Deep Well Pump Seal

Final Design Review

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Introduction

Lifewater International, a Christian non-profit, trains locals to repair water well hand pumps in various third world countries. It would be beneficial to retrofit difficult-to-repair hand pumps with a locally-made pump cylinder such as HydroMission's "SlapShot". The majority of the components in the "SlapShot" can be easily obtained in rural third world villages. However, the thick leather gaskets required to seal the water cylinder during the pumping operation are imported. These thick leather gaskets are expensive, and when they fail, this results in pumps being out of commission for extended periods of time. Lifewater has presented this problem to a team of three undergraduate mechanical engineering students at California Polytechnic State University, San Luis Obispo with the goal of being able to locally source and manufacture an adequate seal to replace the current thick leather seal.

Background and Information Gathering

The sponsor of the Project Water senior design project is an affiliate and water specialist for Lifewater International named Fred Proby. His goal for this project is to have a group of a Cal Poly mechanical engineering students design a hand pump seal that can be sourced, built, and repaired locally.

There are currently four main models of hand pumps that are being used in Africa: the India Mark II, the India Mark III, the Afridev, and the Bush Pump. A generic layout of these pumps can be seen in Figure 1. These pumps and their replacement parts are built and manufactured in India, and can result in long delivery times. This duration of time with no drinking water is devastating to the rural villages in Africa.

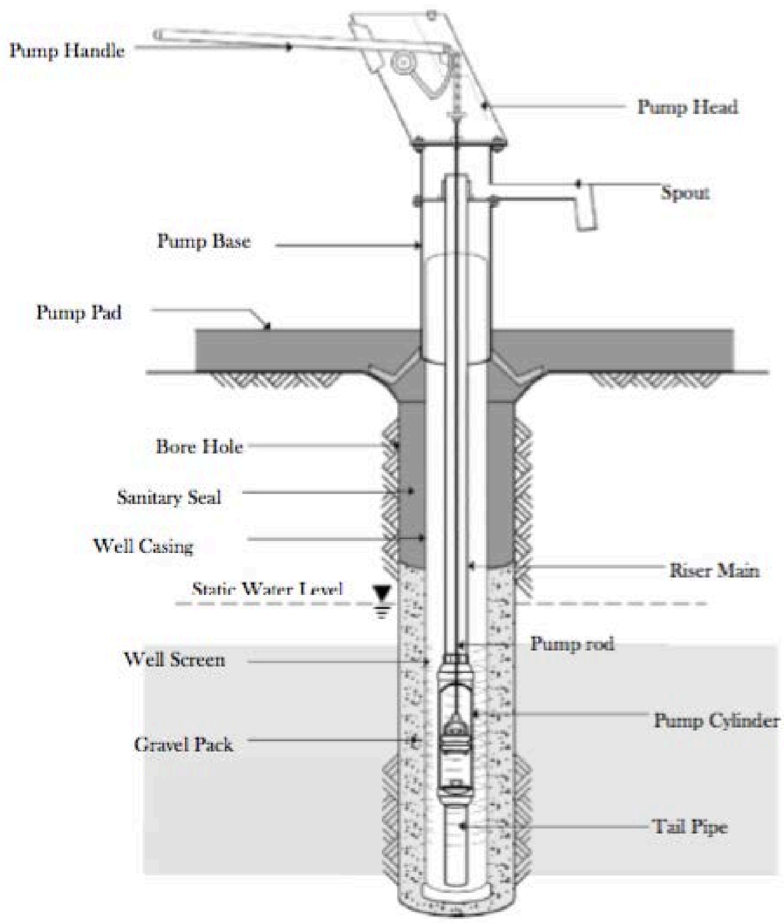

Figure 1. Basic Pump Configuration

The main source of failure on hand pumps lies in the pump cylinder seal. The repetitive nature of the pumping motion means it experiences the most dynamic stress, wear, and fatigue. The pump seal lifts the water column up the riser main as well as draws water up into the lower cylinder from the water table during the up-stroke of the pumping. During the down-stroke, the seal pushes down on the water from the lower cylinder that opens the one-way valve and fills the upper cylinder (Figure 2).

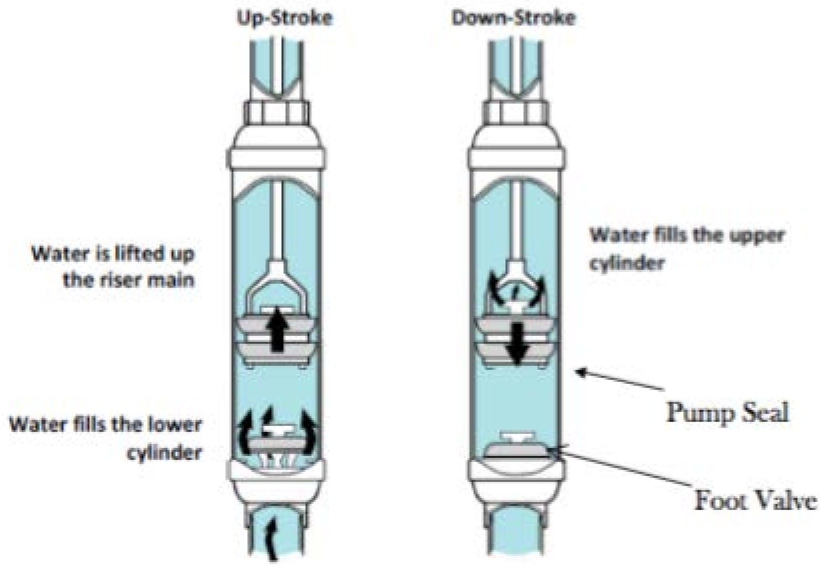

Figure 2. Valve Configuration

The leading pump seal design currently is the cup seal geometry. Cup seals can be made from a variety of material, but are primarily made from thick leather. The India Mark II and III both use thick leather cup seals that are manufactured by foreign suppliers. The Bush Pump also uses two thick leather cup seals. In certain locations where these pumps are used, repair time can be greatly reduced by manufacturing the cup seals locally. In order to make these seals, tanned leather is first cut into washer like shape. Next, the leather is soaked hot paraffin wax in order to be shaped. Then the leather is placed in to a wooden mold that forms the leather into a cupped shape. Thick leather cup seals typically last 6-12 months, before being replaced.

Figure 3. Thick Leather Cup Seal

Additionally, pumps (such as the Afridev), use cup seals made from neoprene rubber. O-rings, U-rings, and other rubber gaskets are also commonly used hand pump seals.

Mr. Proby has been working on a solution to this problem since 2007. He has determined that the best option for these pumps is a design by Hydromissions called the "SlapShot"(Figure 3). The SlapShot is a universal deep well pump cylinder specifically designed for the developing world. It can be retrofitted to all the previously mentioned pumps. It is composed of off the shelf parts that can being purchased at local hardware stores around the world (2). Another benefit with using the SlapShot design is that the internal components of the cylinder are easily accessible when repairs are needed. This design allows the user to pull out the piston and pump rod without having to remove the riser main and pump cylinder.

Figure 4. SlapShot Assembly Layout

However, this pump cylinder design still requires a seal that is not local to Africa. Currently the SlapShot uses a thick leather gasket as the pump cylinder seal. From his years of experience, Mr. Proby knows that this specific design and material is inadequate for use of the SlapShot in Africa.

Objectives

There are four areas that Project Water will focus on: material, manufacture, design, and testing of a seal. The material of the pump seal must be easily sourced in rural Africa. The manufacture of the seal must not require heavy machinery or complex fabrication techniques. Finally, the performance of the seal must be comparable to commercially available imported piston seals. This means that the new seal should have similar life cycle, and leak rate as the others. The current seals are difficult to replace because they are either too expensive to import or they are made from a material that is inaccessible in Africa. The new seal must be comprised of locally sourced material, have a simple manufacturing process, and a design that will hold up to constant pumping.

Project Water has decided to begin the design process by focusing on the specific requirements that Mr. Proby desires from this seal; local material and simple construction. The characteristics of the final seal design will be determined from these requirements. To start defining these characteristics, a "QFD", or "Quality Function Deployment", has been developed. A QFD is a powerful tool that allows quick comparison between multiple designs with numerous requirements and specifications. It appears complex, but is quite simple to navigate once the reader knows where to look. For referencing, the QFD can be found in Appendix A.

The first part of the QFD is ‘Who’, as in who are the customers. It is located on the very far left of the QFD. This is not simply who will be using the final product, but also the manufacturers of the product, the people repairing it, and the people who are paying for the product. For this product, the ‘Who’ are Mr. Proby, the pump mechanics, the pump users, and the seal manufacturers.

The next part of the QFD is the 'What' section, which is to the right of the 'Who' section. This section is a list of the customer requirements. This is not what an engineer thinks the customer might want, but instead is supposed to be as close to the customer's own words as to what they want the final product to accomplish. Once this section is complete, the 'Whos' are weighted against the 'Whats'. This is where the designer decides which requirements are most important to certain customers, and which ones are of lesser importance. For example, Mr. Proby has a high priority on locally sourced material, but probably has less of an interest in how many parts the seal is made of. Upon completion, a relative weight can be seen for each of the customer requirements.

The next section is the 'Now' section, placed on the far right of the QFD. This is where current alternative products are located. For this QFD, the current products that will be compared to the Project Water seal are the Indian Mark II cup leather seal, the thick leather seal, the Afridev seal, and the Slapshot thin leather seal. These products are then rated by the designer against the customer requirements. A visual representation of how well all the current products perform can be seen next to the number matrix of the Now section.

Next is 'How', in the middle of the QFD. This section determines how the designer will tell if the requirements have been met. Each 'How' should be a quantitative value. These 'Hows' are then compared to the 'Whats', with how strong the relationship is between each ‘How’ and ‘What’. If the relationship is strong, the box is given a filled in circle. If it is moderate, it is given an outline of a circle. A weak relationship gets an outline of an upside-down triangle. If there is no relationship, the box is left blank. The relative weight of how important each of the 'Hows' is located towards the bottom of the QFD, as well as the targets for each of the specifications. For this QFD, the cost and time to manufacture specifications are the highest weighted, with the availability of the material coming in at a strong third.

The final two sections of the QFD are the very top and bottom of the chart. The very top is an area where each specification is compared against the others. This lets the designer know which specifications could potentially conflict with each other. One major specification that could affect the seal design is cost. If the seal is too cheap, the life cycle and leak rate could be negatively affected. The very bottom of the QFD is how well the current products perform the 'Hows'. This is visually represented at the bottom of the chart. The final product should meet all specifications and customer requirements listed on the QFD.

For the engineering specifications, specific targets are created to verify that the design is a viable option. Each specification has its own target, and each target is quantifiable. They cannot be evaluated subjectively like some of the customer requirements. The specific engineering specifications are as follows: life cycle, leak rate, cost, availability of material, and manufacturing time. These can be found in either the QFD in Appendix A, or in Table 1.

Table 1 lists the specifications and their respective targets in a clear format. Included in the table are the sections of tolerance, risk and compliance. The tolerance section provides a range of acceptable values for each specific requirement. Table 1 also includes a column for risk of each specification. The levels of risk are high (H), medium (M), and low (L). The last column is the compliance section. This is how each design requirement is to be verified. There are four possibilities: analysis (A), test (T), similarity to existing design (S), and inspection (I). Each of the requirements will be explained into further detail below.

When it comes to life cycle, the exact number of cycles is hard to determine. It is difficult to acquire data on how much the water pumps are being used; therefore, an educated estimate must be made. Mr. Proby has witnessed the pumps in Africa being used all day long until they break. The point of failure for most commercially available pumps is somewhere around 6 months. A conservative calculation is shown with the following values:

10 pumps per minute

60 minutes an hour

12 hours a day

180 days a year

This yields a result of 1.3 million cycles over a sixth month span before the seal needs replacing. All the current products either meet this standard or are close to it. The goal of Project Water's design is to be comparable with the India Mark II and Afridev pumps.

The next specification is the leak rate. From a previous project, it was found that the cup leather seal leaked 0.06 liters per minute at 80 psi. This will be a specification of the new seal. However, it must be noted that the leak rate specification can be outweighed by more important requirements. The requirements of ease to manufacture, material availability, and cost, are more crucial to the overall design goals than life cycle and leak rate.

Cost is the highest priority in terms of customer requirements. The cost of the material and manufacturing should be no more than five dollars. Both the thick leather and thin leather seals do not meet this requirement. This specification is a hard objective, meaning that our design cannot exceed it. If a design exceeds this cost, it will be thrown out. The reason cost is not a high-risk requirement is that if the material can be readily found in Africa, it will naturally not cost very much.

The next requirement is the availability of the material. This specification's target will be a simple yes or no question: "Is the seal made from a material that is readily available throughout most South-Saharan African countries?" Currently all the commercially available products fail to meet this target in that spare pump parts tend to only be available in the capital cities. This specification, while not weighted as heavily as cost or time to manufacture, is still a hard objective. If the material for our seal cannot be found in the necessary areas, that design will be thrown out. The reason this parameter is high risk is because it may be difficult to find material, or a combination of materials, that will perform as well as commercial seals.

The last specification is the time it takes to manufacture and replace a broken seal. The benchmark for this specification is two hours. The quicker it is to manufacture a new seal means the quicker it will be for the pump to be working again. Currently, pumps go down for fifty or more days because the local mechanics may not be available or may lack the parts to fix them. While this specification is important, it is not a hard target. As long as the design results in of a downtime less than two hours, it will be considered adequate.

Ideally, the final objective would be to optimize all aspects of the pump, to meet as many of the customer requirements and engineering specifications. The three main objectives that are most important to this design are: cost effectiveness, locally sourced material, and simple to manufacture.

Table 1. Project Water design specifications

Spec#	Parameter Description	Requirement or Target (units)	Tolerance	Risk	Compliance
1	Life Cycle	800,000 (cycles)	-	M	T, S
2	Leak Rate	0.06 (Liters/minute at 80 psi)	max = .56L/min	M	T, S
3	Cost (Relative to Africa)	1.00 (dollars)	maximum	M	I
4	Available in South-Saharan African Countries	Y/N	-	H	I
5	Manufacture Time	Maximum of 4 (hours)	-	M	T
6	Pump Down Time	Maximum of 5 (hours)	-	L	T

[M=Medium, H= High, T= Test, S= Similarity to Existing Design, I= Inspection.]

Design Development

Project Water's initial task was to research and think of alternative materials that are locally available near rural villages in Africa. Using Mr. Proby's expertise and knowledge of the area, Project Water consulted him on whether proposed materials are available in the expected locations. Some examples of materials that were being considered for the seal construction are: bike inner tubes, PVC, and recyclable plastics (HDPE). Ideally the seal will be made from a recyclable material, to reduce waste and cost.

Due to the nature of the project, not all the design specifications can be fully addressed in this design development. Since there is no simple numerical analysis that can be performed to determine which materials should be used for the seal, the life cycle and leak rate parameters will be evaluated through extensive testing. The primary deciding factors for each seal design are: the cost of the design, the availability of its materials, and the manufacturing time. These will also double as the go/no-go values that were used to assess whether a design is a suitable solution.

After all the possible designs were ran through the go/no-go factors, eliminating the improbable ideas like using nuclear waste or solid gold; the remaining were entered into a Pugh Matrix. The Pugh Matrix compares potential designs with a datum in reference to the customer requirements. The datum is usually a current design. Each concept is then given either a '+', '-', or 'S', to show that that idea is better than, worse than, or the same as the datum. These are then summed up, and each concept was compared against each other. Any negatives that were seen in strong concepts were evaluated to see if they can be reversed, and any strengths in weak concepts were assessed to see if they would be viable in a stronger design. The weak concepts were then eliminated.

The Pugh Matrix was run with 9 concepts that featured a variety of materials and geometries, as seen in Appendix C. The three cone designs feature an upside-down cone made from various materials. The stacked designs are constructed of alternating materials, with one material functioning as the seal with the other making up the spacers. The spacer materials for

the four stacked designs are PVC and foam from flip slop soles. The seal materials are rubber from bicycle tubes and thin leather cut from common leather products like purses and shoes. The final two designs listed in the Pugh Matrix consist of a two-part design that will require a molding manufacturing process. The two parts consist of a hard-plastic spacer made using a recycled HDPE / coconut oil / saw dust composite, and an elastic seal using a to be determined material, depending on what is accessible in rural Africa. The main reason for the implementation of a molding process is to allow for tighter tolerances between the cylinder wall and the seal, ultimately resulting in a better performing seal. These tighter tolerances are achievable by removing the human error that is associated with manual manufacturing process. It should also be mentioned that using a mold would allow for higher repeatability in the finished product. All the designs were evaluated against each of the customer requirements, except for pump efficiency. There is no way to tell how efficient a design will be without testing the design. This parameter was assessed later in the testing portion of the project.

After the Pugh Matrix was completed, four desirable designs, two mediocre designs, and three poor designs were distinguished. The four desirable designs consisted of an alternating stacked spacer/seal design and a two-part spacer/seal design that would use a molding process to manufacture. Both designs would have two different material combinations, which results in the mentioned four desirable designs. The two designs that couldn't be determined to be stronger or weaker than the benchmark were the stacked concepts with foam as the spacer. The three weak designs were all the cone designs. The molds had one weak spot, and that was in their difficulty of manufacturing, but this could be acceptable if the finished design performs much better than all other designs.

The next step is to run a weighted decision matrix with the strong designs. This evaluation showed which designs met the engineering specifications the best based on a weighting scale. Each engineering specification received a weight, developed from the QFD. Each design was then assigned a value from 0 to 100 on how well it completed each engineering specification. This number was multiplied by the weight of the spec, and then summed up to get an overall satisfaction number. The result showed how well each of the designs satisfied the overall goal of the project.

The four strongest designs from the Pugh Matrix were chosen to be put into the weighted decision matrix, found in Appendix D. These were evaluated against the different engineering specifications with their respective weights. Both the specifications and the weights for the specifications came from the QFD. Unfortunately, two of the specifications were not able to be evaluated. The life cycle and leak rates cannot be determined without testing, so these were left blank. Even though these specifications weren't included, they only combine to make up 20% of the weighting factor. This is equal to the next lowest specification. This is representative of what would happen in Africa with one of these pump seals. The users would continue using the pump until absolutely no water was coming out, making life cycle and leak rate not be as important as the other factors. The other specifications were filled in, and the two stacked designs came out on top, both with a score of 72.6. Even though it seems strange that they would tie, it makes sense. They would both have the same success in the cost, availability, and manufacture criteria. The

differences between the two was determined during testing. The same thing is true with the two mold designs.

Failure Method and Effect Analysis (FMEA)

An additional technique implemented in the design decision process was a Failure Method and Effect Analysis chart. Project Water constructed an FMEA chart that listed possible failure modes of the seal that needed to be considered while designing a seal. It also listed the possible causes and effects of each failure mode. For each failure mode the severity of the effects and the occurrence of the cause were numerically quantified by Project Water. These values were then used in calculating the criticality of each potential cause of failure. The criticality value helped indicate which failure modes were most important to consider while designing a pump seal. Associated with each failure mode is a 'Recommended Action' section that outlined a brief description of how to avoid or remedy the failure effects. Reference appendix E to view the entire FMEA chart.

The results from Project Water's FMEA indicated that the most critical failure method and safety considerations were during the manufacturing process. Once the seal is installed, there is very little risk to the user; however, the manufacturing of the seals will require close attention to the manufacturing process and safety detailed later in this document.

Final Four Proposed Designs

The first two proposed seal designs both used a stacked geometry, often referred to as a "Labyrinth Seal". The first version of this type of seal incorporates a method of heating up PVC pipes and deforming them into flat disk spacers. In-between these disks, there would be a butyl rubber gasket made from bicycle inner tubes. The second version would use the same method of PVC spacers but would use thin leather as the seal material instead of rubber. To assist in the manufacturing process a punch may be constructed to cut out the leather and rubber in to the desired shape. When manufactured well, the stacked geometry has proven to be a good seal design. Results from the Appropriate Technology class show that the labyrinth geometry performed better than the seal design with a single gasket. (4).

Figure 5. Stacked Seal Design

The second set of proposed designs both consist of a two-part spacer/seal assembly that would be manufactured using a molding process. In both variations of this design, the spacer would be made by creating a composite consisting of recycled polyethylene, a binder oil, and natural fibers. Based on research completed by Joyce Koranteng, a PhD student from Kwame Nkrumah University of Science and Technology, we will produce initial prototypes using recycled HDPE, coconut oil as a binder and sawdust as a fiber (3). It has yet to be determined if these materials will be used in the final design, as there is uncertainty as to the availability of materials to the customers. The second part of this design consists of a soft seal. Currently, there are two different proposed materials to manufacture these seals: the first being silicone rubber and the second being a composite composed of finely ground bicycle inner tubes mixed with polyurethane.

There are two ways that the mold making process can proceed, the first being a custom-made mold that could be manufactured by Project Water in the Cal Poly Machine Shops and shipped overseas. The other method being a mold that could be pieced together using standard components found in any hardware store in Africa. If the second method of making the mold is easily achievable, the design becomes much more desirable as Project Water has been asked by the sponsor to avoid manufacturing processes, including the mold fabrication, that cannot be replicated in Africa.

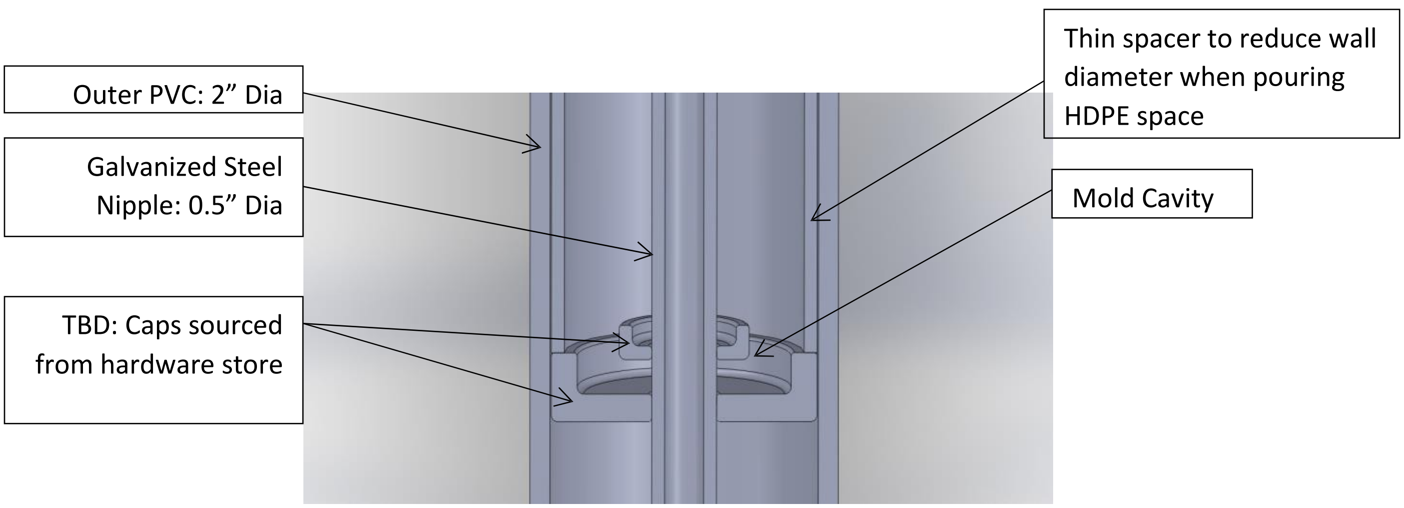

Figure 6. Preliminary Mold design

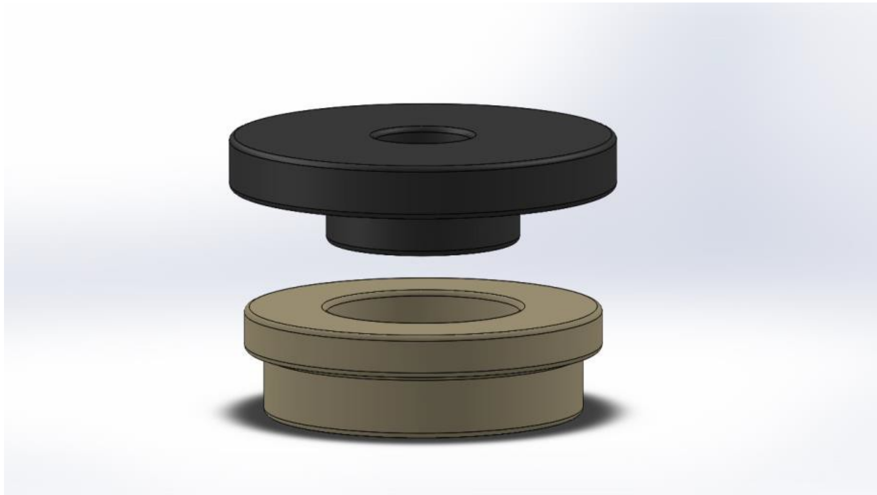

Figure 7. Molded Seal Design

Description of Final Design

Due to the nature of this project, Project Water had decided to continue into the next portion of the design process without eliminating any of the previous conceptual designs. Instead, each conceptual design was developed to the point in which it could be prototyped and eventually tested. It is this testing stage of the design process that ultimately lead to the decision of the final design. It is in this section of the design report that each of the two designs will be described in detail, including the manner in which they will be manufactured.

Labyrinth Design

The labyrinth design consists of an alternating stack of flat PVC support spacers in conjunction with seals. Flattened 2" Schedule 40 PVC will be used to create the support spacers, and recycled bicycle tubes will be used to create the seals.

The support spacers will provide the necessary rigidity to the seal in order to allow it to resist deformation during the pumping process. Since the seals will be made of rather flimsy material, it will be important to create a spacer with minimal clearance of the pump cylinder wall to ensure the seals success. The outer diameter of the spacer is the only critical dimension to be met during the manufacturing process of the support spacer. This is due to the fact that we will be drilling the inner diameter of spacer using a 7/8” drill bit, .875” nominal, and the 1/2” galvanized nipple that the spacers will be connect to in the pump assembly have a nominal outer diameter of 0.840”. Clearance and concentricity issues have been investigated between the ID of the spacer and OD of the 1/2” galvanized nipple; GD&T hand calculations are attached in Appendix J. The outer diameter of the spacer will be guided thru the use of 18-8 stainless steel washers that will act as guides during the sanding operation. The 18-8 washers have an ID of 0.938” and an OD of 2.000 +.03”, - .007”. Therefore at LMC (least material condition), the manufactured support spacers should have an OD of no less than 1.993”. Following PVC manufacturing specs, it can assumed that at LMC the ID of PVC pump cylinder should be no greater than 2.061”. During a worst-case scenario, with the worst scenario being the largest

clearance fit, a diametrical clearance of no greater than 0.068" can be expected. Considering that the manufacturing process of these support spacers is rather rudimentary, this is a surprisingly tight tolerance and should be able to allow us to achieve a good seal with the pump cylinder wall. The entire manufacturing process of the support spacers is outlined in appendix J.

The seals will be manufactured using a custom designed steel punch. This punch will consist of two concentric steel pipes connected via a flat steel plate. The punch will create a donut shaped seal with an OD = 1.925" at LMC, and an ID = 0.809" at MMC (most material condition). This means that there is the possibility of an interference fit occurring between the seal and the nipple of 0.147" when both are at MMC and an assumed position tolerance of .1", developed during the manufacturing of the punch, is taken into consideration. Typically, this would be considered an unacceptable design, but considering that Project Water has been asked to use only of the shelf components and simple manufacturing processes, this interference fit will be considered acceptable. To alleviate fit issues, the last step to manufacturing process of the seals will be to cut 8 – ¼" radial slits from the center of the seal outwards towards the OD. This should both allow for interference issues to be overcome, and also allow for better concentricity between the galvanized nipple and the ID of the pump cylinder wall to be achieved during the assembly of the labyrinth seal. The largest clearance fit, with the both 2" PVC and the seal being at their respective LMC's, there will be a diametrical clearance of 0.136". Since each labyrinth unit will consist of multiple seals, it is statistically realistic to believe that the majority of the seals will have a much tighter fit with the cylinder wall. To reiterate, the entire manufacturing process of the seals is outlined in appendix J.

Molded Design

The molded design consists of two parts. The first component being a rigid spacer made using an injection process that utilizes the use of recycled HDPE. The second component of the assembly is a rubber like seal made of silicon. Both components of the assembly will be manufactured in the same mold, which should ultimately minimize interference between the two mating components.

Within the Appendix is a preliminary outline of the purposed manufacturing process for the molded design. This procedure is subject to change and will be further refined once the manufacturing has begun.

General Safety Considerations

General safety precautions should be used during the manufacturing of tools, seals, spacers, the testing of prototypes and the final installation of the product. The simplicity of the designs, and their respective manufacturing process lends to there being no use of considerably dangerous processes. Regardless, the individual completing said task should be competent with the equipment they are using and ask for assistances if they at any point feel unsure about how to complete a requested procedure in a safe manner. Special safety considerations regarding the usage of testing equipment is outlined in their respective testing procedures, which is attached to the end of this document.

Analysis

The nature of this project has resulted in there being little analysis completed before prototyping. Project Water will instead be relying on collected data to validate the final design. Testing procedures, including necessary data sheets have been attached to end of this document.

Cost Analysis

The only materials that will need to be purchased by the end user will be PVC to create the flat spacers and raw silicon to manufacture the seals. Everything else should be recycled, which would lend itself to either being free or close to it. Assuming a price of $0.15/Kg of silicone, a rough estimate of cost to manufacture a silicone seal would be about $0.01/piece. Assuming a price of $10.00 for a 2in x 10ft piece of PVC, and making conservative estimates on material used, it equates to approximately 5-10 cents per spacer. The design specification price limit per seal is $1.00. The purposed seal designs are well below that limit, and may be able to be manufactured for even less in Africa. There are price differences in Africa, and the materials required can often be found for less or even free.

The manufacturing and tooling cost for the labyrinth seal design punch is estimated to cost around $40. This includes the price of constructing the metal punch (~$25.00) and the all-thread rod assembly (~$12.50). The molded seal tooling cost is estimated to cost slightly less than $20. This is for the PVC pieces (~$7.00), all thread rod (~$10.00), and steel fasteners (~$1.50). The parts for both of these manufacturing processes would be a one-time purchase. They can be reused for the construction of future seals.

Design Verification Plan (DVP)

In order to determine the success of the final design, Project Water has devised a test plan in order to detail the process. The DVP consists of three main items of interest: static testing, dynamic testing, and abrasion testing. The static testing will be the baseline test to determine which seal design meets the minimum requirements. It is considered to be the 'Concept Verification’ stage of testing. The 'Design Verification' stage of testing will consist of the dynamic and abrasion tests. The full DVP chart can be located in appendix F

Final Design Details and Results

The final design that Project Water has determined to best meet the requirements is the multi-stacked labyrinth seal design using PVC spacers and bicycle inner tubes. The ability to mass-produce the components of these types of seals quickly, while also keeping them consistently within tolerance, makes them the most advantageous design for the target customers. There were two tested designs in various geometry. There was a single seal stacking, meaning a single rubber seal separated each spacer. In addition, there was a multi-layer stacked seal, meaning that each spacer separated a stack of four rubber seals. These two geometries were than varied by height and number of seal-spacer attached to the galvanized steel nipple. The best variant of this seal design used two stacks of four rubber seals separated by PVC spacers (Sample #3).

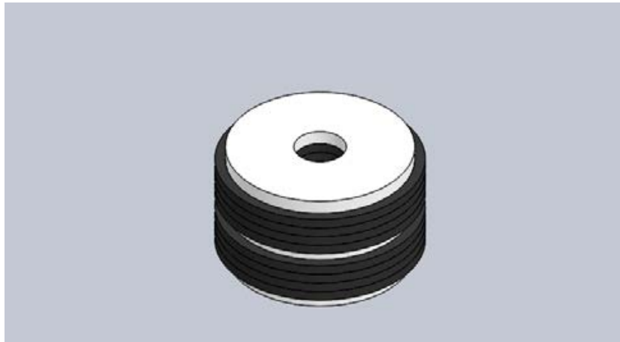

Figure 8. CAD Model of Sample #3

This design's performance during the static test validated itself in being chosen as the final design. It averaged a leak rate of 0.075 liters/min over a range of 20-80 psi. This was the lowest leak rate of all the tested designs and closest in comparison to the control test. A leak rate of 0.075liters/min falls within our predetermined tolerances, and thus, can be considered as an adequate design.

The total time of manufacturing of the final design takes approximately 10 minutes per seal. The manufacturing requires two special tooling set ups, a jig to sand the PVC spacers to size, and a steel punch for the inner and outer diameters of the rubber seal. Fortunately, once the manufacturing tools have been set up, multiples of the spacers and rubbers can be made simultaneously. This allows for quick production of many seals. This is ideal for achieving a short manufacturing and pump down time.

Overall, this seal meets all the design specifications previously stated in this report, except for the life cycle requirement. This is due to the inability to test and verify its performance using the dynamic test system. Unfortunately, the dynamic test system required repairs that were too expensive and time consuming to complete during this projects timeline. For future considerations, this final design should be tested dynamically to determine its ability to perform under a more realistic situation.

Manufacturing

The manufacturing processes used to create the final design ended up being very similar to the processes described in the previous Design Development section. As a result, necessary changes were made to the supplemental Manufacturing Process Sheets in Appendix G: Labyrinth Seal Manufacturing. The following sections will discuss the small changes made to the manufacturing process as well as describe in detail the tooling that we developed to complete these manufacturing processes.

Tooling

In order to create a seal that could maintain a low leakage rate at sustained high pressure, it was necessary to develop a manufacturing process that would allow for the manufacturer to

create seals with tight tolerances. To ensure repeatability of the manufacturing process, we developed tooling to guide the operator during the manufacturing process. The following sections will describe the tooling developed for both the PVC Spacer and the Bicycle Inner Tube Seal.

PVC Spacer

The most critical geometry on the PVC spacer is the OD. To ensure that repeatable tight tolerances could be achieved, tooling was developed for the OD sanding operation. The following parts were used to create the tooling:

- 12” long - 7/8” 14TPI threaded rod
- 2 - 3/4" flat washer with OD = 2.00”
- 2 - 7/8” bolts

The only alteration made to any of these parts was the enlarging of the ID of the flat washer from 3/4” to 7/8”. To do this, a 7/8” drill bit was used with a vertical mill to drill out the ID of the flat washer.

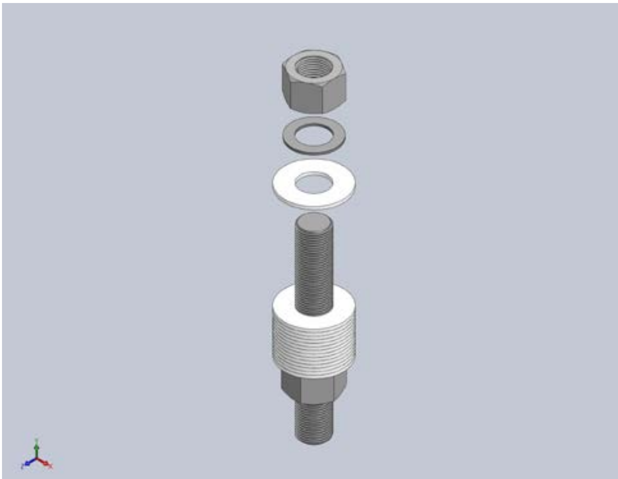

Figure 9. PVC spacer tooling

Bicycle Inner Tube Seal

The bicycle inner tube seal is arguably the most critical component of the entire design. In order create a seal that could achieve low leakage rates at high pressures, it was necessary to design tooling to cut out seals that would remove the possibility of human error being introduced into the process. To achieve this, three punches of varying diameters (2.05in, 2.00in and 1.95in) were created.

All three punches were manufactured using schedule 80 steel pipe. The entire manufacturing process was completed on a manual lathe and included the following steps:

1. Facing of the Schedule 80 steel pipe.
2. Turning of OD to the desired diameter of seal.
3. Chamfering of ID to make a sharp edge.

Figure 10. Show is the facing of the steel pipe and the finished punch

These punches were then placed inside a vice to cut out the outer and inner diameters of the seals. A full manufacturing process can be found in Appendix G.

Testing

There are currently two pieces of testing apparatus that Project Water have access to. They were used to determine the effectiveness of the seal designs. One is a static test of the pump cylinder and the other is a dynamic testing system.

The static test system was originally constructed by Mr. Proby to be used by a group of students in an Appropriate Technology course at Cal Poly in 2010. To conduct the static test, the pump cylinder is filled with water and then pressurized, simulating the column of water above the seal during pump operation. A collection container is then placed underneath the pump cylinder to collect water that leaks past the pump seal during a given time period. From the volume of water collected, the leak rate can be calculated at given pressures for different types of seals. To determine the effectiveness of each type of seal Project Water compared the leak rates

of their designs to the leak rate of current seals. As stated before, an ideal base line leakage rate is around 0.06 liters per minute.

Figure 11. Static Testing Apparatus

The dynamic testing system was constructed by a previous Cal Poly senior design project team in 2010. This testing system was attempted to be used to determine the number of cycles the prototyped seal designs are able to withstand before failure. The dynamic testing device actively circulates and pumps water through the cylinder and is equipped with a counter that displays the number cycles. The system has a fail point level of 80% of flow.

Figure 12. Dynamic Testing System

Testing the life cycle of the proposed seals must be simplified due to time restraints. The dynamic testing system runs at approximately 40 rpm, which equates to 40 pump cycles per minutes as well. To fulfill the 1.3 million cycle standard, the test would have to run for 22.6 straight days for each seal design. To compensate for this lack of time, Project Water would have interpreted data from a shorter cycle period to determine if the seal would be able to meet life cycle requirements. Measurements of pump rates in gallons per minute (GPM) would be collected for a set time interval, and then extrapolated to illustrate the theoretical life cycle. If there is a decline in pump-seal effectiveness, then the amount of water being pumped will decrease. Pump rates would give Project Water information on how well the pump seal is performing relative to the initial pump rate.

Since the dynamic testing system was an old senior project that had not been used in a few years, Project Water wanted to make sure that it was safe to use before turning it on to perform testing. Eric Pulse and George Leone, two machine shop technicians at Cal Poly's Mustang '60 Machine Shop, were contacted to evaluate what needed to be repaired on the system before operation. They gave the recommendation of finding or creating a wiring diagram for the internal electronics of the device. They also said that since the motor on the system runs on 220-Voltage an electrician would need to be contracted to connect the motor. They suggested that Jim Gerhardt, the Cal Poly safety officer, be contacted to set this up. Project Water took these recommendations and moved forward with them.

The first step was creating a wiring diagram. Luckily, the old senior project team had included a wiring diagram in their report, but the diagram was not very representative of the

actual wires in the system. Because of this, and for general knowledge of the device, each wire was chased through to make sure it connected to what is was supposed to be. Each wire was also checked for signs of corrosion or damage. Once all of this was completed, Jim Gerhardt was contacted. In addition to the wiring diagram, Mr. Gerhardt asked that a block diagram of the system, a testing procedure, and a user interface description be written before talking to an electrician. All of these can be seen within the appendix. Project water is now waiting on a response form Mr. Gerhardt to see what the electrician thinks of the dynamic testing apparatus.

One last hurdle that needed to be overcome is the price of the electrician. Project Water was given a rough budget of five hundred dollars to fix the dynamic testing system. Since an electrician was needed to set it up, the fees could quickly build up. Because of this, no spending involving an electrician has been approved by Mr. Proby, the project sponsor, until a written cost estimate is provided. If the cost was too high, Project Water would search for an alternative solution to the problem.

The final stage of testing is the abrasion test. This test is needed to determine how the seal affects the inner wall of the pump cylinder. Since the seal will be moving up and down during the pumping action, it will be rubbing against the inside of the cylinder. It is inevitable that there will be some amount of wear, however it is ideal to minimize these effects in order to avoid major damage to the cylinder. To determine the amount of abrasion that comes from the seal the wall thickness of the pump cylinder will be measured with a bore gage before and after the dynamic test. Multiple thickness measurements will need to be taken around the area of interest. This is due to the low tolerance in PVC pipes and irregularities in the wall thickness

Using these testing procedures, Project Water evaluated their seal designs and kept record of the data. The information gathered from the tests was be crucial when deciding which design is most optimal at meeting requirements. Full testing procedures and data sheets can be found in appendix G, H and I.

Static Testing Results

The static test yielded results that were very promising for both of the designs. Surprisingly, for both designs, the fewer the number of spacers and seals, the better the results, as seen in Table 2 and Figure 13 below. Both Sample 1 and 2 had one seal between every pair of spacers with Sample 1 having 9 spacers and 8 seals and Sample 2 having 6 spacers with 5 seals. Sample 2 performed significantly better than Sample 1 for all pressures besides 60 psi. This data point may be an anomaly though because it is simultaneously Sample 2’s worst performance and Sample 1’s best. This could be due to a variety of factors, but most likely, it was a function of how the seals were orientated inside the pipe cylinder. If they folded upwards or bent so that the rubber was not in contact with the cylinder walls, the leak rate could be affected. At the main point of interest of 80 psi, though, Sample 2 outperformed Sample 1 by 0.12 L/min, and was below the goal of 0.06 L/min.

The design for the 3rd and 4th samples was slightly different than the first two. For both designs, stacks of 4 seals were placed between the spacers. Sample 3 had 2 stacks of 4 seals with 3 spacers while Sample 4 had 3 stacks of 4 seals with 4 spacers. Once again, it was the variation

with less seals that performed better. Sample 3 outperformed sample 4 across the board, and had very similar leak rates to sample 2. The best design at 80 psi, though, was sample 2, with a leak rate of 0.05 L/min.

Static Pressure [psi]		20	40	60	80
Leak Rate [L/min]	Control	0.01	0.01	0.01	0.01
	Sample 1	0.56	0.3	0.08	0.17
	Sample 2	0.05	0.1	0.16	0.05
	Sample 3	0.06	0.085	0.075	0.08
	Sample 4	0.275	0.19	0.18	0.17

Table 2. Static Testing Results

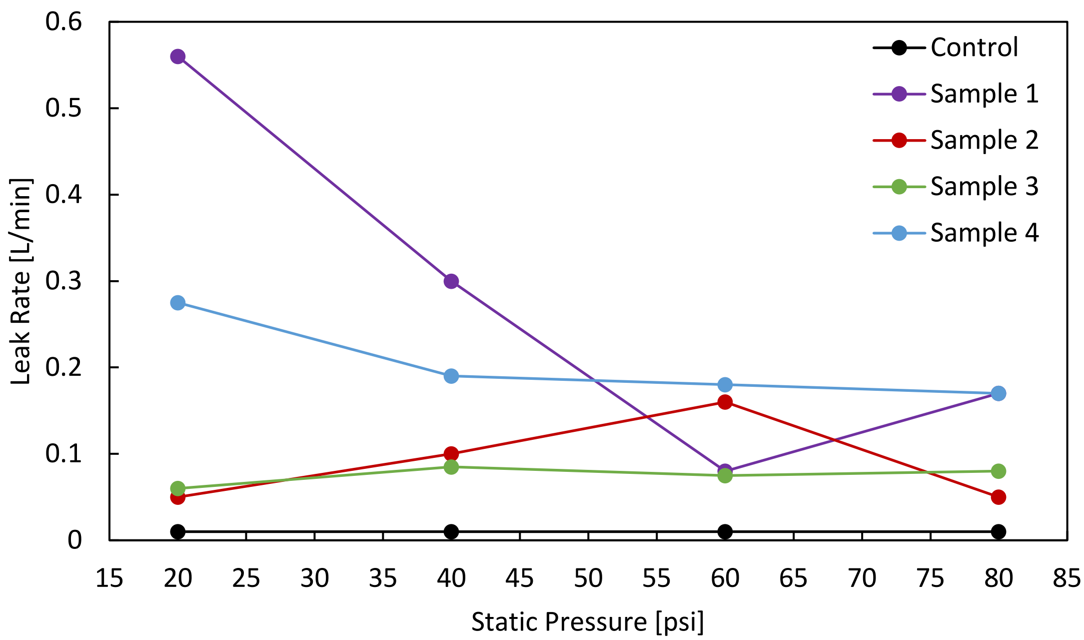

Figure 13. Static Testing Results

The leading thought as to why less seals equals better results is pressure. The rubber seals are able to deform, and tend to spread out more when they are under higher pressures. So, when the seals are put under pressure in the pump cylinder, the rubber spreads out and reaches the walls of the cylinder. This effect only happens to a certain extent, and needs to be maximized for the bottom seal. There are no more rubber seals below the last one to take energy away from the pressure being applied, so this one needs to be spread out all the way to the cylinder wall. While the top seal experiences the pressure directly, the soft rubber seals below it take away some of

the force by also spreading out. The result is the bottom seal being the most crucial part in the whole assembly. To maximize this effect, there cannot be too many seals above the last one. More seals mean more pressure being taken away from the bottom, increasing the leak rate. Therefore, the variation with less seals for both stacks is the better design.

Dynamic Testing Results

Due to unforeseen circumstances, the dynamic testing of the seals never took place. The apparatus was deemed unsafe to work on by Cal Poly students, and professional help was unavailable. This test would be the next step in the design process for the seals. If the stacks passed this and the abrasion test, they would be ready to manufacture in Africa, or any other third-world county that has hand-pump water wells.

Management Plan

The members of this senior project team have decided to define management roles that each individual would hold during the entire project. This document has no intentions of limiting an individual's contribution to components of the design process other than their defined roles but simply designates a member to coordinate and manage each specific category of the design process. These defined roles lend themselves to be living, and have the capability of evolving over the course of the senior project. The roles are as follows:

Peter Gordon	• Scheduling / Deadlines • Team budgeting • Documentation of project process
Matt Johnson	• Develop testing procedures • Oversee data acquisition and product validation • Design for manufacturing considerations
Dylan Smith	• Point of contact with sponsor • Meeting facilitator • Prototype fabrication and validation

To manage this senior project effectively and efficiently, Project Water constructed a Gantt chart that listed all important milestones and the days on which they were completed. This chart also evolved as the project continued to develop and has been attached to this document in the appendix. See Attachment B.

Conclusion

Over the past year, after many iterations and alterations, Project Water was able to develop an inexpensive seal, made from locally sourced materials, alongside an effective manufacturing process that is achievable within the constraints and limitations of a rural African machine shop. The final design was statically tested and proved its ability to hold a column of water up to nearly 200ft. The next steps in completing and verifying Project Water's labyrinth

seal design would be to repair the dynamic testing machine and then test the seal to determine its lifecycle and wear on the pump cylinder. If the seal is able to perform adequately and meet these two design specifications, then Lifewater International should be able to implement the design in hand pumps throughout Sub-Saharan Africa.

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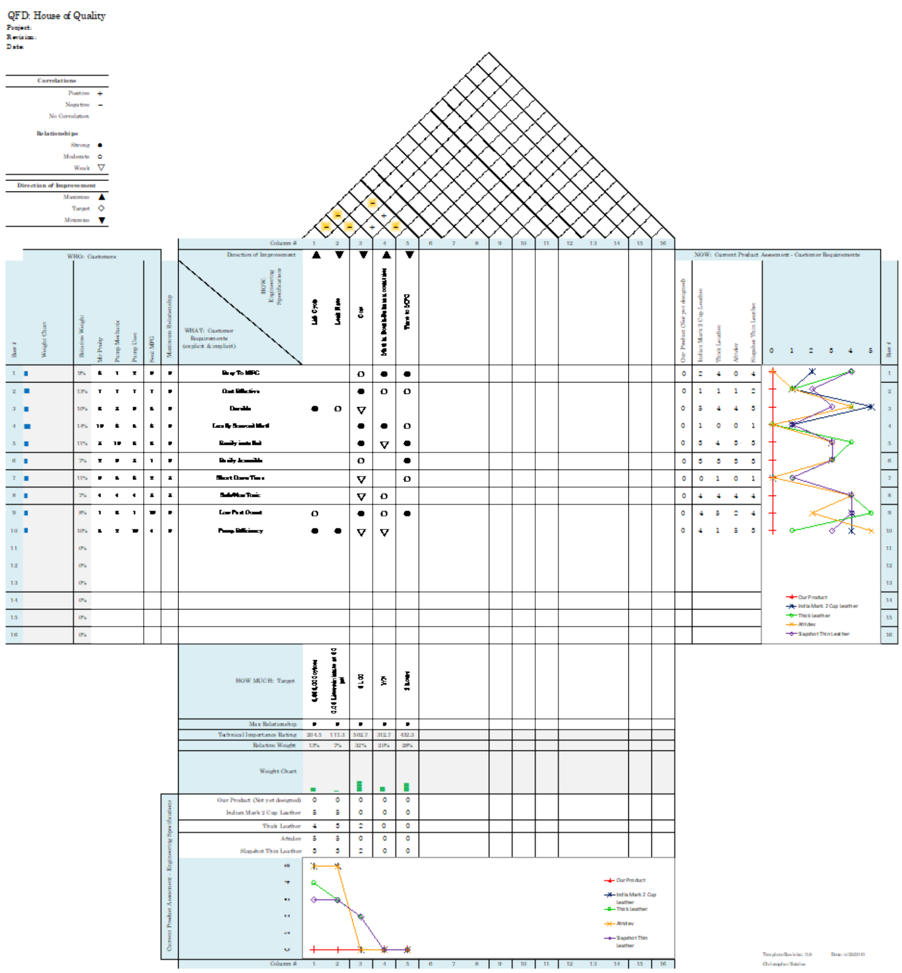
Appendix

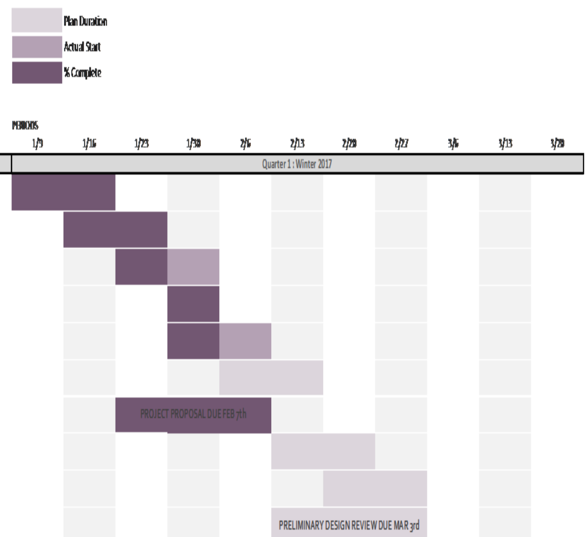
Appendix A: Quality Function Deployment



Appendix B: Gant Chart

Project Water Timeline

ACTIVITY	PLAN START	PLAN DURATION (Days)	ACTUAL START	ACTUAL DURATION (Days)	PERCENT COMPLETE
Quarter 1 : Winter 2017					
Teaming and Sponsor Contact	1/9	8	1/9	8	100%
Background Research and Team Contract	1/16	8	1/16	8	100%
QFD	1/23	8	1/23	8	85%
Obtain Testing Equipment	1/30	1	1/30	1	10%
Creativity - Idea Generation	1/30	8	1/30	8	85%
Concept Modeling/ Project Planning	2/6	8	-	6	0%
PROJECT PROPOSAL DUE	1/23	8	1/23	8	100%
Idea Selection / Decision Schemes	2/13	8	-	-	0%
Design for Manufacturing	2/20	8	-	-	0%
PRELIMINARY DESIGN REPORT	2/13	15	-	-	0%



Appendix C: Pugh Matrix

Pugh Matrix

Criteria \ Concept	1	2	3	4	5	6	7	8	9	Datum
Easy to MFG	-	-	-	+	+	+	+	-	-	D
Cost Effective	+	+	+	+	+	+	+	+	+	
Durable	-	S	S	+	-	+	-	+	+	
Locally Sourced Material	+	+	+	+	+	+	+	+	+	A
Easily Installed	S	S	S	+	+	+	+	+	+	
Easily Accessible	S	S	S	S	S	S	S	S	S	
Short Down Time	-	-	-	+	+	+	+	+	+	T
Safe/Non-toxic	S	S	S	S	S	S	S	S	S	
Low Part Count	+	S	S	-	-	-	-	-	-	
Pump Efficiency										U
Sum '+'	3	2	2	6	5	6	5	5	5	
Sum '-'	3	2	2	1	2	1	2	2	2	
Sum 'S'	3	5	5	2	2	2	2	2	2	M

Concepts	
1	Rubber Cone
2	Metal Cone with Rubber Lip
3	PVC Cone with Rubber Lip
4	Stacked PVC / Rubber
5	Stacked Foam / Rubber
6	Stacked PVC / Thin Leather
7	Stacked Foam / Thin Leather
8	Recycled HDPE Spacer with Silicone Rubber Seal using Mold
9	Recycled HDPE Spacer with Experimental Material Seal using Mold
Datum	Cup-Leather Seal

Appendix D: Weighted Decision Matrix

Weighted Decision Matrix

	Design Criteria	Life Cylce	Leak Rate	Cost	Local Material	MFG Time	Overall Satisfaction
Weighting Factor		0.13	0.07	0.32	0.20	0.28	1.00
Designs							
1				90	100	85	
		0	0	28.8	20	23.8	72.6
2				90	100	85	
		0	0	28.8	20	23.8	72.6
3				75	90	75	
		0	0	24	18	21	63
4				75	90	75	
		0	0	24	18	21	63

Designs	
1	Stacked PVC / Rubber
2	Stacked PVC / Thin Leather
3	Recycled HDPE Spacer with Silicone Rubber Seal using Mold
4	Recycled HDPE Spacer with Experimental Material Seal using Mold

Appendix E: Failure Method and Effects Analysis

Product: ______________________ **Design Failure Mode and Effects Analysis** Prepared by: ______________________

Team: ______________________ Date: ______________ (orig)

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s) / Mechanism(s) of Failure	Occurence	Criticality	Recommended Action(s)	Responsibility & Target Completion Date	Action Results: Actions Taken	Severity	Occurence	Criticality
Material Selecton	Release toxins into water supply	Cause illness to user	9	Water soluable material	1	9						
				Material reactive with other materials in pump	2	18						
				Foreign substace on material	5	45						
				Manufacturing process followed incorrectly	8	72						
				Release of material due to abbrasion	7	63						
		Cause death to user	9	Water soluable material	1	9	Ensure manufacturing process is simple and easy to follow; limit abbrasion by picking materials with low coefficients of friction; include a "Cleaning Materials" section in manufacturing process					
				Material reactive with other materials in pump	2	18						
				Foreign substace on material	5	45						
				Manufacturing process followed incorrectly	8	72						
				Release of material due to abbrasion	7	63						
		Cause injury to user	8	Water soluable material	1	8						
				Material reactive with other materials in pump	2	16						
				Foreign substace on material	5	40						
				Manufacturing process followed incorrectly	8	64						
				Release of material due to abbrasion	7	56						
		Create corrosion in pump	6	Water soluable material	1	6						
				Material reactive with other materials in pump	2	12						
				Foreign substace on material	5	30						
				Manufacturing process followed incorrectly	8	48						
				Release of material due to abbrasion	7	42						
		Detstroy pump	7	Water soluable material	1	7						
				Material reactive with other materials in pump	2	14						
				Foreign substace on material	5	35	Ensure manufacturing					

FMEA.xlsx Page 1 of 4 Revision Date: 5/4/17

Design Failure Mode and Effects Analysis

Product: ______________________ Prepared by: ______________________

Team: ______________________ Date: ______________ (orig)

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s) / Mechanism(s) of Failure	Occurence	Criticality	Recommended Action(s)	Responsibility & Target Completion Date	Action Results: Actions Taken	Action Results: Severity	Action Results: Occurence	Action Results: Criticality
				Manufacturing process followed incorrectly	8	56	Ensure manufacturing process is simple and easy to follow; limit abbrasion by picking materials with low coefficients of friction; include a "Cleaning Materials" section in manufacturing process					
				Release of material due to abbrasion	7	49						
		Contaimnate groundwater	8	Water soluable material	1	8						
				Material reactive with other materials in pump	2	16						
				Foreign substace on material	5	40						
				Manufacturing process followed incorrectly	8	64						
				Release of material due to abbrasion	7	56						
	material not easily accesible	alternative material used	7	uncommon material	2	14						
		longer manufacture time	4	uncommon material	2	8						
	expensive	won't be maufactured	8	uncommon material	2	16						
		won't be purchased	8	uncommon material	2	16						
make a seal	seal fails	water does not pump	8	seal cracks	6	48	Ensure material selection does not cause severe abrasion with the cylinder wall					
				wear on edge of seal	7	56						
				seal deforms	4	32						
		well goes unused	8	seal cracks	6	48						
				wear on edge of seal	7	56						
				seal deforms	4	32						
		water shortage develops	7	seal cracks	6	42						
				wear on edge of seal	7	49						
				seal deforms	4	28						
	difficult to manufacture	won't get manufactured	8	complex design	2	16						
				uses complex manufacturing process	1	8						
		not manufactured correctly	5	complex design	2	10						
				uses complex manufacturing process	1	5						
		cause injury/harm to manufacturer	9	complex design	2	18						
				uses complex manufacturing process	1	9						
		long manufacturing time	4	complex design	2	8						
				uses complex manufacturing process	1	4						
				toxic to manufacture	1	8						

Product: ____________________ **Design Failure Mode and Effects Analysis** Prepared by: ____________________

Team: ____________________ Date: ______________ (orig)

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s) / Mechanism(s) of Failure	Occurence	Criticality	Recommended Action(s)	Responsibility & Target Completion Date	Action Results: Actions Taken	Severity	Occurence	Criticality
manufacture	dangerous to manufacture	won't get manufactured	8	uses manufacturing process that is new to manufacturer	5	40						
				toxic to manufacture	1	5						
		not manufactured correctly	5	uses manufacturing process that is new to manufacturer	5	25						
				toxic to manufacture	1	9						
		cause injury/harm to manufacturer	9	uses manufacturing process that is new to manufacturer	5	45						
				toxic to manufacture	1	4						
		long manufacturing time	4	uses manufacturing process that is new to manufacturer	5	20						
	time-consuming to manufacture	long lead time	4	long manufacturing process	5	20						
				complex manufacturing process	2	8						
				long lead time on material	7	28						
				low yield	4	16						
	expensive to manufacture	not manufactured correctly	5	uncommon material	2	10						
				needs complex machinery	1	5						
				many manufactring components	4	20						
				low yield	4	20						
		won't be maufactured	8	uncommon material	2	16						
				needs complex machinery	1	8						
				many manufactring components	4	32						
				low yield	4	32						
		won't be purchased	8	uncommon material	2	16						
				needs complex machinery	1	8						
				many manufactring components	4	32						
				low yield	4	32						
		won't be used	8	doesn't fit on nipple	3	24						
				doesn't fit in cylinder	3	24						

FMEA.xlsx Page 3 of 4 Revision Date: 5/4/17

Product: ____________________ **Design Failure Mode and Effects Analysis** Prepared by: ____________________

Team: ____________________ Date: ______________ (orig)

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s) / Mechanism(s) of Failure	Occurence	Criticality	Recommended Action(s)	Responsibility & Target Completion Date	Action Results: Actions Taken	Severity	Occurence	Criticality
integration	doesn't integrate			no interface for bushing	2	16						
		cause wear	6	doesn't fit on nipple	3	18						
				doesn't fit in cylinder	3	18						
				no interface for bushing	2	12						
		doesn't seal	8	doesn't fit on nipple	3	24						
				doesn't fit in cylinder	3	24						
				no interface for bushing	2	16						

Appendix F: Design Verification Plan and Report

Project Water DVP&R														
Report Date	4/11/17		Sponsor	LifeWater		Component		Labyrinth / Molded Seals			REPORTING ENGINEER:		Matt Johnson	
TEST PLAN										TEST REPORT				
Item No	Specification or Clause Reference	Test Description	Acceptance Criteria	Test Responsib	Test Stage	SAMPLES		TIMING		TEST RESULTS			NOTES	
						Quantity	Type	Start date	Finish date	Test Result	Quantity Pass	Quantity Fail		
1	Static Testing	Preliminary testing used in order to validate prototypes before investing the time in dynamic testing	.06 liters/minute @ 80 PSI	Matt Johnson	CV	5+	A	5/6/17	5/20/17					
2	Dynamic Testing	Testing used to validate final designs. Will use dynamic testing apparatus developed by previous senior project	310 hours w/ Flowrate > %80 Initial Flowrate	Matt Johnson	DV	1	B	5/13/17	Indefinite					
3	Wall Abrassion Testing	Measuring of the change in inside diameter of cylinder wall to ensure that final design will not degrade pump cylinder wall	ΔWall thickness < 2.5mm radially @ end of Dynamic Testing	Matt Johnson	DV	1	B	5/13/17	Indefinite					
4														

Appendix G: Labyrinth Seal Manufacturing

Manufacturing Process: PVC Support Spacer

Overview:

The following procedural guidelines should be used to facilitate the manufacturing of PVC Support Spacers used in Project Water's Labyrinth Seal Design. It is of much importance to following these instructions strictly to ensure that the PVC Support Spacers are manufactured to their necessary tolerances to ensure the function of the SlapShot pump.

Material/Equipment List:

- **4 - 2" Diameter Schedule 40 PVC, 2.5" long sections**
- **1 - 7/8" -14 threaded rod, 6" long**
- **4 – 7/8" – 14 hex nuts**
- **2 – 18-8 washers, for 7/8" rod, OD 2.0", ID 0.938"**
- **7/8" Drill bit**
- **Drill press / Mill**
- **Compass**
- **Ruler / Calipers**
- **Large pot filled with water (optional)**
- **Flame source**
- **Disk / Belt sander**
- **2 - Flat surfaces (e.g cutting board/ plywood/ baking sheet)**

Manufacturing Procedure:

1. Creating flat PVC stock

1.1 **Cut 2" Schedule PVC into 2.5" long sections.** Use any appropriate method to cut the PVC into 2.5" sections. 1- 2.5" section should produce 3 support spacers. Refer to callout in final design packet to determine how many support spacers are necessary.

1.2 **Cut 2.5" PVC longitudinally.** Use any appropriate method to cut the 2.5" PVC sections longitudinally (down the pipe).

1.3 **Bring PVC to working temperature.** Heat the PVC, using any appropriate method, to a temperature where it is malleable. It is however most desirable to using boiling water, as the PVC cannot be scorched. Scorching the PVC will lead to creating a brittle support spacer, which could ultimately fail inside the pump cylinder.

1.4 **Flatten PVC.** When the PVC has reached a malleable state, unfold the PVC into a flat plate. Use two flat surfaces to sandwich the PVC.

1.5 **Repeat Steps 1.3 and 1.4 .** Repeat the previous two steps until the PVC sheets are completely flat. The flatter you can get the PVC, the better the results will be of the final seal.

2. Drilling inner diameter

2.1 **Marking center line.** Determine the center of the first support spacer by first finding the longitudinal centerline. Divide the width of the strip by 2, this is the location of the centerline. Mark the centerline in 3 different spots along the length of the PVC strip and draw a straight line connecting all three dots.

2.2 **Marking center points.** Mark center of first individual support spacer by measuring 1 1/8" along the centerline from either side of the PVC strip. Measure 1 1/8" along centerline from previous center point to find the center of the next support spacer. Repeat the process to find the last center point.

2.3 **Marking outer diameters.** Once the center points have been, use a compass to draw a circle with a radius of 1" at each location.

2.2 **Drill inner diameter.** Use an appropriate method to drill out the inner diameter of the all support spacers using the required 7/8" drill bit. It is recommended that either a drill press or mill is used to ensure better tolerances. Ensure that drill bit is perpendicular to PVC sheet during drilling process.

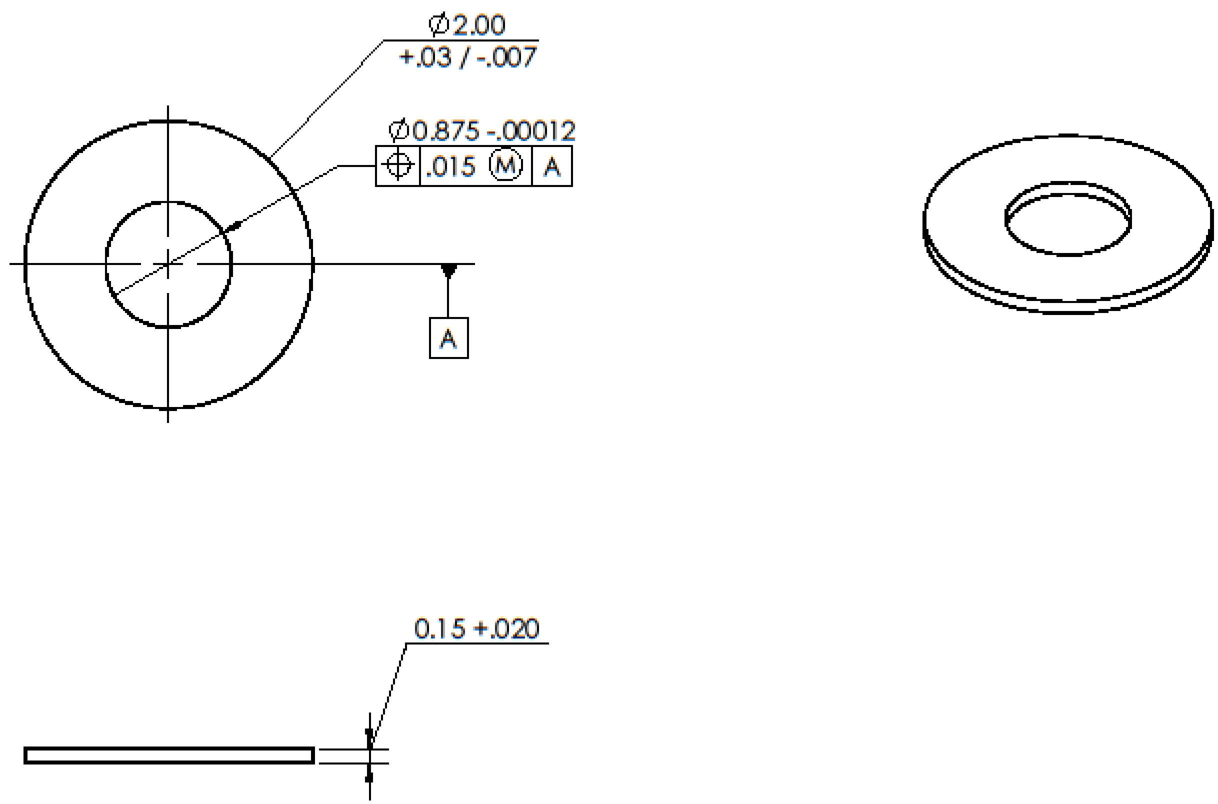
3. Rough cutting outer diameter

3.1 **Rough outer diameter.** Using an appropriate method, roughly cut the outer diameter of the spacer out. Make sure to leave excess material for the sanding process.

4. Sanding to precise outer diameter

4.1 **Assemble threaded rod fixture.** Take all support spacers and put them on the 7/8" threaded rod. Add 2 – 18-8 Steel washers to each side of the threaded rod and use the 7/8" hex nuts to compress the entire assembly together.

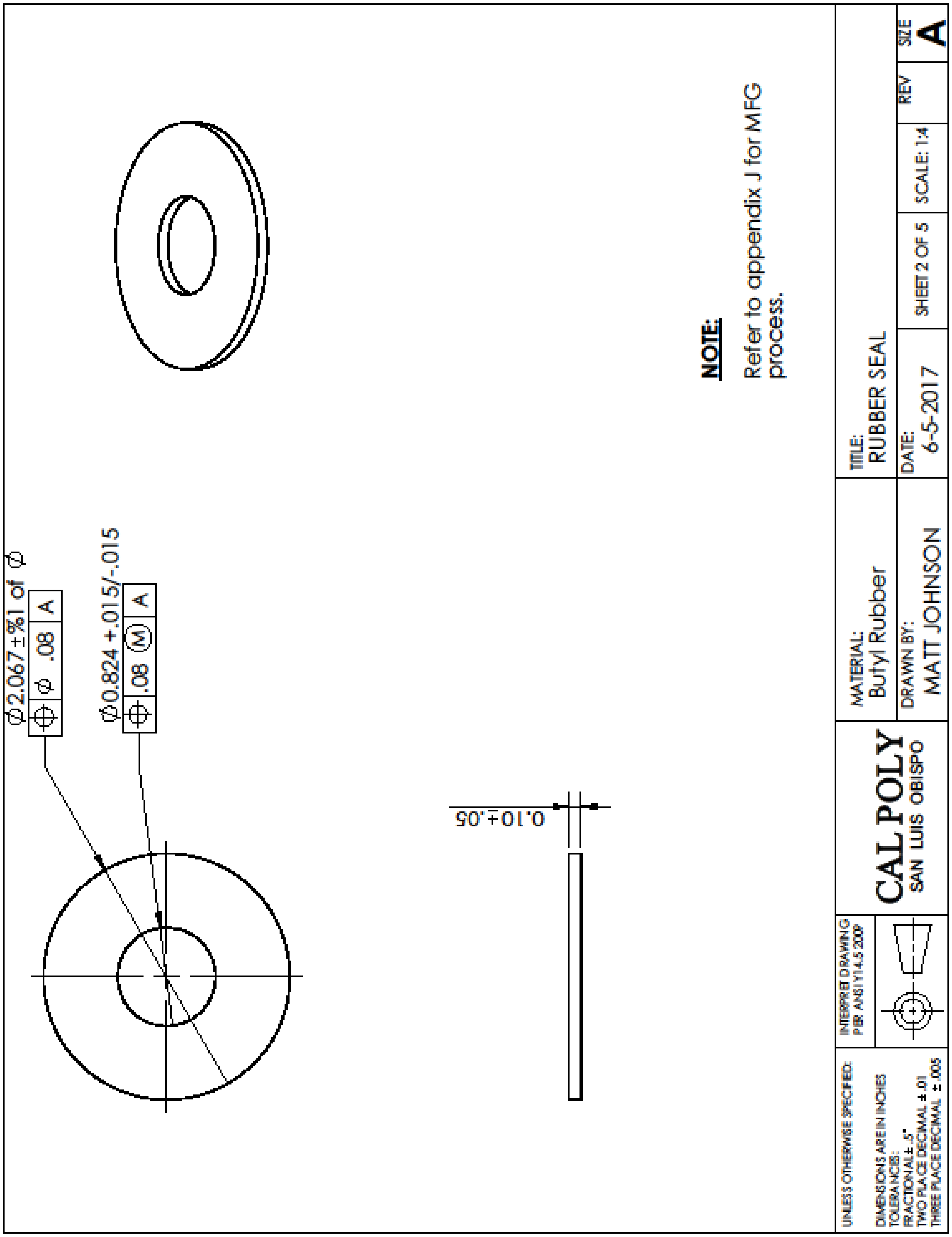
4.2 **Sand support spacers.** With all support spacers on the 7/8" threaded rod and secured in place by the two 7/8" hex nuts, carefully sand away PVC support spacers until the outer diameter is the same size as the washers. The washers should be used as a guide, therefore periodically check fit within a 2" PVC tube.

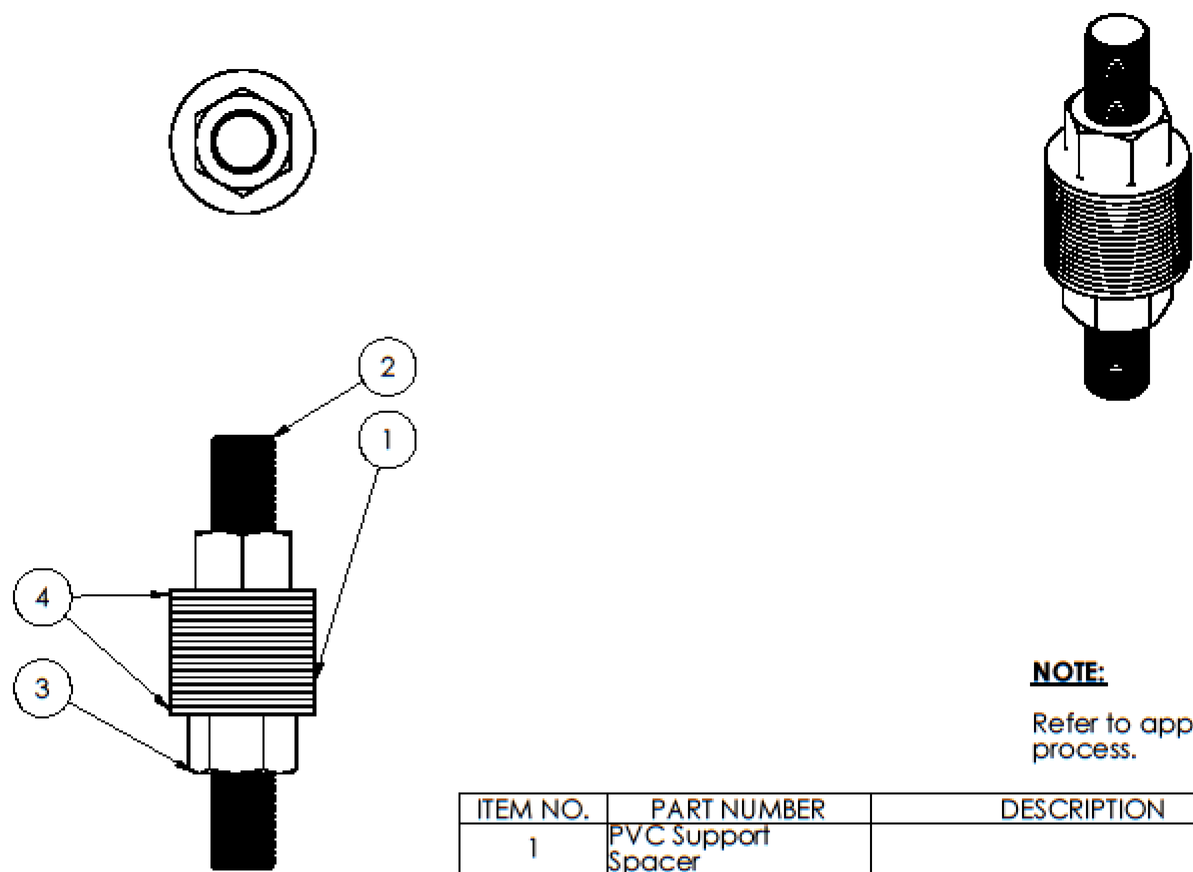


NOTE:

Refer to appendix J for MFG process.

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± .5" TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005	INTERPRET DRAWING PER ANSI Y 14.5 2009	CAL POLY SAN LUIS OBISPO	MATERIAL: Schedule 40 PVC	TITLE: PVC SUPPORT SPACER		
			DRAWN BY: MATT JOHNSON	DATE: 6-5-2017	SHEET 1 OF 5	SCALE: 1:4
					REV	SIZE A


Ø2.067±%1 of Ø
⊕ Ø .08 A
Ø0.824+.015/-.015
⊕ .08 Ⓜ A
0.10±.05
NOTE:
Refer to appendix J for MFG process.
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± .5"
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005
INTERPRET DRAWING PER ANSI Y14.5 2009
CAL POLY
SAN LUIS OBISPO
MATERIAL:
Butyl Rubber
DRAWN BY:
MATT JOHNSON
TITLE:
RUBBER SEAL
DATE:
6-5-2017
SHEET 2 OF 5
SCALE: 1:4
REV
SIZE
A



NOTE:

Refer to appendix J for MFG process.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	PVC Support Spacer		15
2	90322A210	7/8" All Thread Rod	2
3	95036A043	7/8" Hex Nut	2
4	92141A037	7/8" Washer, 0.875" ID, 2.030" OD	2

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± .5°
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005

INTERPRET DRAWING PER ANSI Y14.5 2009

CAL POLY
SAN LUIS OBISPO

MATERIAL: N/A

DRAWN BY: MATT JOHNSON

TITLE: PVC SUPPORT SPACER SANDING JIG

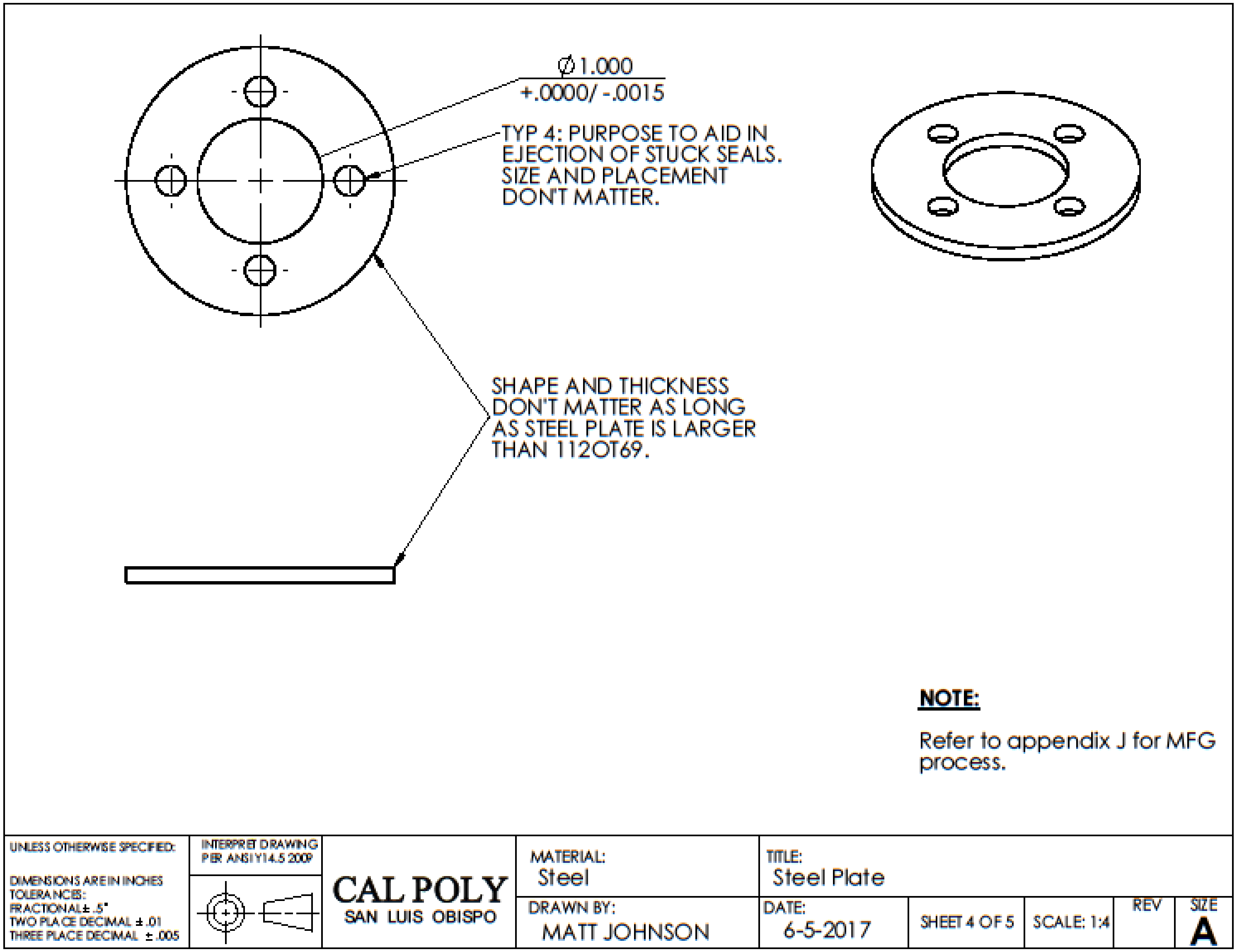
DATE: 6-5-2017

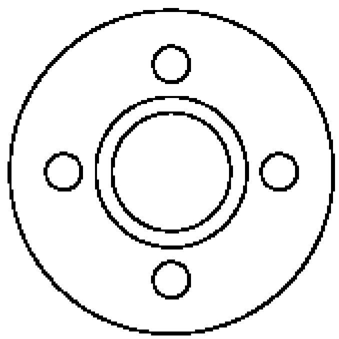
SHEET 3 OF 5

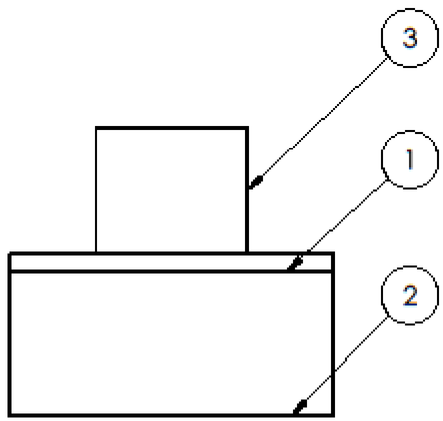
SCALE: 1:4

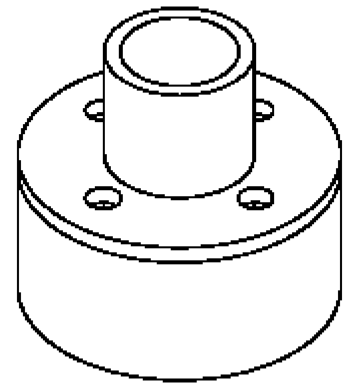
REV

SIZE A


Ø1.000
+.0000/ -.0015
TYP 4: PURPOSE TO AID IN EJECTION OF STUCK SEALS. SIZE AND PLACEMENT DON'T MATTER.
SHAPE AND THICKNESS DON'T MATTER AS LONG AS STEEL PLATE IS LARGER THAN 112OT69.
NOTE:
Refer to appendix J for MFG process.
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± .5°
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005
INTERPRET DRAWING PER ANSI Y14.5 2009
CAL POLY
SAN LUIS OBISPO
MATERIAL:
Steel
DRAWN BY:
MATT JOHNSON
TITLE:
Steel Plate
DATE:
6-5-2017
SHEET 4 OF 5
SCALE: 1:4
REV
SIZE
A







NOTE:

Refer to appendix J for MFG process.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	.25Plate	Custom 1/4" Steel Plate	1
2	1120T69	2" - Black Steel Unthreaded Pipe Nipple	1
3	1120T44	3/4" - Black Steel Unthreaded Pipe Nipple	1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± .5"
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005

INTERPRET DRAWING PER ANSI Y14.5 2009

CAL POLY
SAN LUIS OBISPO

MATERIAL: STEEL

DRAWN BY: MATT JOHNSON

TITLE: Seal Punch

DATE: 6-5-2017

SHEET 5 OF 5

SCALE: 1:4

REV

SIZE A

<u>CENTER DRILL OP</u>

1/2" GALV NIPPLE

OD ~ .840 ± .01562"

⟶ Ⓜ = .8556"

7/8" DRILL BIT

OD ~ $.875^{+.0000"}_{-.0012"}$

⟶ WILL DRILL HOLE WITH Ⓜ = 0.8738"

∴ CENTER DRILL OP WILL RESULT IN A CLEARANCE FIT THAT IS EQUAL TO 0.0182"

.8738" − .8556" = 0.0182"

<u>OD SANDING OP</u>

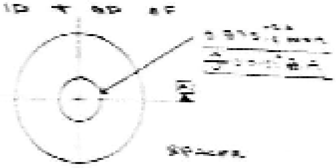
7/8" ALL THREAD ROD

MAJOR DIAMETER: Ⓜ = .8734"
Ⓛ = .8579"

∴ WORSE FIT WILL RESULT IN CLEARANCE = 0.0151"

⟶ THIS IS THE POSITIONAL TOLERANCE THAT WE MUST DESIGN FOR WITH RESPECT TO CONCENTRICITY BETWEEN THE ID + OD OF THE SPACER.

.8738" − .8579" = 0.0151"

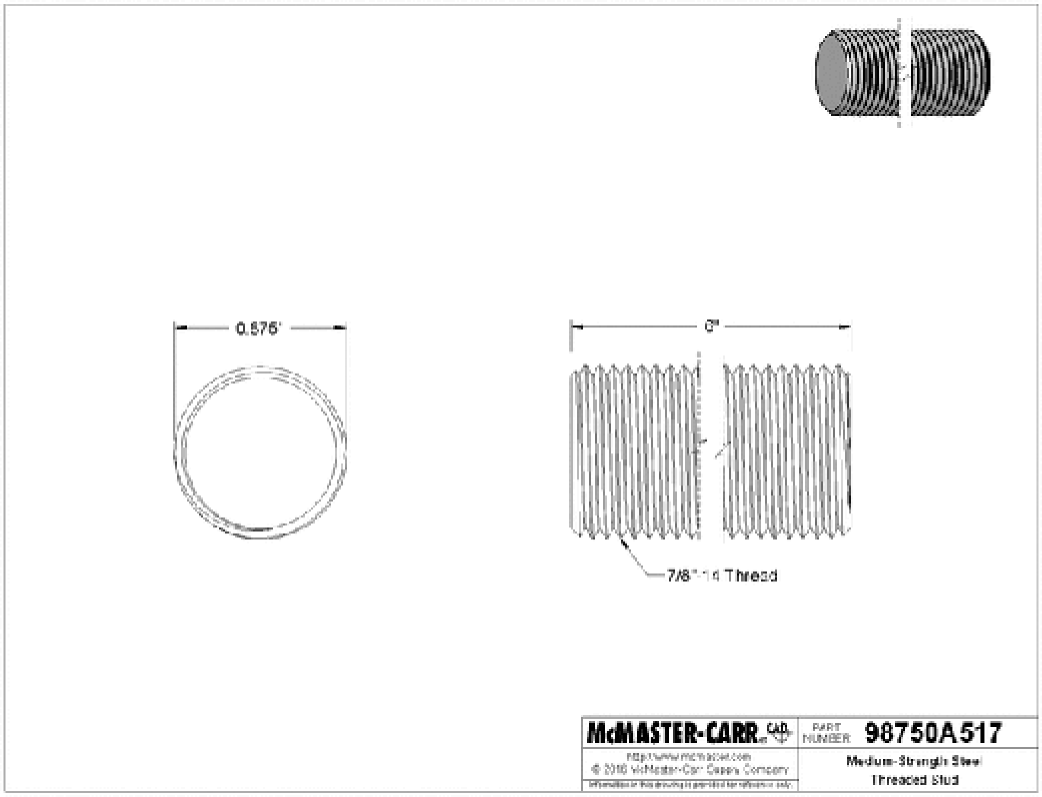


<u>ASSEMBLY OP</u>

THE CENTER HOLE AT Ⓜ WITH ⌖ ACCOUNTED FOR ACTS LIKE A HOLE WITH AN DIAMETER = 0.889"

.8738" + .0151" = 0.889"

SINCE THE SPACER IS GOING ON A PIPE WITH OD = .8556", THERE SHOULD BE NO INTERFERENCE



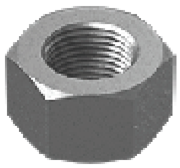
The information in this 3-D model is provided for reference only.

McMASTER-CARR.

Low-Strength Steel Hex Nut

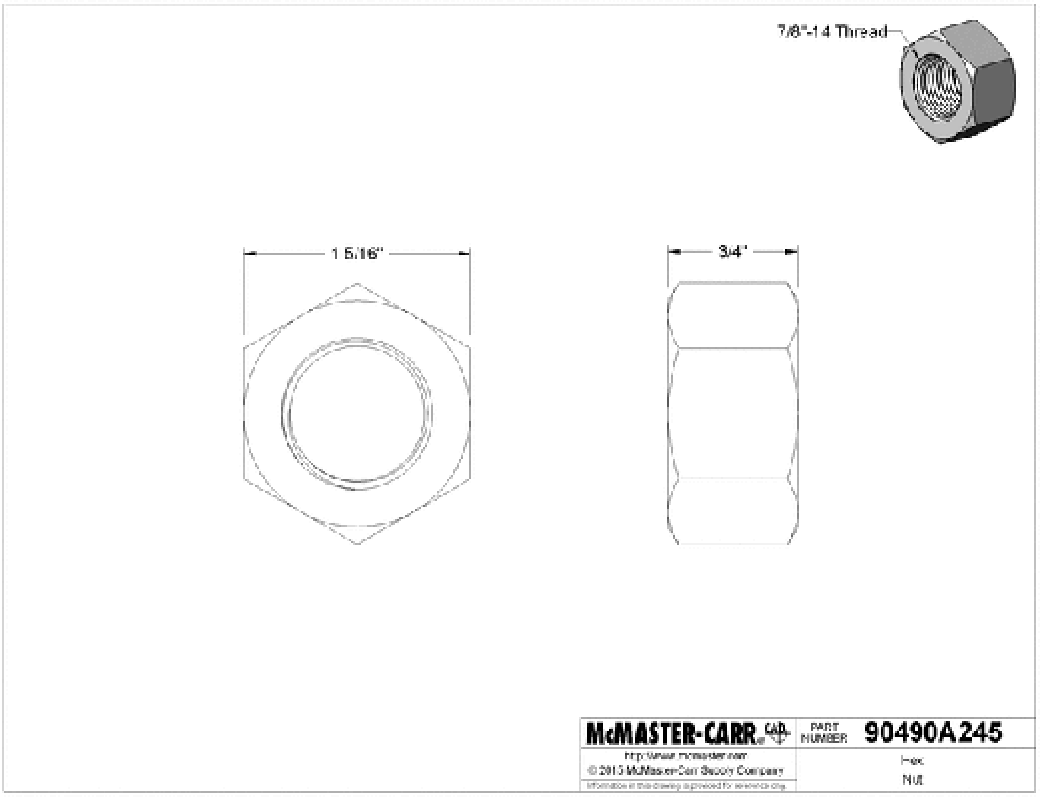
Grade 2, 7/8"-14 Thread Size

In stock
$6.83 per pack of 10
90490A245



Material	Steel
Fastener Strength Grade/Class	Grade 2
Thread Size	7/8"-14
Thread Type	UNF
Thread Spacing	Fine
Thread Fit	Class 2B
Thread Direction	Right Hand
Width	1 5/16"
Height	3/4"
Drive Style	External Hex
Nut Type	Hex
Hex Nut Profile	Standard
System of Measurement	Inch
RoHS	Compliant

About half the strength of medium-strength steel nuts, these nuts are for light duty fastening applications, such as securing access panels.



The information in this 3-D model is provided for reference only.

Home / Hardware / Fasteners / Washer Fasteners / Flat Washers

Model # 43760 Internet #204775342

The Hillman Group

7/8 in. Stainless Steel Flat Washer (6-Pack)

★★★★★ (1) Write a Review Questions & Answers (4)

$7.29 /package

Quantity - 1 +

Not In Your Store - We'll Ship It There

Add to Cart

We'll send it to San Luis Obispo for free pickup

Available for pickup
June 9 - June 14

Check Nearby Stores

We'll Ship It to You

Add to Cart

Free Shipping on $45 order

Get it by
June 12

See Shipping Options

Or buy now with

We're unable to ship this item to:
AK, GU, HI, PR, VI

Easy returns in store and online
Learn about our return policy

Product Overview

Flat washers are used in applications with nuts and bolts. The flat washer provides a greater bearing surface which helps prevent a nut or bolt head from tearing through the material. The called out size is the inner diameter of the washer.

- Commonly used in decks and fence building
- Can also be used as a spacer
- Stainless steel material
- Available in various materials and finishes

Specifications

Dimensions

Inside Diameter	0.875	Product Height (in.)	1.6
Outside diameter (in.)	2.030	Product Width (in.)	2.6
Product Depth (in.)	2.4	Washer Size	7/8 in

Details

Fastener Plating	Stainless Steel	Package Quantity	6
Fastener Type	Flat Washer	Product Weight (lb.)	0.420lb
Finish Family	Stainless Steel	Returnable	90-Day
Material	Stainless Steel		

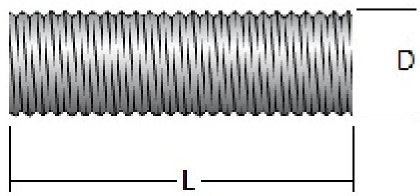
Warranty / Certifications

Manufacturer Warranty	N/A

How can we improve our product information? Provide feedback.

Threaded Rod, ASTM A193/A193M and ASME SA193/SA193M, B7, Plain

The information below lists the required dimensional, chemical and physical characteristics of the products in this purchase order. If the order received does not meet these requirements, it may result in a supplier corrective action request, which could jeopardize your status as an approved vendor. Unless otherwise specified, all referenced consensus standards must be adhered to in their entirety.



Diameter	Nominal Size	D (Major Diameter)	
		Max.	Min.
10-24 *	.1900	.1890	.1818
10-32 *	.1900	.1891	.1831
1/4-20	.2500	.2489	.2367
1/4-28	.2500	.2490	.2392
5/16-18	.3125	.3113	.2982
5/16-24	.3125	.3114	.3006
3/8-16	.3750	.3737	.3595
3/8-24	.3750	.3739	.3631
7/16-14	.4375	.4361	.4206
7/16-20	.4375	.4362	.4240
1/2-13	.5000	.4985	.4822
1/2-20	.5000	.4987	.4865
9/16-12	.5625	.5609	.5437
9/16-18	.5625	.5611	.5480
5/8-11	.6250	.6233	.6051
5/8-18	.6250	.6236	.6105
3/4-10	.7500	.7482	.7288
3/4-16	.7500	.7485	.7343
7/8-9	.8750	.8731	.8523
7/8-14	.8750	.8734	.8579

Diameter	Nominal Size	D (Major Diameter)	
		Max.	Min.
1-8	1.000	.9980	.9755
1-14 *	1.000	.9984	.9881
1 1/8-7	1.125	1.1228	1.0982
1 1/8-8 *	1.125	1.1229	1.1079
1 1/8-12	1.125	1.1232	1.1060
1 1/4-7	1.250	1.2478	1.2232
1 1/4-8 *	1.250	1.2479	1.2329
1 1/4-12	1.250	1.2482	1.2310
1 3/8-6	1.375	1.3726	1.3453
1 3/8-8 *	1.375	1.3728	1.3578
1 3/8-12	1.375	1.3731	1.3559
1 1/2-6	1.500	1.4976	1.4703
1 1/2-8 *	1.500	1.4978	1.4828
1 1/2-12	1.500	1.4981	1.4809
1 5/8-8 *	1.625	1.6228	1.6078
1 5/8-12	1.625	1.6232	1.6118
1 3/4-5	1.750	1.7473	1.7165
1 3/4-8 *	1.750	1.7477	1.7327
1 3/4-12	1.750	1.7482	1.7368
1 7/8-8 *	1.875	1.8727	1.8577
2-4.5	2.000	1.9971	1.9641
2-8 *	2.000	1.9977	1.9827
2-12	2.000	1.9982	1.9868
2 1/4-8 *	2.250	2.2476	2.2326
2 1/2-8 *	2.500	2.4976	2.4826

Length	Tolerance
3'	+/- 1/4"
6' - 12'	+/- 1/2"

Length shall be measured form end to end

Specification Requirements:

- Dimensions: ASME B18.31.3
- Material & Mechanical Properties: ASTM A193/A193M and ASME SA193/SA193M, B7
- Thread Requirements: Roll threaded to ASME B1.1 UNC, UNF, 8UN and UNS Class 2A
- Finish: Light Protective Oil
- Product Marking: Marked with predetermined color on rod end. Vendor to supply color code with the MTR and purchase order.
- Material Test Reports: The MTR must have documented lot traceability, dimensional results, full chemical test results and full mechanical test results to the specification(s) above. In addition, the MTR shall be in full compliance with Fastenal's MTR Requirements.

Manufacturing Process: Rubber Seal

Overview:

The following procedural guidelines should be used to facilitate the manufacturing of the rubber seals used in Project Water's Labyrinth Seal Design. It is of much importance to following these instructions strictly to ensure that the rubber seals are manufactured to their necessary tolerances to ensure the function of the SlapShot pump.

Material/Equipment List:

- **1 – Bicycle Inner tube**
- **1 – 3/4" Pipe, 2" long**
- **1 – 2" Pipe, 1 1/2" long**
- **Steel plate at least 1/4" thick**
- **1" Drill bit**
- **Welding equipment***
- **Drill press / Mill**
- **Punch / Hammer**
- **Compass**
- **Ruler / Calipers**

***Welding process choice at operator's discretion.**

Manufacturing Procedure:

1. Manufacturing Punch

1.1 **Turn down OD of 2" Pipe.** Grab OD of pipe in lathe 3 jaw chuck. Set spindle speed between 225 - 400RPM. Chafer OD of pipe at 45 degrees. The pipe should now have a sharp edge with diameter equal to the ID of the pipe.

1.2 **Turn down OD of 3/4"Pipe.** Repeat same steps as described in step 1.1, but spindle speed should now be between 650 - 1100RPM.

1.3 **Mark steel plate.** Use a punch and hammer to mark the center of the seal punch on the steel plate. With the calipers, set the compass to a radius of 1.1875". Mark the OD of the punch using the compass centered on the marked center.

1.4 **Drill 1" hole in steel plate.** Using a drill press or mill, drill out the marked center on the steel plate using the 1" drill bit.

1.5 **Welding pipes to steel plate.** First weld 2" pipe to steel plate, using marked OD to align correctly. With the open end of the punch laying on a flat surface, insert 3/4" pipe thru the 1" drilled hole. Weld 3/4" pipe to steel plate, insuring that the both the 2" pipe and 3/4" pipe remain on the flat surface.

2. Cutting inner tubes and punching out seal

2.1 **Prepare inner tube.** Cut inner tube longitudinally and cut off valve. Clean out anything that may be inside tube.

2.2 **Punch seal.** Lay inner tube out flat on a hard surface. Place punch on top of inner tube. Use hammer to hit top of seal punch. Repeat hammering process until the punch cuts through the inner tube.

Thick-Wall Steel Seamless Pipe Nipple

Threaded on Both Ends, 2 Pipe Size, 4" Long

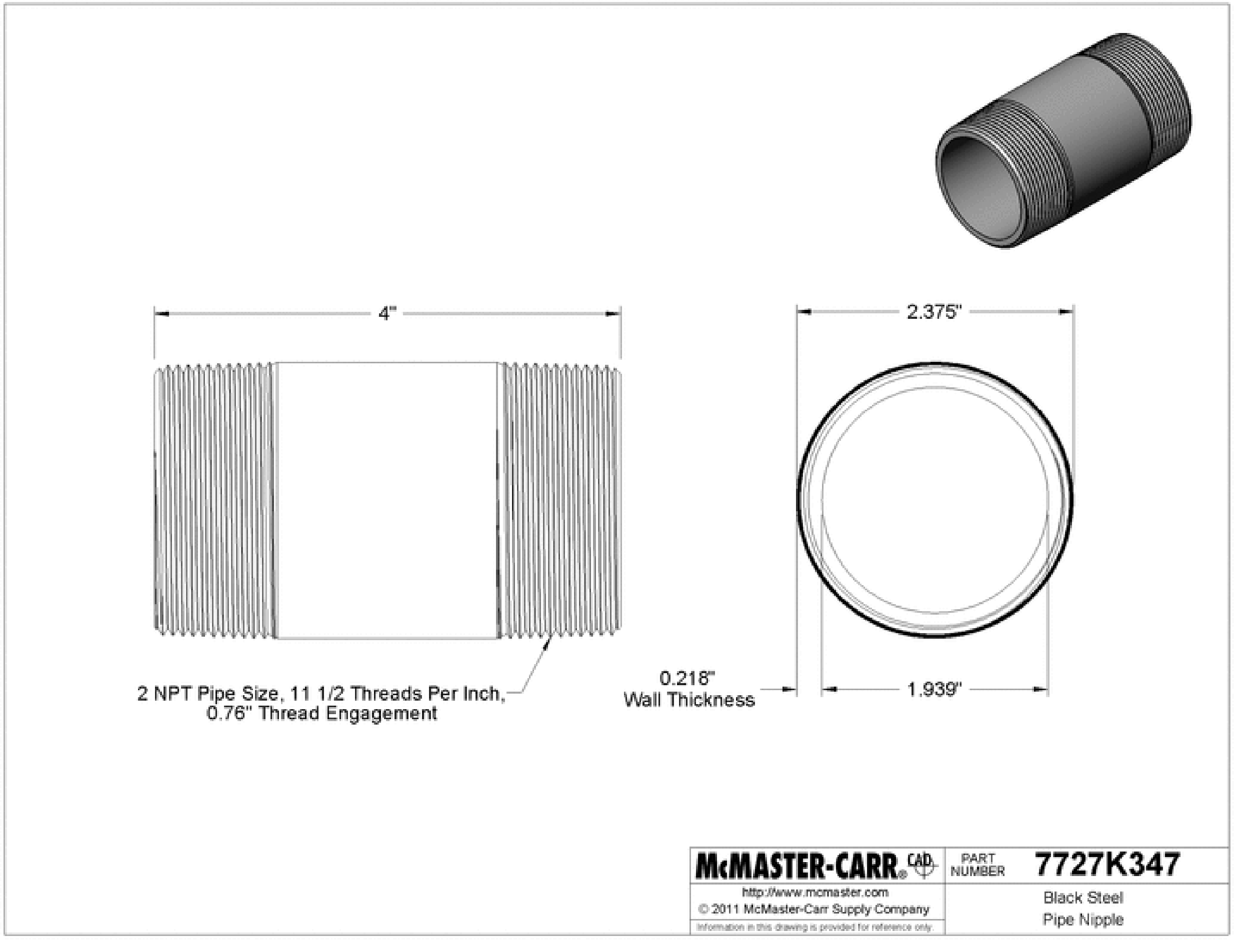
Each

ADD TO ORDER

In stock
$8.08 Each
7727K347

For Use With	Air, Natural Gas, Oil, Steam, Water
Shape	Straight
Type	Pipe
Schedule	80
Threading	Threaded on Both Ends
Connection Type	Pipe
Pipe Connection Type	Threaded
Gender	Male
Pipe Size	2
Length	4"
Thread Type	NPT
Construction	Seamless
Color	Black
Material	Steel
For Fitting	
Material	Iron
Class	300
For Flange	
Class	300
Material	Steel
Specifications Met	ANSI/ASME B1.20.1, ASTM A106, ASTM A53, ASTM A733
RoHS	Compliant

Also known as Schedule 80 pipe, this pipe has the strength to handle medium-pressure applications. Seamless pipe has a smooth interior for unrestricted flow and is stronger than welded pipe.


4"
2.375"
2 NPT Pipe Size, 11 1/2 Threads Per Inch,
0.76" Thread Engagement
0.218"
Wall Thickness
1.939"
McMASTER-CARR
CAD
PART NUMBER
7727K347
http://www.mcmaster.com
© 2011 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
Black Steel
Pipe Nipple

McMASTER-CARR.

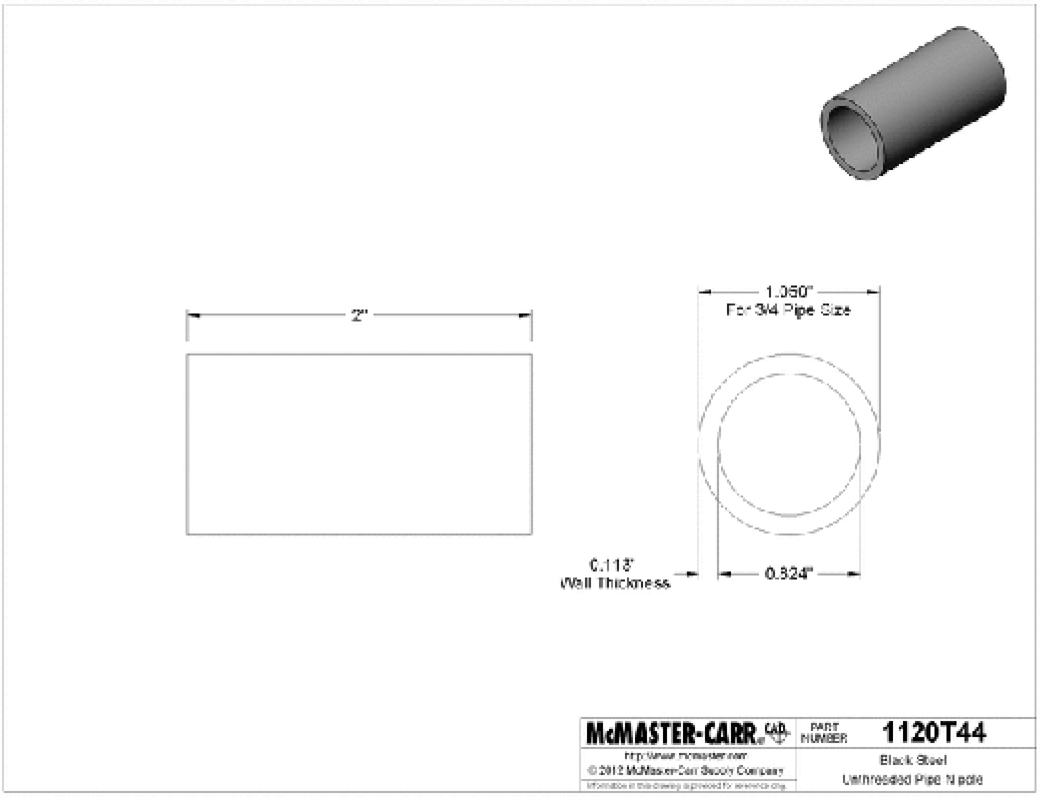
Standard-Wall Steel Unthreaded Pipe Nipple

3/4 Pipe Size, 2" Long

In stock
$2.77 Each
1120T44

For Use With	Air, Natural Gas, Oil, Steam, Water
Shape	Straight
Type	Pipe
Schedule	40
Threading	Unthreaded
Connection Type	Pipe
Pipe Connection Type	Butt Weld, Socket Connect
Gender	Male
Pipe Size	3/4
Length	2"
Material	Steel
Construction	Welded
For Fitting	
Material	Steel
Schedule	40
For Flange	
Material	Steel
Class	150
Specifications Met	ASTM A733
RoHS	Compliant

This pipe is unthreaded for welded connections, which are stronger than threaded connections and less likely to leak. It is also known as Schedule 40 pipe. It is welded, so there is a weld bead on the insde. Use in noncorrosive environments.



The information in this 3-D model is provided for reference only.

WEIGHT — PIPE

Schedule Number	Tolerance Allowable deviation from theoretical weight
5 and 10	For schedule 5 and 10, only diameter, wall thickness, and length tolerances apply.
20 and greater	+8%

[1] Mean diameter is the average of any two diameter measurements taken at right angles to each other at any point along the length.

[2] Maximum wall thickness is controlled by weight tolerance

[3] For schedule 5 and 10, only diameter, wall thickness, and length tolerances apply.

[4] Minimum weight is controlled by tolerances for outside diameter and wall thickness.

LENGTH — PIPE

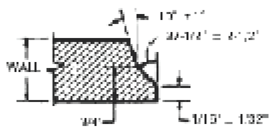
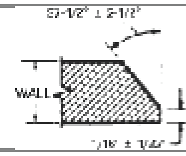
Specified length Ft	Tolerance, Inches plus Allowable deviation from theoretical length
Up thru 20	1/4
Over 20 thru 40	1/2

STRAIGHTNESS — PIPE

Pipe size Inches	Tolerance[5], Inches Allowable deviation from straight  D (max) In total length or in any measured segment of one ft. or more of total length
Under 6	.010 x measured length, ft.
6 thru 12	.020 x measured length, ft.

CHICAGO TUBE & IRON

STANDARD WELDING BEVELS — PIPE

DOUBLE BEVEL For wall thickness over 0.750 in.	STRAIGHT BEVEL For wall thickness 0.750 in. and less
	

When weight of pipe on flat surface minimizes deviation.

CORPORATE OFFICE

One Chicago Tube Drive , Romeoville, IL 60446

Appendix H: Molded Seal Manufacturing

Manufacturing Process: Molded Seal

Overview:

The following procedural guidelines should be used to facilitate the manufacturing of Project Water's Molded Seal Design. It is of much importance to following these instructions strictly to ensure that the Molded Seal Design is manufactured to the necessary tolerances to ensure the function of the SlapShot pump.

Material/Equipment List:

- **1 – Bushing Adapter with Hex, 2 Socket Male x 3/4 Socket Female**
- **2 – 18-8 washers, for 7/8" rod, OD 2.0", ID 0.938'**
- **2 – 7/8"-14 hex nuts**
- **1 – 7/8"-14 threaded rod, 6" long**
- **1 – 2" Diameter Schedule 40 PVC, 2.5" long sections**
- **1 – 1.5" Diameter Schedule 40 PVC, 2.5" long sections**
- **1 – 2.25' Diameter Schedule 40 PVC, 2.5" long sections**
- **1 – toaster oven**
- **1 – metal pot**
- **1kg of LDPE**
- **1kg of silicon**

Manufacturing Procedure:

1. Creating the Mold

1.1 **Threading the rod.** Hold the threaded rod in a vertical position. Thread one hex nut about 5 inches down the threaded rod. Place one washer on top of the hex nut.

1.2 **Placing the PVC.** Place the PVC hex bushing adapter on top of the washer with the hex side touching the washer. Rest the 2.25" PVC fitting on the hex lip of the bushing. Place the 1.5" PVC fitting inside of the 2.25" one. It should rest on top of the bushing. Continue on with the LDPE Spacer procedure.

1.3 **Changing from Spacer Mold to Seal Mold.** After pouring the LDPE for the spacer, remove the 1.5" PVC fitting. Replace it with the 2" PVC fitting, and then continue with the Silicon Seal procedure

2. Making the LDPE Spacer

2.1 **Melting the LDPE.** Turn on the toaster oven to 350 F. Place the LDPE in a metal pot and put it into the toaster oven. Wait for the LDPE to melt completely, and then remove the pot from the toaster oven.

2.2 **Pouring the LDPE.** Immediately after removing the LDPE from the oven, pour it into the mold. The final height should be about 1/4". Place the second washer on top of the melted LDPE and then thread the second hex nut onto the top of the rod, torqueing down the LDPE. Once the spacer has cooled, remove the nut and washer.

2.3 **Changing the Mold.** See step 1.3.

3. Making the Silicon Seal

3.1 **Setting the Silicon.** Mold the silicon over the LDPE spacer. Place the second washer on top of the silicon and then thread the second hex nut onto the top of the rod, torqueing down the silicon.

3.2 **Removing the Mold.** Once the silicon has set, remove the hex nut and washer. Remove the 2" and 2.25" PVC fittings. Unscrew the hex nut from the bottom and remove the washer. Slide the PVC bushing off the threaded rod and then remove the spacer and seal from the threaded rod.

Appendix I: Static Testing Procedure

Test Procedure: Hydrostatic Leak Test

Overview:

The following procedural guidelines is for the functional testing of pump cylinder seals. Specifically seals that can be fitted to the "Slap Shot" pump cylinder. To properly operate this testing system and for the user to remain safe, all steps and precautions are to be followed carefully.

System Description:

The tests described by this document can be applied to any pump seal design that is capable of being attached on to the recommend pump cylinder. The testing apparatus was designed so that the "Slap Shot" pump cylinder is easily attached to the static testing system. The test system is then filled with water, and pressurized with compressed air. The leakage can then be observed and leak rate can be calculated. The effectiveness of the seal can be evaluated from the results.

Test Procedure:

1. Preparation

1.1 **Create a data sheet.** Before conducting the hydrostatic leak test a data sheet should be prepared to document the results of the test. An example of a proper data sheet can be seen in Attachment 1.

1.2 **Locate a safe testing environment.** Since this testing device requires pressurizing the cylinder with compressed air, a clear, outdoor area is required to prevent any damage to the user or the surroundings. Also ensure there are no electronic appliances in the area in case of water being spilled. Make sure there is a drain or planter nearby to dispose of excess water.

1.3 **Wear safety glasses.** All users observing and operating the testing device should be wearing appropriate safety wear.

1.4 **Time each test run.** Have a device ready to time each trial during testing.

2. Apparatus Setup

2.1 **Attaching the pump cylinder.** With the desired seal design within the "SlapShot" pump cylinder, attach it to the test system via the threaded PVC coupling. Insure that the connection is secure.

2.2 **Collection container.** Place an empty container (i.e. bucket or tub) underneath the pump cylinder to collect the water that may leak during the test. Make sure to measure the volume of water within the container after each trial. Ideally the container would have markings on it to make measuring the volume of the water easier. If the container does not, make handmade markings on the container to show different volumes of water.

2.3 **Filling the system with water.** Close the valve to the pump cylinder. Connect a hose and open the valve on top to allow water to fill the tank. Turn on the water. Continue filling the tank until water shoots out of the air pressure nozzle. Turn off the water. Close the valve on top. Open the valve to the pump cylinder.

2.4 **Pressurizing the system.** Connect an air compressor to the inlet nipple on the top of the apparatus. Turn on the air compressor. Pressurize the cylinder to 20 psi. Turn off the air compressor. (Will repeat this step for 40, 60, and 80 psi).

3. Data Collection

3.1 **Timing the test run.** Once the system has been pressurized to the desired pressure, start timing. Continue timing until the flow of water out of the pump cylinder slows significantly, the collection container is full, or when five minutes is reached. Stop the timer when the first of these conditions is met. Record this time.

3.2 **Measuring the water.** When the timing is finished, remove the collection container from under the pump cylinder. Measure the volume of water by using the markings on the side of the container. Record this measurement.

3.3 **Interpreting the data.** Divide the volume of the water by the time to find the leak rate of the seal. Record this value.

4. Apparatus Breakdown

4.1 **Disconnecting the hose and compressor.** Ensure both the hose and air compressor are turned off. Disconnect the air compressor from the inlet nipple. Disconnect the hose.

4.2 **Disconnecting the pump cylinder.** Close the valve to the pump cylinder. Unscrew the cylinder from the testing apparatus. Dump the water in the pump cylinder into a nearby drain or planter.

4.3 **Emptying the water.** Open all the valves. Remove the part of the apparatus with the valves from its stand. Place it on the ground near a drain or planter to allow the water inside the pressure cylinder to drain. Once all the water is out of the system, place the part with the valves back on its stand.

Appendix J: Dynamic Testing Procedure

Test Procedure: Seal Failure Dynamic Test

Overview:

The following procedural guidelines is for the functional testing of pump cylinder seals. Specifically seals that can be fitted to the "Slap Shot" pump cylinder. To properly operate this testing system and for the user to remain safe, all steps and precautions are to be followed carefully.

System Description:

The tests described by this document can be applied to any pump seal design that is capable of being attached on to the recommend pump cylinder. The testing apparatus was designed so that the "Slap Shot" pump cylinder is easily attached to the dynamic testing system. The test system is then filled with water and turned on to simulate a normal pumping action. The device will then monitor the pressure and flowrate of the pump, turning off when either is at an unacceptable value. The effectiveness of the seal can be evaluated from the results.

Test Procedure:

1. Preparation

1.1 **Create a data sheet.** Before conducting the dynamic test a data sheet should be prepared to document the results of the test. An example of a proper data sheet can be seen in Attachment 1.

1.2 **Locate a safe testing environment.** Ensure there are no electronic appliances in the area in case of water being spilled. Make sure there is a drain or planter nearby to dispose of excess water.

1.3 **Wear safety glasses.** All users observing and operating the testing device should be wearing appropriate safety wear.

1.4 **Optional wear test.** If the technician plans on performing a wear test after the dynamic test, he/she should do a visual inspection of the interior of the pump cylinder walls. He/she should also use a bore gauge to measure the interior diameter of the cylinder wall at various points. Record the values and visual inspection notes.

2. Apparatus Setup

2.1 **Attaching the cylinder.** Connect the internal shaft of the pump cylinder to the actuator arm of the dynamic testing apparatus. Screw the pump cylinder onto the threaded PVC coupling on the dynamic testing device.

2.2 **Setting up the device.** Make sure the power switch is in the off position. Plug in the power chord into a 120V wall outlet. Close the valve on the sediment trap. Close the globe valve under the accumulation tank. Turn the pressure bypass switch to "on". Turn the flow bypass switch to "on". Make sure both outlets of the accumulation tank are over the 55-gallon collection drum.

2.3 **Filling the accumulation tank.** Use a hose to fill the accumulation tank until water flows out of the overflow pipe.

2.4 **Starting the system.** Ensure all previous steps have been followed. Turn on the power switch. Open the globe valve to a pre-determined flow rate. Monitor the water flow, making sure there are no leaks.

3. Data Collection

3.1 **Counting the cycles.** The device has failure switches that will automatically turn off the motor and stop the pumping action. This will also stop the counter on the side of the control panel. Once the testing system has stopped, read and record the number of hours. If the system has run for longer than the pre-determined minimum hour count, it can be turned off.

3.2 **Optional wear test.** If the pump ran for a long enough time, as determined by the technician, a wear test on the pump cylinder can be performed. A visual inspection as well as a bore gauge will be used to determine if there was excessive wear on the walls of the pump cylinder. Record the observations from the visual inspection as well as the bore gauge measurements.

4. Apparatus Breakdown

4.1 **Disconnecting from power.** Make sure the power switch is in the "off" position. Unplug the system from the wall outlet.

4.2 **Emptying the water from the system.** Make sure both outlets of the accumulation tank are over the 55-gallon drum. Open the globe valve all the way to drain the accumulation tank. Once the accumulation tank is completely empty, unscrew the pump cylinder from the PVC coupling. Dump the water out of the pump cylinder into the drum. Water will also be draining out of the system from where the cylinder was connected. Allow all the water to drain from the device. Once the water has stopped draining, move the drum under the sediment trap and open the valve to drain the trap.

4.3 **Disposing of the water.** If no more tests are to be performed, the water in the drum can be disposed of in a drain.

Appendix K: Testing Data Sheets

Attachment 1

Date	
Requested By	
Product Name	
Test Name	Static Testing

Testing Procedure

1. Refer to Static Testing Procedure document for proper preperation and apparatus setup.
2. Charge PVC cylinder to specified static pressure.
3. Open valve to subject seal to pressure from cylinder.
4. Determine leak rate by measuring amount of collected water during experiment.

Testing Data

	Static Pressure (PSI)		Leak Rate(Liters/min)		
Sample #	Target	Actual	Target	Actual	Notes
	20		<.56		
	40		<.56		
	60		<.56		
	80		<.56		
Sample #	Target	Actual	Target	Actual	Notes
	20		<.56		
	40		<.56		
	60		<.56		
	80		<.56		
Sample #	Target	Actual	Target	Actual	Notes
	20		<.56		
	40		<.56		
	60		<.56		
	80		<.56		
Sample #	Target	Actual	Target	Actual	Notes
	20		<.56		
	40		<.56		
	60		<.56		
	80		<.56		

Notes:

Technician:	
Completion Date:	

Attachment 1

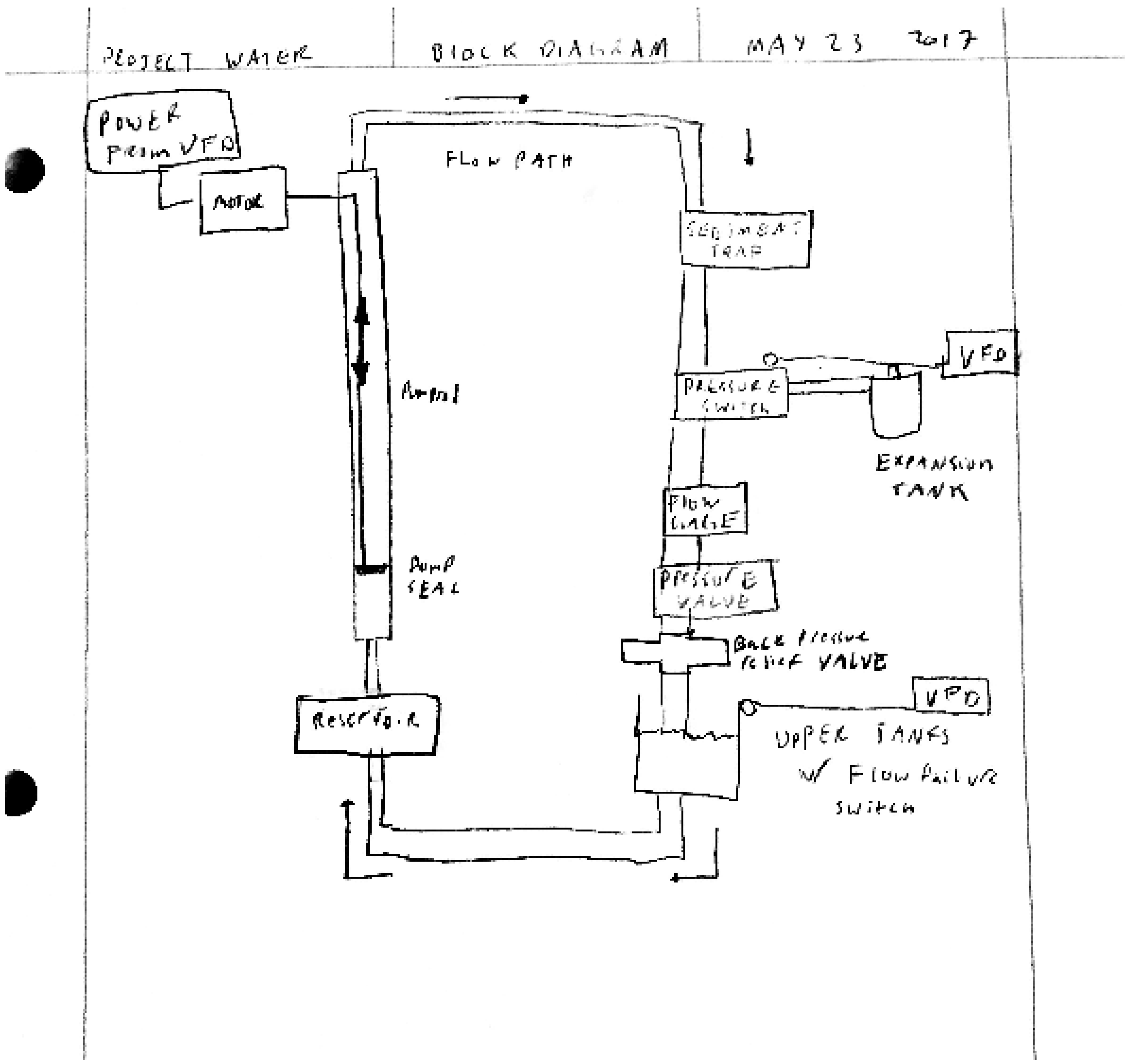
Date						
Requested By						
Product Name						
Test Name	Dynamic Testing					

Testing Procedure
1. Refer to the Dynamic Testing Procedure document for proper preperation and apparatus setup.
2. Set all parameters to failure values.
3. Start the system.
4. Record the number of cycles once the system has stopped.

Testing Data						
	Cycle Count (Hours)		Optional Wear (mm)			
Sample #	Target	Actual	Target	Before	After	Notes
	310		< 2.5 (radial)			
			< 2.5 (radial)			
			< 2.5 (radial)			
			< 2.5 (radial)			
Sample #	Target	Actual	Target	Before	After	Notes
	310		< 2.5 (radial)			
			< 2.5 (radial)			
			< 2.5 (radial)			
			< 2.5 (radial)			
Sample #	Target	Actual	Target	Before	After	Notes
	310		< 2.5 (radial)			
			< 2.5 (radial)			
			< 2.5 (radial)			
			< 2.5 (radial)			
Sample #	Target	Actual	Target	Before	After	Notes
	310		< 2.5 (radial)			
			< 2.5 (radial)			
			< 2.5 (radial)			
			< 2.5 (radial)			

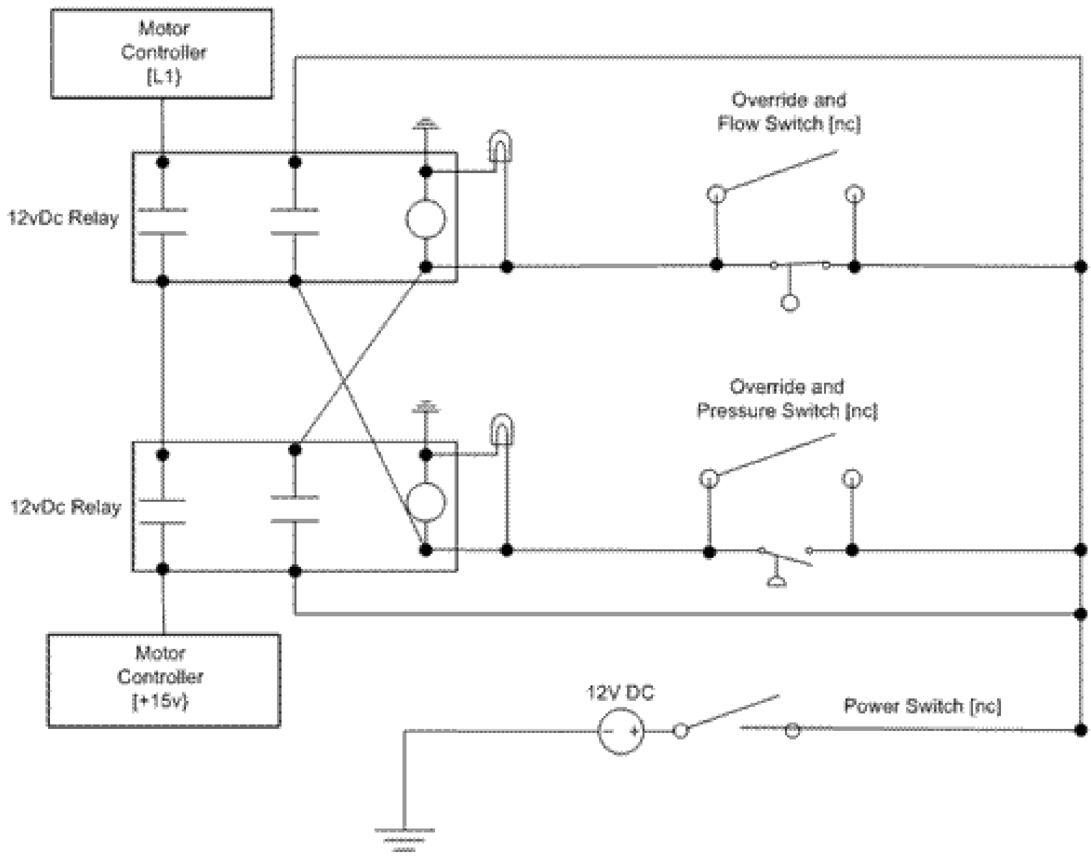
Notes:	
Technician:	
Completion Date:	

Appendix L: Dynamic Testing Apparatus Block Diagram



Appendix M: Dynamic Testing Apparatus Wiring Schematic

Circuit Diagram



Appendix N: Dynamic Testing Apparatus User Interface

Three switches, two lights, and a counter make up the user interface. The top switch and light refer to the pressure failure system. If there is not enough pressure at the head of the pump cylinder, the system will shut off and the pressure failure light will be illuminated. This failure system can be bypassed by turning the pressure bypass switch to the off (vertical) position. The on position is the one shown in the picture above. The third position, which is when the switch is turned all the way counter-clockwise, is not connected and will not be used.

The middle switch and light refer to the flow failure system. If there is not enough flow coming from the pump cylinder, the system will shut off and the flow failure light will be illuminated. This failure system can be bypassed by turning the flow bypass switch to the off (vertical) position. The on position is the one shown in the picture above. The third position, which is when the switch is turned all the way counter-clockwise, is not connected and will not be used.

The bottom switch is the power switch. The position shown in the photo is the off position. Turning the switch clockwise turns the system on. The third position, which is when the switch is turned all the way counter-clockwise, is not connected and will not be used.

The counter at the bottom of the panel counts how many hours the device was running for.