High Sierra Water Pumps

University of Nevada, Reno

Submitted to: Mechanical Engineering Dept. December 13, 2000

Final Report:
The Irrigator
Water Pump Prototype

<u>Team 1</u>

Principle Writer:

Team Leader: Bryan

Jen

Sara

Katie

David

Aaron

-Executive Summary-

Team 1 was presented with the challenge of designing the most effective water pump possible, while following a set of specifications presented by the division leaders of High Sierra Pumps (see table 1). The goals of Team 1 were met, if not exceeded. The Irrigator moved a total of 141 gallons of water in 15 minutes, with a flow measurement accuracy of 92%. Despite some difficulties in design and construction, Team 1 managed to make an effective and attractive water pump, while developing design and teamwork skills.

The Irrigator used a piston and cylinder design that utilizes both sides of the piston to move water. One-way check valves control the direction of the flow of water. A bicycle crank drives the piston shaft, and a steel rod that is connected to the piston shaft at one end, and connected to a bicycle pedal at the other end links the two. For more specific details such as drawings, materials, costs, and project management, please refer to the appendices.

Introduction:

Team 1's goal was to design a double-acting human-powered piston pump, according to the specifications given (Table 1). The pump is meant for irrigation use in third world countries.

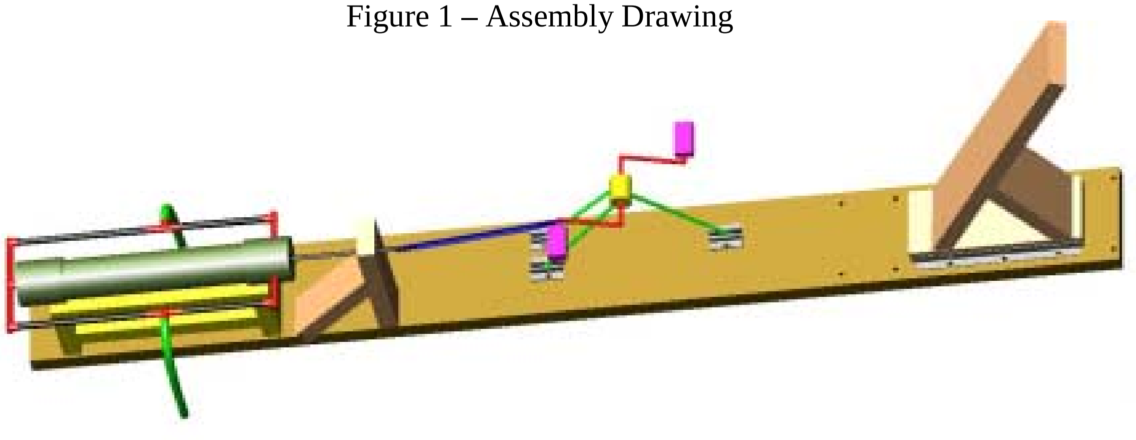
The Team 1 design, the Irrigator, is simply a pump, crank, and a chair attached to a baseboard. It is attractive, easy to assemble and use. The adjustable seat is located at one end of the baseboard, and the pump located at the other, while the crank is in between (Figure 1). The pump is designed to use lower body power to move the piston. A person's lower body can create more force and tires out much more slowly than the upper body. The Irrigator moved a total of 141 gallons of water in 15 minutes, with a flow measurement accuracy of 92%. All of this was done maintaining budget constraints with the highest quality.

CHARACTERISTICS	SPECIFICATIONS
Cost	Less than $150
Power	Human Power and/or 9V or AA Batteries
Assembly/Disassembly Time	15/10 Minutes
Kit Size	Minimize
Accomodations	3 Different People, 1 Female
Flow Rate	Maximize
Performance	Move Water 8 Feet High
Measurement Method	Accuracy of Measurement at Instantaneous Flow Rate

Table 1 -- Design Requirements

This report reviews the Irrigator project completely, including detailed design description, construction, testing, budget, and project management.

Figure 1 – Assembly Drawing



Prototype Description and Principles of Operation:

The overall system is based on the concept of a person sitting in the adjustable chair, applying force to the pedals which push the link and shaft, and water moving on both sides of the piston (See Appendix 1 for a Multiview Drawing).

The first sub-system is the baseboard and chair, which is relatively basic. The operator sits in the chair, which can be moved to adjust the distance between him or her and the pedals. The second sub-system is the crank and link. Pedals still attached to a bicycle crank are used to push the shaft. The link consists of two pieces of one inch flat bar welded into a T-shape for strength. The circular movement of the crank allows the force to be continuously applied to the link piece. The third sub-system is the pump itself (See Appendix 1 – Section A-A). The pump is elevated above the baseboard on a stand to a level equal with the pedals. This maximizes the force by allowing the operator to push directly on the piston. The pump uses oscillating movement to move water on both sides of the piston in the cylinder. The cylinder is four-inch PVC, where the size is based on Equation 1:

$$r = \sqrt{(f)/(p*\pi)} \qquad (1)$$

where r = radius, f = force on piston (50 lbs), p = pressure (3.47 psi) (Dally 81). The result is a radius of 2.14 inches. To prevent the force from exceeding 50 pounds, a two-inch radius is used. The piston is attached to a steel shaft (with one threaded end) using a piece of rubber squeezed between two circular pieces of steel with nuts to make an adjustable seal. The piston travels 13 inches. The design of the pump uses two one-way check valves on each side of the piston to create a directed flow. Each set of valves contains an "in" valve and an "out" valve. On the side opposite of the shaft, the check valves attach to a threaded T-fitting, and placed in the center of the cylinder. On the other side, the valves run 90° to the shaft, as close to the cap as possible. Refer to Appendix 1.

The materials used for the baseboard and chair were wood boards and angle iron. To construct the chair, we used 3/8" pins between the back, the brace, the strut, and the angle iron. The assembled chair was then lined up with holes that Dave Mrowiec drilled through the 14" piece of angle iron into the baseboard (see Appendix 2A), and four 3/8" pins hold it in place. The crank and link are made of a bicycle crank and pedals, one inch flat bar, and angle iron (see Appendix 2B). Two inch pieces of one inch angle iron were attached on opposite sides of the three support rods on the crank with ½" bolts (see Appendix 2C). The left pedal was then removed and the link was captured between the pedal axle and the crank. The pump is made out of PVC pipe, steel, rubber, and one-way check valves. The construction of the pump, including the end caps (see Appendix 2D and 2E), brass T's, and brass nipples, was done with silicon and Teflon tape. To construct the piston, a plumber's plug was attached to the threaded end of the shaft (see Appendix 1 Detail B). Packing material was placed in the depression of the shaft housing plug, a packing ring flange was attached with wing nuts (see Appendix 2F), and the shaft was put through a support bearing (see Appendix 2G) which was then bolted to the baseboard. The support bearing prevents the shaft from engaging in any unwanted motion. The end of the shaft and the link were also bolted together. PVC pipe glue and Teflon tape were used to attach PVC adapters, elbows, and check valves. Hose clamps were used to attach PVC T's and nine inch hose pieces. The pump stand is made out of leftover wood boards and is bolted to the baseboard with 3/8" bolts. Band clamps were wrapped around the pump and the stand to hold it in place. Finally, the complete pump was painted to make it appealing to the eye. Refer to Appendix 2H – 2L for photographs, Appendix 3 for detailed assembly instructions, and Appendix 4 for a complete parts list and an exploded-view drawing.

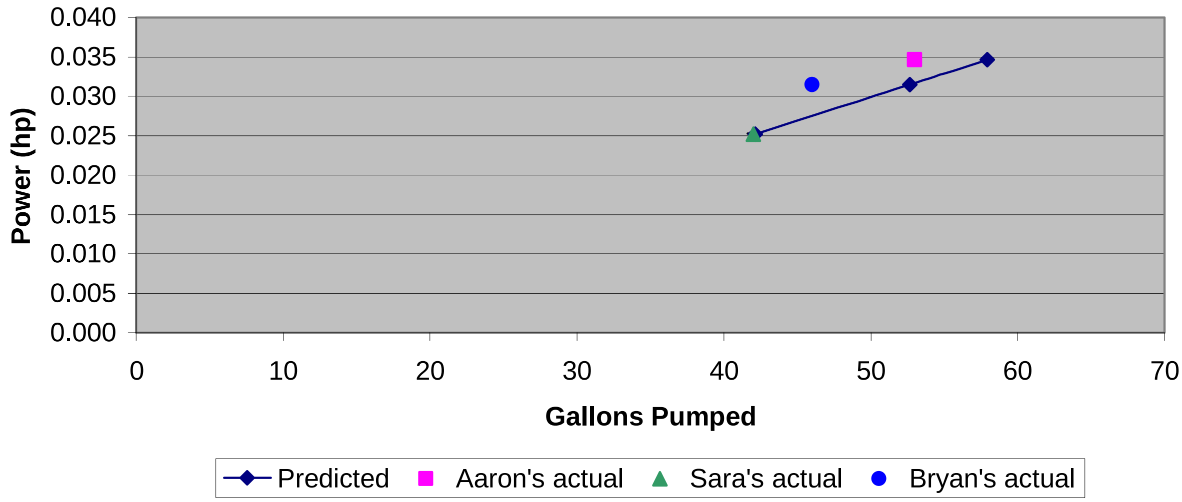
Testing and Analysis:

For the final testing, we were required to pump for 15 minutes. We recorded how much water was actually pumped every five minutes and how many strokes per minute each person completed. We compared these actual values to our predicted for that many strokes. We calculated our predicted flow by using a flow rate calibration, which is the amount of water pumped per stroke.

To get the flow rate calibration, we pumped for ten minutes, counting the number of strokes and recording how much was pumped for each minute (see Appendix 5A for data). The average gallons per stroke is 0.96.

The data from our final testing is represented in Figure 2 (see Appendix 5B for data).

Figure 2
Amount pumped



The line with the (dark blue) diamond shaped points represents the predicted amount assuming 70% efficiency (see Appendix 5C). The actual results are broken down as follows: the (green) triangle is Sara's actual, the (blue) circle is Bryan's actual, and the (pink) square is Aaron's actual amount pumped. Power was calculated using the average number of strokes each person did and Equation 1 in Appendix 5C. Notice that the power is twice that of the result given by the equation. This is because the equation is for a single-acting pump on the discharge stroke. The Irrigator is double acting so each full stroke is two strokes of a single-acting pump. As seen in the graph, Aaron and Bryan's actual vary quite a bit from the predicted.

The largest source of error was due to leakage. The seal around the shaft, as expected, leaked somewhat during the entire testing. Because Aaron was pumping quickly, the valves fluttered as the piston changed direction. This was another source of error due to leakage. This helps explain why an increase in power doesn't necessarily mean an equal increase in flow rate. This is seen in Figure 3 (see Appendix 5B for data). As power increases, the percent error in our

Figure 3
Error

flow measurements also increases. By far the largest was from the caps. When Bryan was pumping the caps on the cylinder came unglued. Luckily, they didn't completely come off. The inlet and outlet PVC piping held it together. It came unglued because we used silicon just in case we needed to take it apart and make adjustments. We should have used JB Weld. Even with sever leaking (about seven gallons), Bryan was still able to pump 46 gallons in his five minutes, and our percent error was still only 12.65% (See Appendix 5B).

Another source of error that accounts for some of the inconsistencies with Bryan's actual occurred from a siphoning effect. When we finished pumping and before we took the final reading, we took the outlet hose off the pump. Because of the difference in pressures, about five gallons was siphoned out of the barrel before we could stop it.

Some other sources of error include imprecise measuring and counting errors. The measurements on the barrels were only incremented by five gallons, so all of our measurements could be off by two or three gallons. In addition, some miscounting of the strokes may have occurred.

The Irrigator moves 0.96 gallons per stroke. It pumped 141 gallons in fifteen minutes. We predicted the Irrigator would pump 153 gallons based on the number of strokes completed. Our flow measurement was fairly accurate with a percent error of only eight percent. The average flow rate was 9.4 gallons per minute (see Appendix 5D). The Irrigator pumped with an efficiency of about 65 % (see Appendix 5B) even while it was leaking.

Project Management:

Team 1's budget was a close call. Creating the Irrigator cost $144.03, leaving $5.97 for emergencies (see Appendix 4 for parts list). As seen in Figure 4, approximately 51% of the budget was spent on the pump. This can be blamed on the high prices of the PVC and caps, and expensive check valves. Another large expense was the miscellaneous items such as fasteners and paint.

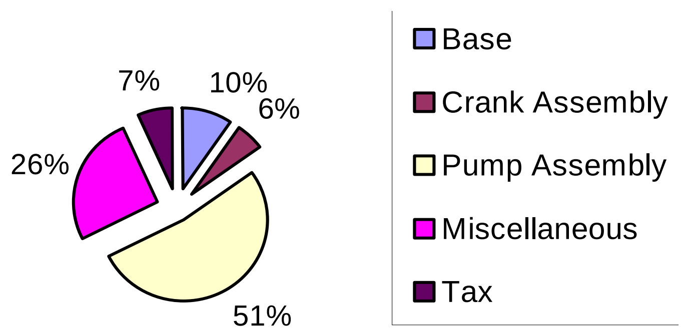


Figure 4 - Budget

Teamwork in Team 1 was amazing. There were practically no problems among team members, and everyone contributed their knowledge and skills to the team. Much of Team 1's success was a result of the team meetings. At the beginning of the year, Team 1 met very often and spent a lot of time preparing to work instead of working. As the semester progressed, meetings lost some importance, and e-mail became very vital. This enabled us to divide up the work among the group without having to meet. We held one or two meetings to put together everything we had worked on. See Appendix 6 for the development schedule we followed.

Team Member Responsibilities:

Bryan: Team leader, drafting, project management

Aaron: Concept Design, Construction

Jen Design Description, Artist

Sara: PowerPoint, Equations, and Treasurer

Katie: Equations, Quality Control, and PowerPoint

Dave: Construction, Welding, and Parts List

Summary and Recommendations:

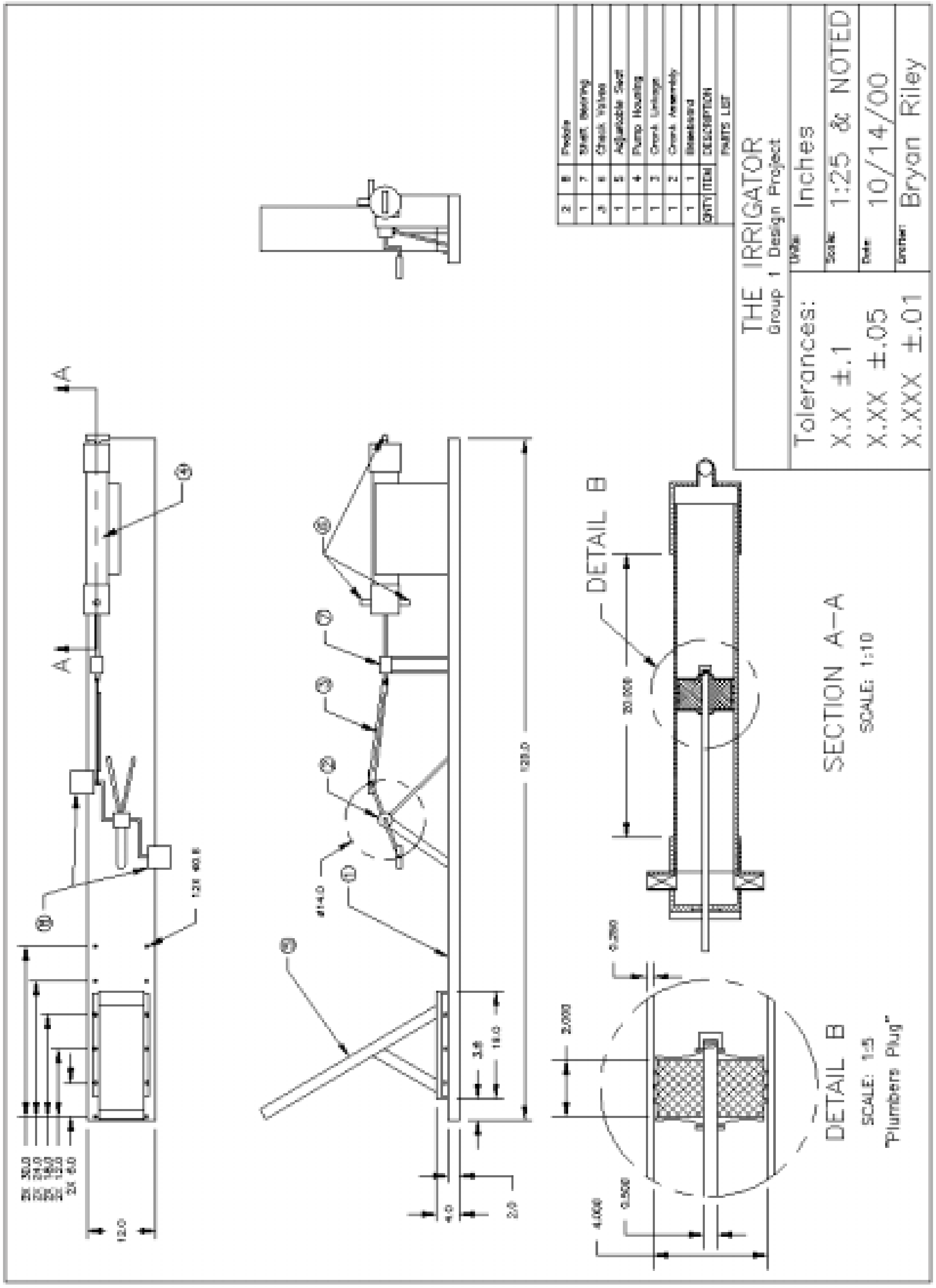
Team 1 feels that the Irrigator is a complete success. The Irrigator meets all of the design specifications and pumps a lot of water. Some key features of the Irrigator are the dual-acting design, the rotating drive, is self-priming, and the Irrigator also sports a coat of painted flames. Advantages to having a pump like the Irrigator include: ease of use, ease of construction, and the overall effectiveness of the pump itself. Some disadvantages to the Irrigator include: a seal around the piston shaft, the pump is expensive to build, bulky, and difficult to move.

Team 1 experienced a few difficulties in the use of the Irrigator. The irrigator leaked through the seal around the shaft and around the cylinder caps. The pump stand was unsteady and moved with the motion of the piston during use. Since we used corrosive materials, the piston shaft and plumbers plug components began to rust. Sara found the seat to be extremely uncomfortable. In addition, the check valves were not completely vertical, so they fluttered when excessive force was applied to the pump.

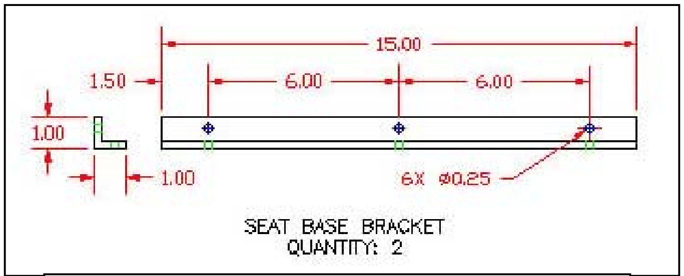
We have several recommendations for anyone who would like to build a pump similar to the Irrigator. First, non-corrosive materials should be used to eliminate rusting. Instead of silicon, the cylinder caps should be attached using J.B. Weld or PVC glue. The seat should be padded for more comfort and the pump base should be reinforced to eliminate unwanted motion. There should be handles on the baseboard to make the Irrigator easier to transport. The check valves should be vertical to reduce fluttering.

Bibliography:

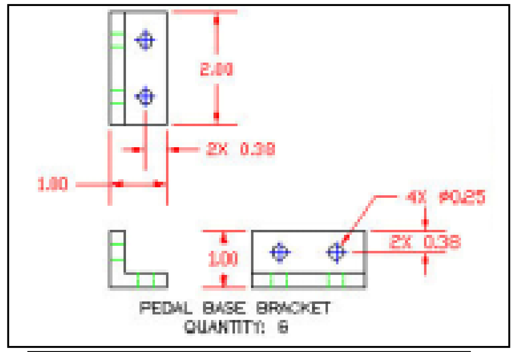
Dally, James W. Introduction to Engineering Design: Human Powered Pumping Systems. Book 4. College House Enterprises, LLC., Knoxville, Tennessee, 1999.



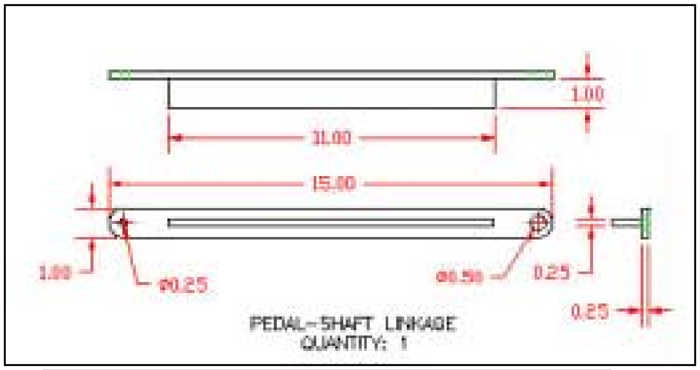
Appendix 1 – Drafting



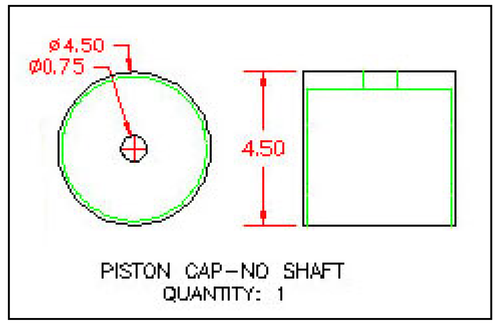
Appendix 2A – Seat Base Bracket



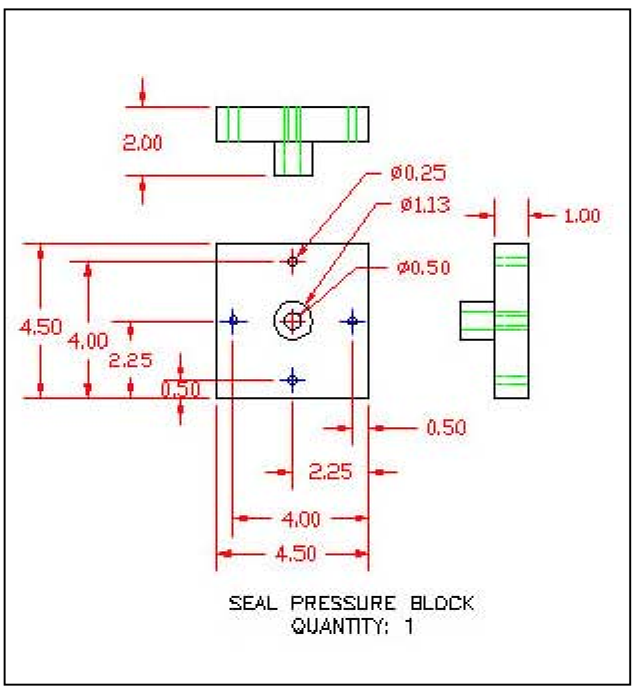
Appendix 2C – Pedal Base



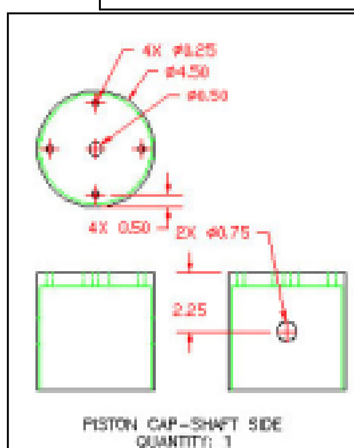
Appendix 2B – Pedal –Shaft Link



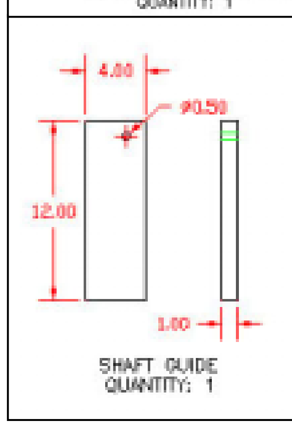
Appendix 2D – Piston Cap



Appendix 2F – Packing Ring Flange



Appendix 2E – Piston Cap – Shaft Side



Appendix 2G – Shaft guide

Appendix 2 – Details and Pictures

Appendix 2H - Crank

Appendix 2I – Crank and Link

Appendix 2J – Shaft Seal

Appendix 2K – Flow!!

Appendix 2L – Flames!!

Appendix 2 – Details and Pictures

Assembly Instructions

Chair Assembly:
Use 3/8” bolts: First, bolt strut (3) to back (5). Then bolt the back (5) to the brace (2). Finish the connection by bolting the strut (3) to the brace (2). Next, bolt the angle iron (4) to the appropriate places on the brace (2). The assembled chair can then be lined up with appropriate predrilled holes in baseboard (1) and kept in place with four 3/8” pins (cut off bolts).

Pump Stand:
Use 3/8” bolts: Construct pump stand (11) before attaching onto baseboard (1). Attach to the baseboard (1) using 4 bolts.

Shaft Support:
Use 3/8” bolts: Construct shaft support (10) before attaching onto baseboard. Attach to the baseboard (1) using 4 bolts.

Piston:
Slide Plumbers’ plug (25) onto the threaded end of the piston shaft (24) and tighten.

Pump Housing:
Use silicon*: First, attach the end housing cap (23) to the pump housing (22). Then, screw a brass nipple (16) into the end housing cap (23).

Shaft Housing Cap:
Use silicon*: screw two brass nipples (16) to shaft housing cap (15). Make sure nipples are 180° from each other.

Bicycle Crank:
Use ½” bolts with washers and nuts: bolt 2 angle iron pieces (6) to each of 3 support rods on crank (8), drilling holes if necessary. Then bolt the angle iron (6) to baseboard (1).

Attaching Pump to Piston Shaft:
Lubricate the piston head with O-ring lubricant, then insert the assembled piston and shaft (24+25) into the open end of the pump housing (22). Next, place the assembled shaft housing cap (15) over the shaft and secure the shaft housing cap (15) to the pump housing (22) using silicon*.

Pump Seal:
First, place packing material (26) into the depression in the shaft housing cap (15). Then, place the packing ring flange (13) onto the shaft and attach to shaft housing cap (15) with ¼” bolts (14), wing nuts (12), and washers (21).

Attaching Piston Shaft to Drive Link:
Slide unassembled shaft end (24) through the shaft support (10). Using one ¼” bolt with washers and nuts, attach the end of the shaft (24) to one end of the drive link (9).

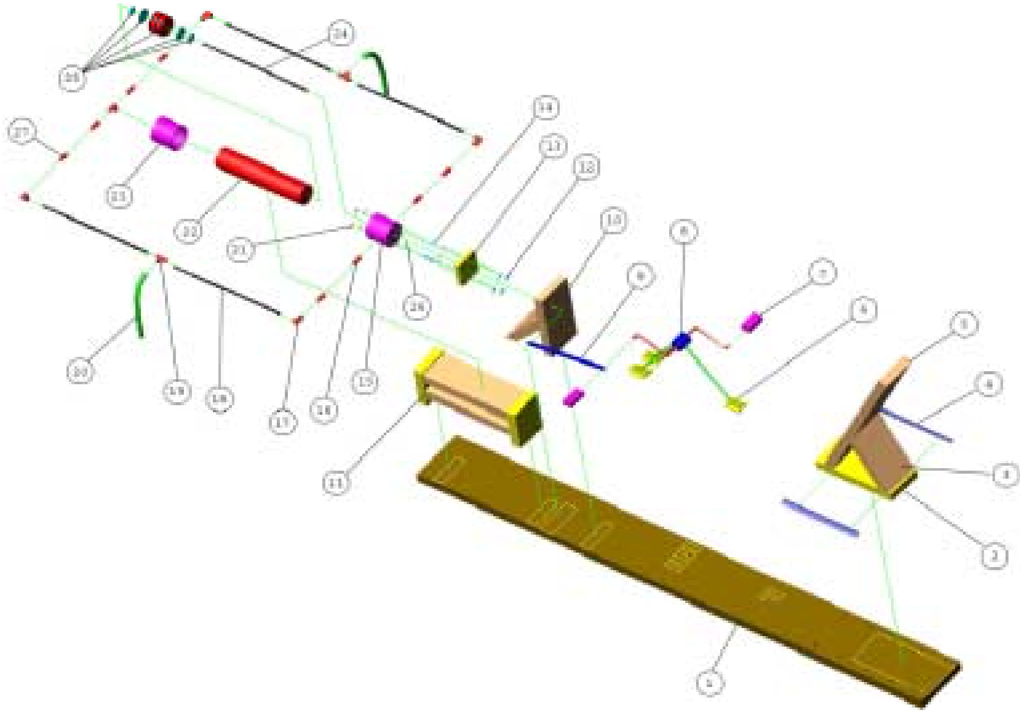
Attaching Drive Link to Bicycle Crank:
Remove one pedal (7) from the bicycle crank (8) and insert the drive link (9) between the pedal axle and the bicycle crank (8) and tighten pedal.

Attaching Pump to Pump Stand:
First, line up pump housing (22) so that the pump is in-line with the Drive link (9). Then, wrap two band clamps (29) around pump and assembled pump stand and tighten.

Inlet-Outlet Plumbing:
Use Teflon tape: First, attach a T-fitting (19) to the nipple on the end housing cap (23), and attach two more brass nipples (16) onto the T-fitting (19). Next, attach all four check valves (27) to the brass nipples (16) so that the “in” check valves are on the same side and the “out” check valves are on the same side. Then, attach ¾” elbows (17) onto the check valves (27), and attach PVC adapters (32) onto the ends of the elbows (17). Using PVC pipe glue, put together the intake and outlet hose assemblies by connecting two lengths of PVC pipe (18) with a T-fitting (19) in the middle.

Hose Assembly:
Use PVC pipe glue to attach the ¾” to 1” hose adapters (31) onto the PVC T (19). Then, use 1” hose clamps (41) to attach the two hoses (20) to the hose adapters (31).

*Note- When the prototype was built, the team anticipated the possible need for changes in the system. To facilitate this the pump was assembled using silicon. Final assembly should use J.B. weld for all nipples and end cap attachments. The cost of additional J.B. weld is offset by the cost of the unused silicon.



			Team 1 Parts List				
Part#	Skue#	Part Name	Description	Dealer or Loc.	Quan	Unit Price	Total
1	73291332105	Baseboard	2"x12"x10'	Home Depot	1	$ 9.24	$ 9.24
	73291328085	Chair:	2"x8"x8'	Home Depot	1	$ 4.65	$ 4.65
2		Brace	2"x8"x18"		1		$ -
3		Strut	2"x8"x30"		1		$ -
4		Angle Iron	4'x1"	Home Depot	1	$ 2.95	$ 2.95
5		Back	2"x8"X40"		1		$ -
7	n/a	Bicycle Pedals	From Bicycle		1		$ -
8	n/a	Crank	From Bicycle	Garage Sale	1	$ 5.00	$ 5.00
9		Link	FlatBar 1"x14"x.6"	Home Depot	1	$ 2.98	$ 2.98
10	n/a	shaft guide	leftover from pump stand				
11	73291326081	Pump Stand	2"x6"x8'	Home Depot	1	$ 2.98	$ 2.98
13	n/a(scrap)	Packing Ring Flange	3"o.d.,7/8"I.d.	Made by Hand	1		$ -
15	IEZC113079	Shaft Housing Cap	4"x Schd.40	W. Nev.Supply	1	$ 7.09	$ 7.09
16	PFB1212020	Brass Nipple	.75" dia.	W. Nev.Supply	5	$ 1.00	$ 5.00
17	38561354072	PVC Elbow	.75"	Home Depot	4	$ 0.37	$ 1.48
18	52381038218	PVC Pipe	.75"x6'	Home Depot	1	$ 6.68	$ 6.68
19	PFB1128390	Brass T	.75" dia.	W. Nev.Supply	1	$ 3.16	$ 3.16
20		Utility Hose	1"x25'	Home Depot	1	$ 5.95	$ 5.95
22	PEZC000145	Pump Housing	PVC #40 4"x2'	W. Nev.Supply	1	$ 10.66	$ 10.66
23	IEZC113686	End Housing Cap	4"x Schd.40	W. Nev.Supply	1	$ 4.62	$ 4.62
24	32888994577	Shaft	.5"dia x 3.5'~4' steel	Home Depot	1	$ 3.98	$ 3.98
25	PPP2119912	Plumbers Plug	4" dia	W. Nev.Supply	1	$ 3.88	$ 3.88
26	37155800742	Packing Material	.25"dia x 2'	Home Depot	1	$ 1.98	$ 1.98
27	32888010058	Check Valve	.75" dia.	Home Depot	4	$ 4.35	$ 17.40
28	30699901050	Shaft-Link Pin	1"x1/4"Bolt	Home Depot	1	$ 0.07	$ 0.07
29	78575163994	Band Clamps	.75" x 3'	Home Depot	2	$ 1.35	$ 2.70
30	30699901226	Washers	.75"dia	Home Depot	2	$ 0.16	$ 0.32
25	32888406759	Plumbers Plug Cap	.5"dia.Cap	Home Depot	1	$ 0.59	$ 0.59
31	48643071764	Hose Adapter	.75"x1"(ribbed)	Home Depot	2	$ 0.98	$ 1.96
32		PVC Adapters	.75" to .75"	Home Depot	4	$ 0.38	$ 1.52
33		Steel Elbow	.75"	Home Depot	4	$ 0.45	$ 1.80
34	30699901197	Bolts	3/8"	Home Depot	24	$ 0.23	$ 5.52
35	30699901141	Bolts	1/4"dia x 2"	Home Depot	11	$ 0.17	$ 1.87
36	30699901067	Nuts	1/4"dia	Home Depot	13	$ 0.06	$ 0.78
37	30699901029	Washers	.75"dia	Home Depot	16	$ 0.06	$ 0.96
38		Silicon	Tube	Supply One	1	$ 1.98	$ 1.98
39	43425826558	J B Weld	Two Part Cold Weld	Home Depot	1	$ 2.69	$ 2.69
40	n/a	Paint	assorted colors	Garage Sale	1	$ 10.00	$ 10.00
41	46878370982	Hose Clamps	1"	Home Depot	5	$ 0.37	$ 1.85
						Subtotal	$134.29
				Nv Sales Tax @ 7.25%			$ 9.74
						Total	$144.03

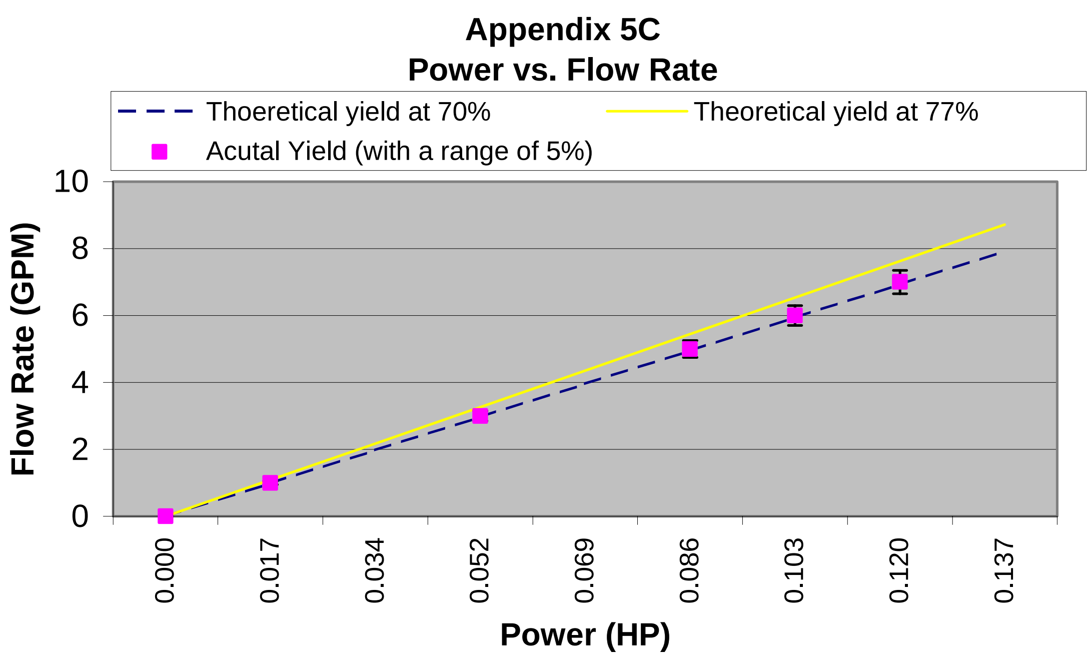
Appendix 4 – Parts Lists and Exploded View Drawing

#strokes	gallons pumped	gallons/stroke
9.5	9	0.947368
11	10	0.909091
10	11	1.1
10	9.5	0.95
10	10	1
11	10	0.909091
10	9	0.9
9	8.5	0.944444
	Average	0.957499

Appendix 5A – Flow Rate Calibration Data

number of strokes	Average Power (hp)	Predicted	Actual	diff	% error	amount @ 100%	efficiency
44	0.025194	42.13	42	0.13	0.31	60.19	69.78
55	0.031493	52.66	46	6.66	12.65	75.23	61.14
60.5	0.034642	57.93	53	4.93	8.51	82.76	64.04
Total		152.72	141		7.67	218.17	64.63

Appendix 5B – Final Testing Data



This graph was constructed for our initial testing. The dashed blue line on the graph in Appendix 5C represents the theoretical yield at 70% efficiency. The solid yellow line represents the theoretical yield at 77% based on stroke length (Dally 82). The pink points are the actual yield values obtain from testing with an error of 5% (from measuring error and leaking). By comparing the theoretical yield to the actual yield, our pump functions at about 70% efficiency. We found the actual flow rate values by setting up our pump, priming it, and pumping the corresponding strokes/min. These values were found with two different people pumping and the data points on the graph are the medians of the data for a given power output. The amount of water was measured using a measuring pitcher.

To construct the graph of theoretical power vs. theoretical flow rate, the independent variable is power. To vary power, the number of strokes per minute must vary. For the graph, the number of strokes per minute starts at 0 and increases in increments of 1 up to 10. To calculate power, use Equation 1:

$$P = p\pi r^2 dn \qquad (1)$$

where P is Power in in·lbs/min, p is the pressure (3.47 psi) (Dally 81), r is the radius of the cylinder (2 inches), d is the stroke length (13 inches), and n is the number of strokes/minute. To convert to horsepower, divide this number by 33,000 * 12 (Dally Equation 3.8). Because this equation is for a single-acting pump, the power is double for a double-acting pump. Therefore, the power varies from 0 horsepower to .17 horsepower by increments of .017 horsepower. The dependent variable (theoretical volumetric flow rate) was calculated using Equation 2:

$$q_v = \pi r^2 dn \qquad (2)$$

where q_v is volumetric flow rate in in^3/min. This is converted to gallons/min by dividing by 231 (Dally 80).

Appendix 5D

number of strokes	Actual (ga)	Ave actual flow rate
44	42	8.4
55	46	9.2
60.5	53	10.6
	Average	9.4

	September	October	November	December
Concept Development	//////////////////			
Initial team construction	////////			
Receive specifications	/////			
Original concept generation	////////////			
Written report	////////////			
Review original concepts		///		
Detail Design		/////////////////		
Revise original concepts		////		
Design, in detail:		///////		
Piston		////		
Pump		/////		
Drive mechanism		//////		
Flow rate		///		
Design Review		///////////		
Oral presentation		/////		
Powerpoint		////		
Presentation preparation		////		
Written presentation		////////////////		
Drawings		//////		
Budget		////////////////		
Parts list		////////////////		
Testing		///		
Manufacturing		//////////////		
Obtain Materials		///////		
Manufacture parts			///////	
Inspect for testing			/////	
Presentation			///////	
Pre-assembly			////	
Testing			////	
Final Report				//////////
Oral presentation				///////
Powerpoint				//////
Presentation preparation				///////
Written presentation				//////
All aspects of project				//////////

Appendix 6 – Gantt Chart