NC STATE UNIVERSITY

Mechanical Engineering Systems
BSE At Havelock

(MES-400 Engineering Lab)

Pump Performance

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I have neither given nor received any unauthorized assistance on this report.

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Abstract

The lab was split up into two parts: for part one, the water height in the tank and the inlet and outlet pipe fitting components were geometrically measured. The loss coefficient (k) values were found using previous lab data, looking up the theoretical values in tables, and theoretically calculated. The inlet and outlet delta pressures were summed up and the difference was taken to find the total pressure losses of the respective inlet and outlets. The pump was then tested at 1-10 GPM flow range, the delta pressure of the system was recorded, and the flow rate vs pump head was compared to the manufacturer data. The experimental pump was found to have low efficiencies less than 10 percent for the tested flow ranges.

The pump is designed for high flow applications and therefore requires more input power to perform well, the current pump is not appropriate for the system due to it being a high flow pump designed for high flow applications, the water bench lab does not require much flow through the system, therefore the pump is not efficient for the lab. A low flow pump would be more appropriate for this application.

Introduction

Objective

The objective of the lab is to determine to performance of the water bench flow pump. And to compare the data to the manufacturer's product cut sheet.

Background

In this experiment a centrifugal pump was used. Work is done on the fluid by the centrifugal action and tangential blade force acting on the fluid over a distance, this creates a large increase in kinetic energy of the fluid that flows through the impellor, the kinetic energy is then converted into a pressure as the fluid flows from the impellor into the casing [1].

Relevant Theory

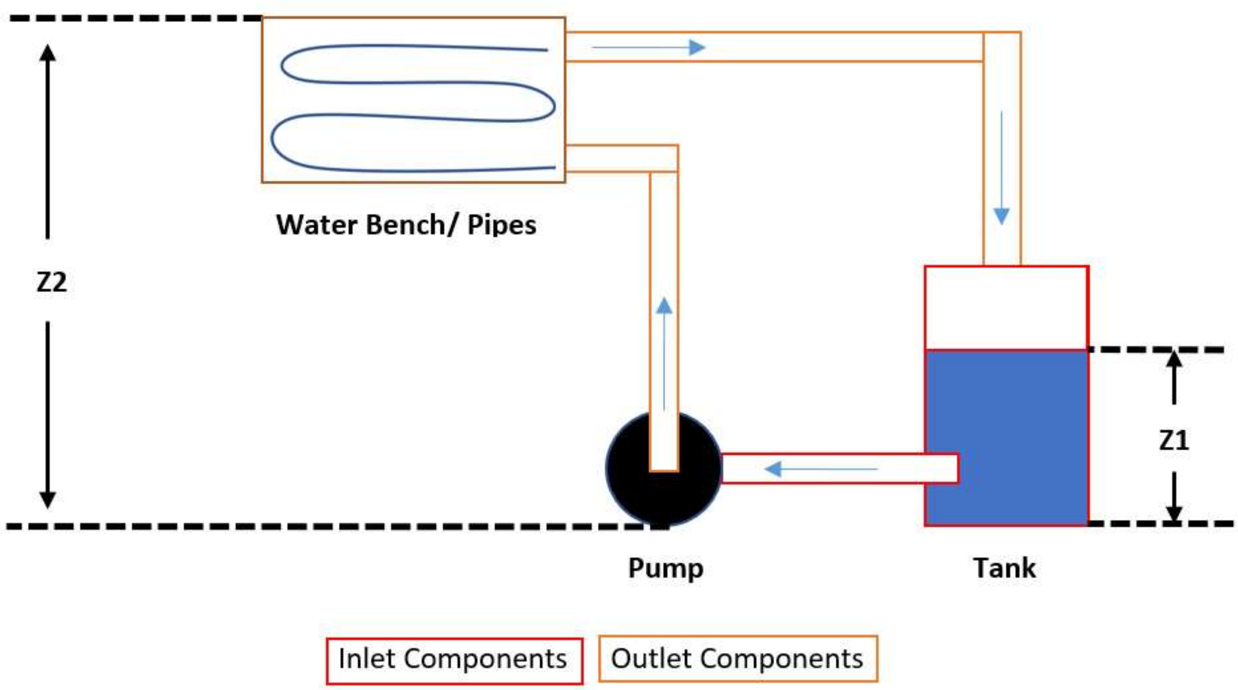

Figure 1: Water Bench Configuration

Figure 1 shows the water bench with pump and tank configuration that was used in the experiment, the blue arrows indicate flow direction. The inlet and outlet components are highlighted with different colors. This is however a simplified diagram of the configuration, the inlet and outlet components are shown in appendix B. The k values were averaged for the respective inlet and outlet components.

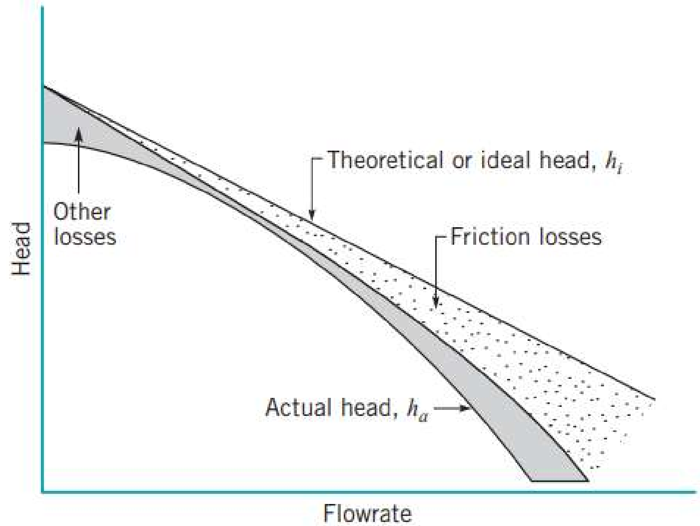

Figure 2: Flow rate curve and effect of losses on pump head [1]

Figure 2 shows the ideal head vs flow rate curve that is typical for centrifugal pumps.

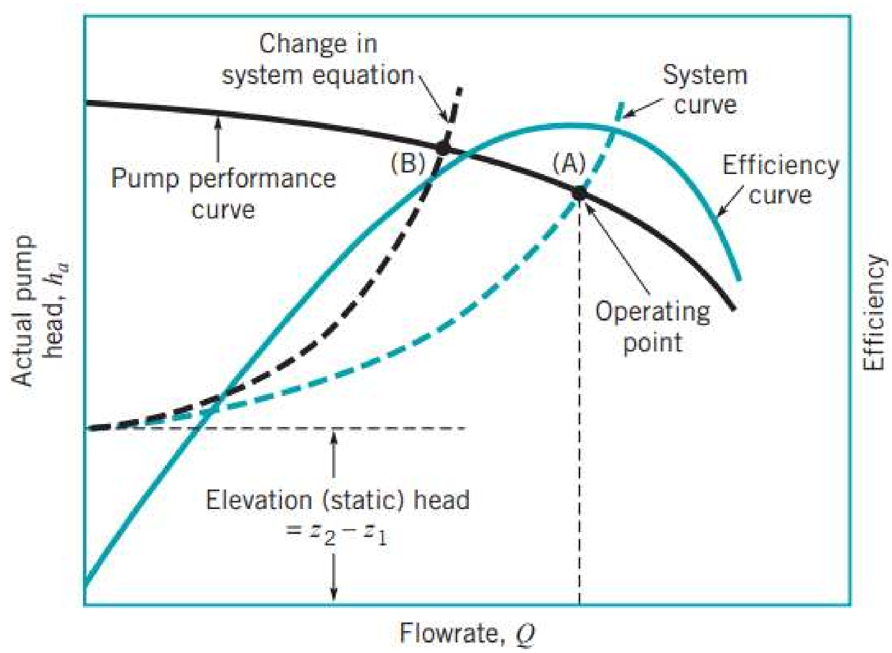

Figure 3: Operating Point of System

Figure 3 shows the system curve and pump performance curve to obtain an operating point for the pump.

The torque applied by the motor to the pump is:

$$T = r * F \tag{1}$$

Where:

F = Force measured by the force scale

r = the distance from the motor shaft centerline to the force scale

The shaft power is:

$$S_p = \omega * T \tag{2}$$

Where:

ω = Pump shaft rotational speed

T = the torque applied by the motor

The shaft power must be expressed in horsepower, the conversion is:

$$H_p = \frac{S_p}{550} \tag{3}$$

Where:

S_p is the shaft power

1 H_p = 550 ft-lb/s

The efficiency of the pump is:

$$n = \frac{P_{out}}{P_{in}} \tag{4}$$

The system curve is calculated from Bernoulli's principle

$$P_1 + \frac{1}{2}\rho V_1^2 + \rho g h_1 + h_{pump} = P_2 + \frac{1}{2}\rho V_2^2 + \rho g h_2 + h_l + \Sigma h_m \tag{5}$$

Because the pressure is assumed to be atmospheric pressure, no velocity, and no initial height, the terms go to zero and the equation can be reduced to

$$h_{pump} = \Delta z + \mathrm{f}\frac{L}{D}\frac{Q^2}{2gA^2} \tag{6}$$

Where:

Δz = the difference in elevation

h_l = The head loss

f = The friction factor

L = The length of the pipe

D = The diameter of the pipe

Q = The flow rate

g = Gravity

A = The area of the pipe

Methods

For the first part of the lab, the inlet fittings were identified, and the appropriate measurements were taken.
The pressure loss of the inlet and exit were calculated
For the second part of the lab

1. The moment arm was measured from the pump centerline
2. The force scale was zeroed out
3. The water bench lab was turned on
4. The bench was run at 3600 RPM at different flows starting with 10 GPM with a change of 1 GPM until roughly 1.5 GPM was reached for the last data point.
5. The pressure was also recorded at these values

Results/Discussions

Table 1: Inlet and Outlet Loss and pressure

Inlet			Outlet		
ITEM	**Loss**	**ΔP (psi)**	**ITEM**	**Loss**	**ΔP (psi)**
1" pipe	0.03	0.01	1" pipe	0.03	0.14
Ball Valve	0.07	0.01	3/4" pipe	0.03	0.02
Expansion	0.2	0.02	Elbow 45	0.236	0.05
Filter	2	0.22	Elbow 90	0.5	0.06
Union	0.3	0.03	Flex Hose	0.025	0.13
Water Height		0.28	Pipe to Bench	0.485	0.69
Total	2.6	0.58	Quick Disconnect	8	1.80
			Reducer	0.25	0.03
			Tee	0.25	0.03
			Union	0.3	0.03
			Total	10.1	2.70

Table 1 is the inlet and outlet loss coefficients and pressure. The pressures and losses were added together to use in the calculations.

Figure 4 below shows the pump performance and system performance along with the efficiency of the pump at different flows.

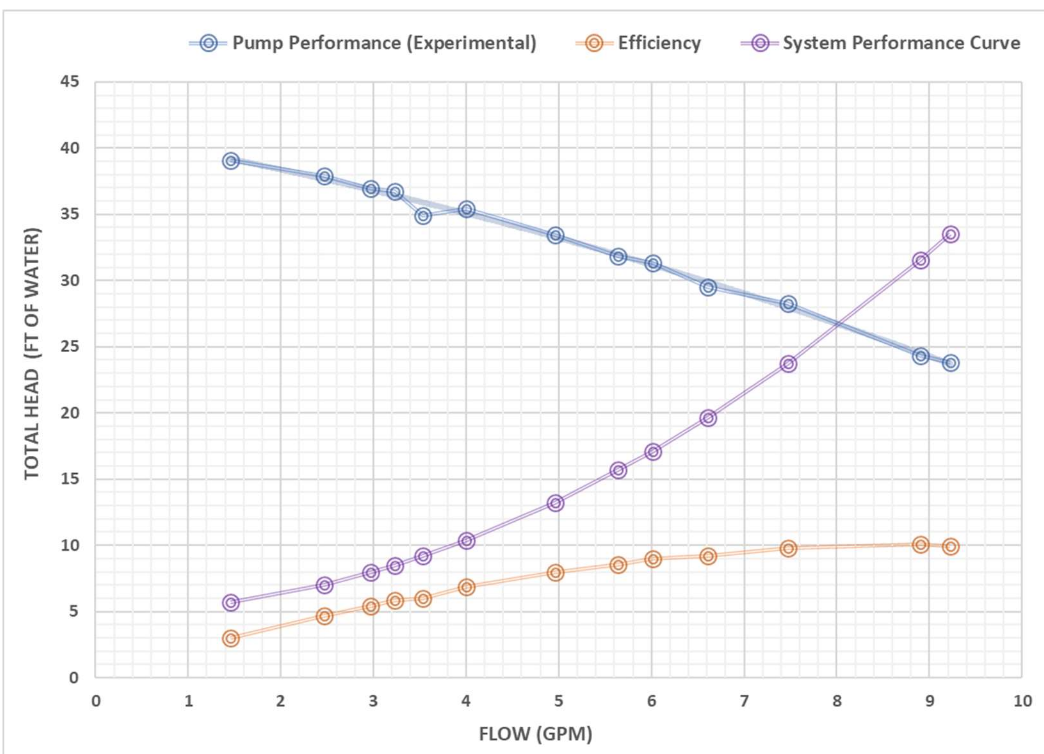

Figure 4: Operating Point of Pump in System

With the pump taken out of the system, and by measuring the inlet and outlet components and calculating the total losses, the performance curve of the system was calculated. The performance curve is what the system/water bench requires. The performance curve for only 1-10 GPM was calculated.

The ideal operating point is found at the intersection of the system curve and the pump curve. Figure 4 shows the ideal operating point of the pump to be 8 GPM. That is where the pump equation and the system equation are both satisfied and where the pump is the most efficient. However, the operating point is not fixed and can be changed because of frictional increases due to fouling in the pipe walls.

Figure 4 is including the Q-H curve of the pump; it shows the total flow against total head of water of the pump. As the flow increases, the head also increases this is due to the increase in pressure.

The efficiency increases as the flow increases, this is common in centrifugal pumps. The efficiency will eventually reach a peak at a set head, the manufacturer recommends a max head of 55 ft for peak efficiency [6].

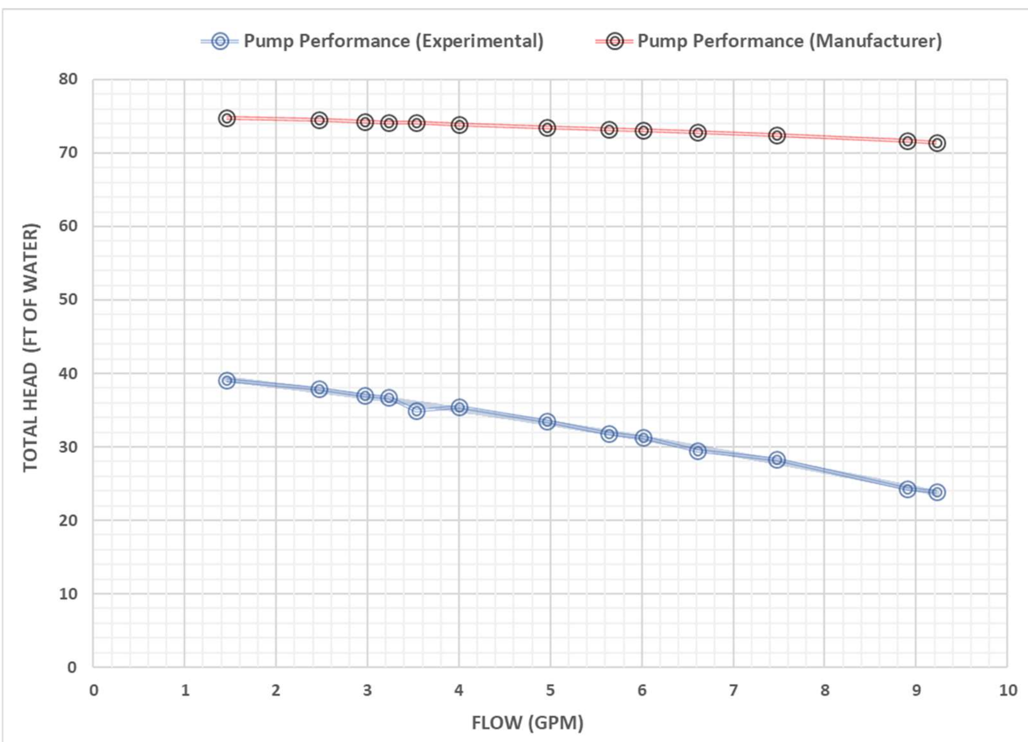

Figure 5: Flow vs Total Head

Since the manufacturer did not provide data for flows less than 10 GPM. The manufacturer data was taken, and curve fitted. The equation from the trendline was used to calculate the head of water at the flows used in the experiment. This data is available in appendix b.

Figure 5 compares the experimental pump performance to the manufacturers comparative data. According to the manufacturer, the head will be around 70-75 GPM for the flows of 1-10 GPM. This is different from the experimental data as it is clear from figure 5 that the head decreases as the flow increases. The manufacturer head data is the ideal head data per figure 2, there is a lot of friction loss in the water bench system, and this is possibly due to the fowling on the pipe walls.

The actual head of the experimental system is less than what the manufacturer recommends, which means that the pump is not optimal for this experiment.

Table 2: Pump Efficiency

Flow Rate (GPM)	RPM	P_{in} (HP)	P_{out} (HP)	Efficiency %
9.225	3528	0.563	0.056	10
8.9	3529	0.546	0.055	10
7.47	3529	0.546	0.054	10
6.61	3530	0.538	0.049	9
6.01	3530	0.529	0.048	9
5.64	3531	0.529	0.045	9
4.96	3531	0.529	0.042	8
4	3532	0.521	0.036	7
3.53	3532	0.521	0.031	6
3.23	3533	0.512	0.030	6
2.97	3533	0.512	0.028	5
2.47	3534	0.504	0.024	5
1.46	3534	0.477	0.014	3

Table 2 shows the pump efficiency and the input and output power, it can be noted that the pump efficiency increases as the flow increases this is due to the pump producing more power towards its output shaft than the power on the input. This is due to the pump being designed more for high flow applications and not appropriate for this bench lab. A low flow pump would be more appropriate for this experiment as the required system horsepower is only roughly 0.50 as shown in table 3 below.

Table 3: Water Bench Power Requirements

Power Requirements		
System Head (ft)	**Flow (GPM)**	**Power Required (HP)**
35.0	20	0.408

Table 2 shows the power requirements needed for the water bench system at a max flow of 20 GPM and a system head of roughly 35 ft; this was calculated using equation 5.

The pump used during the experiment has a 0.75 HP rating, this is too much for the given system which requires roughly 0.5. This is to be expected as the power required for the system is not very

A pump with a rating of 0.5 HP can be purchased commonly through a wide variety of retailers and distributers as this is a standard power.

Conclusions

The operating point found on figure 4 gives the recommended optimal flow that the pump should be used at, in this case it is 8 GPM. The operating point should also take efficiency into account. The efficient operating point can be found at the intersection of the system performance curve and the pump performance curve before the efficiency curve starts to decrease. This is important to know if using a pump in a vehicle, the operating point should be found to establish what conditions the pump can fully operate over for example a temperature range for a vehicle water pump.

There is an offset of -25 of head which is most likely due to increase pressure/friction resistance on the pipe walls due to the turbulent water flow and possible pipe wall fowling. The water was noted to have while particles in the tank, and the filter was visibly dirty. It is unknown if the filter was functioning correctly. The pump used in the experiment has more HP than what was calculated for the system in table 2.

The required HP per table 2 for the water bench is approximately 0.50 HP, this rating can be found on common centrifugal pumps from a variety of manufacturers and are able to be purchased. It would be more efficient to switch to a pump that is close to that power requirement. It can be concluded that while the current pump is able to perform well given the required test flow values, it is not efficient due to being designed for high flow applications. The pump becomes more efficient as the flow increases. This is most likely due to the power input requirements being high for this specific pump and as the flow increases, the power output of the pump increases.

References

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2. https://moodle-courses2122.wolfware.ncsu.edu/mod/resource/view.php?id=17293
3. https://sciencing.com/convert-psi-horsepower-2829.html
4. https://uta.pressbooks.pub/appliedfluidmechanics/chapter/experiment-10/
5. https://pdhonline.com/courses/m128/m128content.pdf
6. https://www.grainger.com/product/DAYTON-Pedestal-Pump-2ZWY3

Appendix A: Data Collection Sheet With Calculations and Notes

Flow Rate (GPM)	Flow (m^3/s)	Velocity (m/s)	Reynolds Number	M dot (kg/s)	System Pressure (pa)	SP (psi)	Pressure (psi)	Pressure (Pa)
9.225	5.820E-04	1.149	14594.645	0.582	660.313	0.096	13.8	95148
8.9	5.615E-04	1.109	14080.470	0.562	614.606	0.089	14	96527
7.47	4.713E-04	0.931	11818.103	0.471	432.970	0.063	15.7	108248
6.61	4.170E-04	0.823	10457.518	0.417	339.016	0.049	16.2	111695
6.01	3.792E-04	0.749	9508.273	0.379	280.263	0.041	17	117211
5.64	3.558E-04	0.703	8922.905	0.356	246.817	0.036	17.2	118590
4.96	3.129E-04	0.618	7847.094	0.313	190.889	0.028	17.9	123416
4	2.524E-04	0.498	6328.301	0.252	124.147	0.018	18.75	129277
3.53	2.227E-04	0.440	5584.726	0.223	96.687	0.014	18.5	127553
3.23	2.038E-04	0.402	5110.103	0.204	80.951	0.012	19.3	133069
2.97	1.874E-04	0.370	4698.764	0.187	68.443	0.010	19.4	133758
2.47	1.558E-04	0.308	3907.726	0.156	47.338	0.007	19.8	136516
1.46	9.211E-05	0.182	2309.830	0.092	16.540	0.002	20.3	139964

Total Pressure (Pa)	Total Pressure (PSI)	Head (Ft)	Head (m)	Force (N)	Torque (N-m)	Ft-lb	RPM	Rad/s	Shaft Power (P_in) (Watts)	P_{in} (HP)	P_out (Watts)	P_{out} (HP)	Efficiency %
71812	10	24	7	6.5	1.138	0.839	3528	369	420.252	0.563	41.795	0.056	10
73191	11	24	7	6.3	1.103	0.813	3529	370	407.436	0.546	41.097	0.055	10
84912	12	28	9	6.3	1.103	0.813	3529	370	407.436	0.546	40.017	0.054	10
88359	13	29	9	6.2	1.085	0.800	3530	370	401.083	0.538	36.848	0.049	9
93875	14	31	10	6.1	1.068	0.787	3530	370	394.614	0.529	35.595	0.048	9
95254	14	32	10	6.1	1.068	0.787	3531	370	394.726	0.529	33.894	0.045	9
100080	14	33	10	6.1	1.068	0.787	3531	370	394.726	0.529	31.318	0.042	8
105941	15	35	11	6	1.050	0.774	3532	370	388.365	0.521	26.735	0.036	7
104217	15	35	11	6	1.050	0.774	3532	370	388.365	0.521	23.210	0.031	6
109733	16	37	11	5.9	1.033	0.762	3533	370	382.000	0.512	22.361	0.030	6
110422	16	37	11	5.9	1.033	0.762	3533	370	382.000	0.512	20.691	0.028	5
113180	16	38	12	5.8	1.015	0.749	3534	370	375.632	0.504	17.637	0.024	5
116628	17	39	12	5.5	0.963	0.710	3534	370	356.202	0.477	10.743	0.014	3

Manufacturer Data	
GPM	Head
10	72
15	67
20	63
30	53
40	41
50	22

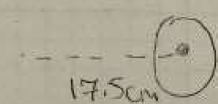
Appendix B: Hand Calculations

Output Power

$T = r \cdot F \rightarrow 0.175\,m \times 6.5\,N = 1.1375\ N\text{-}m$

$Sp = 1.1375\ N\text{-}m \cdot \frac{rad}{s}$

Total pump pressure = Measured P · Pinlet + Poutlet



System Pressure

Assume Atmospheric pressure

Assume 6 bends

Total flow needed 20 GPM

$\frac{1}{2}\rho v^2 + \rho g h + PA \rightarrow \frac{1}{2} \cdot 1000\frac{kg}{m^3} \cdot 1.15\frac{m}{s}^2 + 1000\frac{kg}{m^3} \cdot 9.81\frac{m}{s^2} \cdot 0.6\,m + 100000$

$= 123224 \approx \frac{15\ psi \cdot 20\,GPM}{1714} = 0.18\ HP$

Equipment

Equipment used:
Water Bench Lab
Force Scale
Centrifugal Pump