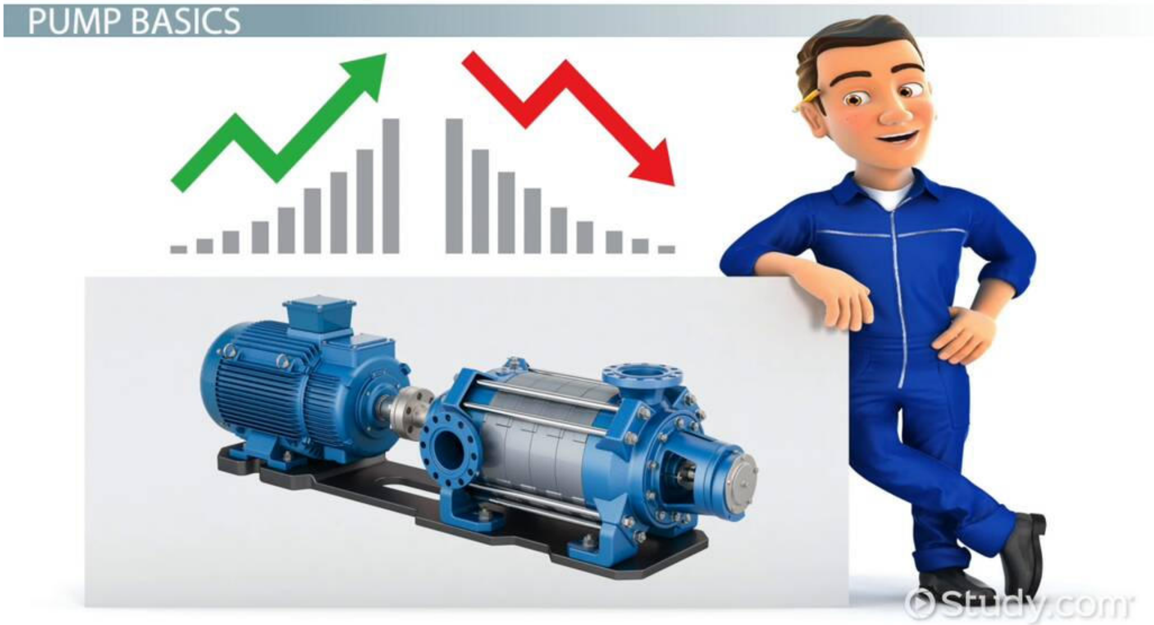
PUMP BASICS
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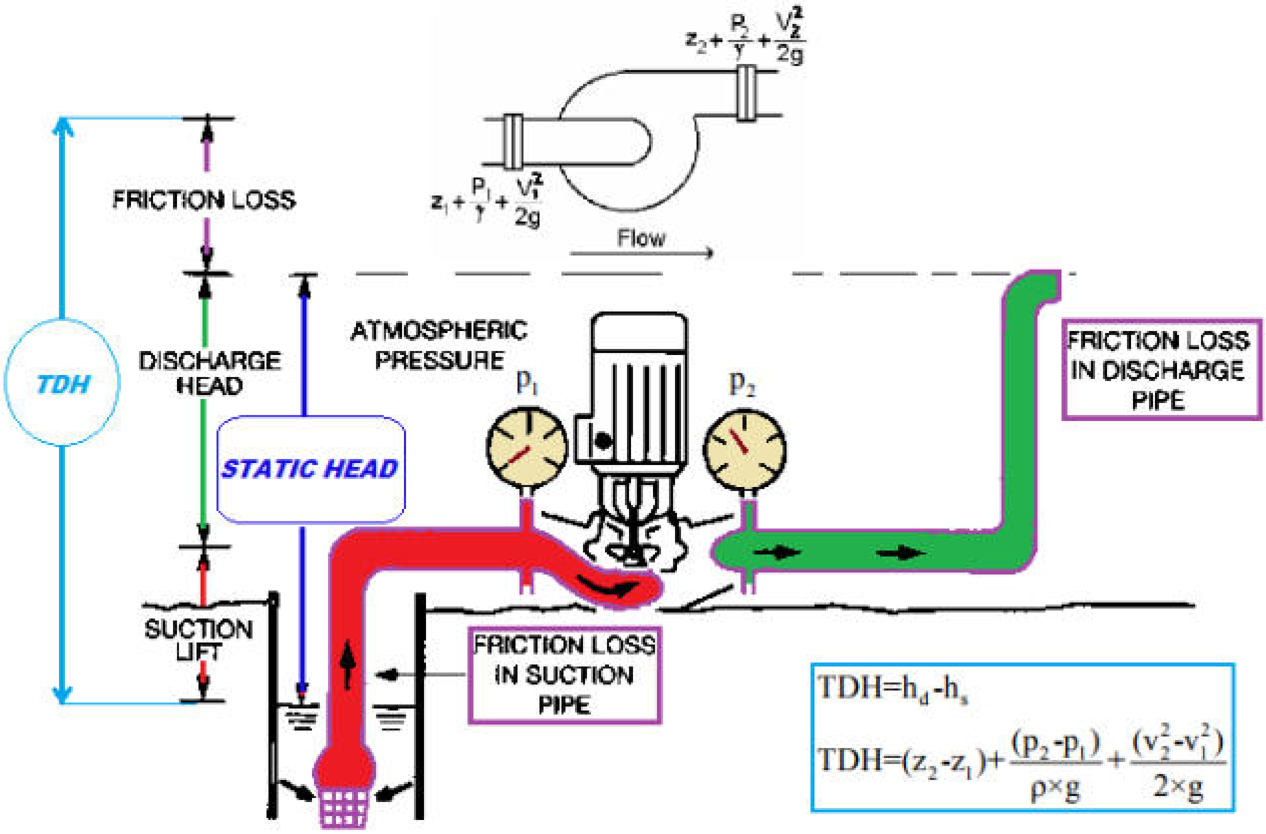
PUMP BASICS


$z_2 + \frac{P_2}{\gamma} + \frac{V_2^2}{2g}$
$z_1 + \frac{P_1}{\gamma} + \frac{V_1^2}{2g}$
Flow
TDH
FRICTION LOSS
DISCHARGE HEAD
SUCTION LIFT
STATIC HEAD
ATMOSPHERIC PRESSURE
p_1
p_2
FRICTION LOSS IN DISCHARGE PIPE
FRICTION LOSS IN SUCTION PIPE
$TDH = h_d - h_s$
$TDH = (z_2 - z_1) + \frac{(p_2 - p_1)}{\rho \times g} + \frac{(v_2^2 - v_1^2)}{2 \times g}$

Centrifugal Pump Performance

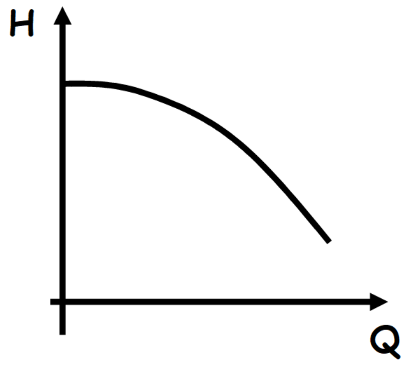
The pump performance can be obtained by testing the pump at different flow rates.

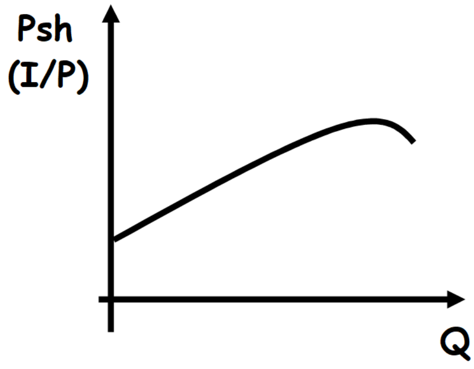
The pump efficiency is related to the shaft (input) power according to the relation:

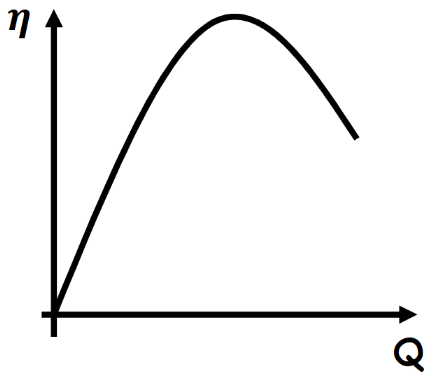
$$P_{sh} = \frac{PQ}{\eta} = \frac{\rho g h Q}{\eta}$$

Where; P = pressure difference across the pump

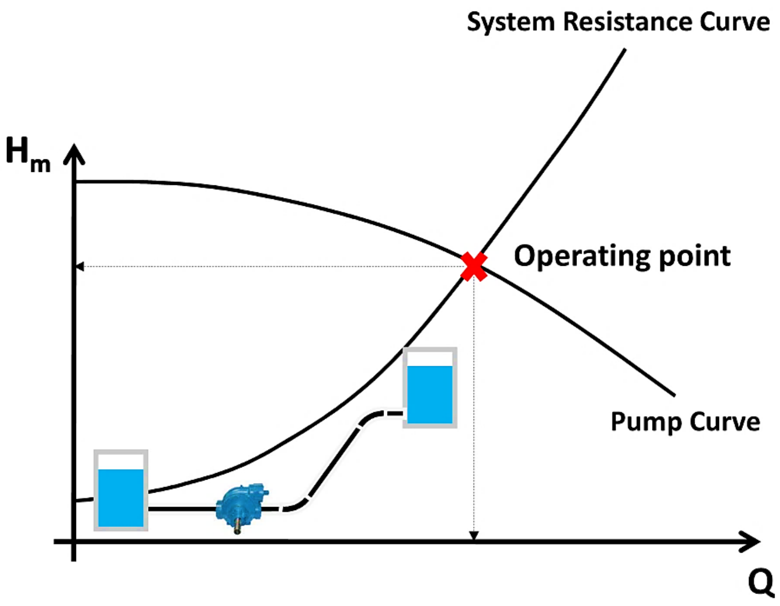
h = head difference across the pump (manometric head)







Operating Point: The operating point is the point at which the force of the pump balances the resistance force of the system. This occurs at the intersection point between the pump performance curve and the system resistance curve. If the flow accidently increases/decreases beyond the operating point the pump force becomes lesser/greater than the system resistance and hence the flow decelerates/accelerates till the two forces get balanced again.

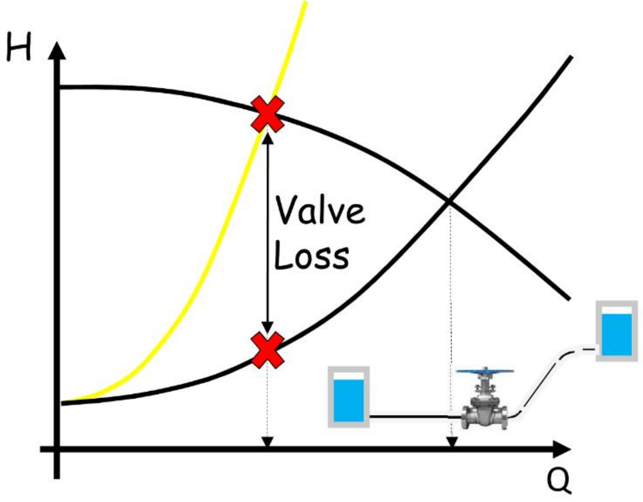


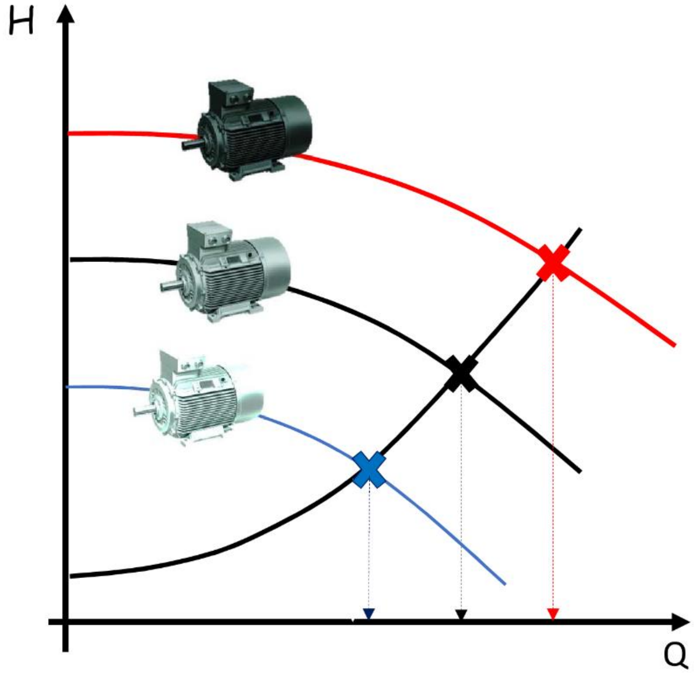
How to Control the pump flow rate?

We have 2 method, by control the system resistance of pump speed.

If the pump delivery valve is partially closed, the system resistance increases. Hence, the operating point shifts to a lower flow rate.

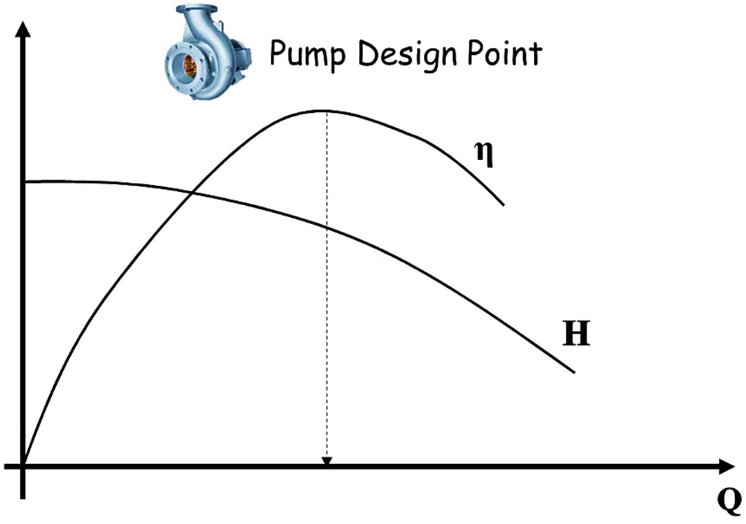
If the motor speed increased, the H-Q curve will change as shown at diagram.



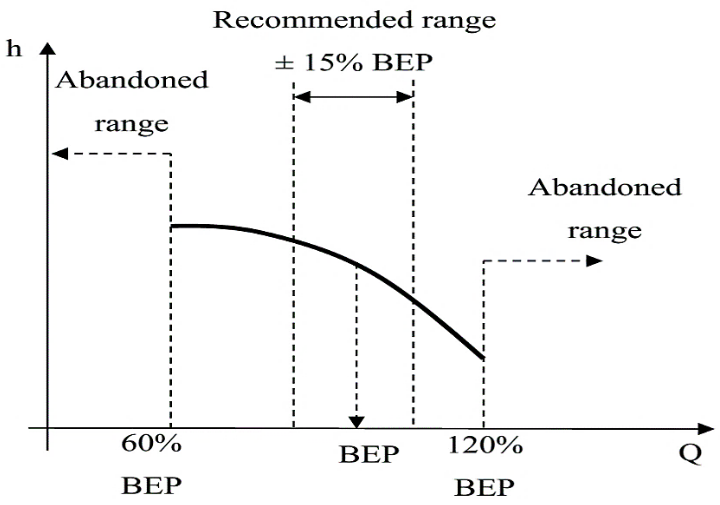


The Best Efficiency Point (BEP)

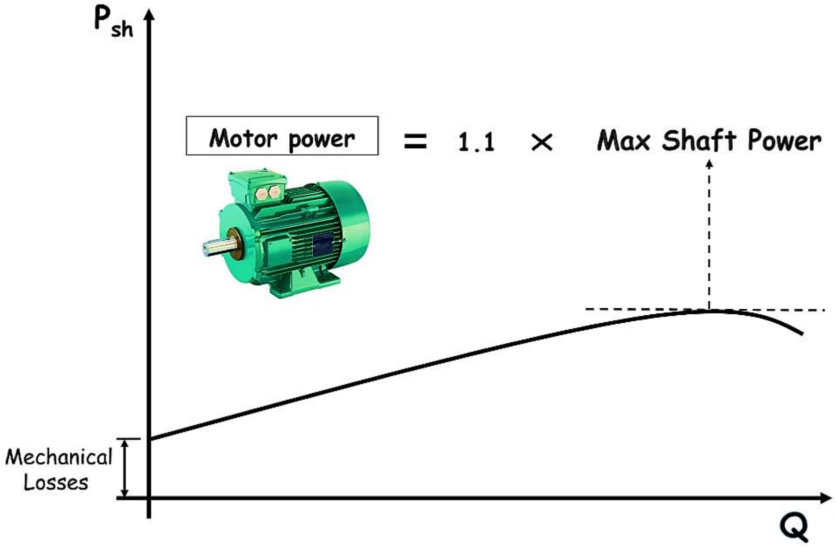
The pump design is held at a single point (flow rate and head) this point is called the Design Point. When operating the pump at this point it has the maximum efficiency. So the point is also called the Best Efficiency Point (BEP). When selecting the pump, it is normally targeted to operate the pump at this point; hence it is also called the normal flow point.



Operating range: Operating the pump beyond the BEP (design point) not only decreases its efficiency but also subjects it to mechanical and hydraulic problems. Therefore the pump is recommended to operate in a range of ±15% around the BEP. On the other hand, the pump should never be operated at a flow rate lower than 60% of the BEP or it will be subjected to excessive vibrations that can destroy its bearings, or at a flow rate higher than 120% of the BEP or it will be subjected to cavitation that destroys its impeller as will be shown later.



Motor selection and starting: The motor is selected based on the pump maximum shaft power. This can be determined from the shaft power curve of the pump. A 15% safety margin is considered when selecting the motor. One of the well-known characteristics of the induction electric motor is its high starting electric current i.e. when it is started it passes a current that is almost three times the load current. So it is preferred to start the equipment driven by the motor at its minimum load to protect the motor from overload. This applies to all the equipment driven by the induction motor such as centrifugal pumps, axial pumps compressors, etc. For the centrifugal pump, the pump loads minimum when the flow is zero. Hence, it is recommended to start the centrifugal pump with its delivery valve completely closed and open the valve gradually after a short period of time.



Cavitation

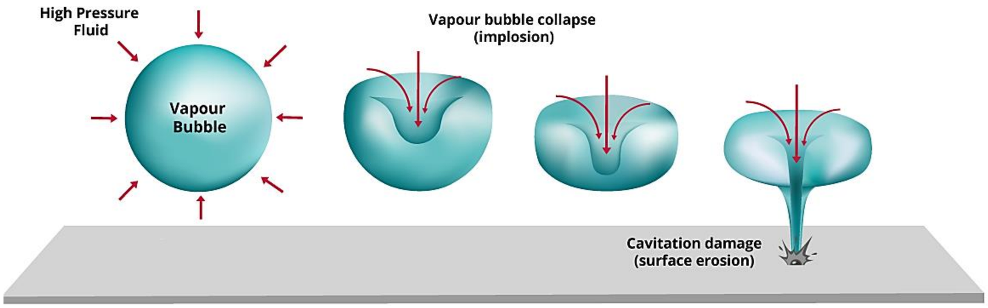
To boil any liquid, there are always two choices; increasing liquid temperature or decreasing its pressure. As the liquid temperature increases, its molecules receive more energy and at a certain temperature (boiling temperature or saturation temperature) the molecules obtain very high energy that allows them to get free from the liquid (evaporate). On the other hand, decreasing the liquid pressure allows the molecules to get free although still having the same energy (at the same temperature). This means we can boil water at the room temperature by only decreasing its pressure. The pressure at which the liquid evaporates at the working temperature is called the "vapor pressure". The vapor pressure of water at 20o C is 0.023 bar (always absolute value).

The flow area at the eye of the pump impeller is usually smaller than either the flow area of the pump suction piping or the flow area through the impeller vanes. When the liquid being pumped enters the eye of a centrifugal pump, the decrease in flow area results in an increase in flow velocity accompanied by a decrease in pressure.

The greater the pump flow rate, the greater the pressure drop between the pump suction and the eye of the impeller. If the pressure drop is large enough, or if the temperature is high enough, the pressure drop may be sufficient to cause the liquid to flash to vapor when the local pressure falls below the saturation pressure for the fluid being pumped.

Any vapor bubbles formed by the pressure drop at the eye of the impeller are swept along the impeller vanes by the flow of the fluid. When the bubbles enter a region where local pressure is greater than saturation pressure farther out the impeller vane, the vapor bubbles abruptly collapse. This process of the formation and subsequent collapse of vapor bubbles in a pump is called cavitation.

Cavitation in a centrifugal pump has a significant effect on pump performance. Cavitation degrades the performance of a pump, resulting in a fluctuating flow rate and discharge pressure. Cavitation can also be destructive to pumps internal components. When a pump cavitates, vapor bubbles form in the low pressure region directly behind the rotating impeller vanes. These vapor bubbles then move toward the oncoming impeller vane, where they collapse and cause a physical shock to the leading edge of the impeller vane. This physical shock creates small pits on the leading edge of the impeller vane. Each individual pit is microscopic in size, but the cumulative effect of millions of these pits formed over a period of hours or days can literally destroy a pump impeller. A cavitating pump can sound like a can of marbles being shaken. Other indications that can be observed from a remote operating station are fluctuating discharge pressure, flow rate, and pump motor current.



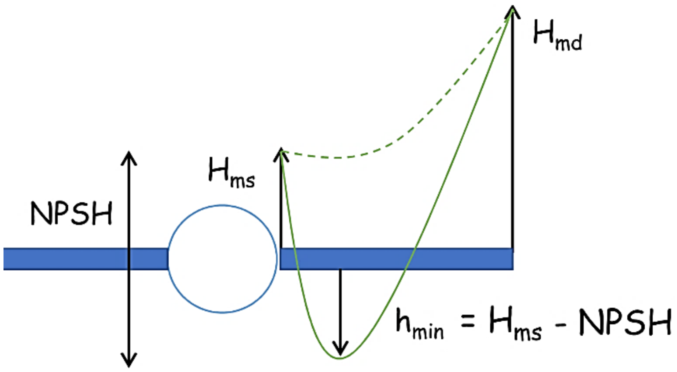
Net Positive Suction Head

To avoid cavitation in centrifugal pumps, the pressure of the fluid at all points within the pump must remain above saturation pressure. The quantity used to determine if the pressure of the liquid being pumped is adequate to avoid cavitation is the net positive suction head (NPSH).

The net positive suction head available (NPSHA) is the difference between the pressure at the suction of the pump and the saturation pressure for the liquid being pumped.

The net positive suction head required (NPSHR) is the minimum net positive suction head necessary to avoid cavitation.

The condition that must exist to avoid cavitation is that the net positive suction head available must be greater than or equal to the net positive suction head required. This requirement can be stated mathematically as shown below. NPSHA ≥ NPSHR



$$\boxed{\underbrace{h_{atm} - h_{vap} + H_{ss} - h_{ls} - \frac{V_s^2}{2g}}_{\text{NPSH Available}} > \underbrace{NPSH}_{\text{NPSH Required}}}$$

Preventing Cavitation

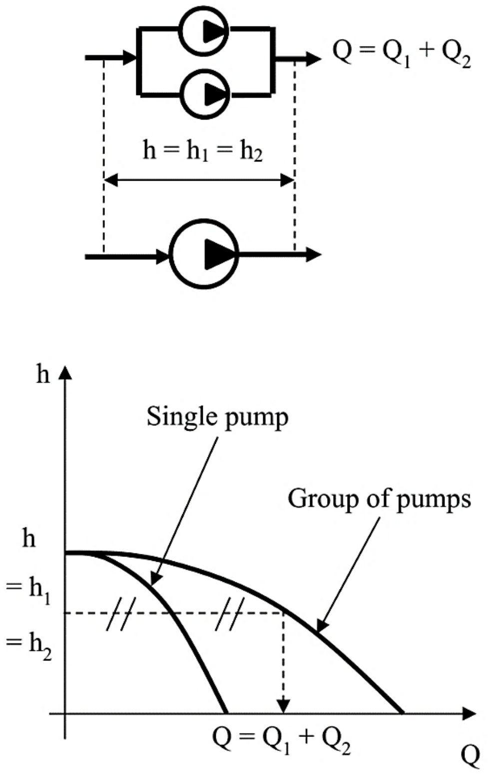
Raising the suction tank level (hss): From a rough estimation for water flow (hatm – hvap = 10 m, Vs = 2 m/s and NPSH = 4 m), we find that the suction level should not drop more than 4 m below the pump level (hss > – 4 m). Some liquids such as gasoline are volatile (hatm – hvap = 4 m). For these liquids the suction level should be much higher than the pump level, so a hole is dug in the ground to place the pump in it.

Decreasing the losses (friction and eddy types) in the suction type: That means placing the pump as close as possible to the suction tank, although theoretically its operating point is not affected by its place along the pipeline, to decrease suction pipe length. Also increasing the suction pipe diameter (sometimes it is designed larger than the delivery pipe) to decrease losses and kinetic energy. Finally, one important point is excluding any unnecessary fittings (e.g. elbows) and using suction valves of types that make minimum losses when fully open (e.g. gate valve and ball valve).

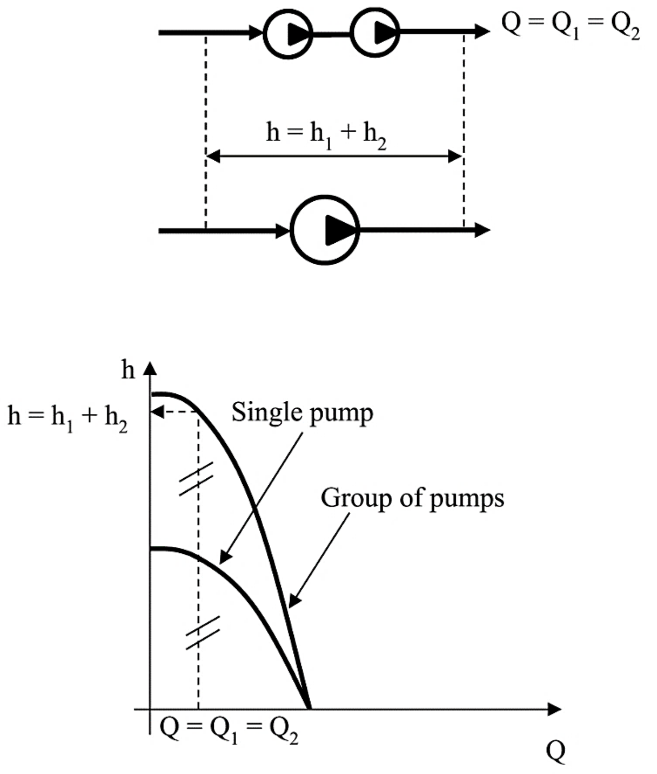
Pump Grouping

In many cases it is required to use more than one pump in the system. A group of pumps can be arranged either in series or in parallel.

Equivalent performance the equivalent performance of two identical pumps connected in series of parallel can be deduced as shown in figure.



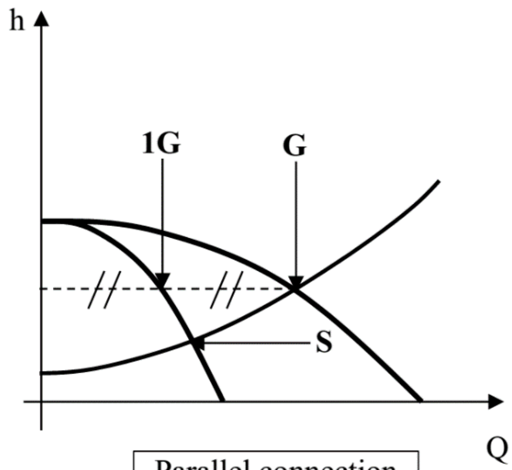
Parallel connection



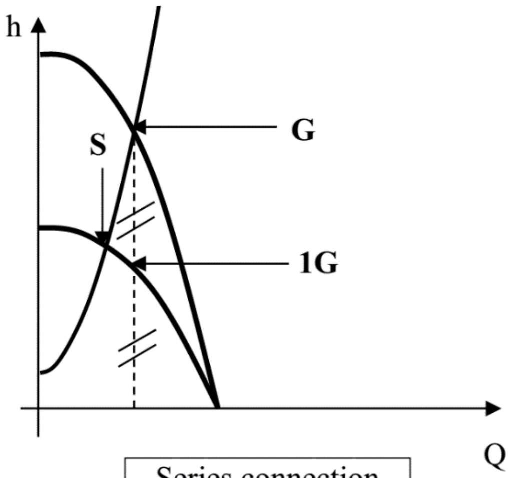
Series connection

On the performance curves of two pumps connected in group exist three operating points:

- S: the operating point when one pump operates alone in the system.
- G: the operating point when a group of pumps operate in the system.
- 1G: the operating point of one pump in a group of pumps that work together in the system.



Parallel connection

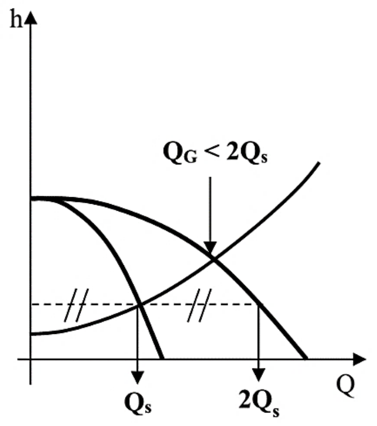


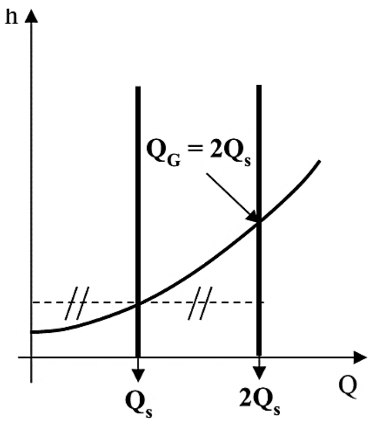
Series connection

Why isn’t the flow doubled?

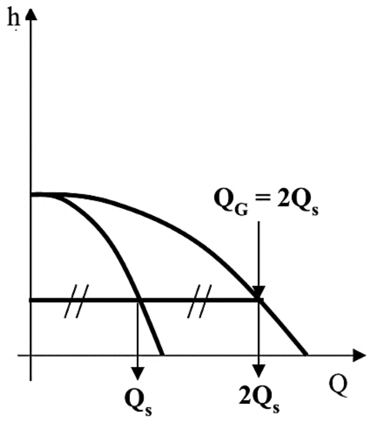
Assume a DHP pump that gives 10 L/s in a system, when another identical pump is connected to it in parallel the total flow rate will be 17 L/s! To get 20 L/s, double the flow, one of two things should happen:

- The pump has a fixed flow rate, which is the case in PDPs.
- The system has constant losses, rather than the parabolic relation with Q.





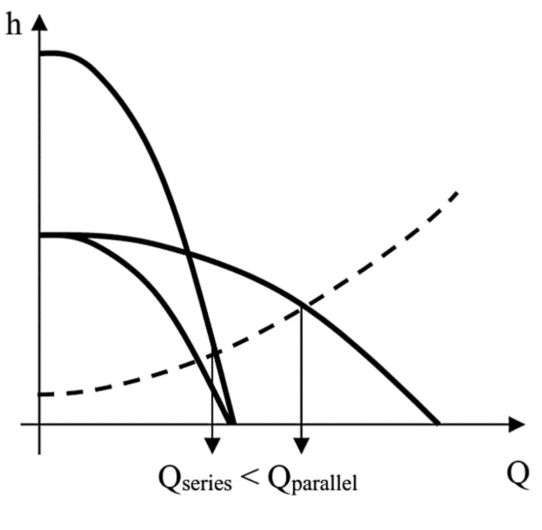
Fixed flow pump (PDP)

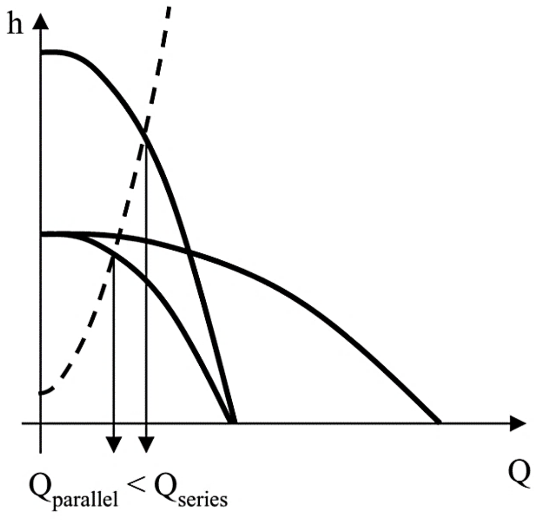


Flat system

Which connection gives more flow rate?

Assume two hydraulic systems as the shown in figure. For both systems, connect two identical in parallel at one time and in series at another time.

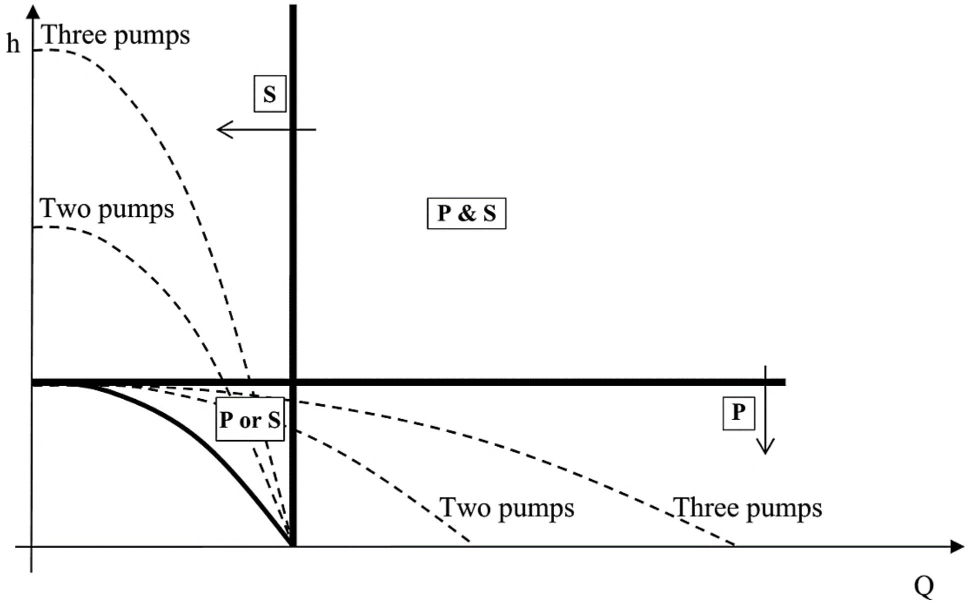




From the graphs it can be concluded that the type of connection that gives higher flow rate depends on the system resistance. If the system resistance is low, the parallel connection gives higher flow rate and vice versa.

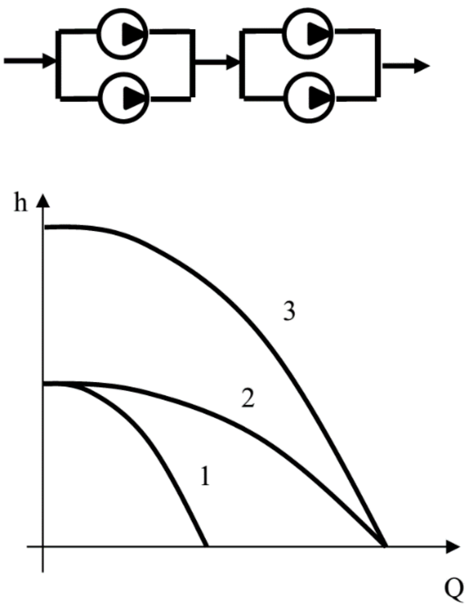
Series or parallel

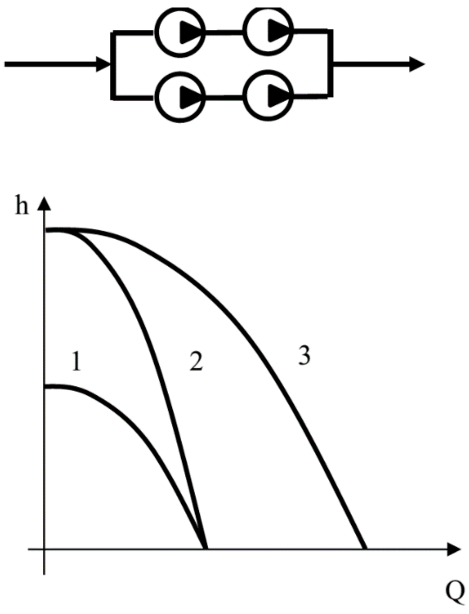
The following graph shows the zones of operation of each type of connection.



From the graph, four regions can be distinguished:

- P: the operating point can be achieved by connecting pumps in parallel.
- S: the operating point can be achieved by connecting pumps in series.
- P & S: the operating point can be achieved by connecting pumps in parallel and in series.
- P or S: the operating point can be achieved by connecting pumps in parallel or in series. In this case the best type of connection is the one that achieves the operating point by minimum number of pumps and minimum power consumption.





Motor selection and cavitation probability

As has been shown from the previous study, a pump in a group of pumps connected in parallel gives lower flow rate than it would give if operating alone and the opposite is true in case of series connection.

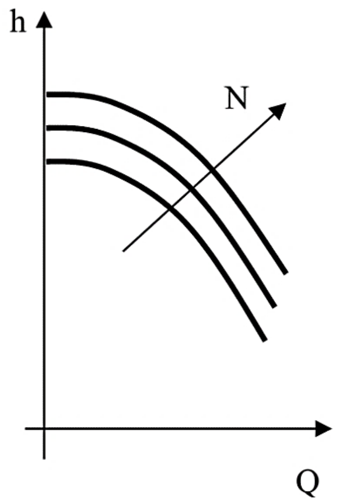
But it is known that the pump power consumption increases as the flow rate increases.

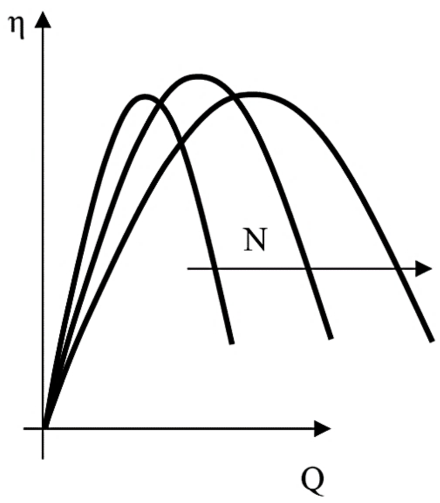
So if a pump is to be operated in a group of pumps connected in parallel, the motor is to be selected based on the power it consumes when operated alone. While if a pump is to be operated in a group of pumps connected in series, the motor is to be selected based on the power it consumes if operated in the group.

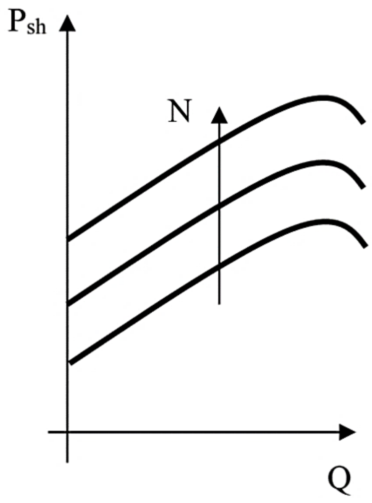
On the other hand, connecting pumps in series increases the flow rate which makes cavitation more probable. Hence, when connecting pumps in series, cavitation must be checked for the pumps in the group connection. Besides, if the two pumps are not identical, the larger pump has a larger NPSH and it is, therefore, recommended to connect the larger pump downstream the smaller pump.

Speed control: The easiest and cheapest method to control pump flow rate is the delivery valve partial closure. However, this increases the losses of the system. The most power efficient way to control flow rate is the shaft speed control.

The figure shows the performance of the pump at different speeds.



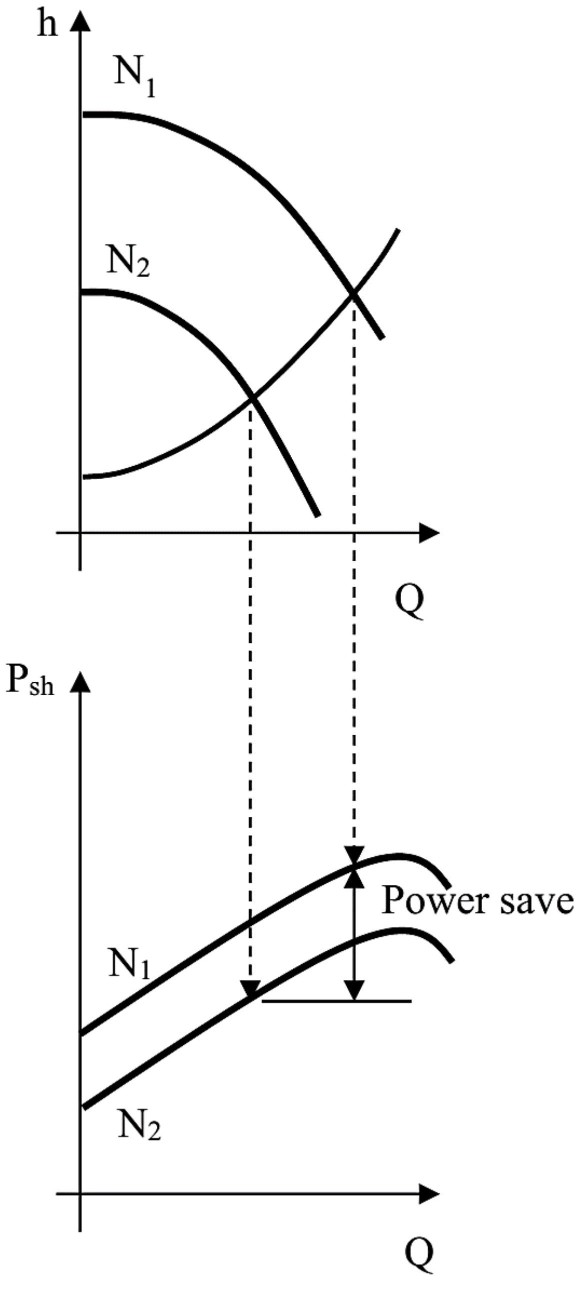




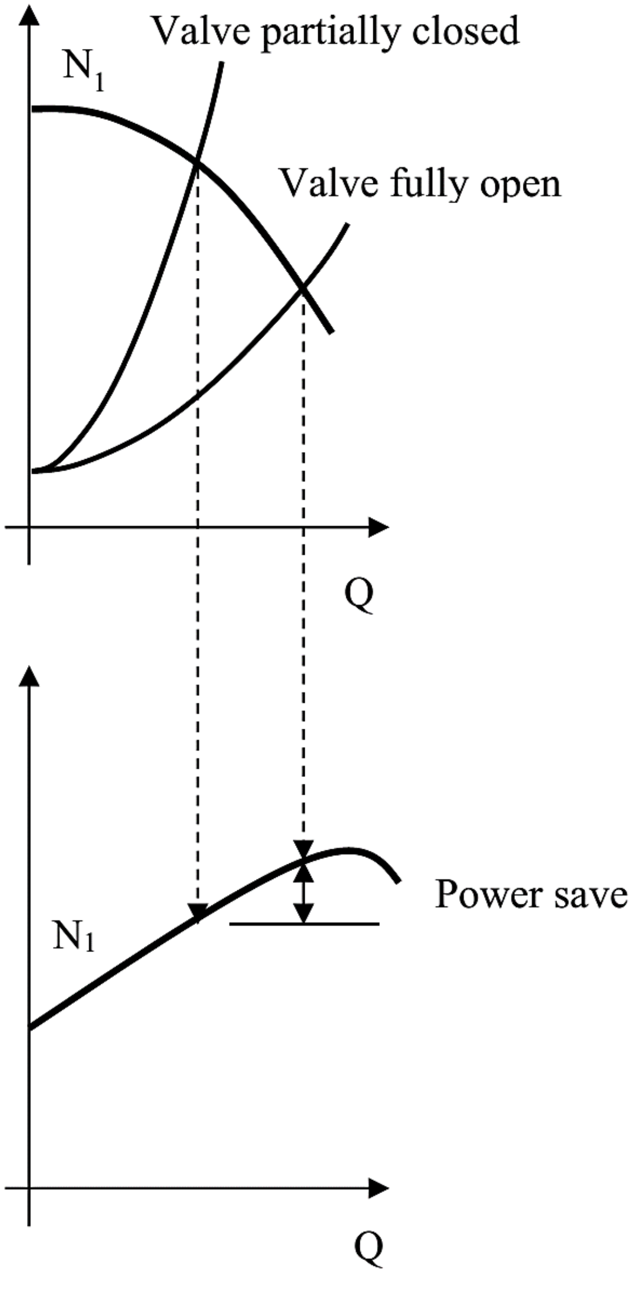
It should be noted that operating the pump at a higher speed, shifts the power curve upwards. This new power curve may not be sustainable by the existing electric motor of the pump and may cause it to overheat.

Speed vs. valve control

The following figure illustrates that the speed control saves power compared with valve closure.



Speed control

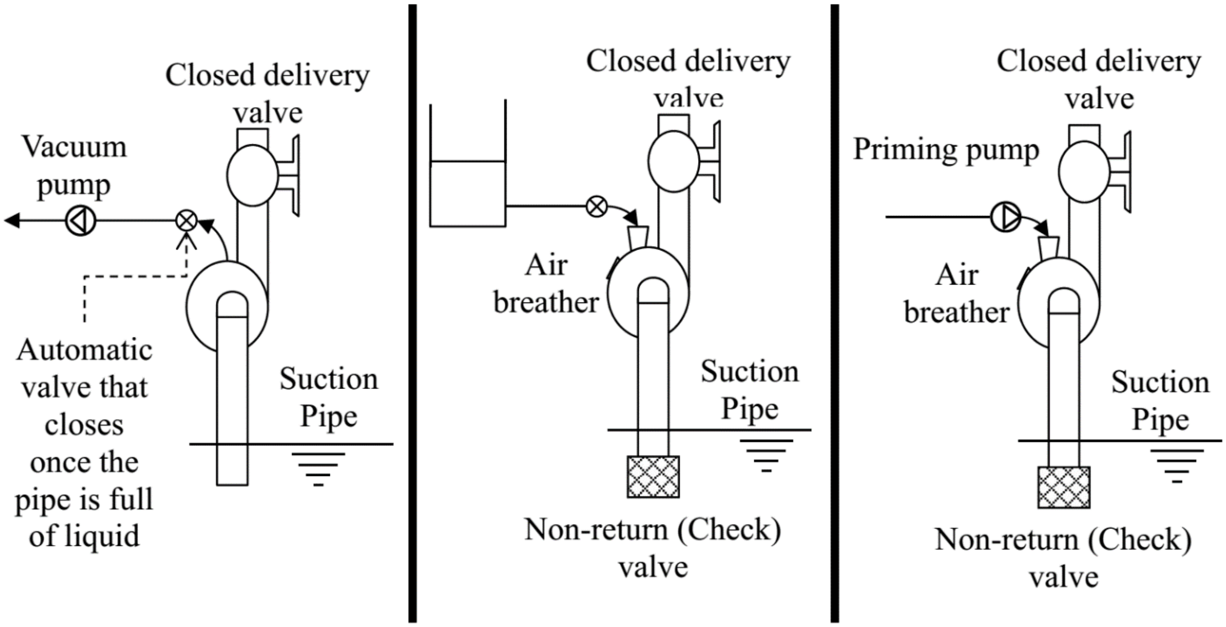


Valve control

Priming

If placed above suction tank level, the DHP can't start liquid flow unless its impeller is flooded with liquid. This is because the centrifugal force depends on the density of the pumped fluid. The density of air is too low to create suction pressure that is capable of raising the heavy liquid from suction tank. To start the flow; the pump casing should first be filled with water which is called "priming".

There are many ways of priming; some of them are illustrated in figure. Also some pumps are designed to be "self-priming pumps".



Centrifugal pump installation