TEXAS TECH UNIVERSITY

DEPARTMENT OF CIVIL, ENVRONMENTAL, AND CONSTRUCTION ENGINEERING

Lab Report #7: Two-Stage Centrifugal Pump Characteristics

CE 3105 – Fluid Laboratory

Section

Team Number:

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Date of Experiment:

Date of Submission:

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THEORY

For this experiment, we use a machine capable of sending water through a single line of flow, flow in parallel, and flow in series. Pressure readings at different points in the machine allow us to analyze changes across different types of flow. **Figure 1** shows the layout of the machine.

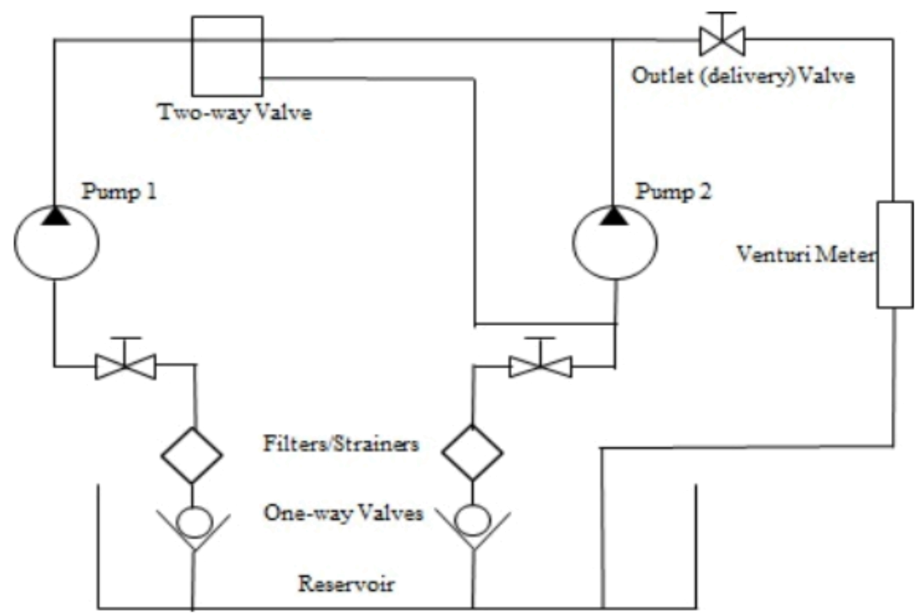

Figure 1: Fluid Pathways Provided by Experimental Machine.
Note that the different paths allow for 3 different types of flow: single, parallel, and series.

For single-line flow, the pressure drop across Pump 1 represents the total head. This is expressed as:

$$= P_{1(out)} - P_{1(in)} \tag{1}$$

For parallel flow, we must consider both pumps. The total head is given as:

$$= \left(P_{1(out)} + P_{2(out)}\right) - \frac{P_{1(in)} + P_{2(in)}}{2} \tag{2}$$

For flow in series, we again consider both pumps. The total head is found using:

$$= P_{2(out)} - P_{1(in)} \tag{3}$$

To find the total mechanical power of the input, we use:

$$W_1 = \frac{2\pi NT}{60} \tag{4}$$

$$W_1 = total\ mechanical\ input\ power\ of\ pump$$
$$N = revolutions\ per\ minute\ (RPM) of\ pump$$
$$T = torque$$

To find the hydraulic power of the pump:

$$W_2 = \qquad (5)$$

$$W_2 = hydraulic\ power\ (horsepower)\ of\ pump$$
$$H = total\ head\ (varies\ based\ on\ flow\ pattern)$$
$$Q = flow\ rate\ (discharge)$$

To find the overall efficiency of the pump:

$$\eta = \frac{W_2}{W_1} \qquad (6)$$

To find the flow rate:

$$Q = C_d A_1 \sqrt{\frac{2\Delta P}{\rho\left(\frac{A_1^2}{A_2^2} - 1\right)}} \qquad (7)$$

$$Q = flow\ rate\ (discharge)$$
$$C_d = coefficient\ of\ discharge\ (0.97)$$
$$A_1 = venturi\ inlet\ area$$
$$\Delta P = pressure\ drop$$
$$\rho = density\ of\ fluid$$
$$A_2 = venturi\ throat\ area$$

Using similarity laws and dimensionless analysis, we derive the following 4 equations:

Table 1: Dimensionless Characteristics of Flow

Solved parameter	Equation	#
Flow coefficient	$C_Q = \frac{Q}{N_r D^3}$	8
Head coefficient	$C_H = \frac{gH}{N_r^2 D^2}$	9
Power coefficient	$C_P = \frac{W_2}{\rho N_r^3 D^5}$	10
Reynold's number	$Re = \frac{\rho N_r D^2}{\mu}$	11

These are the concepts utilized during this experiment and its analysis.

APPARATUS

Figure 2: Two-Stage Centrifugal Pump System and Other Apparatuses used in Experiment

Depicted below is the experimental machine used to collect the data. Not depicted is a thermometer used to measure the temperature of the water.

EXPERIMENT PARAMETERS

1. **Outlet Pressure & Inlet Pressure (lb/ft^2)**

The difference between them is the total head.

2. **Discharge (ft^3/s)**

This is the flow rate.

3. **Input Power & Output Power (ft --- lb/s)**

These were recorded from the machine used during the experiment.

4. **Coefficient of Discharge**

This is a given value. The coefficient of discharge is 0.97.

5. **Flow Coefficient, Head Coefficient, & Power Coefficient**

These can be calculated with equations from the theory portion of the report.

6. **Torque (lbf*ft)**

Torque can be found with the input power and an equation listed in the theory section.

7. **Density (slug/ft^3)**

The density recorded of the water used in the experiment is based on the temperature being 20 degrees Celsius. The density of the water is 1.94 slugs per cubic foot.

8. **Pressure Drop (lb/ft^2)**

This is the change in pressures calculated in the experiment.

9. **Efficiency**

This is the ratio between the output and input powers.

10. **Net Pressure (Pa)**

This is the pressure change across the pump.

11. **Impeller Diameter (ft)**

This is a given value. The impeller diameter is 0.37 feet.

RESULTS

Table 2: Two-Stage Centrifugal Pump Characteristics Collected data – Single Pump Test

Below is the data table of recorded data from the single pump test. The parameters measured were pressure, pressure drop, torque, speed, and power.

P_2	P_3	P_4	ΔP	Torq.	Pump 1 Speed (N_1)	W_1
-.41	.07	.17	.15	.74	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
-.30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
-.22	.80	.96	.04	.55	3025	[illegible]

Table 3: Two-Stage Centrifugal Pump Characteristics Data Sheet – Series Pump Test

Below is the data table of recorded data from the series pump test. The parameters measured were pressure, pressure drop, torque, speed, and power.

P2	P3	P4	ΔP	Torq. (1)	Torq. (2)	Pump 1 Speed (N1)	Pump 2 Speed (N2)	W1 Pump 1	W2 Pump 2
[illegible]	.26	.21	.21	.78	.80	2997	3000	247	252
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.76	3000	3004	[illegible]	240
-.32	.41	1.42	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
-.24	.71	1.96	.06	.58	.60	[illegible]	[illegible]	185	[illegible]

Table 4: Two-Stage Centrifugal Pump Characteristics Data Sheet – Parallel Pump Test

Below is the data table of recorded data from the parallel pump test. The parameters measured were pressure, pressure drop, torque, speed, and power.

P2	P3	P4	ΔP	Torq. (1)	Torq. (2)	Pump 1 Speed (N1)	Pump 2 Speed (N2)	W1 Pump1	W2 Pump2
[illegible]	-.51	.43	.42	.66	.61	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
-.21	-.31	.93	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
-.12	-.14	1.4	.03	.35	.31	3032	3024	[illegible]	[illegible]

Table 5: Two-Stage Centrifugal Pump Characteristics Data Sheet - Calculations

The data table below shows the calculated net pressures, discharges, output powers, and efficiencies of the five trials of each of the three tests.

Test Type	H	Q	W_2	Π

	5[illegible]000	.0[illegible]9	[illegible]20	[illegible]92
	7[illegible]000	.0[illegible]5	1[illegible]8	.[illegible]1
Single Pump	9[illegible]000	.0[illegible]7	1[illegible]	.[illegible]
	9[illegible]000	.0[illegible]8	14[illegible]	.9[illegible]
	1[illegible]8000	.0[illegible]1	1[illegible]6	.9[illegible]
	7[illegible]000	.1[illegible]7	1[illegible]2	.4[illegible]
	9[illegible]000	.1[illegible]2	2[illegible]5	.5[illegible]
Series Pump	12[illegible]000	.1[illegible]3	2[illegible]6	.7[illegible]
	17[illegible]000	.0[illegible]5	3[illegible]9	.9[illegible]
	22[illegible]000	.0[illegible]3	2[illegible]8	1.[illegible]
	84[illegible]00	.1[illegible]8	2[illegible]5	.9[illegible]
	94[illegible]00	.1[illegible]5	3[illegible]3	1.[illegible]
Parallel Pump	119[illegible]00	.2[illegible]7	6[illegible]4	2.[illegible]
	140[illegible]00	.2[illegible]3	8[illegible]5	4.[illegible]
	153[illegible]00	.3[illegible]3	9[illegible]9	6.[illegible]

DISCUSSION

EXPERIMENT PURPOSE

The purpose of this experiment is to observe the performance of a single, series, and parallel connected pumps. From our results we obtained that series pumps had the advantage when it came to achieving a high net pressure(H). Parallel connection provided higher efficiency with a steadier discharge of the higher flow rates.

REPORT QUESTIONS

1. For the Single Pump Test, explain the performance (relation between efficiency, head and flow rate). What do you think is the best efficiency?

From our results we can see that efficiency drops off when the flow rate increases. Flow rate also has an impact towards H and head coefficient. As flow rate decreases both H and the head coefficient increase. We believe that the best efficiency would be around the 80-90% range since the input power increases with a worse efficiency with a lower head coefficient.

2. Compare the performance of series and parallel pump tests against the single pump test.

Both the series and parallel connections tend to achieve a higher H compared to the series pump. The single pump provided slightly better efficiency compared to the series at the with their respective flow rate until they both ultimately achieved better efficiency. The parallel connection yielded a higher H, higher flow rate, and better efficiency to the single pump.

3. How does the total head curve change by parallel and series connections?

The difference in the total head curve between the two is what makes each connection unique. A series connection would have a summation of the heads depending on how many pumps are present. This would result in a much higher head. In a parallel connection the pumps connected would experience the same head in each. The total head curve would be much higher for a series connection compared to parallel.

4. How does the efficiency change by parallel and series connections?

In our results we found that the efficiency of the parallel connections was much higher compared to the series connection. Pumps in parallel are more efficient and provide a steady discharge while series instead in return provide a higher head.

5. Do the efficiencies of this experiment match with the typical large industrial pump efficiency (which is normally about 75%)? Why or why not?

We range of our efficiency varied but found with the curve that our most efficient percentage was close to the large industrial pump efficiency. From our single pump and series connection we saw the most efficient from the results was in the range between 80-90%. Our parallel connections exceeded the percentage. The efficiencies are close but do not match since this experiment was at a much smaller scale.

PRACTICAL APPLICATION

This experiment observers the different behaviors between a single, series and parallel pump. In a practical application, to overcome a very long pipe with a high friction loss or a pipe set up with a high static discharge head, the type of pump would be important. In the experiment we saw that the series pump had the advantage of producing a higher net pressure (H) than the parallel. In this case we would want to use pumps in series to successfully transport the fluid over the very long pipe or pipe with a high static discharge head.

DATA APPENDIX

CE3105 Mechanics of Fluids Laboratory Department of Civil Engineering Texas Tech University

Experiment: Two Stage Centrifugal Pump Characteristics - Data Sheet

Date of Experiment: Name:_

Temperature of water, T= _________ °Celsius Water density, ρ = ________(lb/ft3) Gravity, g= 32.2 (ft/s2

Single Pump Test:

P_2 (bar)	P_3	P_4	Δ P	Torque (1) (N-m)	Pump1 (N_1) rpm	W_1	H kPa	Q ft³/s	W_2 ft/lb-s	η
-.40	.07	.17	.15	.74	3010	235	58	.093	120.23	69 %
-.35	.30	.43	.11	.70	3013	220	72	.085	132.49	85 %
-.30	.47	.61	.09	.66	3016	210	90	.077	144.54	93%
-.28	.57	.71	.07	.63	3017	201	99	.068	140.22	94%
-.22	.80	.96	.04	.57	3024	177	118	.051	126.34	96%

Series Pump Test:

P_2	P_3	P_4	Δ P	Torque (1)	Torque (2)	Pump1 (N_1)	Pump2 (N_2)	Pump1 W_1	Pump2 W_2	H kPa	Q ft³/s	W_2 ft/lb-s	η
-.49	-.26	.21	.21	.78	.80	2997	3000	247	252	70	.117	171.73	[redacted] 47 %
-.46	-.13	.46	.17	.77	.79	2997	3002	242	247	92	.112	214.68	[redacted] 59 %
.24	.07	-.40	.16	.75	.76	3000	3004	235	270	124	.103	265.53	[redacted] 76 %
.32	.41	1.42	.11	.68	.69	3006	3010	215	219	174	.085	308.99	[redacted] 96 %
-.24	.71	1.96	.06	.58	.60	3015	3018	185	188	220	.063	288.49	[redacted] 105 %

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Experiment: Two Stage Centrifugal Pump Characteristics - Data Sh[illegible]

Date of Experiment: [illegible] Name: [illegible]

Parallel Pump Test:

P_2	P_3	Avg Inlet Press	P_4	ΔP	Torque (1)	Torque (2)	Pump1 (N_1)	Pump2 (N_2)	Pump1 W_1	Pump2 W_2	H (kPa)	Q (ft^3/s)	W_2 (ft/lbs)	η
-.31	-.51	-.41	.43	.42	.66	.61	3005	3002	210	194	84	.168	294.88	99%
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.58	3009	3005	300	185	94	.195	383.24	135%
-.21	-.31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]56	119	.247	614.35	255%
-.15	-.20	-.175	1.22	.10	.44	.39	3025	301[illegible]	[illegible]	[illegible]24	140	.283	824.86	425%
-.12	-.14	-.13	1.4	.03	.35	.31	3032	3024	112	100	153	.303	969.13	618%

[illegible]structor's Signature [illegible] Don Bundock

CE3105 Mechanics of Fluids Laboratory
Department of Civil Engineering
Texas Tech University

Experiment: Two-[illegible] al
Date of Experimen[illegible] Jar
Experimental D
Temperature of water, $T=$ celsius   team #2
Water density, $\rho =$ (lb/ft^3)
Gravity, g= 32.2 (ft/s^2)

Single pump Test:

P_2 bar (psf)	P_3 bar (psf)	P_4 bar (psf)	Δ P bar (psf)	Torque (lb·ft)	Pump 1 Speed (N_1)	W_1 (ft·lb/s)	H KPa	Q (ft³/s)	W_2 (ft·lb/s)	η
-0.41	.07	0.17	0.15	0.74	3010 rpm	235	58	0.0993	120	0.692
-0.35	0.30	0.43	0.11	0.[illegible]63	3013 rpm	220	78	0.0850	138	0.851
-0.30	0.47	0.60	0.09	0.66	3016 rpm	210	90	0.0769	145	0.930
-0.28	0.57	0.71	0.07	0.63	3017 rpm	201	99	0.0678	140	0.943
-0.22	0.80	0.96	0.04	0.[illegible]55	3024 rpm	177	118	0.0513	126	0.965

↑ 5 not 4

Instructor's Signature

Series pump Test:

P_2	P_3	P_4	ΔP	Torque (1)	Torque (2)	Pump 1 Speed (N_1)	Pump 2 Speed (N_2)	Pump1 W_1	Pump2 W_1	H KPa	Q	W_2	η
-0.49	-0.26	0.21	0.21	0.78	0.80	2997 rpm	3000 rpm	247	252	70	.117	172	0.465
-0.46	-0.13	0.46	0.19	0.77	0.79	2997 rpm	3002 rpm	242	247	92	.112	215	0.593
-0.40	0.07	0.84	0.16	0.75	0.76	3000 rpm	3004 rpm	235	240	124	.103	266	0.755
0.32	0.41	1.42	0.11	0.68	0.69	3006 rpm	3010 rpm	215	219	174	.0850	309	0.962
-0.24	0.71	1.96	0.06	0.58	0.60	3015 rpm	3018 rpm	185	188	220	.0628	288	1.05

Parallel pump Test:

P_2	P_3	Avg. Inlet Pressure	P_4	ΔP	Torque (1)	Torque (2)	Pump1 Speed (N_1)	Pump2 Speed (N_2)	Pump1 W_1	Pump2 W_1	H KPa	Q	W_2	η
-0.31	-0.51	-0.41	0.43	0.42	0.66	0.61	3005 rpm	3002 rpm	210	194	84	.168	295	.986
-0.28	-0.44	-0.36	0.58	0.36	0.63	0.58	3009 rpm	3005 rpm	300	185	94	.195	383	1.35
-0.21	-0.31	-0.26	0.93	0.21	0.53	0.49	3018 rpm	3011 rpm	170	156	119	.247	614	2.55
-0.15	-0.20	-0.175	1.22	0.10	0.44	0.39	3025 rpm	3019 rpm	138	124	140	.283	825	4.25
-0.12	-0.14	-0.13	1.40	0.03	0.35	0.31	3032 rpm	3024 rpm	112	100	153	.303	969	6.18

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Experiment: Two Stage Centrifugal Pump Characteristics - Data Sheet

Date of Experiment Name:___ ____________

Temperature of water, T= __20__ ◦Celsius Water density, ρ = _______(lb/ft3) Gravity, g= 32.2 (ft/s2

Single Pump Test:

Bar
MSR

P_2	P_3	P_4	Δ P	Torque (1)	Pump1 (N_1)	W_1	H	Q	W_2	η
-.41	.07	.17	.15	.74	3010	235				
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	220				
-.30	.47	.60	.07	.66	[illegible]	210				
-.28	.57	.71	.07	.63	3017	2d				
-.22	.80	.96	.04	.55	3025	177				

Series Pump Test:

P_2	P_3	P_4	Δ P	Torque (1)	Torque (2)	Pump1 (N_1)	Pump2 (N_2)	Pump1 W_1	Pump2 W_2	H	Q	W_2	η
-.49	-.26	.21	.21	.78	.80	2997	3000	247	252				
-.46	[illegible]	[illegible]	.19	.77	.79	2997	[illegible]	242	247				
-.40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	240				
-.32	.41	1.42	.11	.68	.69	3006	3010	215	219				
-.24	.71	1.96	.06	.58	.60	3015	3019	185	188				

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Experiment: Two Stage Centrifugal Pump Characteristics - Data Sheet

Date of Experiment: Name

Parallel Pump Test:

P_2	P_3	Avg Inlet Press	P_4	Δ P	Torque (1)	Torque (2)	Pump1 (N_1)	Pump2 (N_2)	Pump1 W_1	Pump2 W_2	H	Q	W_2	η
-.3[illegible]	[illegible]		43	.42	.66	.61	3005	3002	210	194				
-.28	-.44		[illegible]	[illegible]	[illegible]	[illegible]	3009	3005	200	185				
-.21	-.31		.93	.21	.53	[illegible]	[illegible]	[illegible]	170	156				
-.15	-.20		1.22	.10	.44	.39	3025	301[illegible]	[illegible]	[illegible]				
-.12	-.14		1.4	.03	.35	.31	3032	3024	112	100				

ERROR CALCULATIONS

There are not many sources of error that arise in this experiment since most of our calculations are taken from readings of the indicators on the apparatus. Some of the bar values fluctuated to a range of $\pm .03$.

In our results we also obtained extremely high efficiencies for the parallel connections. We were unable to determine if this error is correct or not, but the calculations follow.

$$\eta = \frac{W_2}{W_1} \; and \; W_2 = (H) \cdot Q \; \rightarrow \; W_2 = \frac{(153000)(.303)}{100000} \cdot 2088.54 = \; 969.13 \, ft \cdot \frac{lb}{s}$$

Then $\eta = \frac{(969.13)}{(156.88)} \cdot 100 = \; 618\%$

We also received very high values when calculating Reynolds number for the single pump. Sample calculation for the possible error.

$$Re = \; \frac{(\rho N_r D^2)}{\mu} = \; \frac{(1.9368 \cdot 315.94 \cdot .37^2)}{2.09e-5} = \; 4009126.7$$

Each Re number ended up having a very high number similar to trial 4 shown above. We also know that the efficiency should not surpass 100 but ended up with values over at the last trial for series and many for parallel.

SAMPLE CALCULATIONS

SINGLE FLOW PLOT

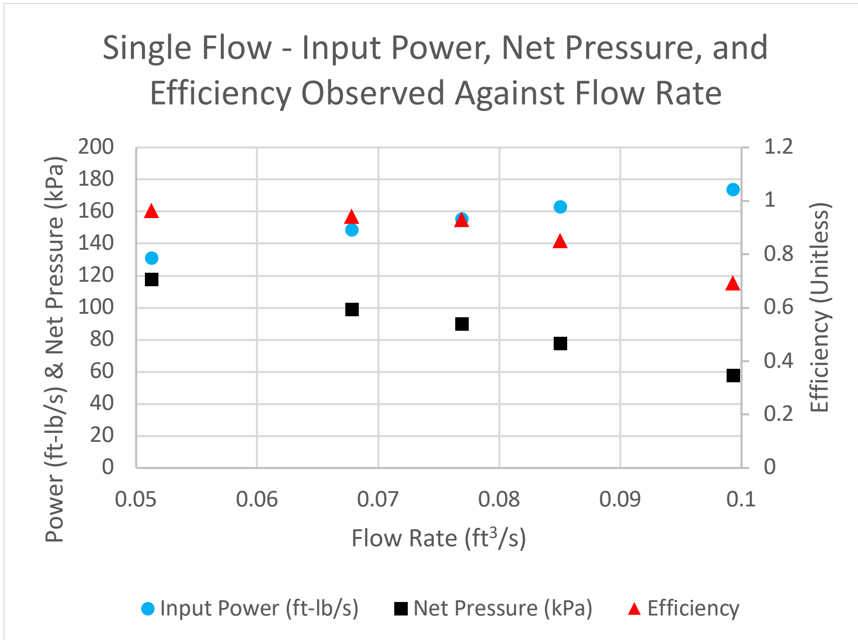

Figure X: Single Flow Parameter Plot. Note the multiple axes.

PARALLEL FLOW PLOT

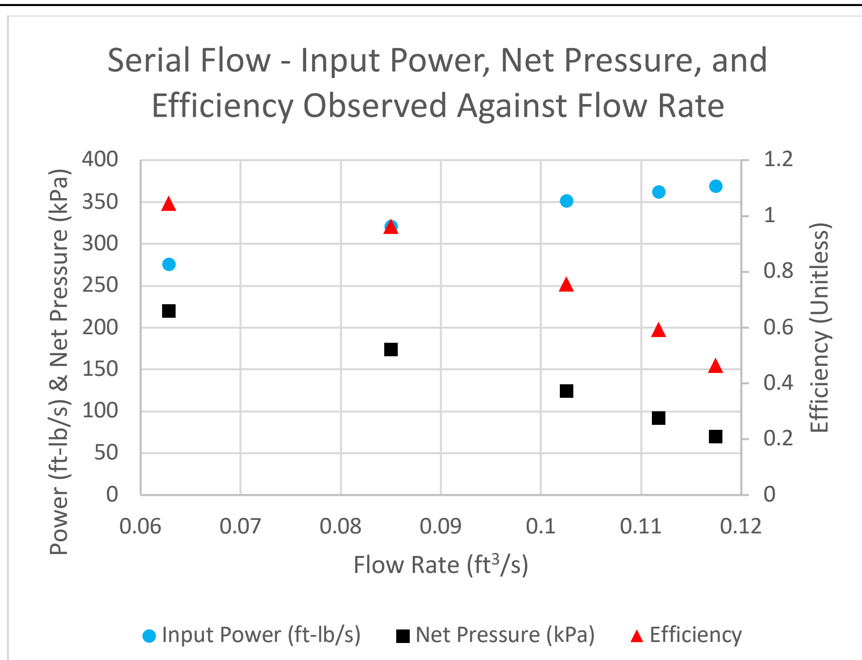

Figure Y: Serial Flow Parameter Plot. Note the multiple axes.

FLOW IN SERIES PLOT

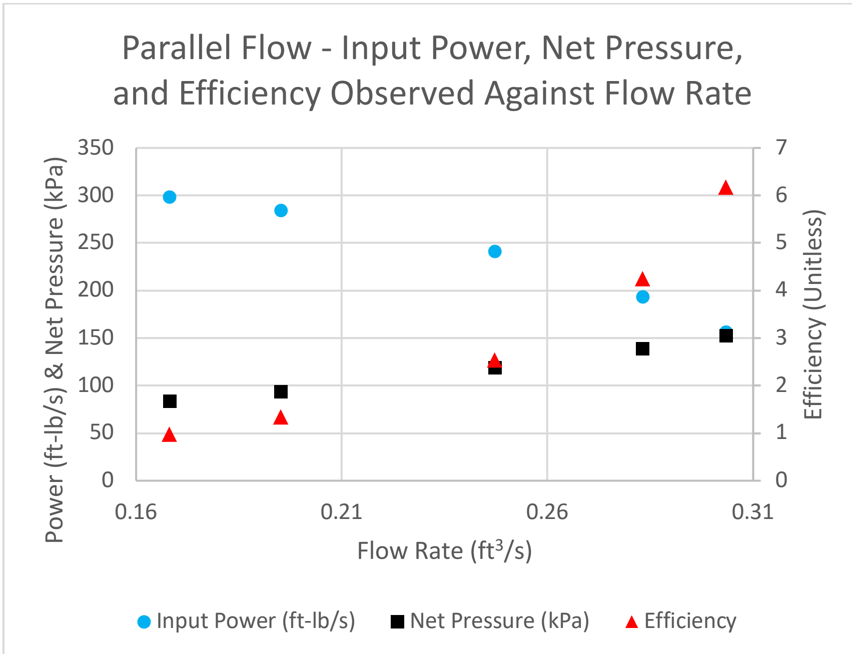

Figure Z: Parallel Flow Parameter Plot. Note the multiple axes.

HEAD LOSS – SINGLE FLOW

Using the formula given in the Calculations portion of the lab handout:

$$H = (P_4 - P_2) * \left(100000\ {}^{Pa}/_{bar}\right)$$

We plug in values from Trial 1 of the single flow arrangement to obtain:

$$H = \left(0.17\ bar - (-0.041\ bar)\right) * \left(100000\ {}^{Pa}/_{bar}\right)$$

$$H = 21.1\ kPa$$

HEAD LOSS – SERIES FLOW

Using the formula given in the Calculations portion of the lab handout:

$$H = (P_4 - P_2) * \left(100000\ {}^{Pa}/_{bar}\right)$$

We plug in values from Trial 1 of the serial flow arrangement to obtain:

$$H = \left(0.21\ bar - (-0.49\ bar)\right) * \left(100000\ {}^{Pa}/_{bar}\right)$$

$$H = 70.0\ kPa$$

HEAD LOSS – PARALLEL PUMP

Using the formula given in the Calculations portion of the lab handout:

$$H = \left(P_4 - \frac{P_2 + P_3}{2}\right) * \left(100000\ {}^{Pa}/_{bar}\right)$$

We plug in values from Trial 1 of the parallel flow arrangement to obtain:

$$H = \left(0.43\ bar - \frac{-0.31\ bar + (-0.51\ bar)}{2}\right) * \left(100000\ {}^{Pa}/_{bar}\right)$$

$$H = 84.0\ kPa$$

DIMENSIONLESS CHARACTERISTICS: SINGLE FLOW

PLOT

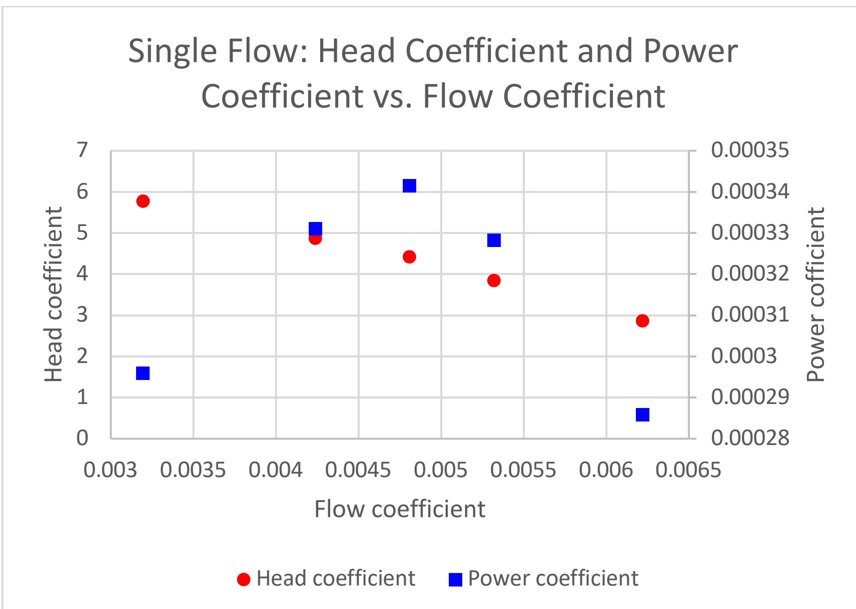

Figure W: Single Flow Dimensionless Characteristics. Note the multiple axes.

REYNOLD'S NUMBER

Despite being checked, double-checked, and triple-checked, these Reynold's numbers ended up being ridiculously high. **Table [INSERT NUMBER HERE!!!]** shows the Reynold's numbers from the various trials. Despite being very high, they are all virtually the same, which is a good sign.

Table 6: Reynold's Numbers for Single Flow Trials

Trial #	1	2	3	4	5
Re	3999824.74	4003811.28	4007797.81	4009126.66	4019757.42