City College of New York **Department of Civil Engineering**

CE 36500 - Hydraulic Engineering

Experiment 4

Pumps

Objectives:

- Learn how a single pump and pump combinations work by measuring flow rate (Q) and pump head (H) for different pump configurations.
- To develop an understanding of pump characteristic curves that address flow rate (Q) vs head (H), power (P), efficiency (E) based on experimentally collected data.
- Obtain an understanding for how Scaling works and to predict the H-Q characteristic for a pump at given speed from measured at different speeds.
- Investigate the effect of changing inlet head on pump performance, and address occurrences of Cavitation when the suction head increases.
- Construct a system curve based on your data [the Qs] and the provided pump characteristic curve to find the duty point.

Background:

Read chapter 5.6, [5.11]; look at example 5.4 (& fig. 5.13) & [5.5 & 5.6]; [] – optional

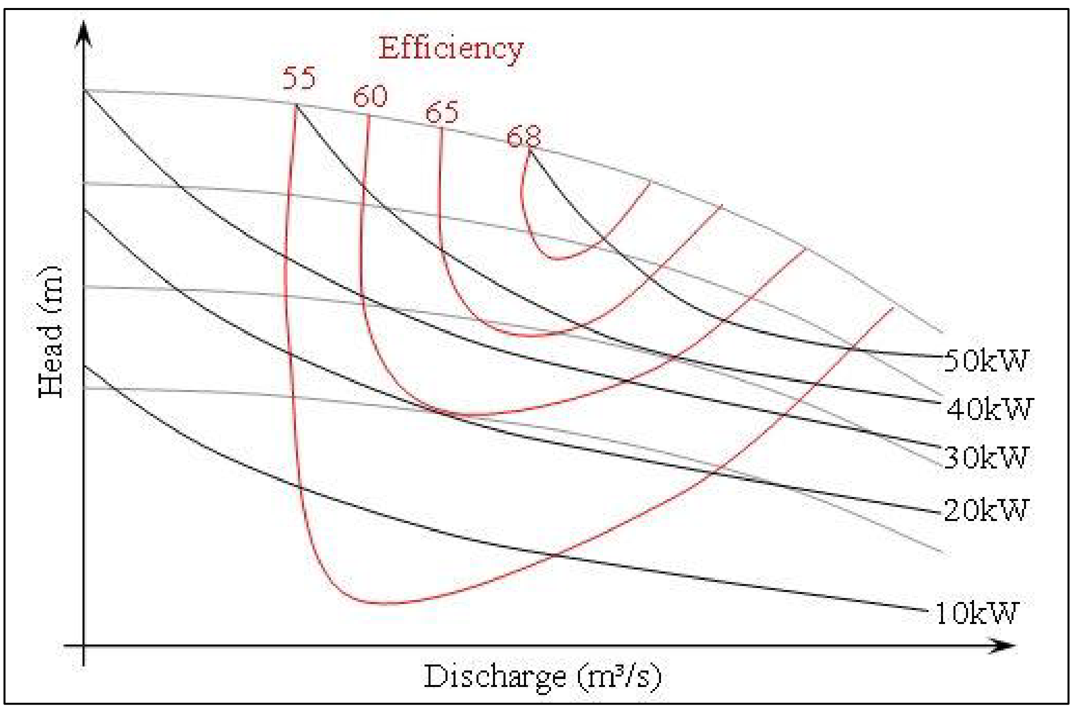


Figure 1 Sample of Pump Characteristic Curves

Pumps are used to transfer fluid in a system, either at the same elevation or to a new height. The obtained flow rate depends on the height to which the fluid is pumped. Each pump has a head-discharge relationship that is inversely proportional. The pump manufacturer provides this relationship, also known as the pump characteristic curve (figure 1).

In civil engineering applications, a single pump often cannot deliver the flow rate or head necessary for a particular system. However, two pumps (or more) can be combined in series to increase the height to which the fluid can be pumped at a given flow rate, or combined in parallel to increase the flow rate associated with a given value of head.

Set up Apparatus:

The apparatus can be set such that

a) Only Pump 1 is operating. Its speed is controllable and thus can be used to develop a set of characteristic curves with various speed, inlet, and outlet settings.

b) Both pumps are operating, combined in either series or parallel. Note that pump 2 can only operate at its 80% (50Hz) or 100% (60HZ) setting, which is optimum setting. Make sure pump 1 also operates at the same setting.

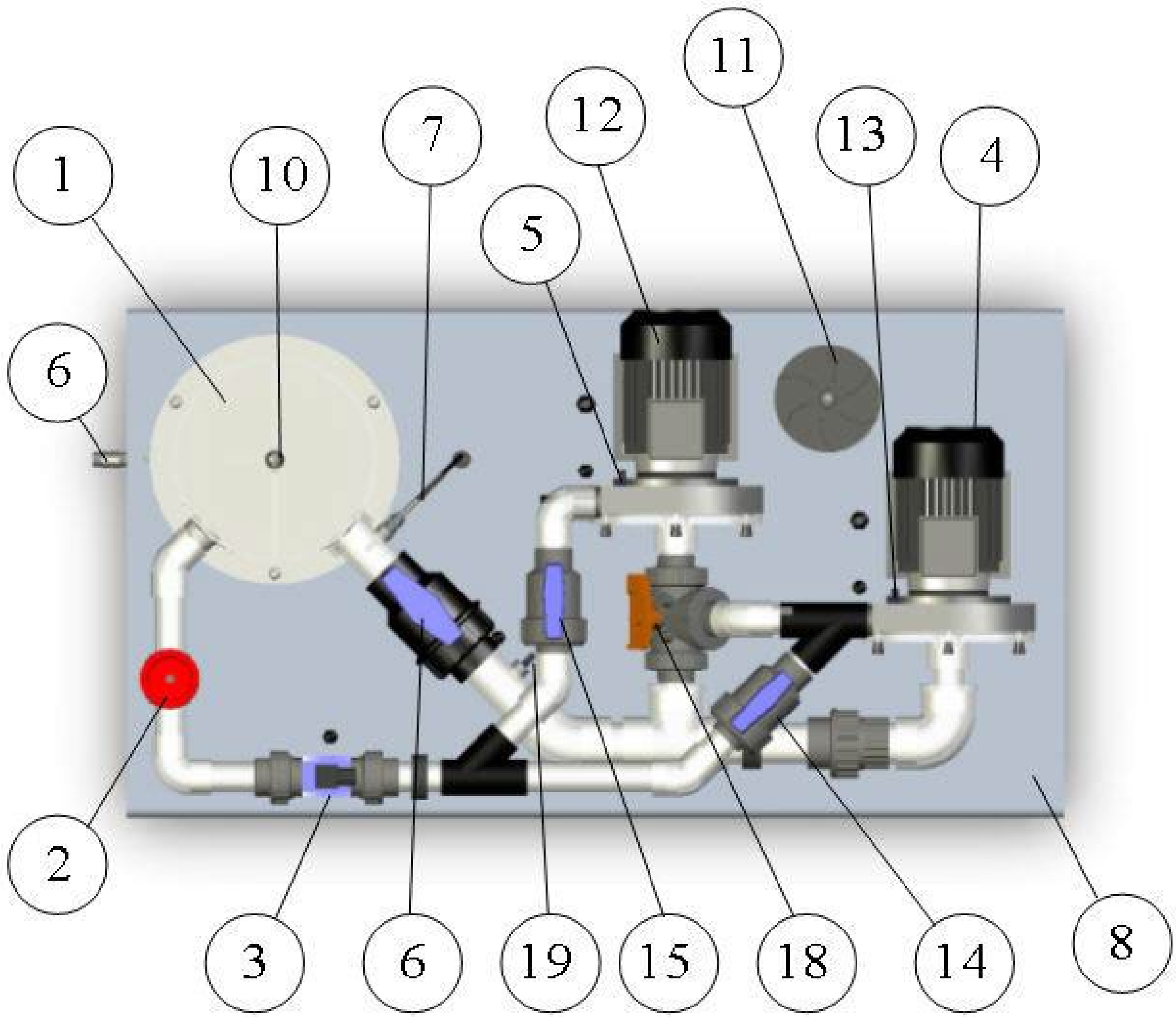
Three additional notes:

1) The flow rate is controlled with gate valve that sits right in front of the return to the reservoir. Closing action will throttle down flow and create back pressure against which the pumps have to work. Also note that when the flow control valve is turned, the system is also changed – a partially closed valve has a higher loss coefficient, and the head loss is as usual proportional to $v^2/2g$

2) In most cases leave the outlet valve fully open. This valve is only used (slowly closing action) to increase the suction head for the pumps. This will eventually lead to cavitation. When the flow control valve is turned, the system is also changed – a partially closed valve has a higher loss coefficient, and the head loss is as usual proportional to $v^2/2g$.

3) In series connection, one pump is pushing, the other is drawing – both must be turned on and have nonzero regulator setting

Refer to the image below for the pump experiment and the details of the components.



<u>Most important components:</u>

2: is referred to as the Gate Valve; it controls the flow rate in the system

6: is referred to as the Inlet Valve; normally fully open it can be set to increase suction head

18: is referred to as the 3-way valve, it sets the flow path when testing for parallel and in series

4: is referred to as Pump1; it has a variable speed controller accessed via software

12: is referred to as Pump 2; its speed is set to 80% or 100% depending on power supply

14: is the Pump 1 outlet valve; if closed no flow leaves pump 1

15: is the Pump 2 outlet valve; if closed no flow leaves pump 2

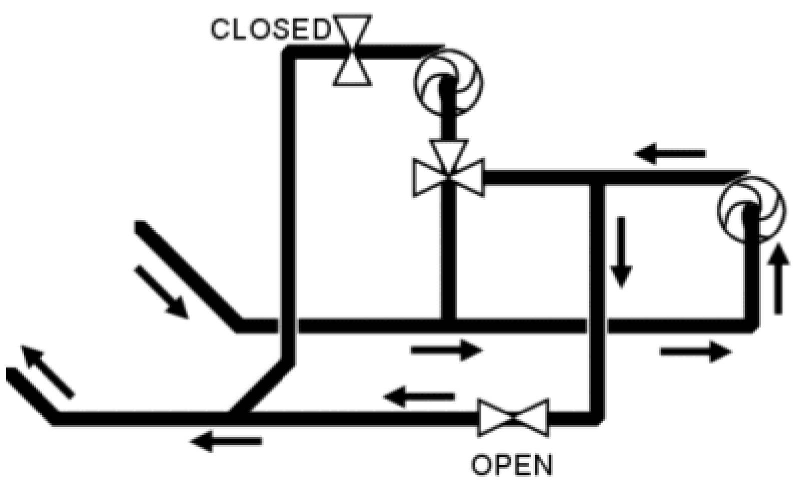
Experimental Tasks:

There is a set of 7 different experiments that can be carried out with this equipment. These are:

Exercise A – Intro to Pump Characteristics	together with Exercise D
Exercise B – Pump Characteristic Curves	together with Exercise C
Exercise C – Intro to Scaling	together with Exercise B
Exercise D – Effect of Inlet Head	together with Exercise A
Exercise E – Identification of Operating or Duty Point	Single
Exercise F – Pumps in Series	together with Exercise G
Exercise G – Pumps in Parallel	together with Exercise F

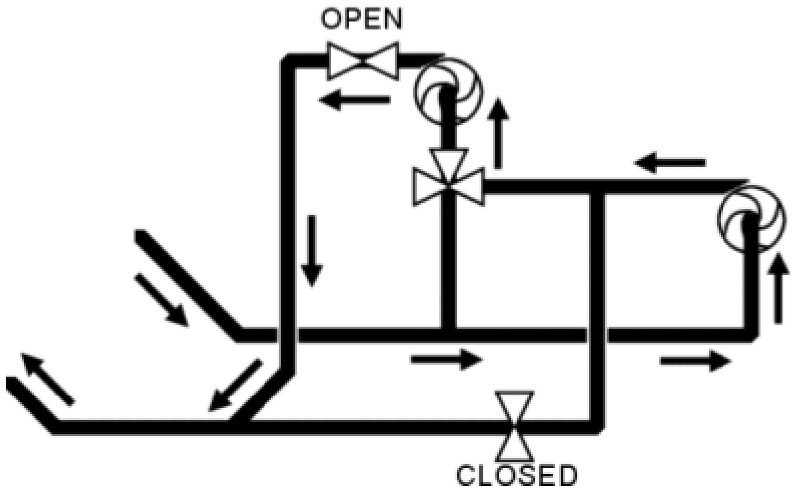
We cannot possibly carry out all of them but will identify two of them for a given lab date. For these specific assignments (2) in any given semester please refer to the course instructor and the website.

System Settings:



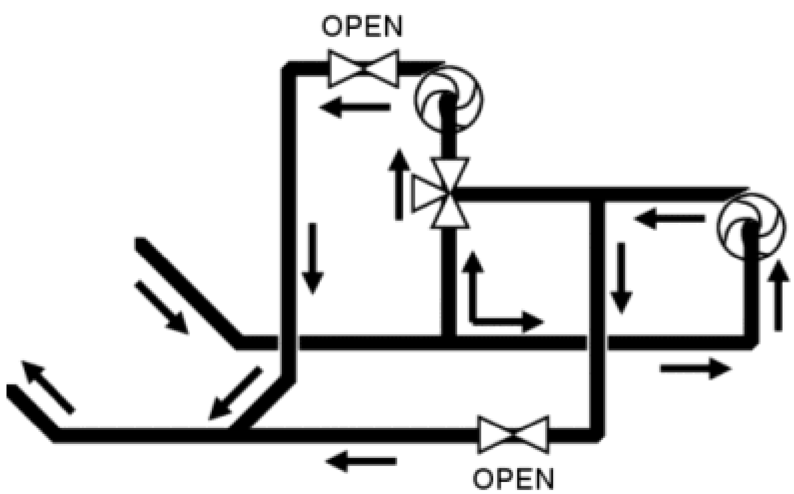
Single Pump Operation

Note the position of the 3-way valve. It can be in either parallel or series (as it shown above in the sketch) configuration. As long as the outlet valve for pump is closed there will be no flow through that pump.



Pumps in Series Operation

Note, the change of the valve settings. While the 3-way valve can remain unchanged from its Single-Pump operation, outlet valve for pump 1 is now closed, while outlet valve for pump is now open.



Pumps in Parallel Operation

Note, the change of the valve settings. The 3-way valve is set to allow throughflow while blocking flow from pump 1 to reach pump 2. On the other side, both pump outlet valves are now in the open position.

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Exercise A – Intro to Pump Characteristics

Theory
The operating characteristics of a centrifugal pump may be described or illustrated by using graphs of pump performance. The three most commonly used graphical representations of pump performance are:

- Change in total head produced by the pump, Ht
- Power input to the pump, Pm
- Pump efficiency, E

Total Head
The change in total head produced as a result of the work done by pump can be calculated as:

H_t = Change in static head + change in velocity head + change in elevation

$= H_s + H_v + H_e$

where

$$H_s = \text{Change in static head} = \frac{(P_{out} - P_{in})}{\rho g}$$

where

P_{in} = fluid pressure at inlet in Pa

P_{out} = fluid pressure at outlet in Pa

(**Note:** Pressure and head are equivalent for water, as water is the benchmark against which other liquids are measured. Water has a Specific Gravity of 1. If a liquid other than water is used, head is obtained by dividing the pressure by the specific gravity)

$$H_v = \text{Change in velocity head} = \frac{(V_{out} - V_{in})^2}{2g}$$

where

V_{in} = fluid velocity at inlet in m/s

V_{out} = fluid velocity at outlet in m/s

H_e = Change in elevation = Vertical distance between inlet and outlet

= 0.075 m for Fm51

Power Input
The mechanical power input to the pump may be calculated as:

P_m = rotational force x angular distance

$= 2.\pi.n.t$

where

n = rotational speed of pump in revolutions per second

t = shaft torque in Nm

Pump efficiency

The efficiency of the pump may be calculated as:

$$E = 100 \times \frac{P_h}{P_m}$$

where

P_h = hydraulic power imparted to fluid

$= H_t.Q.\rho.g$

where

Q = volume flow rate in m^3/s

P_m = mechanical power absorbed by pump

$= 2.\pi.n.t$

Each of these parameters is measured at constant pump speed, and is plotted against the volume flow rate, Q, through the pump. An example of this of graphical representation of pump performance is given in Figure 2, below.

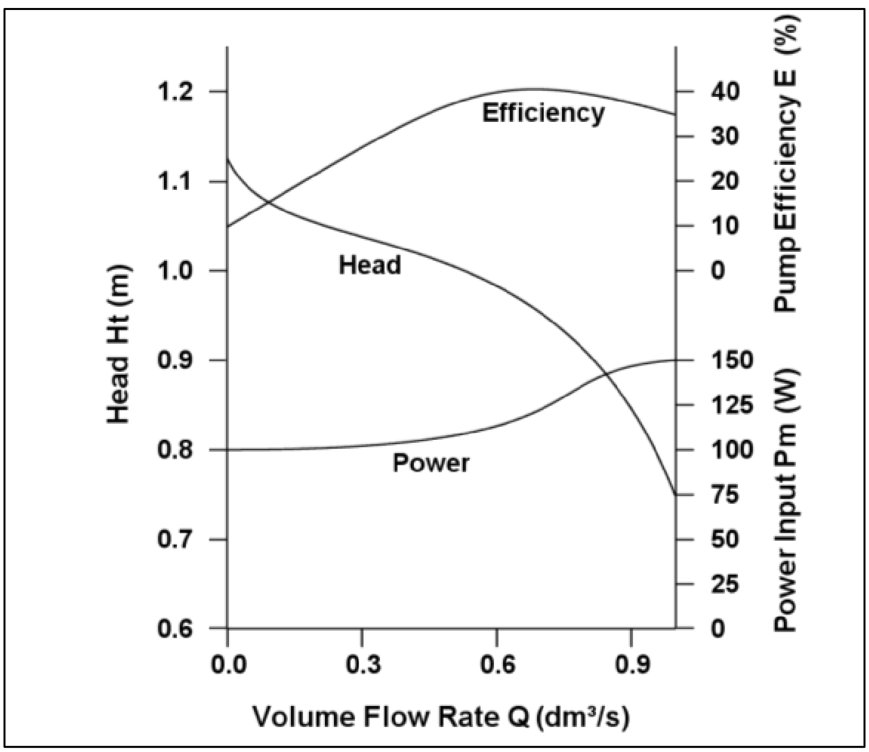


Figure 2 Examples for Pump Performance Curves

Examining Figure 2, the general performance of the pump can be determined.

The Ht-Q curve shows the relationship between head and flow rate. The change in head decreases as flow rate increases (head increases as flow rate decreases). This type of curve is referred to as a rising characteristic curve. A stable head-capacity characteristic curve is one in which there is only one possible flow rate for a given head, as in the example here.

The Pm-Q curve shows the relationship between the power input to the pump and the change in flow rate through the pump. Outside the optimum operating range of the pump this curve flattens, so that a large change in pump power produces only a small change in flow velocity.

The E-Q curve shows the pump capacity at which the pump operates most efficiently. In the example here, the optimum operating capacity is 0.7 dm^3/s, which would give a head of 1.2m. When selecting a pump for an application where the typical operating capacity is known, a pump should be selected so that its optimum efficiency is at or very near that capacity.

Equipment Set Up

Ensure the Drain Valve is fully closed and that the reservoir is filled to within 10 of the rim.

Ensure the inlet valve and the gate (flow control) valve are fully open.

Set the 3-way valve for flow in parallel, and close the Pump2 outlet valve**.** This will prevent flow through Pump2, thus directing all the flow through Pump1.

Make sure the data-interface is switched on, and that it is connected to a PC running the control software for the pump set up.

Procedure

- In the software, set Pump1 to 80%
- Allow water to circulate until all air has been flushed from the system
- Close the gate (flow control) valve to give a flow rate Q of 0 (note that the pump will not run well with the gate valve closed or nearly closed, as the back pressure produced is outside normal operating parameters. The pump should run more smoothly as the experiment progresses)
- Select the GO icon to record the sensor readings and pump settings on the results table of the software.
- Open the gate valve to permit a low flow rate. Allow sufficient time for the sensor readings to stabilize and then select the GO icon to record the next set of data.

- Open the gate valve in small increments, allowing the sensor readings to stabilize then recording the sensor and pump data each time.

- Using the arrow buttons on the software display, reduce the pump speed to 0%. Select “Save” or “Save As …” from the ‘File’ menu and save the results with a suitable file name (e.g. the data and the exercise).

- Turn off the data interface

- Make sure to copy/save the data from the laptop to a memory stick.

Results

1) Plot a graph of Head against Flow Rate.

2) Plot a graph of Mechanical Power against Flow Rate on one axis, and Efficiency against Flow Rate on the secondary axis

3) Examine and describe the shapes of the graphs obtained, relating this to the changing performance of the pump as the capacity (flow rate) changes. Determine the maximum efficiency and the flow rate at which it occurs, and mark the point of max efficiency on the performance curve.

4) Compare the shapes of the curves obtained to the example presented in Figure 2. Discuss any similarities and differences between the example presented and Pump1.

Exercise B – Pump Characteristics Curves

One way of illustrating pump characteristics is to construct contour lines of constant power or efficiency on a graph of pump head plotted against pump discharge. These allow engineers to see the max efficiency of a pump over a range of operating parameters, which can assist in the selection of an appropriate pump to suit particular conditions. An example is given below

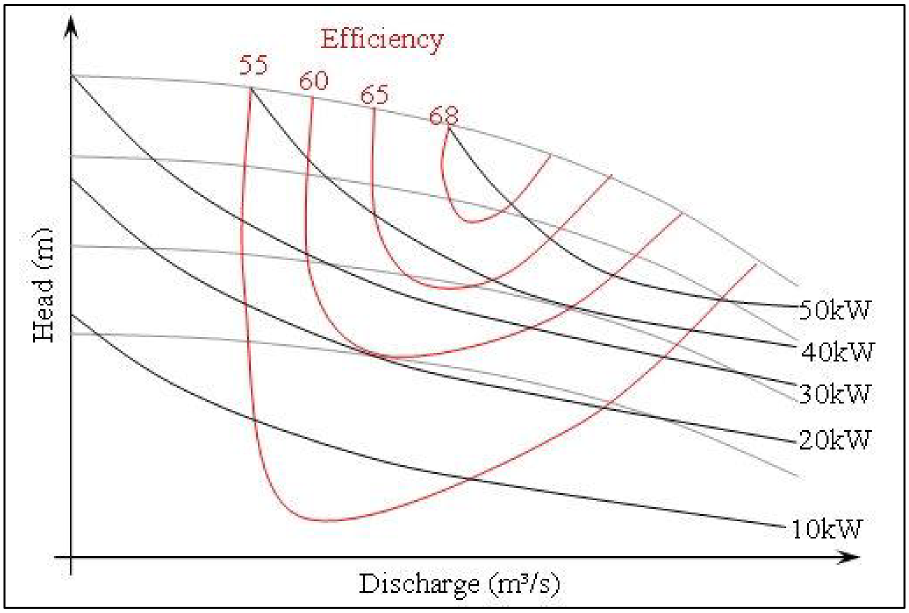


Figure 3 Family of Efficiency Curves overlain with other Characteristic Curves

Pump manufactures typically publish information on the performance of their pumps in the form of this type of chart. In addition to the use of these charts in in initially selecting a pump, the charts may also be used to compare actual pump performance with that expected. If the pump performance deviates significantly then the system must be investigated for problems and design flaws, and if the pump initially performs as expected but later displays a change in performance then the pump should be investigated for faults.

Equipment Set Up

Ensure the Drain Valve is fully closed and that the reservoir is filled to within 10 of the rim.

Ensure the inlet valve and the gate (flow control) valve are fully open.

Set the 3-way valve for flow in parallel, and close the Pump2 outlet valve**.** This will prevent flow through Pump2, thus directing all the flow through Pump1.

Make sure the data-interface is switched on, and that it is connected to a PC running the control software for the pump set up.

Procedure

- In the software, set Pump1 to 100% and allow water to circulate until all air has been flushed from the system

- Close the gate (flow control) valve to give a flow rate of Q of 0. (note that the pump will not run well with the gate valve closed or nearly closed, as the back pressure produced is outside normal operating parameters. The pump should run more smoothly as the experiment progresses)

- Select the GO icon to record the sensor readings and pump settings on the results table of the software.

- Open the gate valve to permit a low flow rate. Allow sufficient time for the sensor readings to stabilize and then select the GO icon to record the next set of data.

- Repeat by opening the gate valve in small increments, allowing the sensor readings to stabilize then recording the sensor and pump data each time.

- Create a new results sheet by selecting the 'Next' icon (you may also wish to save the results at this time to avoid losing the data in the event of problems)

- Close the gate valve and set Pump1 to 90%

- Select the GO icon to record the sensor readings and pump settings on the new results table.

- Open the gate valve to permit a low flow rate. Allow sufficient time for the sensor readings to stabilize and then select the GO icon to record the next set of data.

- Repeat by opening the gate valve in small increments, allowing the sensor readings to stabilize then recording the sensor and pump data each time.

- Repeat the procedure at 80%, 70%, and 60%, creating a new results sheet for each setting (and saving the results if desired – the same file may be overwritten each time as more data is added). We recommend to rename each sheet of results in the software with the corresponding pump setting.

- Ensure results are saved using 'Save' or "Save As …' from the software File menu after taking the final set of results.

- Do not forget to copy or save these files to a thumb stick

Results

1) On the same graph plot total Head, H_T, against Flow Rate Q for each setting.

2) Select a value for efficiency, for example 30%,. On each line plotted, mark the points at which an efficiency of 30% is achieved. Where the pump performance at a particular setting does not ever correspond to the efficiency chosen, note whether the efficiency would lie above or below the line. Join the marked points to form a smooth curve.

3) Repeat for other efficiency values, for example 40% and 50%, to give a family of efficiency curves.

4) Create and/or print a second head-flow rate graph for all pump frequencies. Using the same procedure as for drawing contour lines fo constant efficiency, produce curves for constant mechanical power.

5) Examine and describe the shapes of the efficiency and power graphs obtained. Are the shapes consistent? How do they relate to the head-flow rate characteristic? How do the efficiency and power curves relate to each other?

6) Compare the results to the example pump curves presented in the theory section. How does the pump in the example compare to Pump1 on the experimental set up in terms of capacity, power, and efficiency?

Exercise C – Intro to Scaling

Theory

When selecting a pump for a system, it is seldom practical to test the performance of every size of pump in a manufacturer's range at all speeds at which it may be designed to run. It is therefore useful to have a mathematical solution that allows assumptions can be made about operating characteristics of a pump running at one speed, impeller size, etc. from experimental results taken at another.

The multiple curves obtained from plotting measured pump characteristics on dimensional axes can be reduced to a single curve if appropriate dimensionless groups are used. Provided the effects of fluid viscosity on pump performance are small, and that cavitation is not occurring, the characteristic of a given type and shape of pump may be represented by:

$$\frac{gH_t}{n^2D^2} = f\left[\frac{Q}{nD^3}\right]$$

where

n is the pump speed (rpm), and

D is the impeller diameter (m)

For a single curve of the type suggested by this equation to represent more than one operating condition of the particular type of pump, the criterion of *dynamic similarity* must be fulfilled. That is, all fluid velocities at corresponding points within the machine are in the same direction and proportional to impeller speed. When this is the case, as for a particular pump operated at different speeds, a simple graph of data is formed, as depicted in Figure **4**.

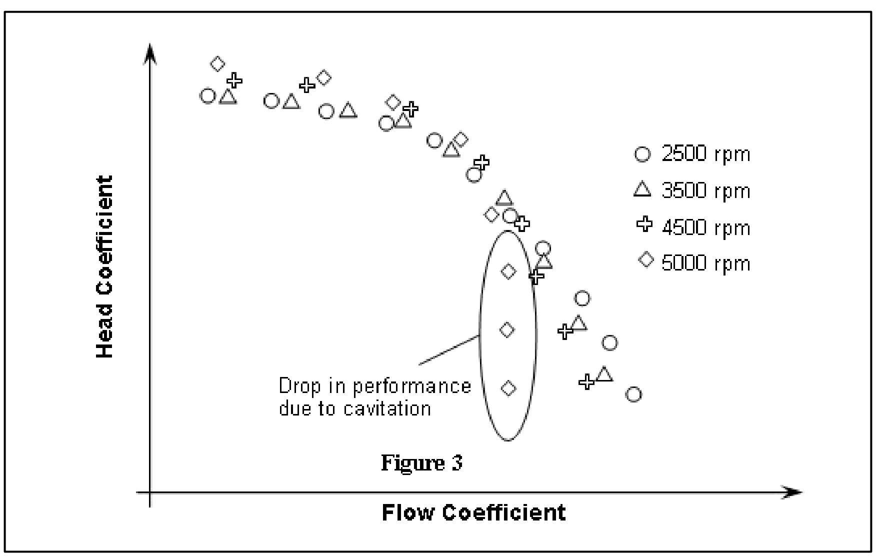


Figure 4 Dim-Less head - flow rate characteristics of a particular centrifugal pump operated at different speeds

The dimensionless equation given previously is the basis from which the *affinity laws* are derived. The affinity laws allow the performance of *geometrically similar* pumps of different sizes or speeds to be predicted accurately enough for practical purposes.

The methods used for deriving the affinity laws will not be presented here, but the laws are as follows:

Power coefficient $\bar{P} = \frac{P}{\rho n^3 D^3}$

Flow coefficient $\phi = \frac{Q}{nD^3}$

Head coefficient $\psi = \frac{gHt}{n^2 D^2}$

These laws are most often used to calculate changes in flow rate, head and power of a pump when the size, rotational speed or fluid density is changed. The following formulae are derived from the above considerations, and allow calculation of head Ht, power Pm and efficiency E at one speed n_1 to be deduced from those measured at another speed n_2:

$$\frac{Q_1}{Q_2} = \frac{n_1}{n_2} \qquad \frac{H_{t1}}{H_{t2}} = \frac{n_1^2}{n_2^2} \qquad \frac{P_{m1}}{P_{m2}} = \frac{n_1^2}{n_2^2}$$

More generally, the relationship between two geometrically similar machines with characteristic diameters D_1 and D_2 operating at rotational speeds n_1 and n_2 is shown in Figure C2. For any two points at which values of (gH / n^2D^2) and (Q / nD^3) are the same, it follows that:

$$H_2 = H_1 \left(\frac{n_2}{n_1}\right)^2 \left(\frac{D_2}{D_1}\right)^2$$

and

$$Q_2 = Q_1 \frac{n_2}{n_1} \left(\frac{D_2}{D_1}\right)^3$$

These are termed *corresponding points*.

The power coefficient $\frac{P_m}{\rho n^3 D^5}$ and the efficiency E can be compared in a similar manner.

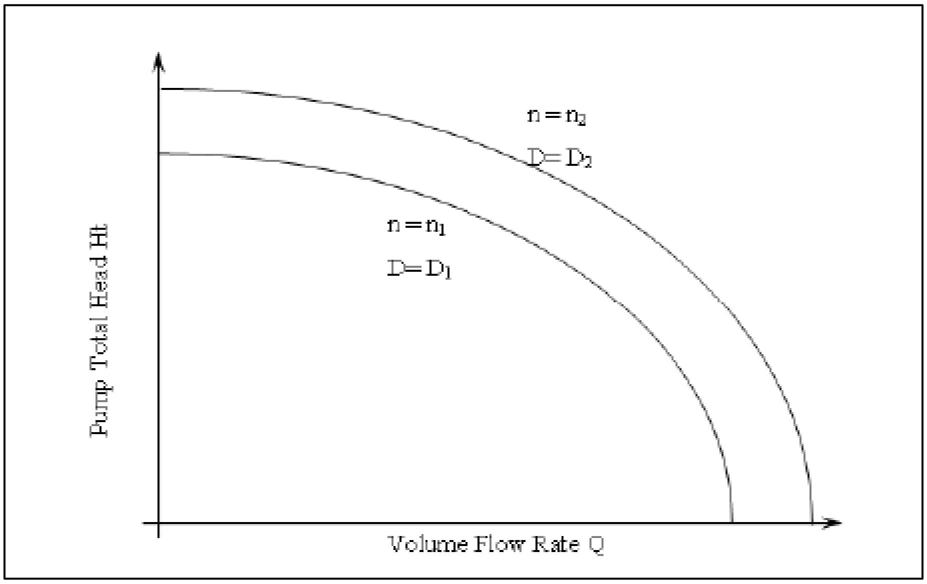


Figure 5 Relationship of performance characteristics for geometrically similar machines operating at different speeds

Equipment Set Up

Ensure the Drain Valve is fully closed and that the reservoir is filled to within 10 of the rim.

Ensure the inlet valve and the gate (flow control) valve are fully open.

Set the 3-way valve for flow in parallel, and close the Pump2 outlet valve**.** This will prevent flow through Pump2, thus directing all the flow through Pump1.

Make sure the data-interface is switched on, and that it is connected to a PC running the control software for the pump set up.

Procedure

- **NOTE!** The results from exercise B may be used to perform the calculations and to create the graphs for this exercise. If no results are available proceed as follows.

- In the software, set Pump1 to 80% and allow water to circulate until all air has been flushed from the system

- Close the gate (flow control) valve to give a flow rate of Q of 0. (note that the pump will not run well with the gate valve closed or nearly closed, as the back pressure produced is outside normal operating parameters. The pump should run more smoothly as the experiment progresses)

- Select the GO icon to record the sensor readings and pump settings on the results table of the software.

- Open the gate valve to permit a low flow rate. Allow sufficient time for the sensor readings to stabilize and then select the GO icon to record the next set of data.

- Repeat by opening the gate valve in small increments, allowing the sensor readings to stabilize then recording the sensor and pump data each time.

- Create a new results sheet by selecting the ‘Next’ icon (you may also wish to save the results at this time to avoid losing the data in the event of problems)

- Close the gate valve and set Pump1 to 60%

- Select the GO icon to record the sensor readings and pump settings on the new results table.

- Open the gate valve to permit a low flow rate. Allow sufficient time for the sensor readings to stabilize and then select the GO icon to record the next set of data.

- Repeat by opening the gate valve in small increments, allowing the sensor readings to stabilize then recording the sensor and pump data each time.

- Ensure results are saved using ‘Save’ or “Save As …’ from the software File menu after taking the final set of results.

- Do not forget to copy or save these files to a thumb stick

Results

The results taken at 80% will be used with the affinity laws to give predicted results at 60%. This will then be compared to the actual results at 60%.

1) Plot a graph of total Head, H_T, against Flow Rate Q at 80% pump setting

2) The software uses the affinity laws

$$\frac{Q_1}{Q_2} = \frac{n_1}{n_2} \quad \text{and} \quad \frac{H_{t1}}{H_{t2}} = \frac{n_1^2}{n_2^2}$$

   to calculate the predicted values of H_{t2} at flow rates Q_2 and a setting of 60% form the measured values of H_{t1} and Q_1 and the values n_1 = 70 and n_2 = 50

3) Plot a graph of Predicted Head against Predicted Flow Rate.

4) Plot a graph of the measured Total Head against Flow Rate at 60%

5) Compare the predicted results at 60% with the measured results. How accurate were the values obtained using the affinity laws? Discuss the advantages and disadvantages of this technique for pump system design.

Exercise D – Effect of Inlet Head

Theory

In both the design and operation of a rotodynamic machine, careful attention has to be paid to the fluid conditions on the suction side. In particular, it is important to check the minimum pressure that can arise at any point to ensure that cavitation does not take place.

Cavitation

If the pressure at any point is less than the vapour pressure of the liquid at the temperature at that point, vaporisation will occur. This is most likely to arise in the suction side where the lowest pressures are experienced. The vaporised liquid appears as bubbles within the liquid, and these subsequently collapse with such force that mechanical damage may be sustained. This condition, known as *cavitation*, is accompanied by a marked increase in noise and vibration in addition to the loss of head.

In addition to the potential for physical damage to the pump from cavitation, both from the resulting vibration and from the explosive force of the collapsing bubbles of vapour, pumps cannot pump vapour effectively. Hence if cavitation occurs then the pump may not be capable of developing the suction head necessary to reach the required operating point.

Net Positive Suction Head Required

Manufacturers commonly specify a Net Positive Suction Head (*NPSH*), based on pump test results. The usual testing to determine the NPSH will involve running the pump with water at different capacities, while throttling (reducing the flow in) the inlet (suction) side. The suction pressures at which the first sign of vaporisation appear are noted for each capacity. These are then converted into head values and are published on the pump characteristic curve as the Net Positive Suction Head Required (NPSHr) or just NPSH. NPSH is the amount by which the pressure at this point must exceed the vapour pressure of the liquid.

Net Positive Suction Head Available

The Net Positive Suction Head Available (NPSHa) depends on the system in which the pump is used, and is calculated according to system conditions. The basic calculation for an existing system using water as the working fluid may be approximated as:

$$NPSHa = H_{atmos} - H_{vapour} + H_{in} + H_v$$

Where

H_{atmos} = Barometric (ambient) pressure, expressed as a head of water in mm.

H_{vapour} = Vapour pressure of water at maximum expected temperature, expressed as an equivalent head of water in mm.

H_{in} = Gauge (sensor) pressure at inlet (note that value is relative to atmosphere, and thus in some circumstances may be negative), expressed as a head of water in mm.

H_v = Velocity head $= \dfrac{V_{in}^2}{2g}$

NPSH here is calculated in mm of water. In some pump datasheets it may be expressed in inches of water. It may also be calculated as a pressure by summing the component pressures. To convert velocity head to equivalent pressure, use

$$P_v \quad = \text{Pressure due to velocity head} \quad = \frac{V_{in}^2}{2g} \times \rho \times g$$

Equipment Set Up

Ensure the Drain Valve is fully closed and that the reservoir is filled to within 10 of the rim.

Ensure the inlet valve and the gate (flow control) valve are fully open.

Set the 3-way valve for flow in parallel, and close the Pump2 outlet valve**.** This will prevent flow through Pump2, thus directing all the flow through Pump1.

Make sure the data-interface is switched on, and that it is connected to a PC running the control software for the pump set up.

Procedure

- In the software set Pump1 to 30%, and fully open the gate (flow control) value to permit water to circulate and flush out remaining air pockets.

- Close the inlet valve just a little but enough to impose a noticeable flow reduction

- Select the “GO” icon to record the sensor readings and pump settings on the results table of the software.

- Close the inlet valve a little more. Allow for sufficient time for the sensor readings to stabilize then select the “GO” icon to record the next set of data.

- Repeat, making small step changes in the setting of the inlet valve, allowing the sensor readings to stabilize then recording the sensor and pump data each time.

- As soon as the inlet valve is fully closed, take one final set of results using the GO icon then fully open the valve again.

- Create a new results table using the TABLE icon.

- Set the pump to 60% then repeat the procedure at this new pump setting.

- Repeat for a pump setting of 90% and remember to create a new results sheet.

- Bubbles will be noted around the impeller during the experiment, as air comes out of solution as a result of decreased fluid pressure. It is, however, very unlikely that true cavitation will occur within the normal operating conditions of the system. If it should occur, cavitation can be readily recognized by a drop or fluctuation in the head developed by the pump, and by the distinctive noise (variously described as sounding like crackling cellophane and sound as if the pump were full of rocks or marbles). If cavitation should begin to develop, use the ‘Note’ facility to describe the observations made then take a set of data to add that note to the sensor readings. As soon as a set of readings has been taken, increase the suction head until cavitation ceases to avoid causing damage to the impeller.

- If cavitation does occur, it is due to a combination of factors which may include high fluid temperature, high fluid flow rate (high impeller speed), low ambient pressure and low inlet head.

- Select ‘Save’ or ‘Save As …’ from the ‘File’ menu and save the results with a suitable file name (e.g. date, group number, and experiment number).

Results

1) On a single graph, plot the pump capacity (flow rate) against the suction head for each set of data.

2) One a single graph, plot the Net Positive Suction Head Available against pump capacity.

3) In the unlikely event that cavitation was observed, print out the second graph and mark on it any point at which cavitation appeared.

4) Describe the effect of changing suction head on pump performance.

5) Discuss the use of NPSH charts in the design of a system and he choice of a suitable pump.

6) If cavitation was observed, describe the conditions under which it appeared.

Exercise E – System Characteristics: Duty or Operating Point

Method

By varying the outlet flow control valve at fixed pump speed (to obtain the pump head - flow characteristic) and varying the pump speed at fixed valve setting (to obtain the system head - flow characteristic) then comparing the curves to obtain the duty point.

Theory

System analysis for a pumping installation is conducted to select the most suitable pump for a particular application by defining the operating point. System analysis involves calculating head - flow curves for the system (frictional losses in valves, pipes, fittings etc.) and the use of these curves with those of available pumps. The system curve is a graphic representation of all possible duty points in so far that the total dynamic head (static lift plus kinetic energy losses) is plotted against discharge flows from zero to the expected maximum, and a typical set are shown in Figure E1 for different systems with the same static head but different frictional losses.

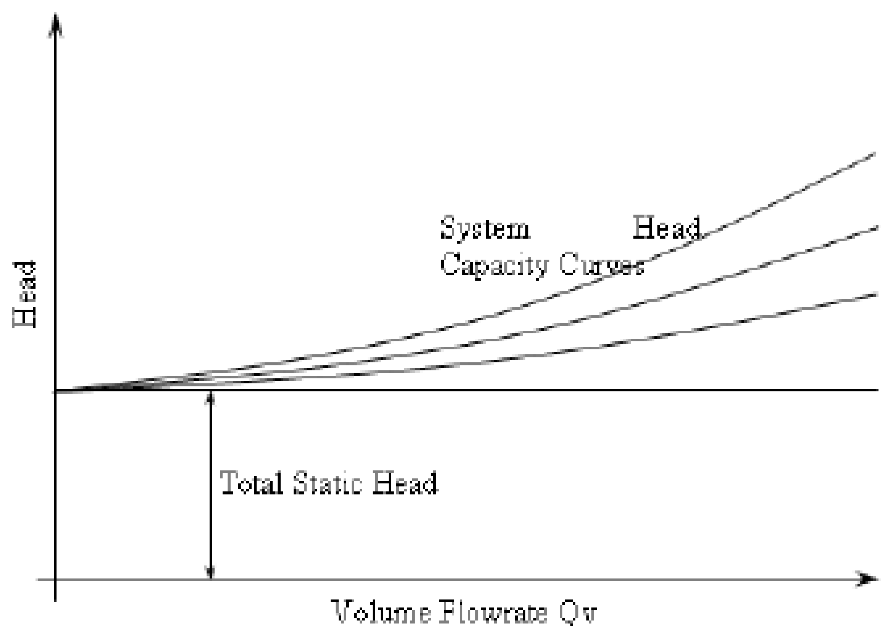


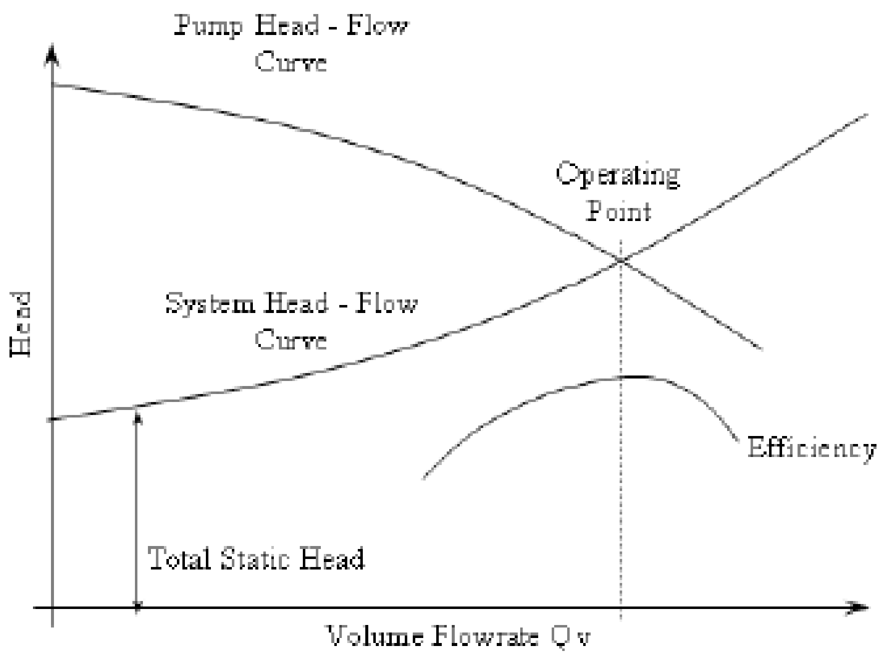
Figure E1: Typical head - flow curves for a pumping installation (pipes, valves etc.)

As demonstrated in previous exercises, pump characteristic curves illustrate the relationship between head, flow, power and efficiency over a wide range of possible operating conditions, but they do not indicate at which point on the curves the pump will operate. The operating point (or duty point) is found by plotting the pump head - flow curve with the system head - flow curve, as shown in figure E2. The intersection of the two curves represents the head and flow that the pump will produce if operated in the given piping system. The position of the operating point will vary if the pump is changed for a similar model with different characteristics or if the system is changed to include different pipe fitting, pipe lengths etc. For efficient operation the operating point and the maximum pump efficiency should occur at the same flowrate.

By varying the outlet flow control valve at fixed pump speed (to obtain the pump head - flow characteristic) and varying the pump speed at fixed valve setting (to obtain the system head - flow characteristic) then comparing the curves to obtain the duty point.

The head - flow curve for the pump is obtained by monitoring the pressure at the outlet of pump 1 while varying the outlet flow control valve operating (speed of the pump fixed).

The head - flow curve for the system is obtained by monitoring the pressure at the outlet of pump 1 while varying the operating speed of the pump (outlet flow control valve fixed at some intermediate setting).



Equipment Set Up

NOTE: Pump2 is not used in this exercise.

Ensure the Drain Valve is fully closed and that the reservoir is filled to within 10 of the rim.

Ensure the inlet valve and the gate (flow control) valve are fully open.

Ensure that Pump2 is switched off in the software then set the 3-way valve for flow in parallel, and close the Pump2 outlet valve**.** This will prevent flow through Pump2, thus directing all the flow through Pump1.

Make sure the data-interface is switched on, and that it is connected to a PC running the control software for the pump set up.

Switch on Pump1 in the software and set Pump1 speed to 100% then allow the system to fully prime and flush out remaining air bubbles.

The exercise will be conducted in two parts; Part1 measures the pump head-flow characteristics, Part2 measures the system head flow characteristic allowing the two characteristics to be compared in the same graph.

Procedure – Part1 (Pump Characteristics)

- In the software set Pump1 to 100%, and fully open the gate (flow control). Make sure the readings are stable.

- Select the GO icon to record the sensor readings and pump settings on the results table of the software.

- Observe the maximum flow rate reading obtained then divide this by 10 to give suitable increments when adjusting the flow control valve.

- Gradually close the flow control valve to achieve 90% of the max flow, allow the readings to stabilize and then select the GO icon again for another result recording.

- 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)

Procedure – Part2 (System Characteristics)

- Flow through the pump will be changed by varying the speed setting using the Laptop software rather than by varying the outlet flow control valve as in the previous set of measurements.

- Select the 'Table' icon to create a new results sheet.

- Select a position for the outlet flow control 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.

- Allow the readings to stabilize then select the GO icon to record the sensor readings and pump settings on the results table of the software.

- Set the pump to 90%, and allow the readings to stabilize then record another set of data using the GO icon again.

- Repeat while reducing the pump speed setting in 10% increments, recording a data sample at each step with a final set of data taken at 0% pump speed. The measurements will produce the 'system' head curve, as described in the Theory section.

- NOTE: Readings can be taken at low settings of pump speed but prolonged operation at low speeds should be avoided to prevent overheating of the motor. After taking readings at low speeds return the pump speed to 100%.

- Select the 'TABLE' icon to create a new results sheet.

- Ensure pump speed is back to 100%

- Readjust the position of the control (flow rate) valve to give approximately 70% of max available flows rate.

- Let readings stabilize and record a new set of data using the GO icon.

- Set the pump to 90% and again record the data set.

- Repeat this while reducing the pump speed in 10% increments., recording a data sample at each step, with a final set of data taken at 0% pump speed. These measurements will produce another, different, 'system' head-flow rate curve.

- Select 'Save' or 'Save As …', form the file menu and save the results with a suitable file name (e.g. your group name and the exercise number).

Results

1) Plot a graph for flow rate (x-axis) against:
   y-axis 1:
   Run 1, Pump1 Total Head (The pump head-flow characteristic)
   Run 2, Pump1 Total Head (The system characteristic at one valve setting)
   Run 3, Pump1 Total Head (The system characteristic with a different valve setting)

   y-axis 2 (different scale):
   Run 1, Pump1 Efficiency (The pump efficiency-flow characteristic)

2) Observe the points on the graph at which the pump head curve intersects the two system head curves to obtain the duty (operating) points of the pump with two different system requirements.

3) Observe the flow rate at which these duty points occur compared with the corresponding flow rate for maximum pump efficiency and comment on the optimum system resistance curve to suite the pump.

4) If you can, repeat the above exercise to obtain a system resistance curve where the duty point of the pump coincides with the maximum pump efficiency.

5) Compare the graph obtained with the example given the Theory section.

Closing Remarks

The duty point of a centrifugal pump occurs where the pump head-flow curve intersects the system head-flow curve.

For maximum pump efficiency, essential when operating a large pump that requires a significant power input, the duty point should be close to the point of maximum efficiency.

Where a pump produces too much flow for a particular system, a restrictor or valve can be used to reduce the flow but this is inefficient and wastes energy.

In a practical application the system resistance curve is calculated by adding the head loss due to the pipe friction and the head loss due to the fittings (minor losses) at different flow rates. This curve is then compared with the manufacturer's head-flow curve for different pumps to determine the optimum combination.

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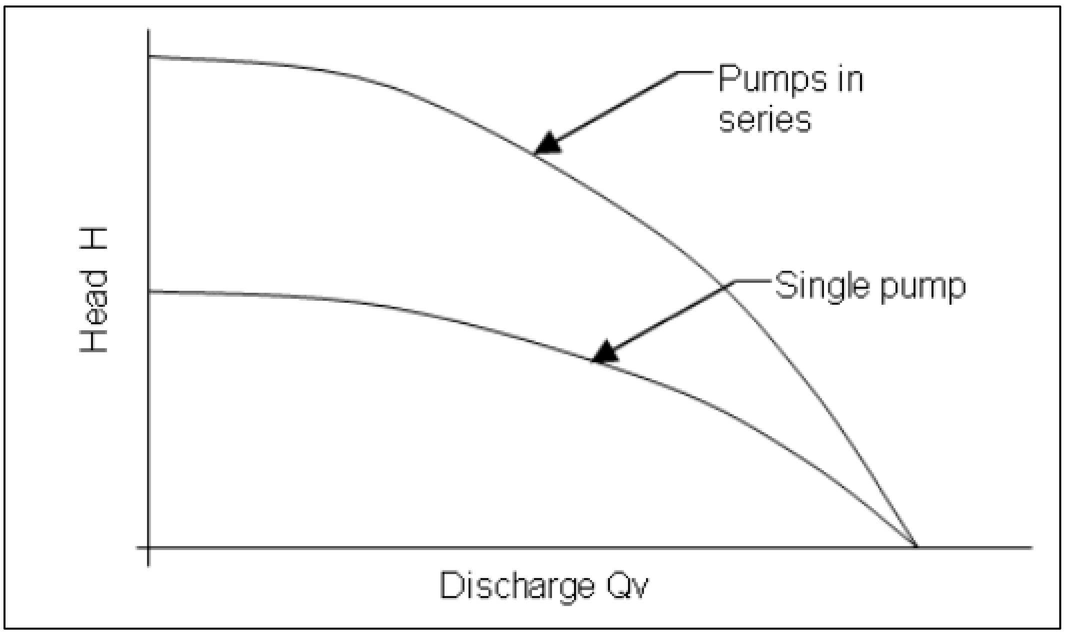
Exercise F – Pumps in Series

Theory

A single pump may be insufficient to produce the performance required. Combining two pumps increases the pumping capacity of the system. 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 flowrate is the same as for a single pump but the total head is increased., The combined pump head-flowrate curve is found by adding the heads of the single pump curves at the same flowrate.



Equipment Set Up

Ensure the Drain Valve is fully closed and that the reservoir is filled to within 10 of the rim.

Make sure both pumps have the same impellers installed.

Ensure the inlet valve and the gate (flow control) valve are fully open.

Set the 3-way valve for flow in series, this is different from the previous set ups that mostly used flow in parallel set ups.

Ensure that the data interface unit is on and that you can see in the software that the ‘IFD: OK’ is displayed in the bottom right corner.

Procedure

- Both pumps must be used at the same setting in this experiment, to ensure identical performance. As the speed of Pump2 is fixed at its design operational point, Pump1 should be set to match – select 80% for a 50MHz electrical supply or 100% for 60MHz.

- Allow water to circulate until all air bubbles have been flushed from the system

- **Part 1: Single Pump Performance**

- Close Pump2 outlet valve and open Pump1 outlet valve

- In software interface set 'Mode' to 'Single' by selecting the appropriate radio button

- Rename results sheet to "Single'

- Use the GO icon to record your first set of data

- Close the gate (flow control) valve to reduce the flow by a small amount and use the GO icon to record your 2nd set of data in the table.

- Continue to close the gate valve to give incremental changes in flowrate, recording the data each time.

- After taking the final set of data, fully open the gate valve.

- **Part 2: Series Pump Performance**

- Create a new results sheet using the "Table' icon. Rename this sheet to "Series'

- In the software, on the mimic diagram, set the 'Mode' to 'Series' by selecting the appropriate radio button

- Open Pump2 outlet valve, close Pump1 outlet valve and wat for any air to circulate out of the system

- Select the GO icon to record the sensor readings and pump settings on the results table of the software

- Close the gate (flowrate) valve to reduce the flow by a small amount. Use the GO icon again to record the data in the table

- Continue to close the gate valve to give incremental changes in flowrate, recording the sensor data each time

- After taking the final set of data, fully open the gate valve again

- **NOTE!** You may proceed straight to exercise G (Pumps in Parallel) now without closing the software; otherwise save the results and make sure they are available for exercise G when required. You may want to save the results anyways before proceeding just to be on the safe side. You can always overwrite this result sheet with the combined results at the end of exercise G, in case it went through without a hitch.

Results

1) Showing flowrate on the x-axis plot a graph of total head gain for the single pump and for two pumps connected in series. Calculate the difference between the total head gain for single and series pumps

2) Does the total head gain for the two pumps in series match the theoretical prediction of twice the head gain for a single pump (assuming the two pumps used gave identical performance?)

3) Give example of application where pumps might be connected in series.

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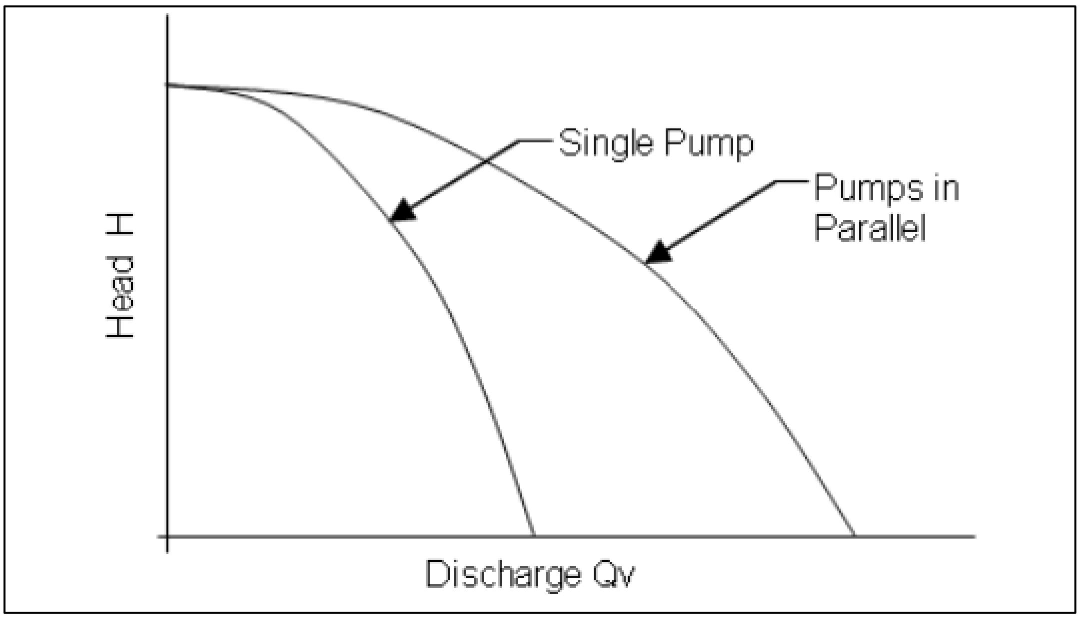
Exercise G – Pumps in Parallel

Theory

A single pump may be insufficient to produce the performance required. Combining two pumps increases the pumping capacity of the system. Two pumps may be connected in parallel, so that half the flow passes through one of the pumps and the other half through the second pump. When two pumps operate in parallel the total head increase remains unchanged but the flow rate is increased. The head-flowrate curve is found by adding the flowrates of the single pump curves at the same head.



Equipment Set Up

Ensure the Drain Valve is fully closed and that the reservoir is filled to within 10 of the rim.

Make sure both pumps have the same impellers installed.

Ensure the inlet valve and the gate (flow control) valve are fully open.

Set the 3-way valve for flow in parallel

Fully open both Pump1 and Pump2 outlet valves; this ensures that the outlet pressure on both pumps is the same.

Ensure that the data interface unit is on and that you can see in the software that the 'IFD: OK' is displayed in the bottom right corner.

Make sure to set the ‘Mode’ to “Parallel on the mimic diagram in the software GUI

Procedure

- Both pumps must be used at the same setting in this experiment, to ensure identical performance. As the speed of Pump2 is fixed at its design operational point, Pump1 should be set to match – select 80% for a 50MHz electrical supply or 100% for 60MHz.

- Allow air to circulate out from the system

- **NOTE!** If the software is still open from the previous exercise (F), create a new results sheet selecting the ‘Table’ icon and name it ‘Parallel’. If it is NOT, load the results from the ‘Single’ experiment carried out from experiment ‘F’.

- Select the GO icon to record your first data set

- Continue to close the gate (flowrate) valve to give incremental changes in flowrate, recording the sensor data each time

- After taking the final set of data, fully open the gate valve. Set Pump1 to 0% and switch off both pumps

Results

1) Showing flowrate on the x-axis plot a graph of total flowrate gain for the single pump and for two pumps connected in parallel. Calculate the difference between the flowrate gain for single and parallel pumps

2) Does the flowrate gain for the two pumps in parallel match the theoretical prediction of twice the flowrate gain for a single pump (assuming the two pumps used gave identical performance?)

3) Give example of application where pumps might be connected in parallel.

4) Compare the graphs for pumps in series and pumps in parallel, and describe the similarities and differences.