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Series and Parallel Pumps

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Abstract

Pumps are used to transfer fluid in a system, either at the same elevation or to a new height. The needed flow rate depends on the height to which the fluid is pumped. Each pump has a head discharge relationship that is inversely proportional. The objectives of the experiment are to compare the performance of single pumps in series or parallel, to determine the efficiency of the pump and to plot the characteristic pump curve by measuring head and flow rate.

With the results in this experiment we will demonstrate that when a pump is in parallel is to increase the flow rate meanwhile when pump in series is to pump the fluid, in this case water, to a specific height that we want. Hypothetically, if two pumps are combined in parallel, the flow rate will be twice as much as if a pump were to be in series for a given head.

Introduction

The trend of the times in power plant equipment shows clearly a movement from the creation following the rotary type of machine, whether blower, motor, pump, or turbine. All but a few pumps used in water utilities are centrifugal pumps. Centrifugal pump is one of the most important developments in this evolution. Apart from its low cost and durability, it has a high pumping elasticity. Centrifugal pumps are mostly used together to increase either the flow rate or the delivery pressure beyond that available from the single pump. Two typical pumping system designs are parallel and series in which each are distinct due to their certain performance criteria. In serial operation, the heads of the pumps are added and in parallel operation the flow rates of the pumps are added.

In this experiment, we will be able to analyze the characteristic behavior for single operation and interaction of two pumps. The machine consists of a tank and pipework which delivers water to and from two identical centrifugal pumps. The unit is fitted with electronic sensors which measure the process variables. Signals from these sensors will be transferred to a computer via an interface device, and the unit is supplied with data logging software as standard.

The required fluid flow rate is dependent on the height to which the fluid is pumped. The relationship is inversely proportional between flow rate of the fluid and the head produced by the pump. In other words, if high discharge is required, the pump will supply lower head and vice versa. Pumps are connected in parallel to increase the flow rate at a given value of head while, pumps are connected in series are to increase the height to which the fluid can be pumped at a given flow rate. When two or more identical pumps are operated in parallel, their individual volume flow rates are summed. The performance of a pump is characterized additionally by its net head H, defined as the change in Bernoulli head between the inlet and outlet of the pump

$$\text{Hp} = \left(\frac{P}{\rho g} + \frac{V^2}{2g} + z\right)_{\text{out}} - \left(\frac{P}{\rho g} + \frac{V^2}{2g} + z\right)_{\text{in}} + \sum head\ losses.$$

Net head is proportional to the useful power actually delivered to the fluid. It is traditional to call this power the water horsepower, even if the fluid being pumped is not water, and even if the power is not measured in units of horsepower.

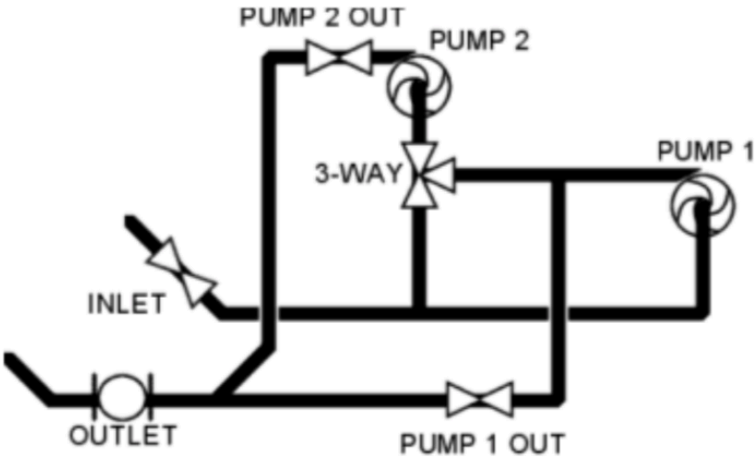


Figure 1: Scheme of the Used apparatus without any flow.

Figure 1 indicates the number of pumps and the pattern of the working machine. In our case, the number of pumps used for this lab is 2. Based on these two pumps, we can determine the flow rate of each pipe when we are using them in series or parallel.

Procedure

Pump Performance Curve:

1. Ensure that the pump speed is set to 100%, the flow control valve is fully open and the readings in the software are stable.
2. Select the icon to record the sensor readings and pump settings on the results table of the software.
3. Observe the maximum flow rate reading obtained then divide this by 10 to give suitable increments when adjusting the flow control valve.
4. Gradually close the flow control valve to achieve 90% of the maximum flow, allow the

readings to stabilize then select the icon again.
5. Repeat while reducing the flow rate in 10% steps, recording a data sample at each step, with a final set of data taken at 0% flow rate (flow control valve fully closed).

System Curve:

1. Flow through the pump will be changed by varying the speed setting using the PC rather than by varying the outlet flow control valve as in the previous set of measurements.
2. Select the icon to create a new results sheet.
3. Ensure that the pump speed is set to 100%.
4. Select a position for the outlet flow control valve (gate valve) such that it is partly closed and forming a significant resistance to flow e.g. approximately 40% of the maximum available flow rate. This setting will be maintained throughout this part of the exercise.
5. Allow the readings in the software to stabilize then select the icon to record the sensor readings and pump settings on the results table of the software.
6. Set the pump to 90%, allow the readings to stabilize then select the icon again.
7. Repeat while reducing the pump speed setting in 10% steps, recording a data sample at each step, with a final set of data taken at 0% pump speed. These measurements will produce the 'system' head-flow curve, as described in the Theory section.

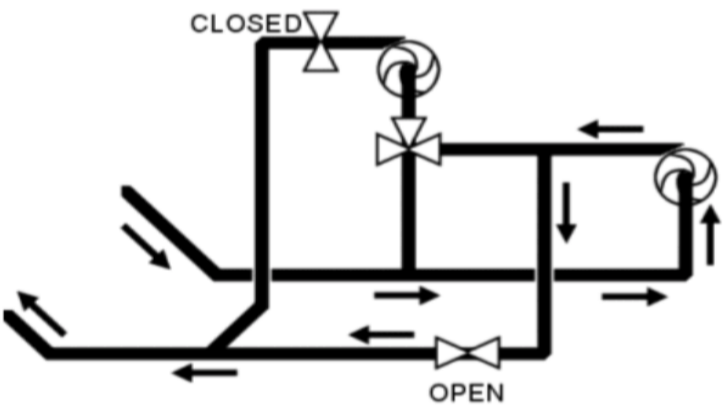


Figure 2: Pump one is being used.

Figure 2 shows that only pump 1(pump on the right) is the only one in operation and the other half of the apparatus has closed pipes.

Pumps in Series:

1. Create a new results sheet using the icon. Rename this new result sheet to 'Series'.
2. In the software, on the mimic diagram, set the 'Mode' to 'Series' by selecting the appropriate radio button.
3. Open Pump 2 outlet valve, close Pump 1 outlet valve and wait for any air to circulate out of the system.
4. Select the icon to record the sensor readings and pump settings on the results table of the software.
5. Close the gate valve to reduce the flow by a small increment. Select the icon again.
6. Continue to close the gate valve to give incremental changes in flow rate, recording the sensor data each time.
7. After taking the final set of data, fully open the gate valve again.

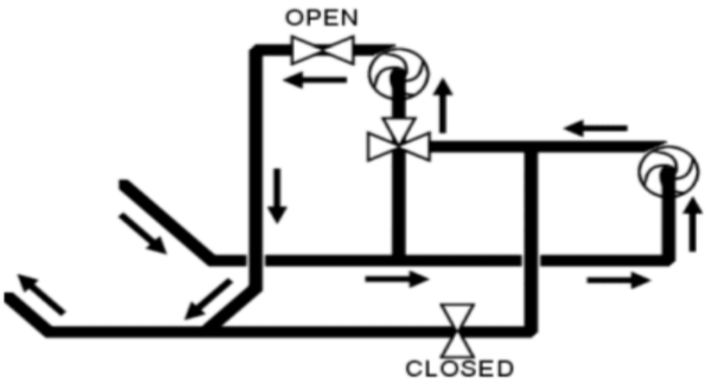


Figure 3: Pump 1 and 2 working in Series.

Figure 3 is similar to figure 2 but this time, we were required to open the other half of the apparatus so we could have two pumps in operation to get a series connection.

Pumps in Parallel:

1. Both pumps must be used at the same setting in this experiment, to ensure identical performance. As the speed of Pump 2 is fixed at its design operational point, Pump 1 should be set to match – select 80% for a 50Hz electrical supply, or 100% for 60 Hz.
2. Allow water to circulate until all air has been flushed from the system.

3. Exercise F should be performed before this experiment, and the results loaded into the software if the software is not still open from that exercise. If the software is still open from Exercise F then create a new results sheet by selecting the icon.
4. Rename the current (blank) results sheet to ‘Parallel’.
5. Select the icon to record the sensor readings and pump settings on the results table of the software.
6. Close the gate valve to reduce the flow by a small increment. Select the icon again.
7. Continue to close the gate valve to give incremental changes in flow rate, recording the sensor data each time.
8. After taking the final set of data, fully open the gate valve. Set Pump 1 to 0% and switch off both pumps.

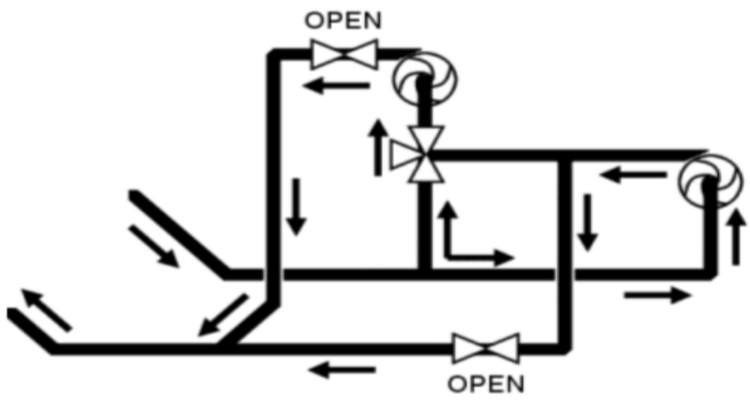


Figure 4: Pump 1 and 2 are in Parallel.

Figure 4 shows that all the pipes and pumps are running at the same time. This means that we will be getting two pumps that are in parallel.

Results

For our experiment, we first were required to obtain the characteristic curve. The pump characteristic curve is influenced by the size and design of the pump, the size of the impeller diameter, as well as the magnitude of the operating rotation. The characteristics of a pump are shown through a head vs flow pump. On this curve also included some information about the associated pump such as BHP, NPSHR, hydraulic efficiency point, and pump power characteristics.

The following table show the number of trials done in the lab while only using one pump. Thanks to a program controlling the apparatus, we were able to obtain important values such as the flow rate and the head for each trial which can be used for future graphs.

Table 1: Single Pump Outside Pump 1 (Pump Performance Curve).

Trial	Q(L/s)	Q(m^3/s)	Total Head(m)
1(100%)	1.731	$1.731 * 10^{-3}$	6.41
2(100%)	1.700	$1.700 * 10^{-3}$	6.50
3(100%)	1.615	$1.615 * 10^{-3}$	7.10
4(100%)	1.231	$1.231 * 10^{-3}$	8.10
5(100%)	0.865	$8.65 * 10^{-4}$	8.93
6(100%)	0.308	$3.08 * 10^{-4}$	9.14
7(100%)	0.000	0.000	9.51

In figure 5, we can see that the performance for a single pump has a concave down curve. This simply means that as we increase the amount of flow rate, the total head decreases. A single pump placed in a pipeline to move water from one reservoir to another reservoir or to a demand point represents the most common pump-application scenario. Determining the flow rate that is produced in these pump-pipeline systems requires knowledge of both pump operation and pipeline hydraulics.

Figure 5: Single Pump Performance Curve

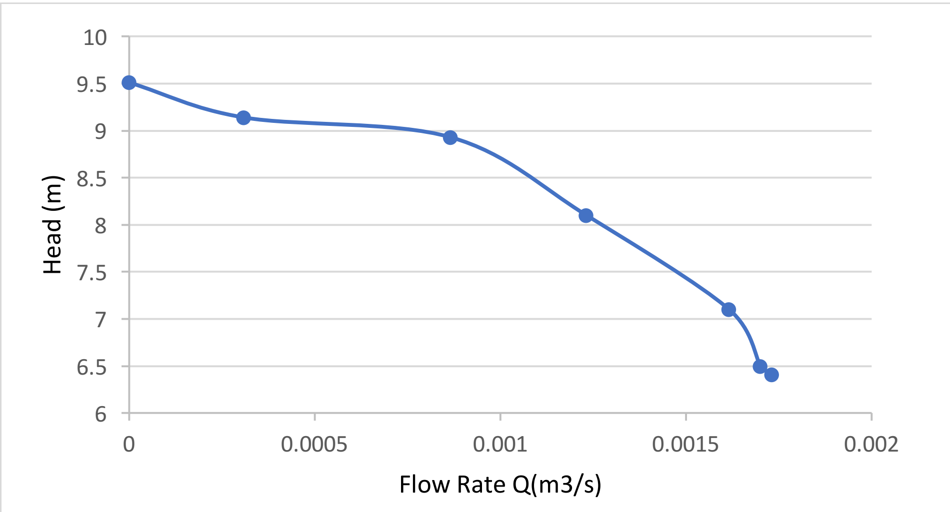


Table 2 is similar to table 1 but this time, we start to close the valve consistently. We can tell that as the flow rate increases, the total head decreases. Based on these values, we are able to obtain our “System Curve” as shown in figure 6. A system head curve is a common type of tool used in pump selection and system design and sizing. It combines elements of the performance (H-Q) curve of the specific pump under consideration with the combined static, operating, and frictional loss heads (the total dynamic head or TDH) of the system under design.

Table 2: Single Pump Outside Pump 1, while valve partially closes 20%(System Curve).

Trial	Q(L/s)	Q(m^3/s)	Total Head(m)
1(100%)	1.711	$1.711 * 10^{-3}$	6.72
2(90%)	1.615	$1.615 * 10^{-3}$	5.61
3(80%)	1.404	$1.404 * 10^{-3}$	4.40
4(70%)	1.122	$1.122 * 10^{-3}$	3.42
5(60%)	1.019	$1.019 * 10^{-3}$	2.44
6(50%)	0.846	$8.46 * 10^{-4}$	1.52
7(40%)	0.673	$6.73 * 10^{-4}$	0.94

Figure 6: System Curve from Single Pump Partially Closed 20%

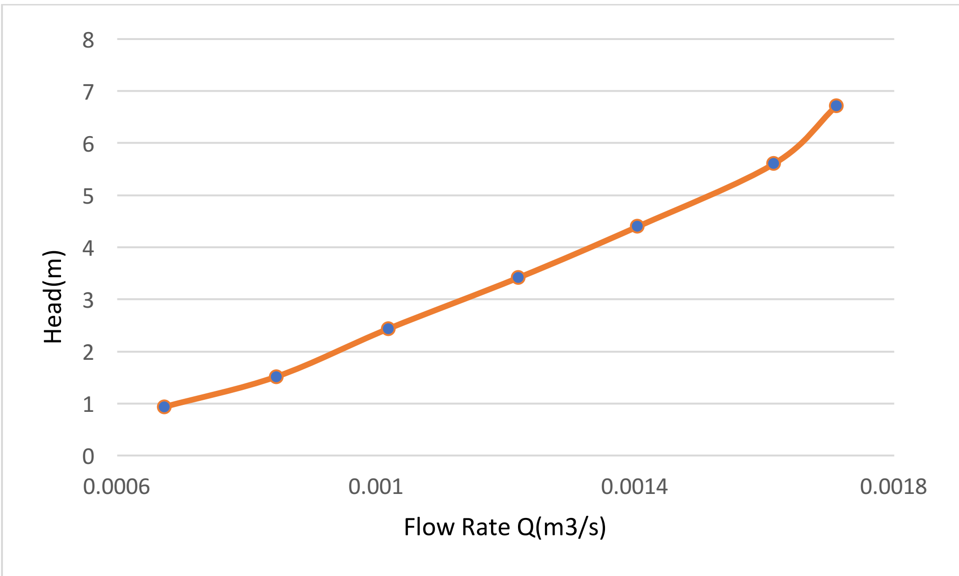


Figure 7 represents the intersection point of the previous two curves which is generally considered as the actual operating point or the condition of service (COS) for the pump. System head curves can be a valuable tool for analyzing pumping systems with different pumps, multiple or variable head conditions, multiple pump speeds. They are adaptable for low or high head conditions, multiple flow conditions, or with one or more pumping units. In our case an estimate for the intersection is where Head is ~6.5 m and Q~0.001615 m^3/s.

Figure 7: Single Pump Analysis

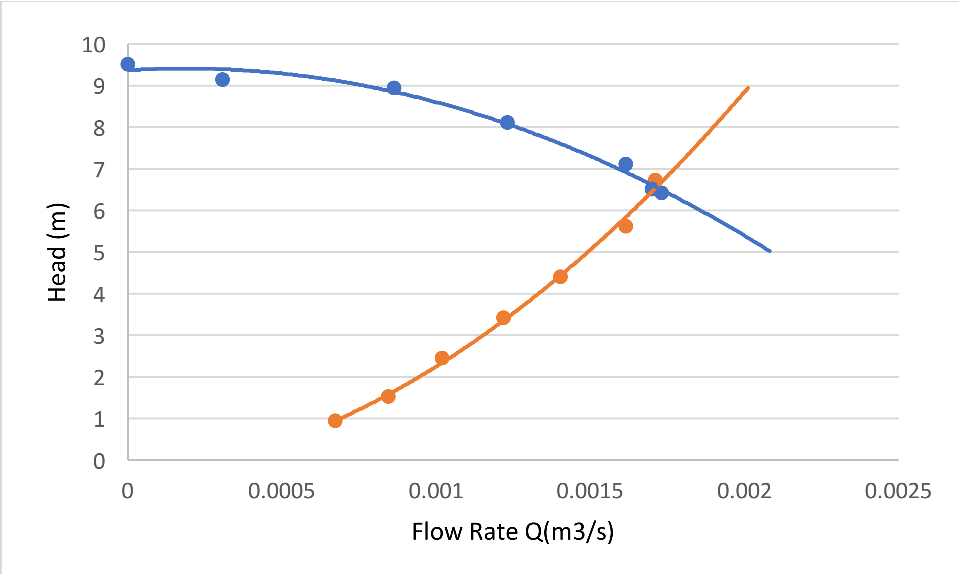


Table 3 represents the 7 trials while using two pumps connected in series. Two pumps may be connected in series, so that water passes first through one pump and then through the second. When two pumps operate in series, the flow rate is the same as for a single pump but the total head is increased. In figure 8, we can notice that as Q starts to increase, the total head is decreasing.

Table 3: Trials for Two Pumps in series

Trial	Q(L/s)	Q(m^3/s)	Total Head(m)
1(100%, 100%)	1.711	$1.711 * 10^{-3}$	6.87
2(100%, 100%)	1.654	$1.654 * 10^{-3}$	7.90
3(100%, 100%)	1.596	$1.596 * 10^{-3}$	8.30
4(100%, 100%)	1.500	$1.500 * 10^{-3}$	9.19
5(100%, 100%)	1.442	$1.442 * 10^{-3}$	9.90
6(100%, 100%)	1.250	$1.250 * 10^{-3}$	11.53
7(100%, 100%)	1.000	$1.000 * 10^{-3}$	13.70

Figure 8: Pump in Series

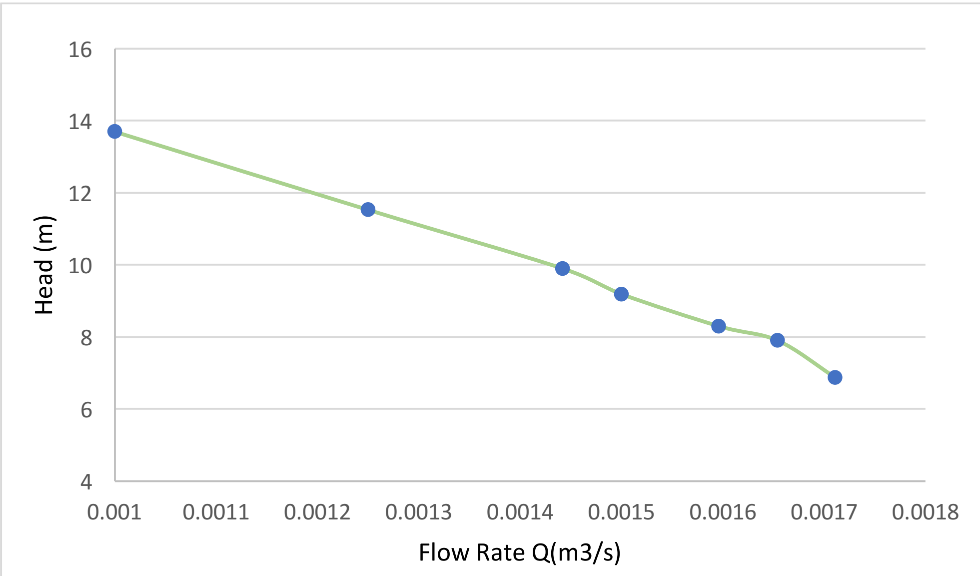


Figure 9 compares the curvature of the single pump and the pumps connected in series. By the graph, we can tell that when we switch to series, we can almost get the double the amount of head from the single pipe meanwhile the flow rate is almost the same.

Figure 9: Comparison of Single Pump and Pumps in Series

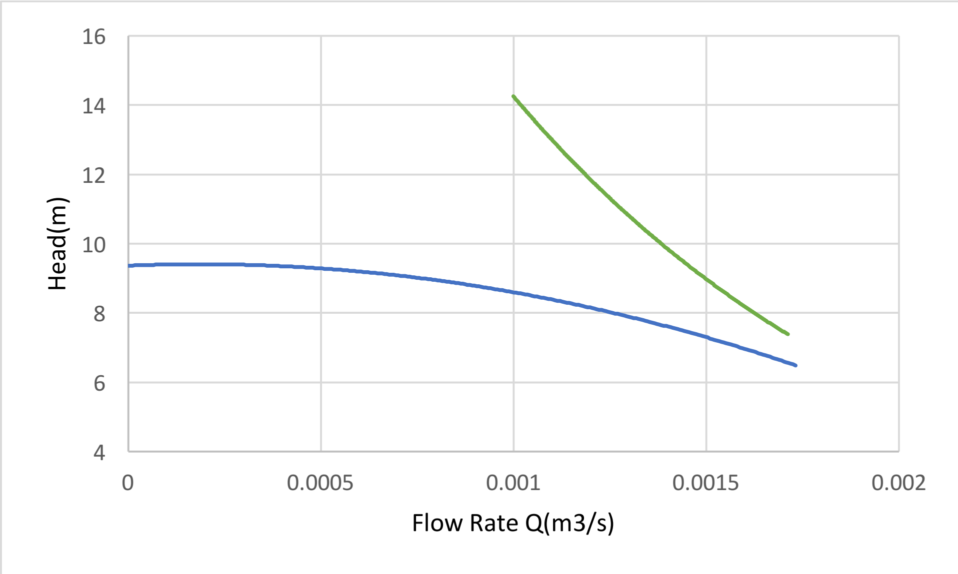


Table 4 includes the data for the trials using parallel pumps. Figure 10 demonstrates more in detail what is happening while the apparatus is running with all opened pipes and two operating pumps. Figure 11 is comparing the single pump and the pipes in parallel. We can see that the curve for the parallel pipes has shifted slightly to the right which makes sense since parallel pumps have the purpose of giving more flow rate to the system.

Table 4: Trials for Two Pumps in Parallel

Trial	Q(L/s)	Q(m^3/s)	Total Head(m)
1(100%, 100%)	2.500	$2.500 * 10^{-3}$	6.96
2(100%, 100%)	2.325	$2.325 * 10^{-3}$	6.83
3(100%, 100%)	2.211	$2.211 * 10^{-3}$	6.76
4(100%, 100%)	2.057	$2.057 * 10^{-3}$	7.10
5(100%, 100%)	1.884	$1.884 * 10^{-3}$	7.13
6(100%, 100%)	1.615	$1.615 * 10^{-3}$	7.14
7(100%, 100%)	1.000	$1.000 * 10^{-3}$	7.65

Figure 10: Pumps is Parallel Curve

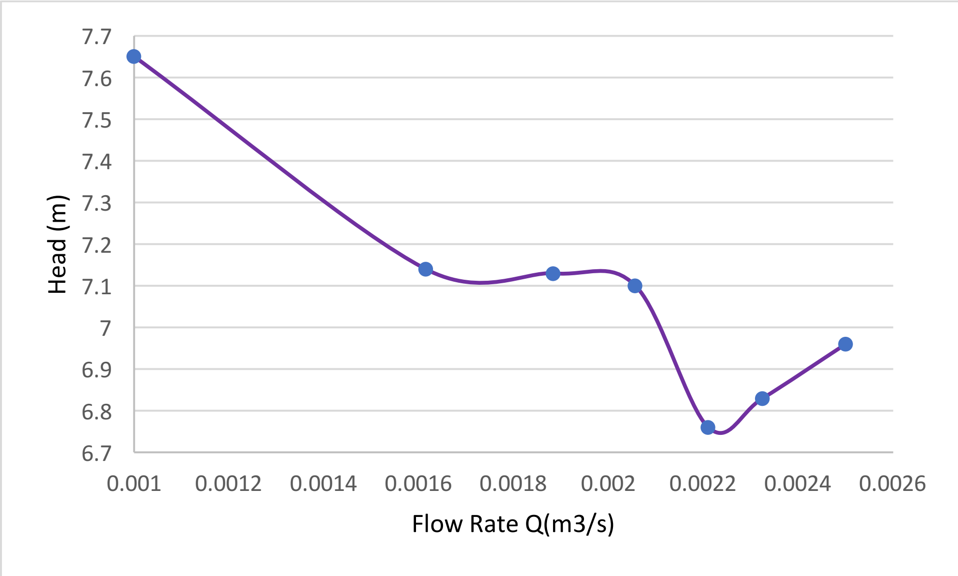
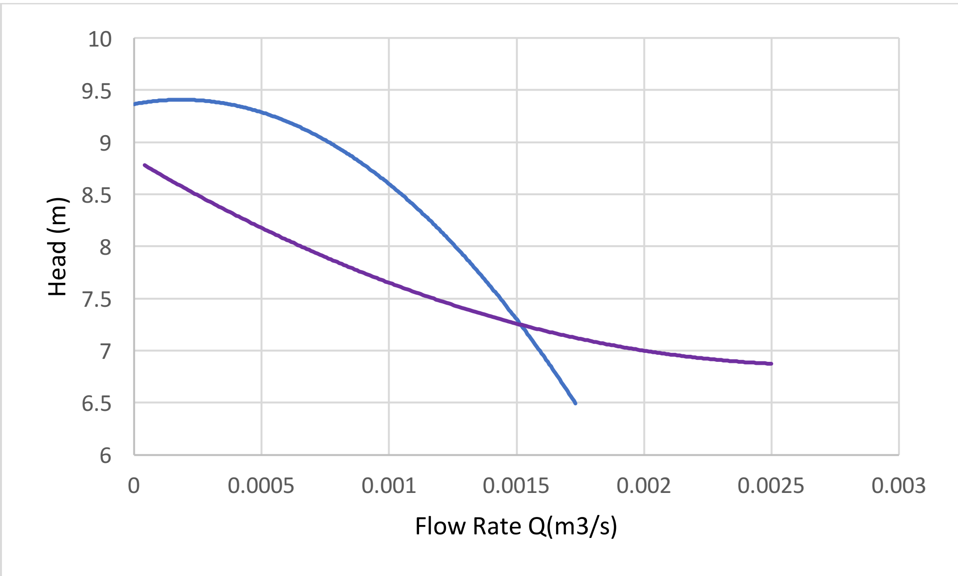


Figure 11: Comparison of Single Pump and Pumps in Parallel



In our next two figures 12 and 13 is a combination of our system along the single pipe, pipes in series and pipes in parallel. To have a better graphical result we had to use polynomial functions to show proper curves for each pump. We can also see that almost all curves have an interaction point at H~ 7 m with a Q of 0.0016.

Figure 12: Single, Series and Parallel Pumps Analysis

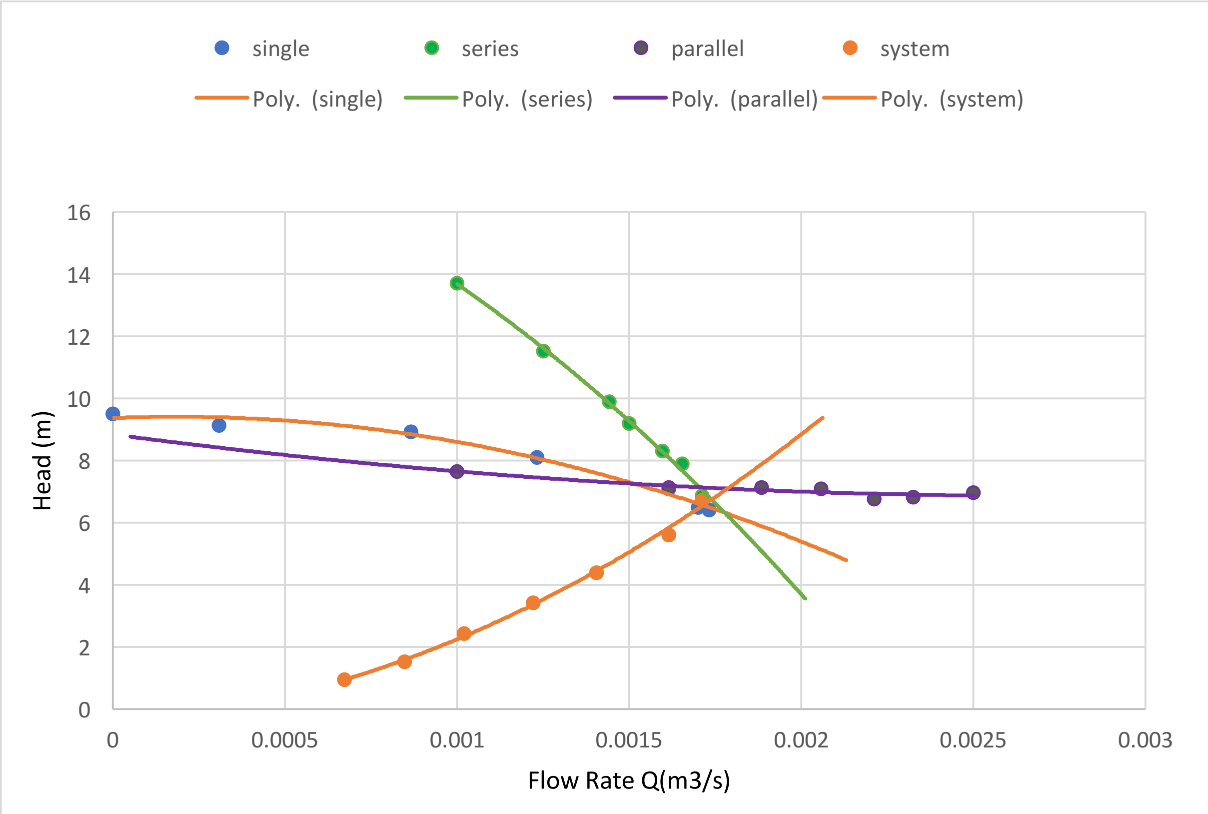
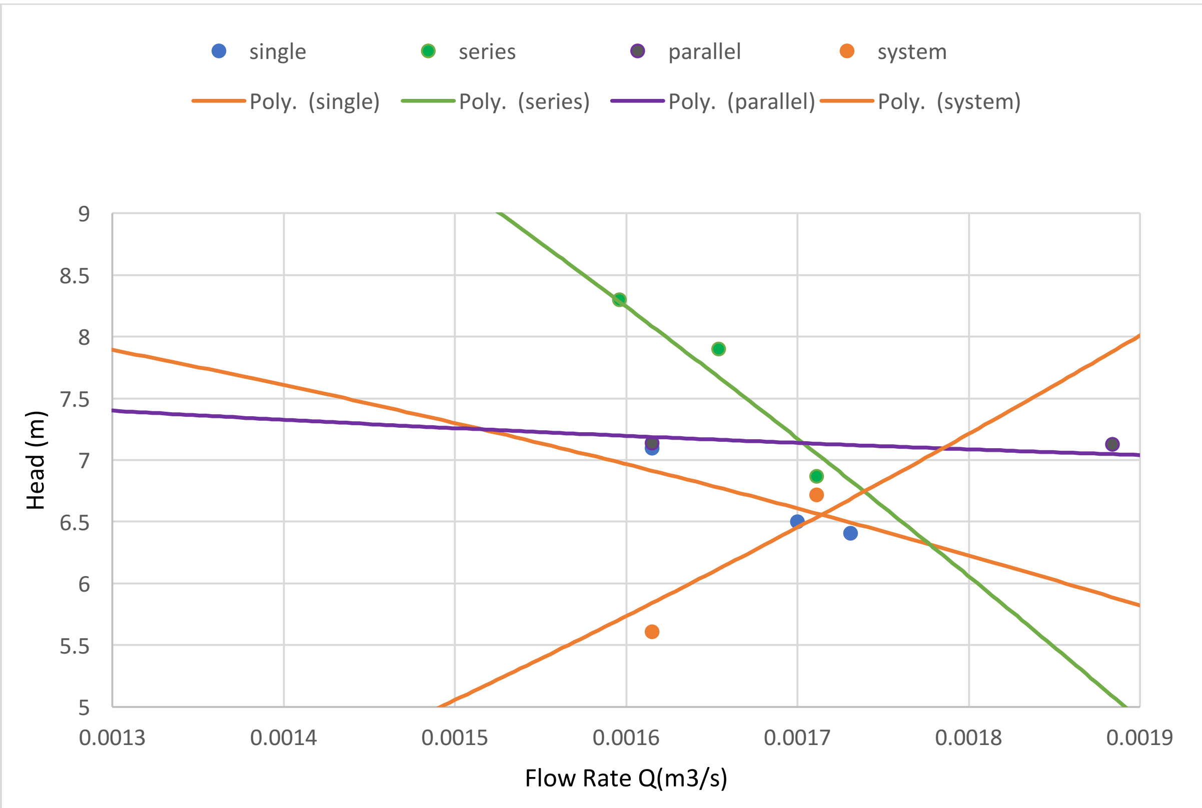


Figure 13: Intersection of Curves



Discussion of Results

For series and parallel pumps, the flow rate is inversely proportional to the total head. The relationship curve for series is steeper than the parallel series curve. Both cases take into account 2 pumps. Both series and parallel pumps need a higher flow rate in order to yield a lower pump head. The performance curve is still however steeper than either the parallel or series pump curves.

A single pump was used to determine a system curve and performance curve. According to the table and graph, the pump head decreases as a higher flow rate is generated.

However, a lower flow rate is generated for a lower pump head than either the series or parallel curve.

When two pumps operate in series, they produce same discharge, but the total head is increased. It is good to use pumps in series where we have to pump fluids over long distances and need to increase pressure along the way to overcome friction losses and pressure drop. One of the examples would be oil pipes that transport crude oil over long distances. In theory, if two pumps are combined in series, the pumping system will produce twice the head for a given flow rate. We analyzed a figure 3 (flow rate versus total head for single and series pump) and calculated the difference between the total head gain for single and series pumps:

Table 5: difference between the capacity for Single and Series pumps.

Single Pump Total Head(m)	2 Pumps in Series Total Head(m)	ΔH
6.41	6.87	0.46
6.50	7.90	1.20
7.10	8.30	1.20
8.10	9.19	1.19
9.14	9.90	0.76
9.51	11.53	2.52
8.93	13.70	4.77

When two pumps operate in parallel, they produce higher discharge, but the total head stays the same. Parallel pump arrangements are very common in industrial applications. Sometimes pump in parallel can be used as back up pump – if main one fails, or higher flow rate has to be achieved at the particular moment. Used in wastewater or industrial water supply applications. In theory, if two pumps are connected in parallel, the pumping system will produce twice the flowrate for a given head. To check this statement in real life we did this experiment. We analyzed a figure and calculated the difference between the total flowrate gain for single and series pumps.

Table 6: difference between the capacity for Single and Parallel pumps.

Single Pump Total Head(m)	2 Pumps in Parallel Total Head(m)	∆H
6.41	6.96	0.55
6.50	6.83	0.33
7.10	6.76	0.34
8.10	7.10	1.00
9.14	7.13	2.01
9.51	7.14	2.37
8.93	7.65	1.28

Conclusion

As a conclusion, based on the data obtained, some of the objectives of the experiment are accepted and have been achieved successfully. By measuring flow rate and head, we were able to analyze and compare the results of pumps in series and parallel. Pumps in parallel, the flow rate Q is split between the pumps at the inlet. Whereas, in a series positioning, each pump handles the same flow rate except the total head produced by the combination of pumps will be additive. The efficiency curve of two or more identical pumps in series or parallel will be the same as each individual pump.

References

1) Hydraulic Engineering Laboratory Experiments for CE 365, Hydraulics and Hydrology. 2014 Department of Civil Engineering The City College of New York. [Online]. Available: http://faculty.environmentalcrossroads.org/~michael/

2) Cengel, Y., & Cimbala, J. (2010). Fluid mechanics: Fundamentals and Applications (4th ed., pp. 76-111). Boston: McGraw-Hill Higher Education.

Appendix

Suppose pipe characteristics, pump characteristics, and the upstream and downstream water surface elevations are given, but the flow rate is unknown. To analyze this system for the flow rate, neglecting the minor losses, we can write the energy equation as:

$$E_A + H_p = E_B + h_f$$

The previous formula can also be represented as: $H_p = 1E_B - E_A2 + h_f$ where H_p is the required pump head and E_A and E_B are the water surface elevations of the two reservoirs. This expression can be explained as follows. Part of the energy added to the flow by the pump is expended in raising water from elevation *Ea* to *Eb* , and part of it is expended to over *AB* come the flow resistance. With Hs = Eb - Ea = elevation rise: $H_p = H_s + H_f$

Figure 14: Typical Curve Performance connected in Parallel and in Series.