Team 9
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Hydro-Pro Pump Specialists

Executive Summary:

The Hydro-Pro Pump Specialists have designed a human powered pump that consists mainly of a flexible vane pump that is driven by a bicycle gear chain configuration. The frame is made from steel and supports the pump and driving system. The human that is powering the pump will sit in a chair, which has adjustable settings, that is secured to the frame by a sliding channel and pin. Either the operators' legs or hands can power the crank-set that drives the pump. The pump design allows the user to operate the pump from a horizontal position. The flexible vane pump is a type of centrifugal pump that incorporates rotational motion and energy to propel liquid with great force and volume. Water being delivered to the pump passes through flexible tubing, the water is being drawn into the inlet of the pump and then propelled out the outlet. Once the water is propelled out the outlet it is then transferred to the flow measurement devise with the use of more flexible tubing. Water is then measured by a float, which rises to the top of the water level and, in turn, shows the float rate by way of a calibrated scale.

Introduction

The object of this project was to be able to build a human powered pump that can be used in a third world country to aid in irrigation purposes, and the transfer of water for drinking and living purposes. The pump must fit the following criteria: 1) this pump is to cost a reasonable amount. For each person in the group a $25 maximum spending limit was set. 2) The pump will be easy to set up. During testing the pump will have to be set up within 15-minutes. 3) The pump has to be able to be powered by three people, one of which must be a female. 4) In addition to being easy to set up it must also be easy to take down. During testing the pump will have to be disassembled within 10-minutes. 5) Maximum water will be delivered to the holding tank that is 8 feet vertically up. 6) While the water is being delivered to the holding tank there will be minimum spilling. 7) Finally, once the water is through the pump and before it's in the holding tank it must be accurately measured.

In order to successfully complete the criteria above we have built a human powered water pump that will do the job efficiently. The following eight categories are ways that this pumping system can be classified and evaluated. The first category is performance. The Hydro-Pro series 1 will project from 3-7 gallons per minute of water with 8 feet of head. Also this series uses a prefabricated pump, so the leakage is negligible. In a time period of 10 minutes the system delivered 46 gallons of water to a site 8 feet above the water source.

The next category is Measurement method. The measurement method of this system is a float style design that will show the flow rate both instantaneously and easily. The system flow meter is accurate, within a .5 gallon per minute error, and with the calibrated gauge the instantaneous flow measurement is very easy to record. User merely has to see how the pointer lines up with the gauge to determine it's instantaneous flow rate. The cost of the system is a very important thing in the development of this system. The materials that were used were as low cost as possible to maintain the product reliability and durability of the product. Common steel and lumber made up most of the design. Additional components are also affordable, such as flexible and pump components.

The flexible vane pump is one that requires rotational motion to engage. The bicycle drive system allows us to use the rotational motion of the bike to power the pump, without the problems of converting rotational motion to linear motion or vice versa. The unique concepts of this system are the dual gear drive system and the float flow meter. The first concept is the use of two pairs of gears in the drive system. This is needed for this pump because of the high rpm rate that is needed to operate the pump. The system is advantageous over a one-gear system because it allows the user to more than double their mechanical advantage, and therefore increase the pump's rpm rate. The use of the pump itself is also very simple: one would just sit in the seat and pedal the crank, no other instructions required. The simplicity of the pump is partly due to the low number of components that were used in production. A combination of 5 systems with no more than six components per system leads to a very simple and basic design.

The quality of a product that will go into a third world country is very important as well. This pump was built accordingly. The parts for the pump are very durable. Most parts are made from steel or lumber and will survive abuse. The workmanship of the product is also very high. All parts were machined by a high quality technician on a in house mill or by a welder. The prefabricated pump requires minimal maintenance and provides a steady flow of water. Also the flow meter, once calibrated is very accurate, and will provide accurate measurement with low maintenance.

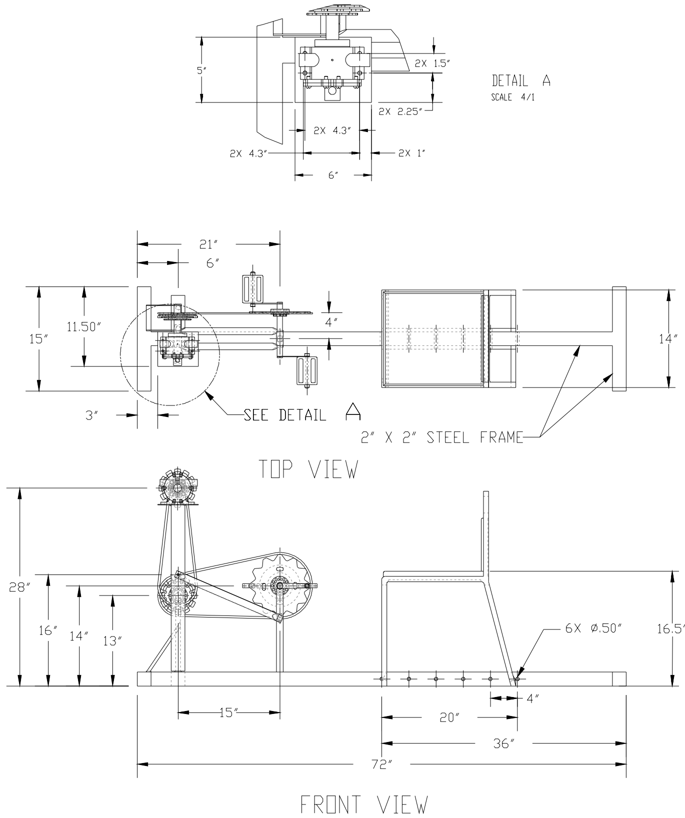


Figure 1

Prototype Description and Principles of Operation

The Hydro-Pro team decided to use a vane pump because of the accessibility of such a pump and also because of the corresponding motion of the bicycle drive system. The problem that must be overcome is the lack of efficiency at lower RPM. Most centrifugal pumps are effective above 500-700 RPM. To get an idea of how much this really is, you can compare it to a car at idle speed. To use human power to get a pump to revolve at car idle speed seemed a bit of a challenge to our team.

We wanted to use a design concept that was relatively simple yet effective at pumping water. If we want to get our pump to the target RPM, the pump must be capable of turning at that speed. The system is powered from a primary wheel (see Figure 1) that is eight inches in diameter. This wheel is used to power a 1.5-inch diameter wheel (see Figure 1) that is attached to another gear of eight inches that then runs a bicycle chain to a smaller, 1.5-inch gear that is attached to the water pump. Bicycle chains can be lengthened and shortened by taking out links, which makes it a good choice for deciding the length from wheel to wheel. The large wheel rotates at a slower speed than the small wheel. At these dimensions the small wheel will rotate at 5 2/3 times the RPM of the large wheel, the second set of gears with allow the pump to operate at approximately 12 times the speed of the gear being pedaled. When pedaled this will give us the high RPM that are needed to use the pump efficiently. On the driving wheel there will be pedals that your feet rest upon to drive the gear much like a bicycle. The seat can also be adjusted all the way forward for the ability to be used with arm power if your legs get tired or arm use is the only option. With the use of arm power, the pump is not be able to spin at target RPM, but it will be able to pump water. This loss of efficiency is made up in the great versatility our pump has. To be able to use hands and feet to power the pump provides a wide range of users with the opportunity to partake in this wonderful experience.

The driving gear position had to be taken into consideration when adding this feature. If the pedals where too low, when using your hands the body position would be very awkward, and if the gear was too high, it would be awkward when using your feet. To solve this problem we found a medium point at which the gear could be pedaled with feet comfortably and also with hands comfortably.

The pump itself is the next component of the series 1 pump. The flexible vane pump is a positive displacement pump that is capable of moving a large amount of water in a minimal time period (See Appendix A). The way this is done is as follows: as the flexible impeller passes the input opening in the pump housing, water is drawn into the housing by a difference in atmospheric pressure. After the compartment containing the water is sealed, the vanes flex, or distort and pressurize the water inside. When the vane passes the exhaust opening of the housing, the pressure is released and the water is projected out. A high RPM is needed to operate this pump because the volume per revolution of the pump is very small. Therefore you must make many revolutions to sustain a good flow rate.

The actual pump is held only by two bolts, which can easily be removed. There are also four different points of adjustment, two for each chain assembly. Adjustments should only be made two at a time for each of those assemblies; one bolt should never be adjusted solely. To adjust, you should un-tightened, move assembly to desired tension and re-tightened for best results. Nuts must be re-tightened after ever use. Assembly of the seat should be done while thinking of desired length from pump. Remove pin, set seat at desired length and replace pin. The pump system itself is placed on a table, when placing the pump above the ground extra head pressure was not created.

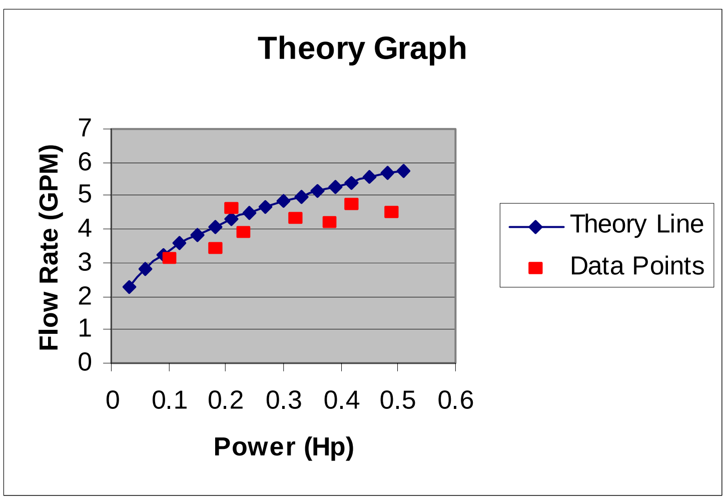
Construction of our pump took place at the house of member Adam Pruitt. The pump was first built by construction of the frame. Pieces of 2x2 inch metal tubing was welded together to form a shape much like the upper case letter I (see Figure 1, and Appendix B). Next the pedal assembly was added, also by welding. When building, many factors had to be taken into account such as rotation straightness of the gears, lining them up crooked could result in disastrous effects at such high RPM. Also distance from the pump bracket to the pedals had to be carefully measured as to keep the right amount of allowance for adjustment with bolts. After the pump bracket was welded into place, holes were drilled at the top to allow the pump to be bolted on. Later in construction we added a second set of gears to double the amount of RPM we were getting. To do this we had to weld a second set of gears to our assembly. A large gear was welded to a small one and secured to the bottom of the pump (see Figure 1, and Appendix C). After the frame and driving gears were attached to the assembly, work on the chair began. A regular chair with four legs was use as our seat. Roshelle Olson milled a bracket system for the chair that gave not only bracing for the chair, but an assembly that would go hand in hand with the pump frame (see Figure 1, and Appendix C). This bracket allowed for the adjustment of the seat, to cater to different size operators. After a hole was drilled for the multiple adjustment lengths, the pump was ready to go. David Welge did construction of the flow meter. Pieces of 1x4 inch lumber were used to create a flume that the water would run down. Then a float was created using a car gasoline float. The float was removed and modified to fit into the flume.

Then and hanger was used to attach the float to the pivot, which was also a small length of hanger wire. On the other side of the pivot point a length of the coat hanger was left, in order to serve as a pointer for the flow measurement. One problem that was encountered in the calibration of the meter was that the float did not account for the variable speed of the water that the float would encounter from the pump. In order to eliminate that problem was to eliminate that variable. In order to do this a small compartment was added to the top end of the meter, (See Appendix E). This compartment is composed of an angled block that serves as a stopper for the water as it enters the meter. After the water is stopped it falls down to the main channel and down to the float. By doing this the water will be going at a uniform speed when it encounters the float. This eliminates the need for any speed calculations in the flow measurement.

Testing and Analysis

The testing of the Hydro-Pro water pump revealed to use that we were very close to our predicted flow-rate. To get our theory line we created a function using the work ($Work=C_pDw^3d^2$) and flow rate ($Flow\ Rate=C_qwd^3$) equations. By using the equations for flow rate and power and combining them we came up with Flow Rate=1.25(work/.0055)^$^{1/3}$ as a theoretical line. (See appendix for derivation F)

Figure 2



This theory line assumes that we will have a 40 percent efficiency level. (See Appendix G for basis)

There are many things that contributed to the discrepancy in error. The factor that reduces the efficiency the greatest is the nature of the pump itself. This vane style pumps uses a scrub fit to seal the impeller. This means that there is a lot of pressure on the inside of the housing to keep a seal. This pressure creates friction and makes the pump hard to turn. The second thing that contributed to the error is the hose that was used to supply the water. This tubing was too thin and collapsed slightly because of the pressure. This made it harder to operate the pump and decreased efficiency. Also the flow meter contributed to the loss of water. The water flowed out some unsealed cracks and also out the back of the meter. These losses were contained however, in the flume that was already there and was counted in the final flow measurement. The last thing that decreased our efficiency was human error. During the final 5 minutes of testing, the chain came off the gear and lodged between the gear and the shroud. Pumping was stopped and we were unable to repair the system in time to pump any more water.

Project Management

Our goal was to develop and manufacture a prototype of a human powered pump machine. Each team member was specific responsibilities: David, the team leader coordinated the scheduled meetings, did the writings and reports, and was responsible for the fabrication of the flow gauge meter; Adam, was responsible for the fabrication of the pump assembly, he also coordinated with Ian in the power point presentations; Roshelle did the modification of the movable chair and provided research and information on assigned topics; Emy was responsible for all the drawings needed for the initial design, power point presentations, and reports. Each team member contributed whatever parts or materials are needed for the fabrication of the pump assembly.

Group Meetings

Team 9 members are working students; some working and studying full time and so meetings were scheduled on the team members' availability. Meetings are held Mondays and Thursdays after Mech 150 classes, and Sunday nights prior to presentations or if an important discussion is needed. Other means of communication is through e-mail and telephone. Due to the team members busy schedules, rehearsals for the power point presentations were not sufficient enough to produce a well-rehearsed presentation. (See Appendix H for CPM)

Budget

The goal is to develop a pump assembly that will cost no more than $125.00. In actuality, we almost did not spend any money except for the purchase of one used bicycle that Roshelle bought. Another used bicycle was taken from Emy's backyard, the used vane pump was David's donation from his Dad's garage, and the steel stock frame was from Adam's garage. Roshelle donated a used chair and had the fabrication of the chair frame (to make it adjustable) done at her place of work at Bentley. Adam used his dad's welding equipment and welding rods. However, we have to attach a price for each part to give our product cost representation and so we came up with $106.82, (See Appendix I) which could actually be lower because we have wasted some undesired parts from the bicycles.

Despite busy schedules, individual differences and opinions, group 9 managed to pull through and finish the project. The experience gained, had given us the importance of what designing a product as a team meant.

Summary and Recommendations

The Hydro-Pro pumping system did achieve all the design specifications. The pump was low cost and came in nearly $20 under budget. It was effective in moving water, and the water was measured easily and accurately. The three key features of the Hydro-Pro are the frame (Appendix), the pump itself (Appendix A), and the Gearing system (Figure 1 and Appendix). There were three main advantages to our pump. The first is that the design was simple. It has very little components and a simple setup. Also our pump is reliable, all the parts are made from durable material, and the pump itself is built to last a long time with minimal maintenance. The last advantage is that the pump is easy to operate. Merely sit in the seat and pedal. There is one major disadvantage. This is that the pump requires a lot of energy to operate. More modifications are needed to allow for extended use.

The tubing that was used had a tendency to collapse under pressure causing more viscosity and making it more difficult to pump the water. A different type of tubing should have been used that could resist collapsing under pressure. The pedals could have had straps on them to make it so the users feet didn't slip off quit so easy. The chair/pin design needed an additional pin to prevent the chair from tipping back when the user had to apply a great amount of force to the crank-set. In order to correct the problem with the difficulty in operation for long period of time, and way to change gears would be a good answer. Using a derailer the operator could change gears and make it easier to operate. Finally, the chain needed to be designed to where it wouldn't have a lot of slack in it after use.

Appendices Table of Contents

Appendix A
Flexible Vane Pump

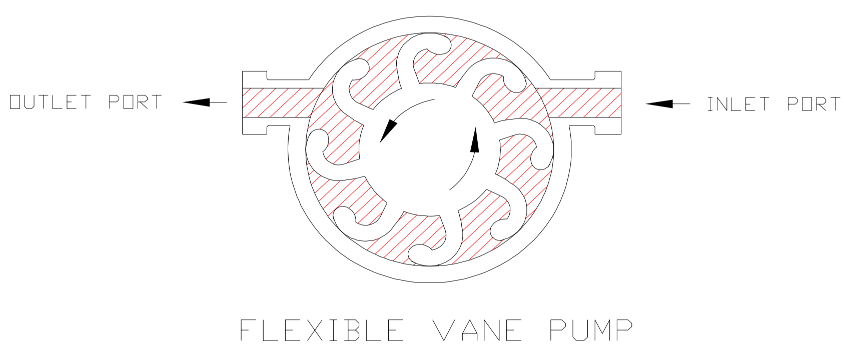


Figure 1

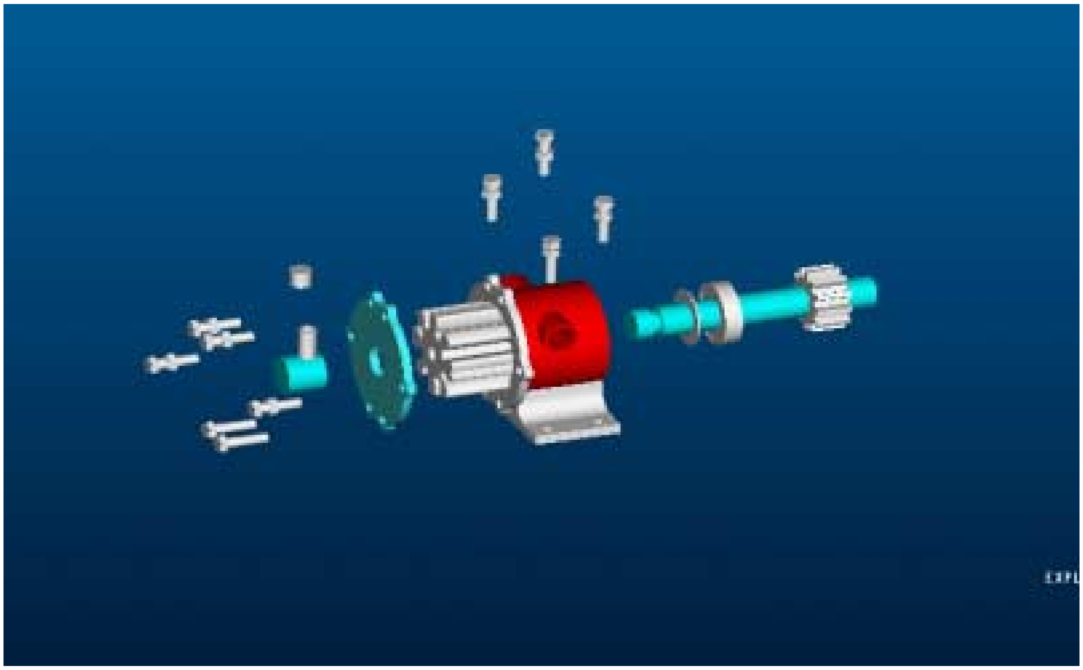
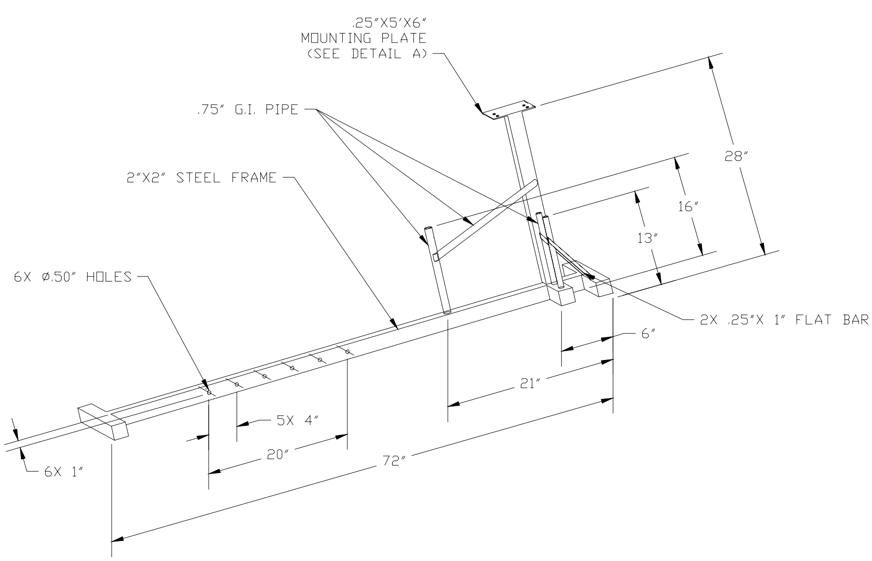


Figure 1 shows the basic workings of the vane pump as discussed on page 4. Some of the major components of the vane pump are the impeller, the housing (red) and the drive gear (white, right)

Appendix B

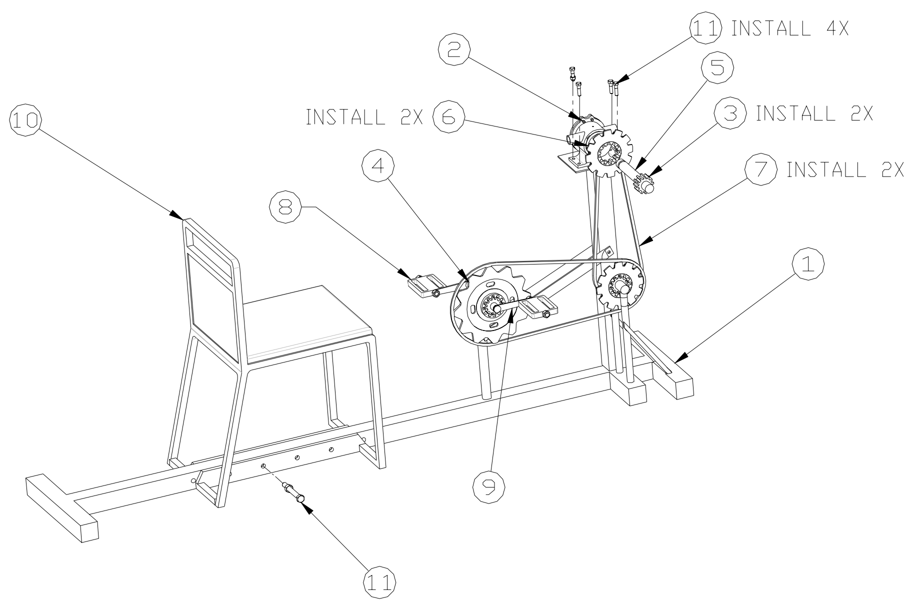
Frame



This figure show the frame of the system without the other major components attached to it. Some of the important features of this frame are all the attaching areas, where other components attach to the frame and also the metal stability braces on either end of the frame to keep the system from falling over during operation.

Appendix C

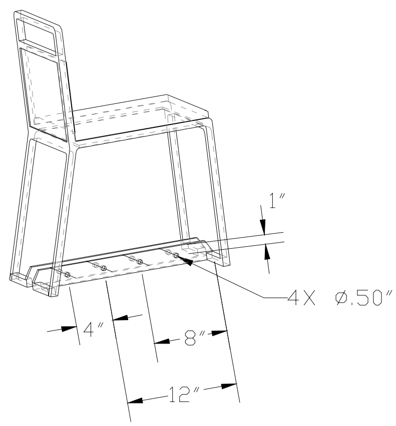
Assembly Drawings



PARTS LIST		
ITEM	QTY	DESCRIPTION
1	1	**2” X 2” STEEL FRAME STOCK**
2	1	**1 SET VANE PUMP**
3	2	**2” DIA. GEAR**
4	1	**SPROCKET**
5	1	**1” DIA. SHAFT**
6	2	**CHAIN WHEEL ASSEMBLY**
7	2	**BYCYCLE CHAIN**
8	1 SET	**PEDALS**
9	1	**CRANKSET**
10	1	**CHAIR**
11	4	**.213 DIA HEX BOLTS W/NUTS**
12	1	**.50 DIA ROUND BOLT W/NUTS**

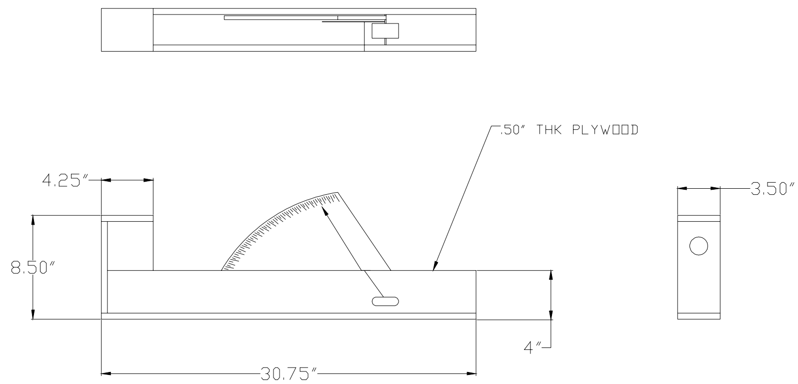
These figures show the general assembly drawing of the pumping system. Included is also a parts list. Some of the most important components of the system are the crank set (#9) and the vane pump (#2)

Appendix D
Chair



Appendix D shows the chair of the pumping system. It also shows the specific distances between the adjusting holes, and overall size.

Appendix E
Flow Meter



Above, the flow meter is shown. The additional block to stop the flow of water as discussed on page 5 is on the right end of the meter and accounts for the top 3.5 inches of the meter. The circle on the rear drawing indicates the entrance for the water.

Appendix F

Flow rate Theory derivation

TEST PREDICTIONS

Given:

$C_Q = .0625$ $\rho = 1.94$ slugs/ft^3

$C_P = .014$ $d = .45$ ft

C_Q + C_P are generic coefficients

ρ is the density of water

d is the diameter of the pump.

$\dot{W}$ -> work

w -> spin rate

Q = Flow rate

$$\dot{W} = C_P \rho \omega^3 d^2 \qquad Q = C_Q \omega d^3$$

$$\frac{\dot{W}}{C_P \rho d^2} = \omega^3 \qquad Q = C_Q d^3 \sqrt[3]{\frac{\dot{W}}{C_P \rho d^2}} \quad (ft^3/sec)$$

$$\omega = \sqrt[3]{\frac{\dot{W}}{C_P \rho d^2}} \qquad Q = C_Q d^3 \sqrt[3]{\frac{\dot{W}}{C_P \rho d^2}} \cdot 7.48 \frac{gal}{ft^3} \cdot 60 \frac{sec}{min} = gpm$$

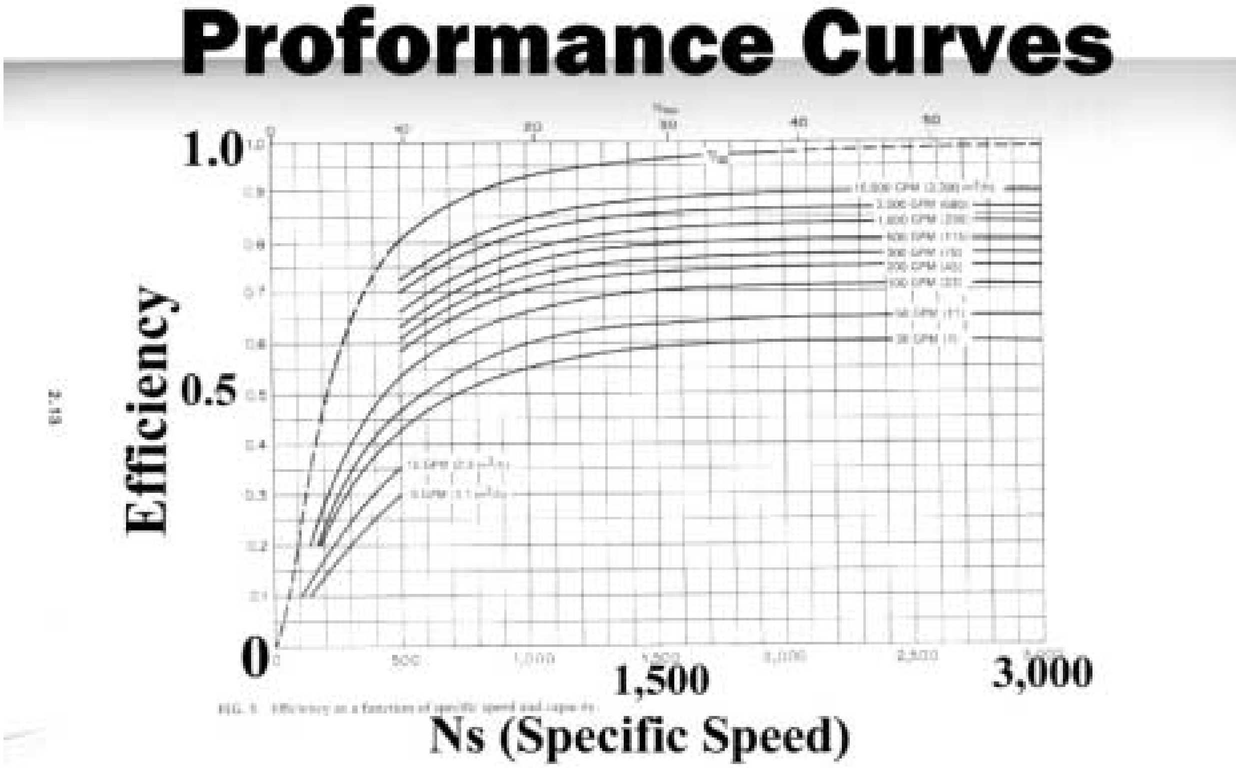
$$Q = 2.55 \sqrt[3]{\frac{\dot{W}}{.0055}} \rightarrow 100\% \text{ efficiency}$$

$$Q = 1.275 \sqrt[3]{\frac{\dot{W}}{.0055}} \rightarrow 50\% \text{ efficiency}$$

Theory assumes 40 percent efficiency, due to low specific speed. Error has been estimated to be 4-8 percent of efficiency, therefore approximate efficiency is 45 percent.

Appendix G

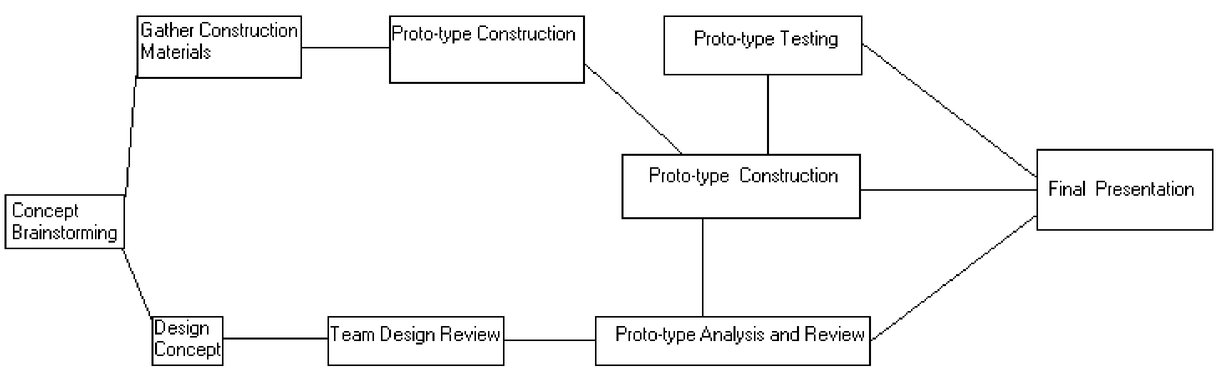
Assumed efficiency graph



This is the graph that we used to allow us to assume that our pump would pump at 50% efficiency. Our approximate Ns was 780 at 1000 RPM. This RPM was not always maintained during testing.

Appendix H

CPM chart



This figure illustrates the general organization of our semester. As is shown. There were many times where multiple tasks were taking place at the same time. For example the construction, testing, and analysis were all going on at the same time.

Appendix I

Budget Table

PART	DESCRIPTION	QUANTITY	COST
1	STEEL FRAME STOCK	N/A	$20.00
2	VANE PUMP ASSEMBLY	1 SET	$25.00
3	GEARS	2	$30.00
4	SPROCKET ASSEMBLY	2 SETS	INCLUDED IN ITEM 3
5	SHAFT	1	INCLUDED IN ITEM 2
6	CHAIN WHEEL ASSEMBLY	2 SETS	INCLUDED IN ITEM 3
7	CHAINS	2	INCLUDED IN ITEM 3
8	PEDALS	1 SET	INCLUDED IN ITEM 3
9	CRANKSET	1 SET	INCLUDED IN ITEM 3
10	SEAT	1	$10.00
11	NUTS, BOLTS, AND SCREWS	14	$3.50
12	LUMBER STOCK	N/A	$10.00
13	HANGER	1	$0.10
14	10 FT. GARDEN HOSE	1	$1.00
	TAX		$7.22
	TOTAL COST		$106.82

[1] Items 3,4,6-9, are all taken from 2 units of used bicycle @$15.00 per unit.
Item 5 is a sub-assembly of the vane pump.

This figure shows the budget for our system. The total comes to $106.83, this is $19.18 under budget or approximately 15.3% under budget.