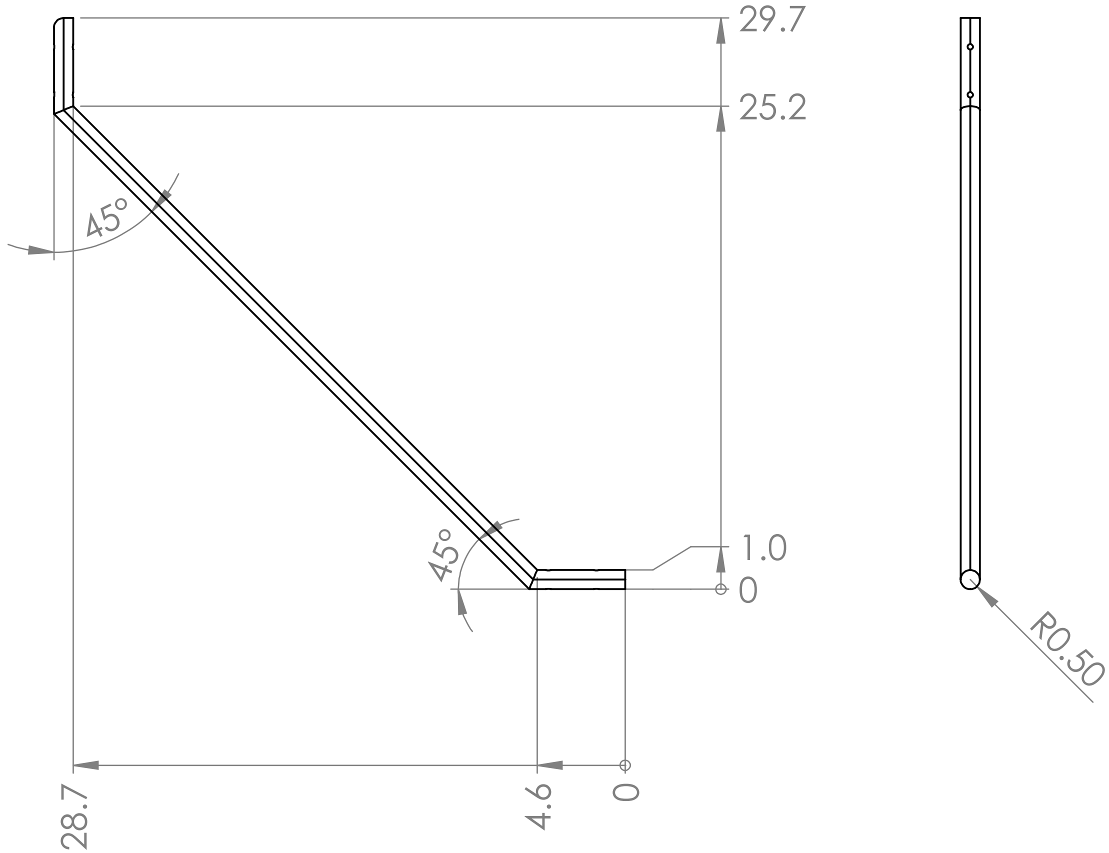
Changes Made:

- Instead of attaching channel end cap to the channel end flange using screws secured into the tapped holes of the flange, we will thread 1/4”-20 steel bolts through the tapped flange holes to create studs. These bolts will be secured into the flange using torque (applied by wrench) and liquid threadlocker.
- The pipe holder on the side will be lengthened to 4.5” long, and have holes drilled in it that allow it to be held in place by the heads of two of the stud bolts.
- These changes will apply to the front endcap/front flange/front pipe holder (all typ., not pictured).

Reason for Changes: The reason for this change is to increase the life of the unit by minimizing the stresses put on the tapped aluminum flange threads. We believe this change will also reduce the amount of time it will take to remove/replace the endcap. Furthermore, we believe this change will increase the life of the neoprene seals (no longer will they be slid on and off of the bolts).

Change made by: [Redacted], 11/15/2012

Approved by:



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±0.05
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
1" Galv. Conduit

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

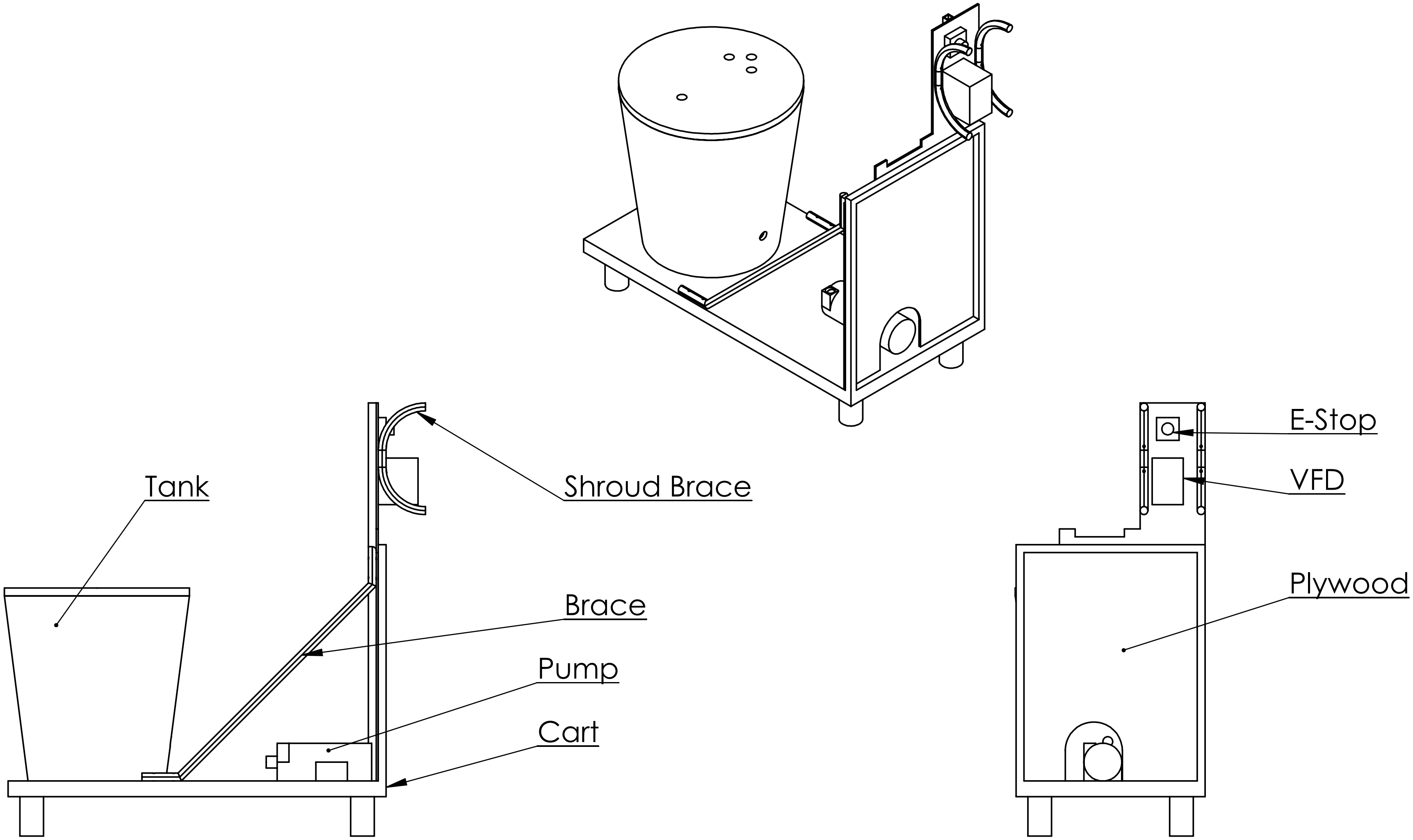
SIZE	DWG. NO.	REV
A	Cart Brace	

SCALE: 1:10 WEIGHT: SHEET 1 OF 1

NEXT ASSY | USED ON

APPLICATION

5 4 3 2 1



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			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

PROPRIETARY AND CONFIDENTIAL

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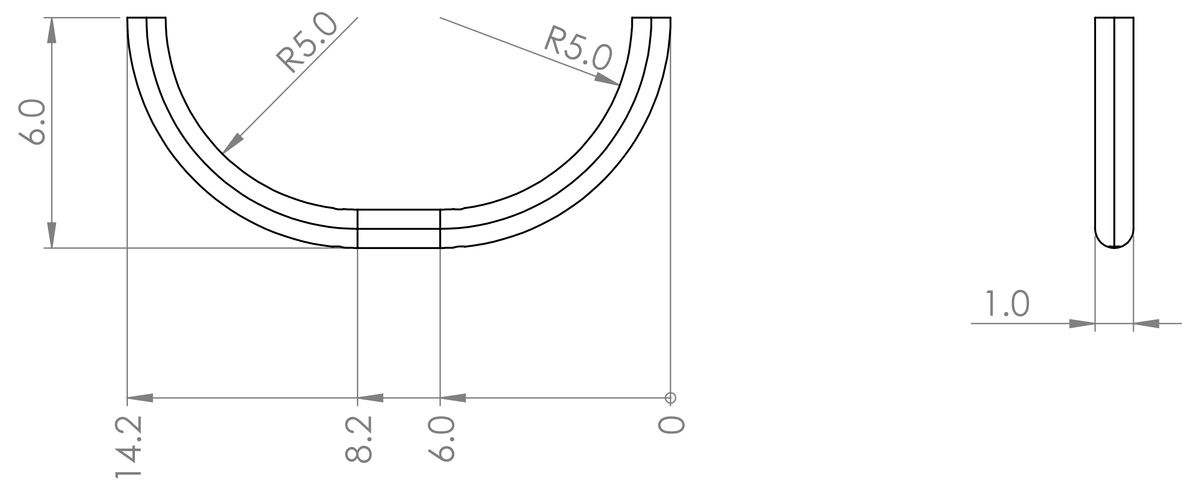
TITLE: Layout Dwg of Cart

SIZE: A | DWG. NO.: Assembly_Cart | REV

SCALE: 1:20 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±0.05
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
1" Galv. Conduit

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

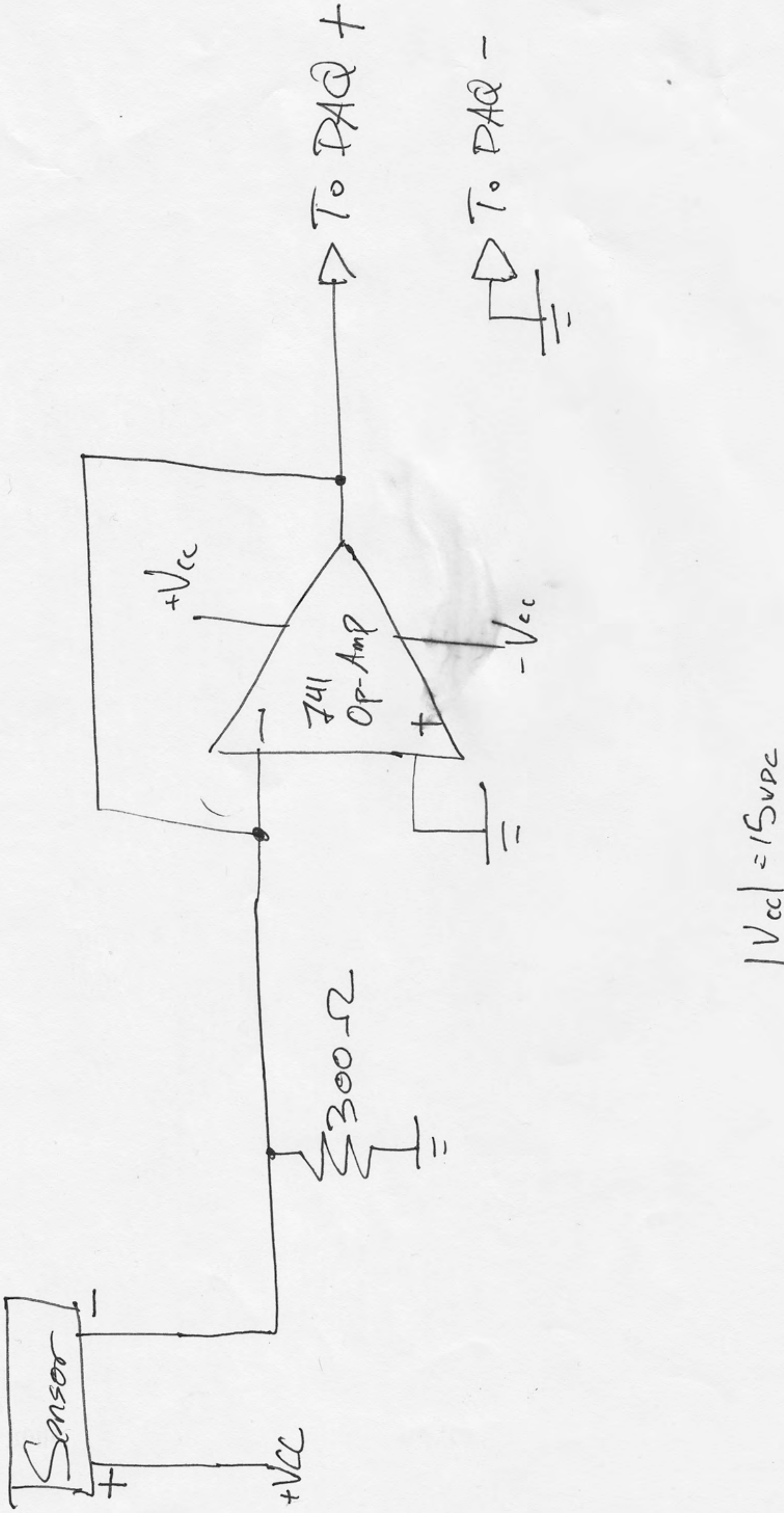
NEXT ASSY	USED ON
APPLICATION	

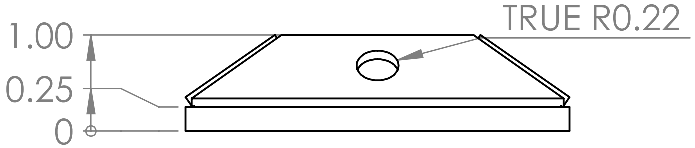
TITLE:

SIZE	DWG. NO.	REV
A	Shroud Holders	

SCALE: 1:5 WEIGHT: SHEET 1 OF 1

5 4 3 2 1


Sensor
+
-
+VCC
300Ω
741
Op-Amp
+Vcc
-Vcc
To DAQ +
To DAQ -
|Vcc| = 15VDC

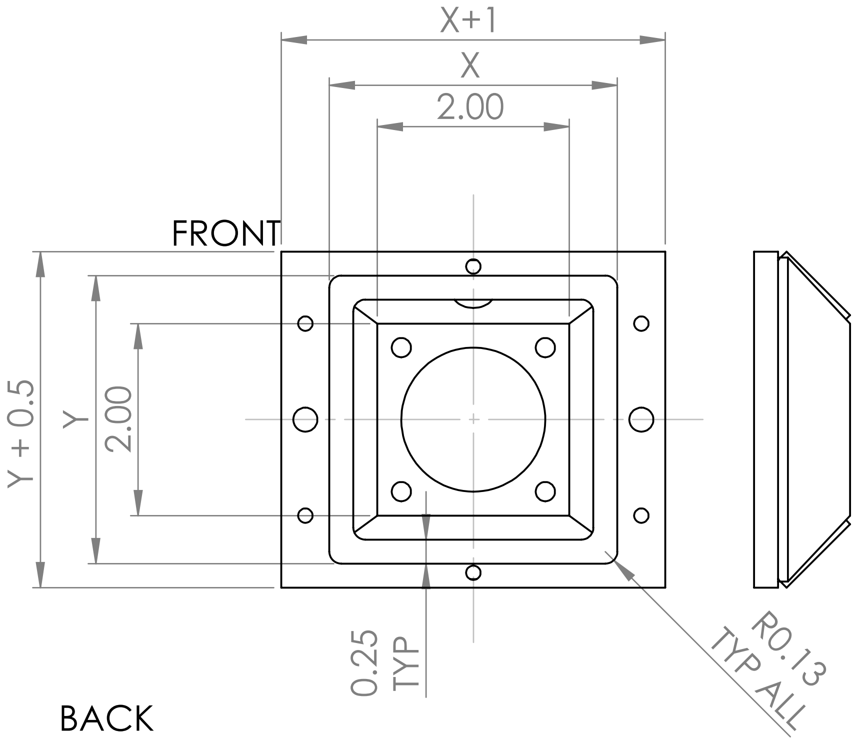


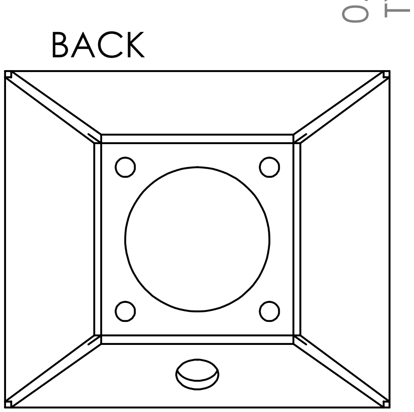
Let X = width of filter, Y = height of filter

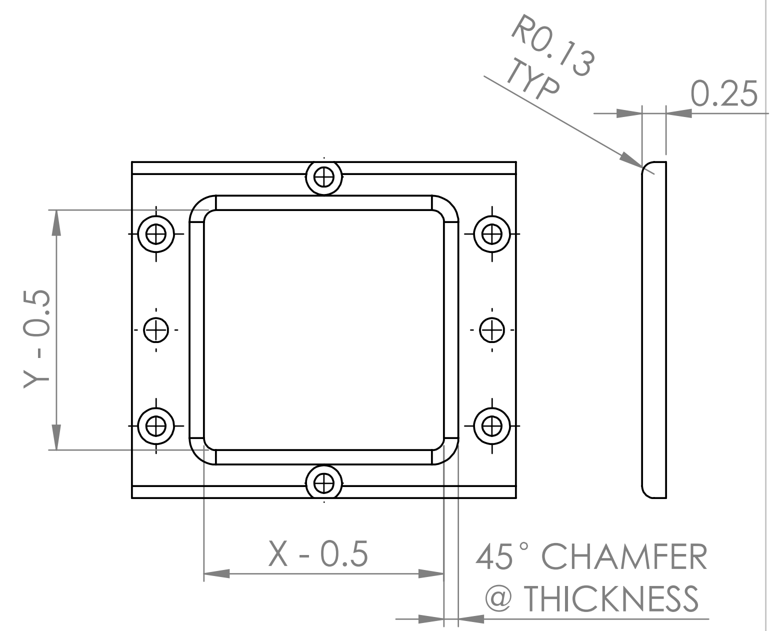
Bolt pattern on front of retooled chambers is discretionary.

Inclusion of dowel pins for alignment is optional

All Chamber joints welded GTAW







NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±0.05
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL Aluminum

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE: Retooling Guide for Chamber and Retaining Ring

SIZE A | DWG. NO. | REV

SCALE: 1:2 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1