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Centrifugal Pump Performance and Cavitation Analysis

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Abstract:
In this project, a centrifugal pump was utilized to further understand how to select the correct pump for a system and understand the working principle and performance characterization of the pump. Once analysis was completed, the rpm's of the centrifugal pump were increased and a valve was slowly shut to observe cavitation take place. This process occurs when the pressure drops and bubbles begin to form ahead of the impeller. These bubbles then make the system two phases, in which both liquid and gas are introduced into the centrifugal pump. Studying this phenomenon, cavitation consequences such as decrease in efficiency, louder noise, and damage to the impellers may be learned for future prevention. This lab was conducted to gain a greater overall understanding of centrifugal pumps to learn how to implement them for forthcoming engineering applications.

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I. Introduction:

Water is the lifeblood of our planet that without it, would leave the planet a barren rock. Water is versatile fluid that under the right conditions can perform a multitude of tasks, however there are caveats to these other functionalities. In most cases for water to perform these other functions specifictic constructions are needed such as a pump.

Pumps come in several sizes, they come with a vast array of different components, makes and models but they all share the same function of the transportation of fluids through pipes. For this experiment we would be using a centrifugal pump, this configuration uses kinetic energy to rotate a fluid, i.e. water, that would allow the hydrodynamic energy to pass the fluid through the pump where the rotational kinetic energy is provided by a external motor/ engine. However such a system can be affected when power fluctuates or the characteristics of the pump head are changed. Using this we can replicate the system to experiment on the aforementioned power fluctuations and changes in the pump head to test the level of efficiency the pump system would exhibit.

The main focus of this paper is to compare/ contrast the experiment's different parameters of the centrifugal pump to determine the most effective configuration, based on the data given to us. Our plan is to first determine which pump would be right for the job by testing the different voltage to electricity ratios, this allows us to see which pump head and impaler size would best fit the BHP, brake horsepower, of the pump. Next we would run different tests to compare the difference in the pumps use from its efficiency, flow rate, torque, to its bhp, after word we would plot the data to visualize the differences. Finally calculating the pumps NPSH, net positive suction head, to determine any change to the suction/ discharge head as a way for us to understand how cavitation can happen and how we can prevent it.

Theoretical Background:

A Pump is generally used to induce flow or to increase the pressure of the liquid. Centrifugal pumps are a Dynamic Pumps type. Centrifugal pumps' operating theory involves imparting energy to the liquid by means of a centrifugal force produced by rotating an impeller that has multiple blades or vanes. The basic operating theory of centrifugal pumps consists of the following operating phases

-Liquid is entering the pump housing in the impeller eye.

-The velocity energy is transmitted to the liquid by means of the centrifugal force produced by the rotation of the impeller and the liquid is radially pushed out towards the periphery of the impeller.

-The velocity energy of the liquid is converted to the pressure energy by directing it to an expanded volute design housing in a volute type centrifugal pump or a diffuser in a turbine pump.

Pumps are primarily classified as dynamic and positive displacement pumps. As explained in the theory above, dynamic pumps operate at a high liquid velocity. Positive displacement pumps are operated by forcing a fixed volume of liquid. The dynamic action in the operating principle of the centrifugal pump makes it relatively less efficient than the positive displacement pumps. However, they operate at relatively higher speeds, allowing a high flow rate of liquid in relation to the physical size of the pump. They also usually require less installation and maintenance costs. Because of these advantages, centrifugal pumps are the most commonly used pumps in industry.

Experimental Setup and Procedure:

Part A

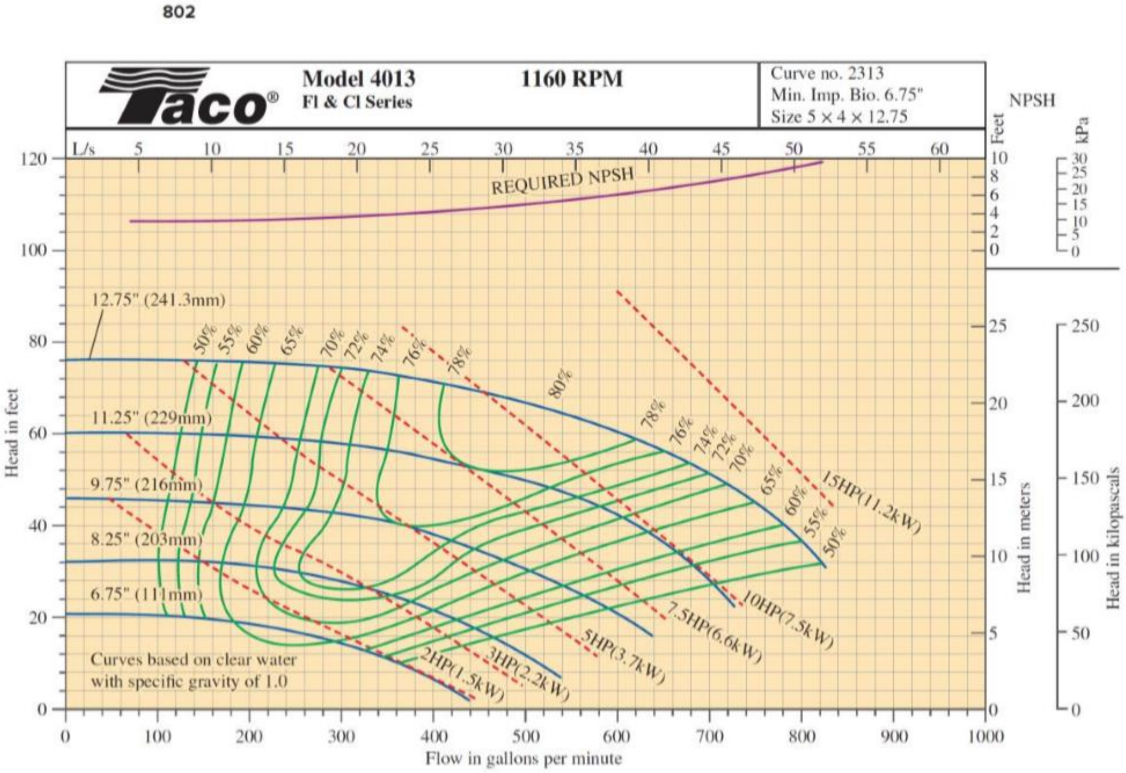


FIGURE 14–15

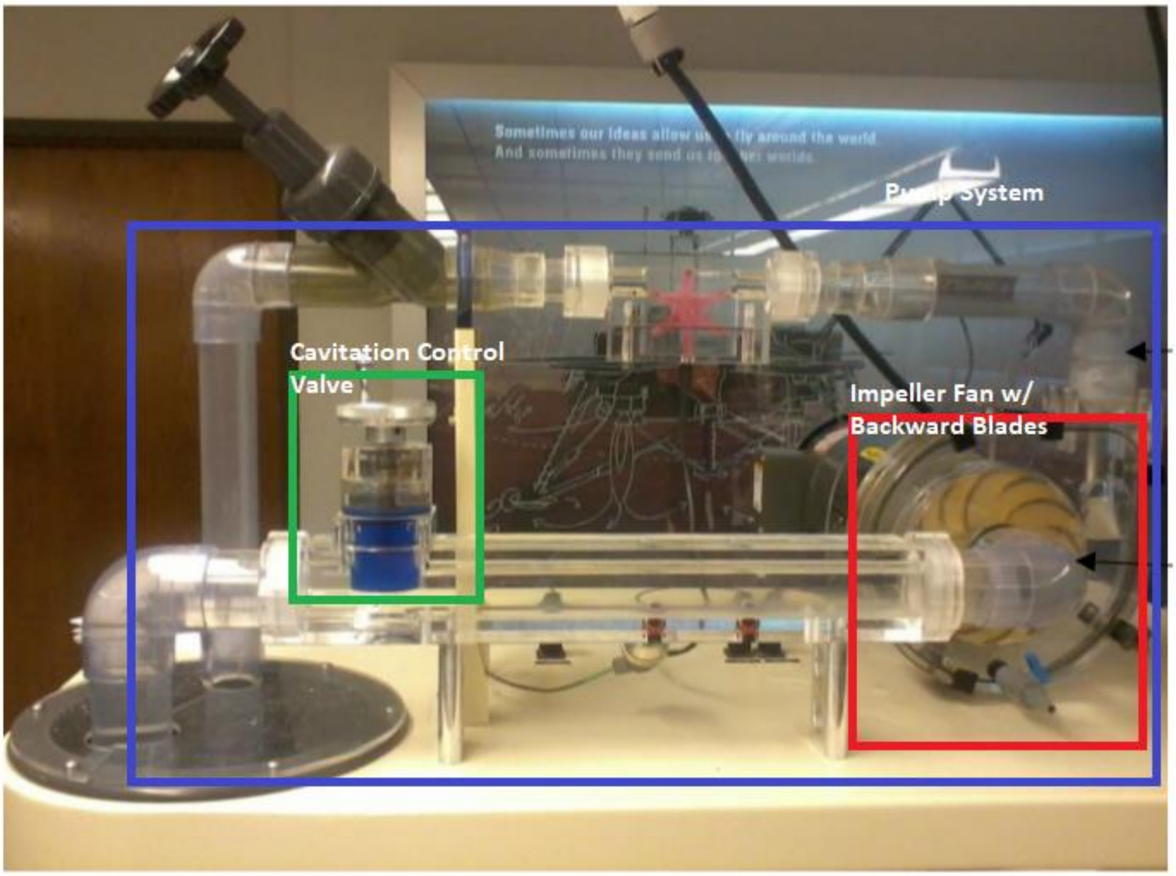
Example of a manufacturer's performance plot for centrifugal pumps. Each pump has the same casing, but a different impeller diameter.

Courtesy of Taco, Inc., Cranston, RI. Used by permission. Taco® is a registered trademark of Taco, Inc.

Fig 1.

Step 1. With the chart provided above, determine a centrifugal pump that would work for a water transportation system using the following formula P=V*I. (power in watts = voltage * current)

Part B



Schematic of Centrifugal Pump Setup

Fig 1.

Step 1. Find the properties of the pump system; diameters of the pump pipes, length of the pipes to the pump and valve, any angle of deviation, properties of water . Picture below helps illustrate this.

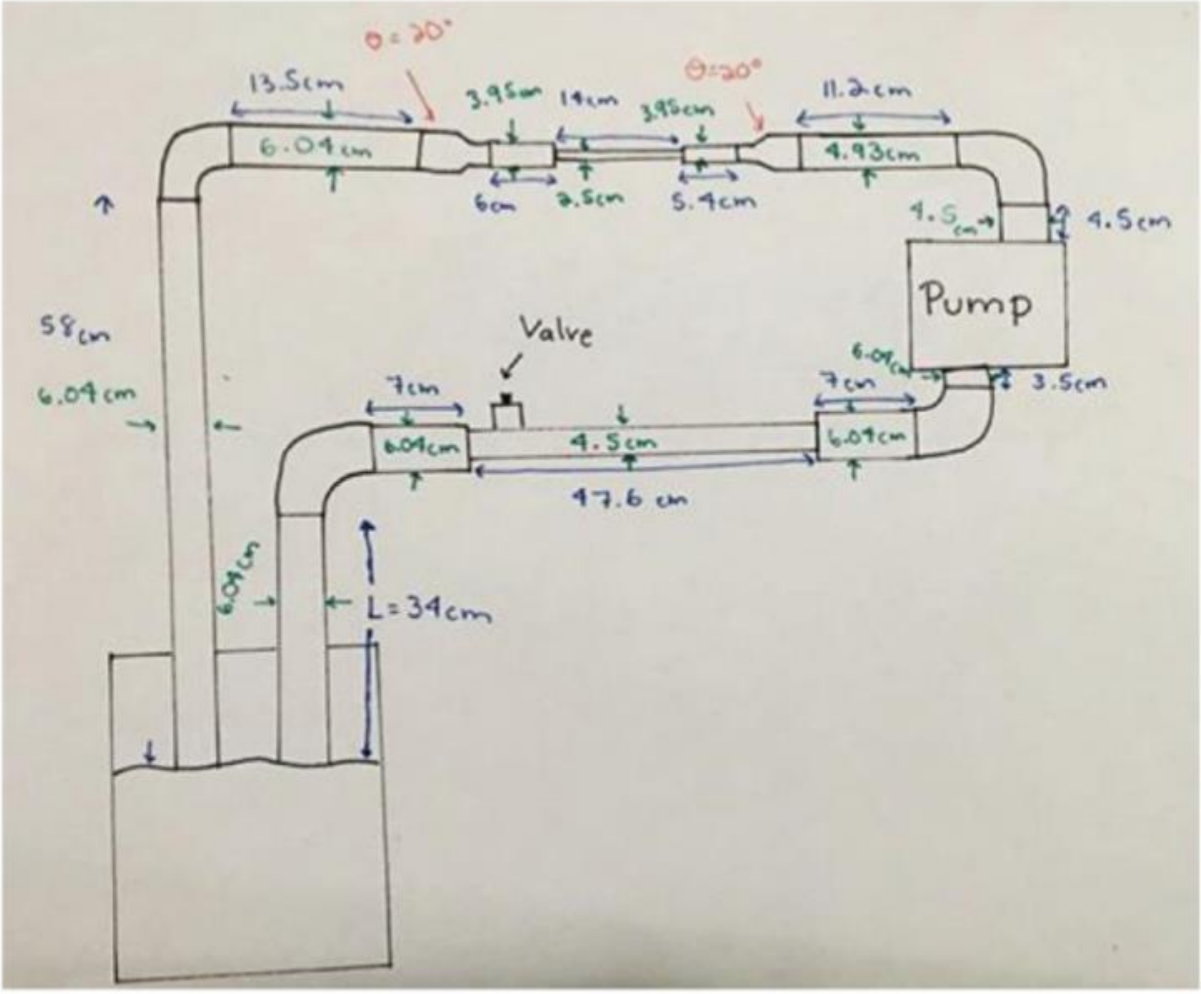


Fig 1.

Step 2. With the collected values we calculate for; velocities of the inlet and outlet flow of the pump, find Re determine if the flow of the water is turbulent, then find the friction factor of the water. Use Equations 8-50, 8-51 or Moddy Chart for help in the calculations.

Step 3. Calculate Head loss of the pump, using formulas 8-59, 8-60 from here you would take the values to calculate the Net Head using a derived form of Bernoulli's Equation.

Step 4. Calculate the efficiency of the pump. Plot the different calculated values due to the change in the RPM. (Hint - calculating the horsepower for the water (14-3) and the braking force of the pump(14-4) helps when calculating the efficiency (14-5))

Part C

Step 1. Calculate the NPSH of the system using eq. 14-8. This is used to help with detection of cavitation. However there are 2 types of NPSH calculations that are required, NPSH that is required, this data is provided by the manufacturer, and NPSH that is available, data acquired by us.

Step 2. With the values we calculated from the previous step, determine if there is a chance of cavitation.This can be calculated by seeing if the available NPSH is less than the required NPSH + the margin of error. If so determine what needs to change to lessen or prevent it from happening.

II. Results and Discussion

Part 1: Selecting the right centrifugal pump for the water transport system.

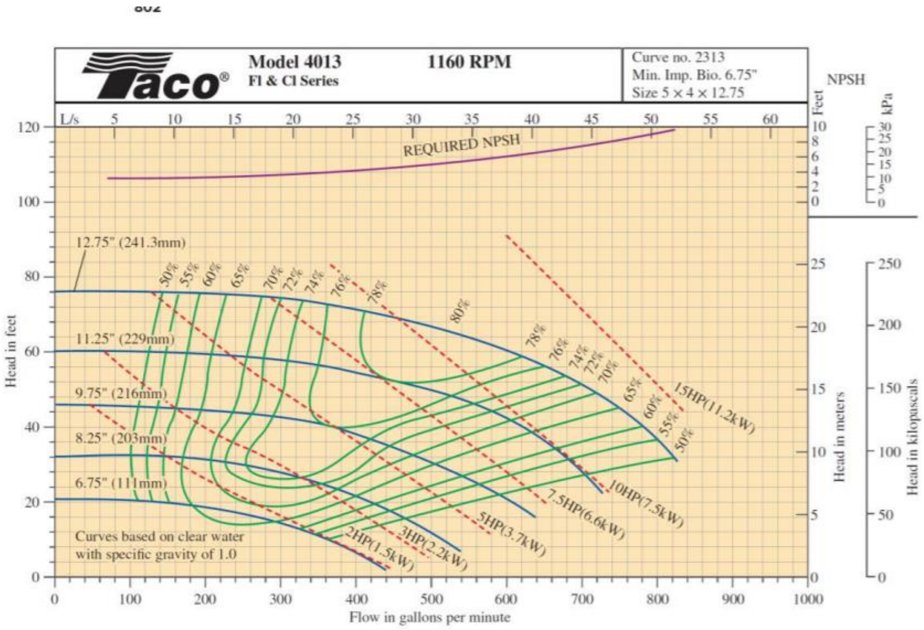
For this first part, we are going to follow a selection process in order to try and select the best pump for the given conditions. In this case our voltage rating will be between 208-230 V, the electricity rating between 8.2-8.3 Amps, 1750 RPM, and a maximum volumetric flow rate of 65 GPM.
We will begin by calculating our Brake Horsepower (BHP) using the following equation:

$$P=VI$$

The result that we will get from this equation is going to be given in watts. We will need to convert it to horsepower using the following relation:

$$1Hp=745.7\ Watts$$

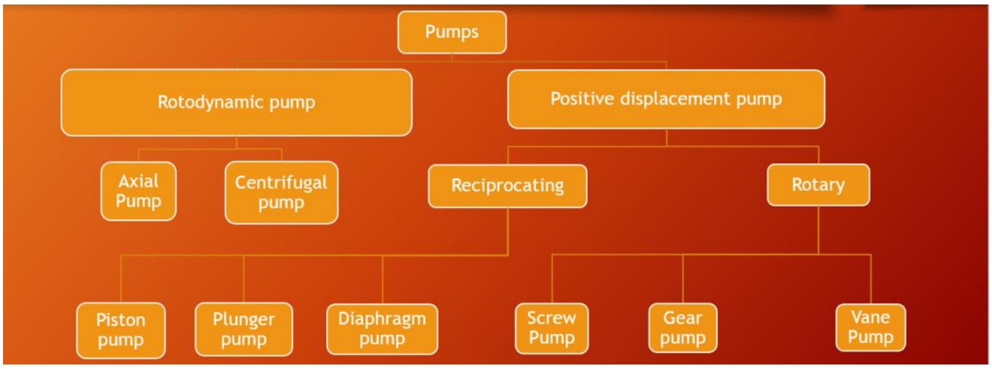
Our power will be equal to ***2.56 Hp.*** We will now figure out our optimum net head, impeller size and efficiency using the following table:



We can see that for this case, our appropriate head will be around 45 feet, an impeller size of 9.75¨, and an efficiency of less than 50%. We may assume that there is a low efficiency because the flow is relatively low. If we increase the flow, we can achieve an efficiency of around 70%. If we wanted even more efficiency we could use a pump with higher HP.

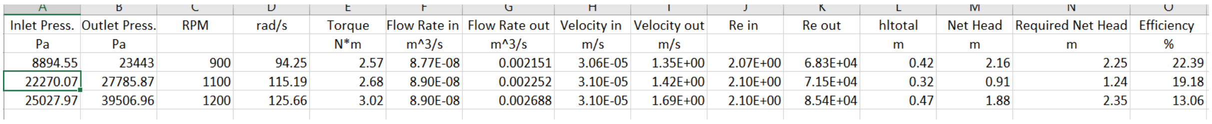
Part 2: Working principle and performance characterization of the centrifugal pump.

A pump is a mechanical device that transfers external mechanical energy into fluids. It generally converts mechanical energy to hydraulic energy. There are various types of pumps, which are:

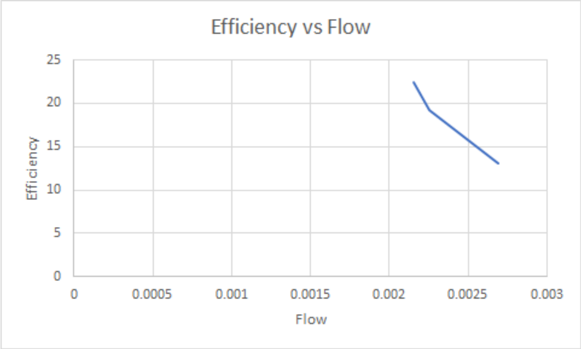


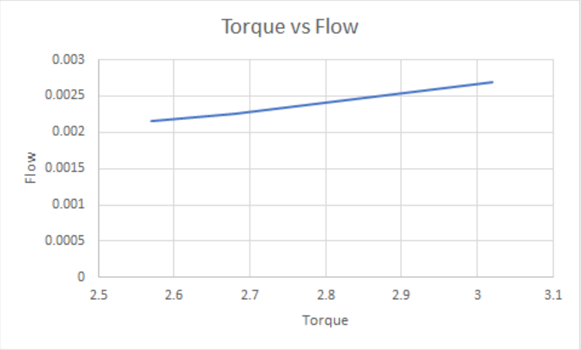
For this specific case, we are going to be focusing on the centrifugal pump. This is a type of rotodynamic pump. It transports fluid from a lower level to higher level with the conversion of rotational K.E to the hydrodynamic energy of the fluid flow. The rotational energy normally comes from electric motors or some external sources such as engines. Rotational force displaces fluid of its center of the axis and increases its energy. Mainly used for incompressible fluids (constant density)

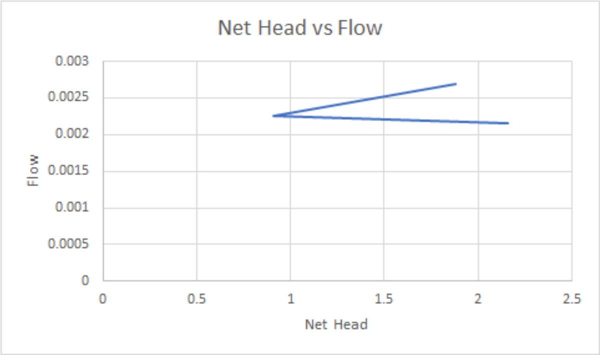
The following table and graphs represent the values of a pump running at different RPMs:

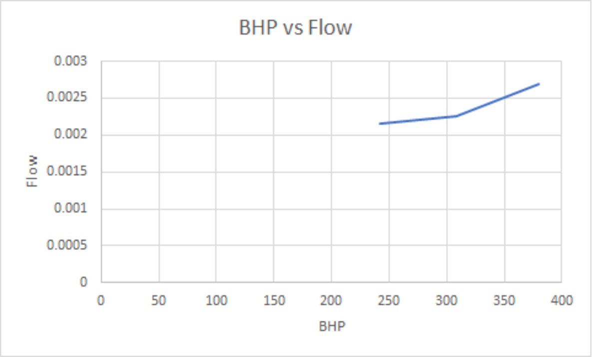


A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Inlet Press.	Outlet Press.	RPM	rad/s	Torque	Flow Rate in	Flow Rate out	Velocity in	Velocity out	Re in	Re out	hltotal	Net Head	Required Net Head	Efficiency
Pa	Pa			N*m	m^3/s	m^3/s	m/s	m/s			m	m	m	%
8894.55	23443	900	94.25	2.57	8.77E-08	0.002151	3.06E-05	1.35E+00	2.07E+00	6.83E+04	0.42	2.16	2.25	22.39
22270.07	27785.87	1100	115.19	2.68	8.90E-08	0.002252	3.10E-05	1.42E+00	2.10E+00	7.15E+04	0.32	0.91	1.24	19.18
25027.97	39506.96	1200	125.66	3.02	8.90E-08	0.002688	3.10E-05	1.69E+00	2.10E+00	8.54E+04	0.47	1.88	2.35	13.06









We can see with the given information that the more RPMs we have, the less the efficiency that the pump produces. This could be because of the cavitation that it is forming in the pump which will cause the pump to eventually fail.

Part 3: Cavitation, its consequences and prevention.

Cavitation is the phenomenon of bubble formation at the suction side of the pump due to pressure drop in the system. Cavitation occurs when pressure drops below the vapor pressure of the liquid. Some adverse Effects Due to Cavitation are:

- Creates a shock wave upon implosion.
- Damage to the impeller can occur.
- Noise and sealing damages.
- Efficiency decreases as cavitation increases.

Cavitation can occur for many different reasons, and each case has its own way to prevent it. This are some of the actions you can take to try and avoid this phenomena from happening:

- Design the pump suction piping and routing to avoid excess turbulence
- Take precaution while fixing the pump suction line size to avoid turbulence and have sufficient NPSHa
- Respect the maximum allowable flow limit of the pumps.

For this specific pump that we are working with, the NPSH is equal to 2.27 m. Thanks to this, we can see that depending on the flow rate that we have, our suction and discharge head changes. This is because the more flow we have, the more space we need for it to pass. And we also have to take into consideration how clase our valve is. With our valve closing, our area of flow is reduced, so the velocity increases, and because of this cavitation starts to form. This means that our suction and discharge head will have to change.

III. Conclusions:

The conclusion that we made that with an increase of speed of the pump it causes the properties and characteristics to vary accordingly which in turn affect the overall efficiency, and with the increase of speed it is relevant that the efficiency also increased. The maximum operating condition achieved is 70% at the maximum operating condition of the pump. In this experiment the value could not be achieved due to some unavoidable factor such as the condition of the experiment where the apparatus is not in a good working condition and the experiment is conducted not under a standardized condition.

The main objective of the lab was to study centrifugal pumps, aligned in different configurations with varying hydraulic input power, and then analyseits performance. Reviewing the results, it is seen that hydraulic power does not generate more significant efficiency. The head curve for a flow pump is relatively flat and that the head decreases gradually as the flow increases. Note that the brake horsepower increases gradually over the flow range with the maximum generally at the point of maximum flow.

Possible ways to improve this performance could be the reduction of fluid flow rate. A turbulent flow could cause significant resistance to the pump. Another way to improve the performance might be to do the experiment again with more variables. This would contribute to converging on the variable to cause the most considerable performance reduction even though there are many sources of error, the trends that help to see the differences in performance due to shifting alignment and supplied power.

References:

1.) Md Amzad Hossin, PhD Candidate, Pictures and Graphs: https://learn-us-east-1-prod-fleet01-xythos.s3.us-east-1.amazonaws.com/5cc0bc5a4bb1d/7751309?response-content-disposition=inline%3B%20filename%2A%3DUTF-8%27%27Centrifugal%2520Pump%2520Project%2520%2528Experimental%2520Setup%2520and%2520Aligned%2520Theories%2529.pdf&response-content-type=application%2Fpdf&X-Amz-Algorithm=AWS4-HMAC-SHA256&X-Amz-Date=20200421T215005Z&X-Amz-SignedHeaders=host&X-Amz-Expires=21600&X-Amz-Credential=AKIAZH6WM4PLTYPZRQMY%2F20200421%2Fus-east-1%2Fs3%2Faws4_request&X-Amz-Signature=7b12efc5e078a1986cd3300d142763fef95699d33ae63a2247bfd4594874bc93

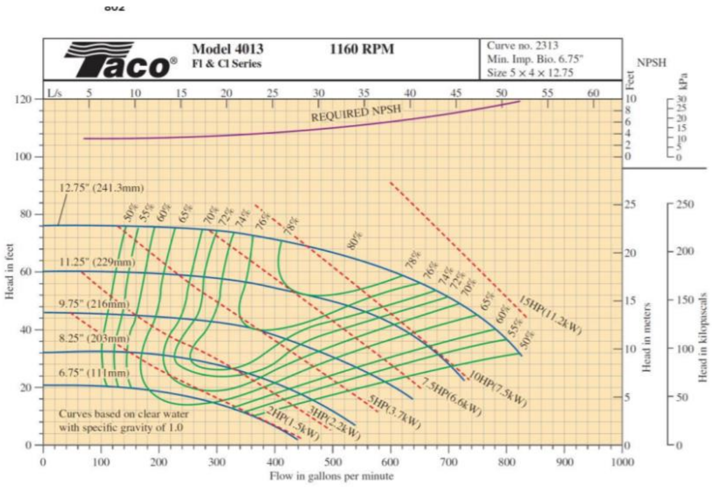
Appendices:

Appendix A: Pump Selection

Calculating power:

Formula: P=VI
Example: 8.3A*230V= 1903 Watt
1909 Watt = 2.52 HP

Appendix B: Net Head:



$$\frac{1}{\sqrt{f}} = -2.0\log\left(\frac{\varepsilon/D}{3.7} + \frac{2.51}{\text{Re}\sqrt{f}}\right) \quad \text{(turbulent flow)} \qquad \textbf{(8–50)}$$

Total head loss (general):

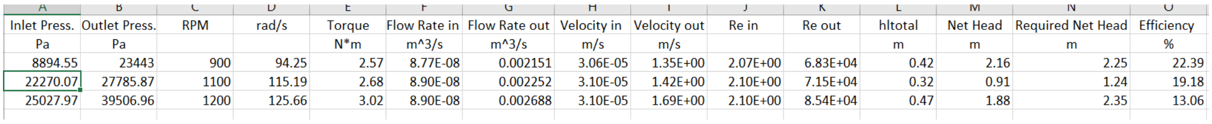
$$h_{L,\text{ total}} = h_{L,\text{ major}} + h_{L,\text{ minor}}$$

$$= \sum_i f_i \frac{L_i}{D_i}\frac{V_i^2}{2g} + \sum_j K_{L,j}\frac{V_j^2}{2g} \qquad \textbf{(8–59)}$$

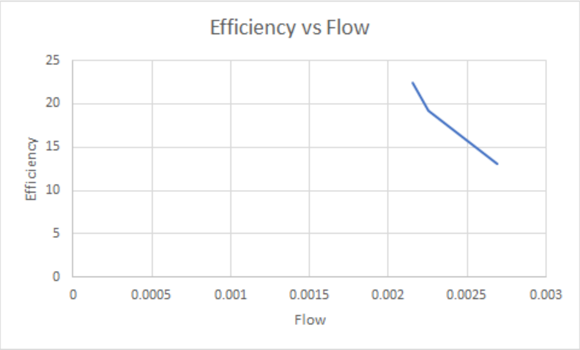
Net head:

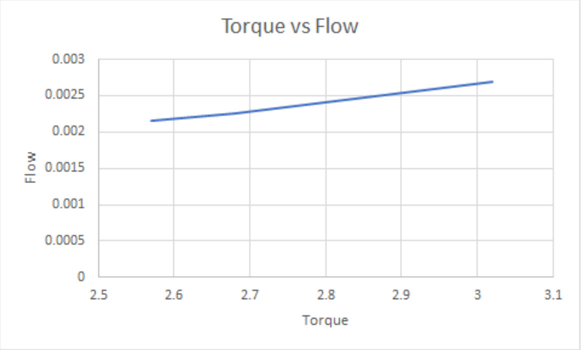
$$H = \left(\frac{P}{\rho g} + \frac{V^2}{2g} + z\right)_{\text{out}} - \left(\frac{P}{\rho g} + \frac{V^2}{2g} + z\right)_{\text{in}} \qquad \textbf{(14–2)}$$

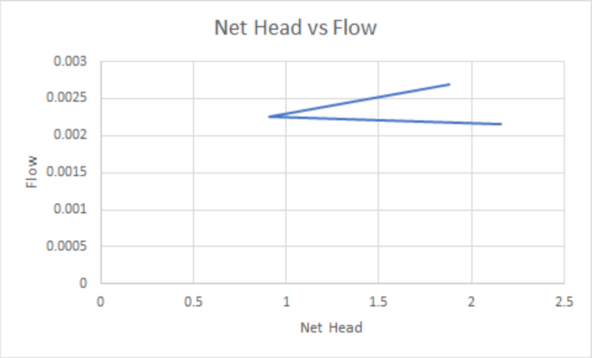
Appendix C: Pump Running at Different RPMs:

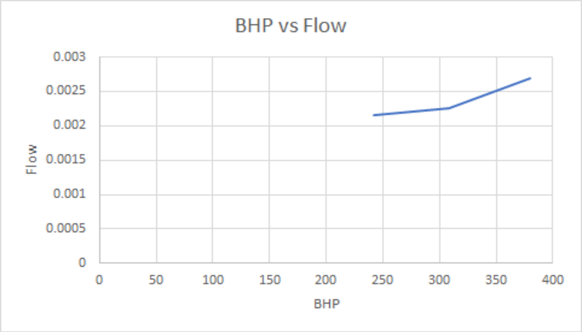


A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Inlet Press.	Outlet Press.	RPM	rad/s	Torque	Flow Rate in	Flow Rate out	Velocity in	Velocity out	Re in	Re out	hltotal	Net Head	Required Net Head	Efficiency
Pa	Pa			N*m	m^3/s	m^3/s	m/s	m/s			m	m	m	%
8894.55	23443	900	94.25	2.57	8.77E-08	0.002151	3.06E-05	1.35E+00	2.07E+00	6.83E+04	0.42	2.16	2.25	22.39
22270.07	27785.87	1100	115.19	2.68	8.90E-08	0.002252	3.10E-05	1.42E+00	2.10E+00	7.15E+04	0.32	0.91	1.24	19.18
25027.97	39506.96	1200	125.66	3.02	8.90E-08	0.002688	3.10E-05	1.69E+00	2.10E+00	8.54E+04	0.47	1.88	2.35	13.06






Net Head vs Flow
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
Flow
0
0.5
1
1.5
2
2.5
Net Head


BHP vs Flow
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
Flow
0
50
100
150
200
250
300
350
400
BHP