## 3.1 Introduction

To transport water through pipes energy has to be fed to the water. The energy is needed to overcome the dynamic friction losses in the pipe. Also energy is needed to compensate differences in level between the beginning and the end of a pipe (lift energy). Basically a pump is a piece of equipment to feed energy to a water flow. Two types of pumps can be distinguished:

- Pumps capable of lifting water from one free surface to another: open pumps or Archimedean screws (fig. 3.1).
- Pumps capable of feeding energy to water in combination with a closed pipe: centrifugal or impeller pumps (fig. 3.2).

*Fig. 3.1 - Archimedean screw*

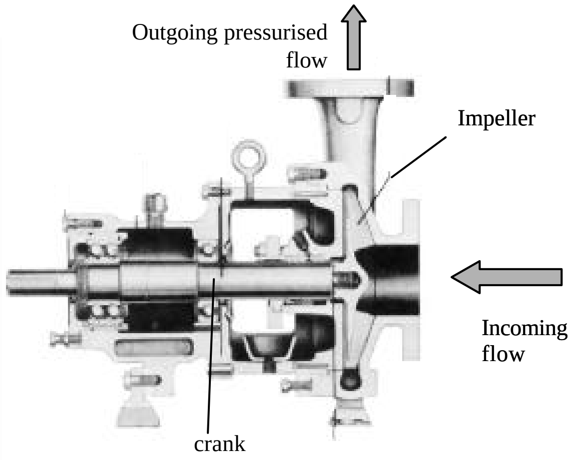

*Fig. 3.2 - Centrifugal pump*

Pumps are used for instance to pump water out of the ground, to overcome level differences in treatment processes, to transport drinking or sewerage water over large distances in combination with pipes or to dispose of rain water from polders. Numerous other applications of pumps can be given, but they won't be dealt with in this chapter, as they are less relevant for the actual bulk transport of water.

Pumps that work in combination with pipes can be categorised in displacement pumps and impeller pumps. The impeller pumps can be further categorised based on the type of impellor in Radial flow pumps, mixed flow pumps and axial flow pumps. All types of pumps will be described in this chapter.

## 3.2 Pump characteristics

The hydraulic properties of a pump can be described by some characteristics:

- Q-H curve
- Efficiency curve
- Power curve
- Net Positive Suction Head (NPSH) curve.

Each of the characteristics is explained in the next sections for propeller pumps.

### *3.2.1 Q-H curve*

The Q-H curve is the relation between the volume flow and the pressure at a constant speed of the pump crank. The H in the curve is the difference in energy level between the suction and the pressure side of the pump. Q-H curves will be given by the manufacturer of the pump and can normally be considered as a simple quadratic curve.

An example of a pump curve is given in figure 3.3.

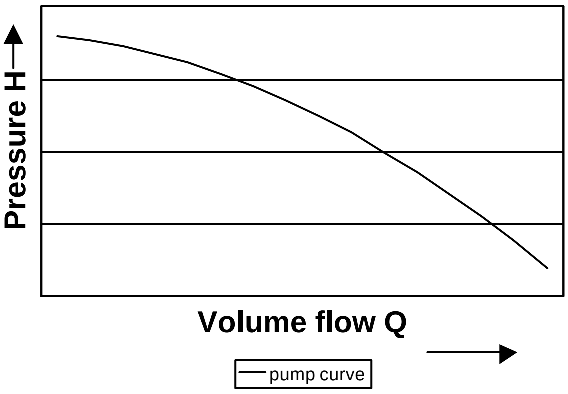

*Fig. 3.3 - Pump curve*

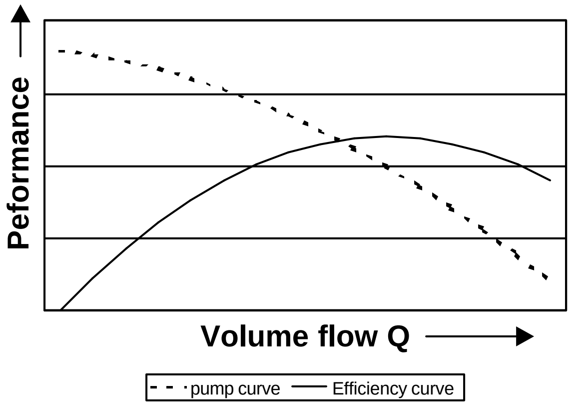

*Fig. 3.4 - Pump and efficiency curve*

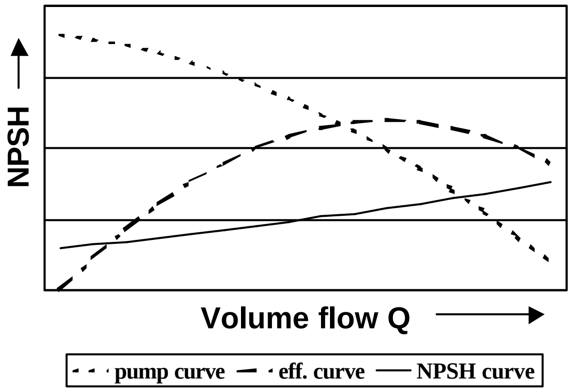

*Fig. 3.5 - Pump efficiency and NPSH curve*

### 3.2.2 *Efficiency curve (fig. 3.4)*

The hydraulic efficiency of the pump with the motor is given with the efficiency curve. The hydraulic efficiency is the relation between the absorbed hydraulic energy (pressure and velocity) and the provided mechanical energy at the pump crank including the power efficiency of the motor.

### 3.2.3 *NPSH curve*

The Net Positive Suction Head curve is the relation between the volume flow Q and the needed margin between the energy level at the suction side of the pump and the vapour pressure of the water to prevent too much cavitation in the pump (fig. 3.5).
At the suction side of a pump negative pressures, i.e. pressures below the atmospheric pressure, can occur, especially when the actual weir of the pump is above the level of the reservoir the water is drawn from. (see paragraph XX) This negative pressure is limited to the actual vapour pressure of the fluid at the current temperature. If this allowable negative pressure is subsided, cavitations will take place in the pump. Although a small amount of cavitations within a pump cannot be avoided, this should be limited. The NPSH requirements of a pump give these limitations. The effect of cavitation is extra wearing of the pump, which can be unacceptable. The bubbles that are formed at the suction side of the pump will be pressurised at the outlet side. The pressurised bubbles will act as actual grains or small stones and wear the material out.
To avoid unacceptable cavitations the available NPSH should be larger or equal to the needed NPSH. The available NPSH is defined as:

$$NPSH_{available} = H_a + h_0 - h_v$$

With $H_a$ = *suction head at the impeller*
$h_0$ = Atmospheric pressure
$h_v$ = Vapour pressure

$$H_a = h + \frac{v^2}{2g}$$

with h the pressure at the impeller entrance, v the velocity of the water at the impeller entrance.
The varous pump curves are provided by the pump manifacturer.

## 3.3 Classification of pumps

A pump can feed energy to water, which can be expressed in the pressure or lift of the water or in the volume flow. Based on the combination of pressure/ lift and volume flow a classification of pumps can be made, which can be quantified with the specific speed (see previous paragraph):

| | | |
|---|---|---|
| Pressure/lift | High pressure, low flow | High pressure, high flow<br>• Drinking water transport<br>• Sewerage water transport |
| | Low pressure, low flow<br>• Dosing pumps<br>• Drainage pumps | Low pressure, high flow<br>• Surface water intake<br>• Rain water discharge |
| | Volume flow | |

Based on the classification the type of pump needed can be determined.

### 3.2.1 Archimedean screw

The Archimedean screw is used in situation that large quantities of water have to be pumped from one free surface level to another with a level difference of a few meters. A typical use of Archimedean screws is drainage of polder areas to pump out large volumes of storm water (fig. 3.6). The screw can also be used if water is polluted with debris as wood, plants and other floating objects.

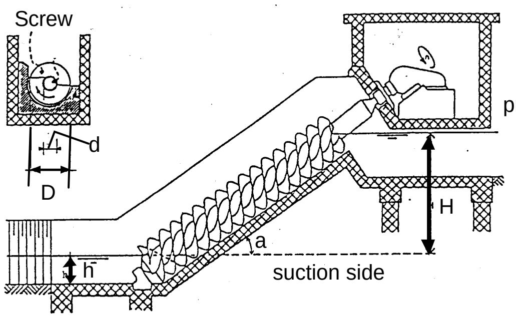

*Fig. 3.6 - Picture of Archimedean screw*

The capacity of the screw is dependant of the head H (difference between fluid surfaces), the slope of the screw with the horizontal $\alpha$ the diameter of the screw D and the diameter of the casing d, the number of blades and the pitch S and the rotating speed of the screw n.

The basic formula for estimating the capacity of an Archimedean screw is

$$Q = knD^3 \quad \text{with} \quad k = f\left(\frac{S}{D},\frac{d}{D},a,n\right)$$

Some typical values of k are given in table 3.1

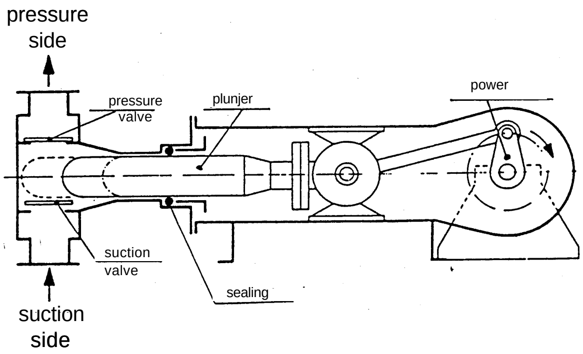

*Fig. 3.7 - Displacement pump*

### 3.3.2 Displacement pumps

A positive displacement pump works following the principle of figure 3.7. Several types of displacement pumps are available all working following the principle that a fixed amount of fluid is “encapsulated” and pushed to the pressure side of the pump. Another example is shown in figure 3.8.

*Fig. 3.8 - Displacement pump open (left) and closed (right)*

Displacement pumps are mostly used for ‘difficult’ fluids like very high viscous fluids or for applications a high pressure is needed. The pump curve is typically very steep (figure 3.9). This means that a more or less constant volume flow is produced with a range of pressures.

*Table 3.1 - k-values for 3 and 4 blade screws*

| d/D | $a = 22^O$ | | $a = 26^O$ | | | $a = 30^O$ | |
|---|---|---|---|---|---|---|---|
| | S=1D | S=1,2D | S=0,8D | S=1,0D | S=1,2D | S=0,8D | S=1,0D |
| | | | | | | | |
| 0.3 | 0.331 | 0.336 | 0.274 | 0.287 | 0.286 | 0.246 | 0.245 |
| 0.4 | 0.350 | 0.378 | 0.285 | 0.317 | 0.323 | 0.262 | 0.271 |
| 0.5 | 0.345 | 0.380 | 0.281 | 0.317 | 0.343 | 0.319 | 0.287 |
| 0.6 | 0.315 | 0.351 | - | .0300 | 0.327 | - | 0.273 |

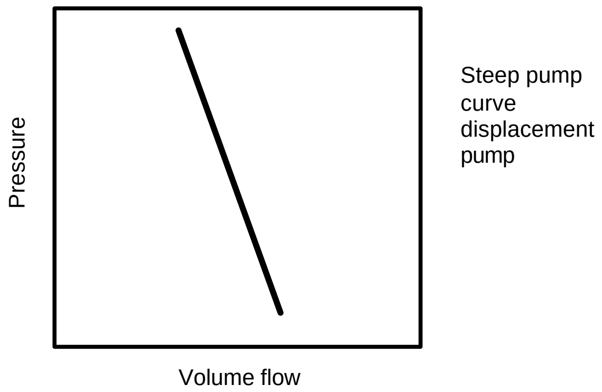

*Fig. 3.9 - Steep pump curve displacement pump*

### 3.3.3 Impellor pumps

Impellor pumps are by far the most used pumps. A indicative figure is that of all the pumping capacity 90% is of the impellor type, covering 75% of all pumps. Most important reason is the broad application possibilities in combination with relative low maintenance and high efficiency.

The impellor pump has an axle in a bearing with one or more (multi stage pump) impellors with a number of blades. The principle is that the rotation of the impellors accelerates the fluid and ‘fling’ the water in the house, which is connected to the pipes. Figure 3.10 gives a principle drawing of an impellor pump.
The axle can be motored with all kinds of engines varying from conventional combustion engine to solar power driven motors.
Three different blades are possible (fig. 3.11):

- Centrifugal impellor with axial inflow and radial or tangential outflow
- Mixed flow impellor with axial inflow radial, axial and tangential outflow
- Axial flow impellor with axial inflow and axial tangential outflow

The different types are illustrated in figure 3.11.

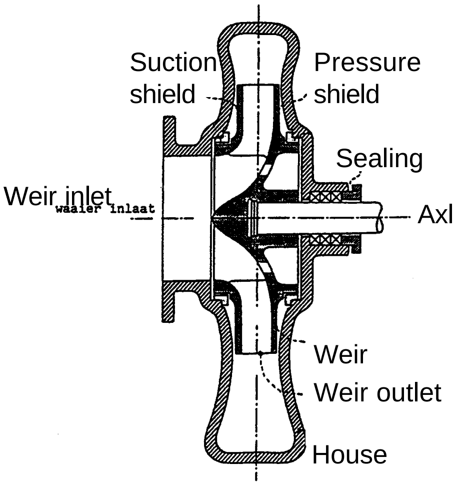

*Fig. 3.10 - Principle impellor pump*

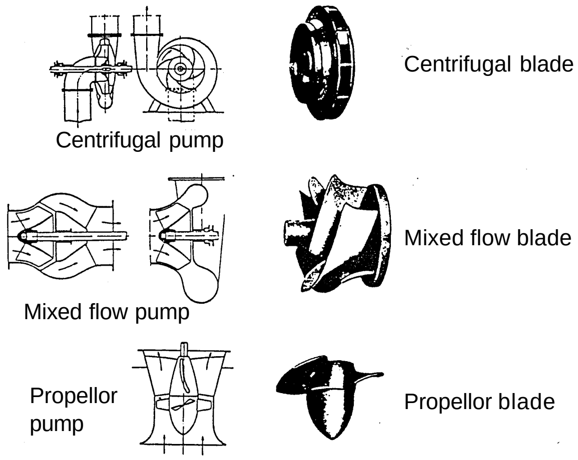

*Fig. 3.11 - Different types of impellor pumps*

Figure 3.12 gives a five stage centrifugal pump. The blades of this pump are closed.
Figure 3.13 gives a two stage ground water abstraction pump. The motor is under the stages and also sub merged. This is a common way of powering these kind of pumps. Long shafts are difficult to balance and sensitive to failure and are not preferred to a direct connection between pump and motor.

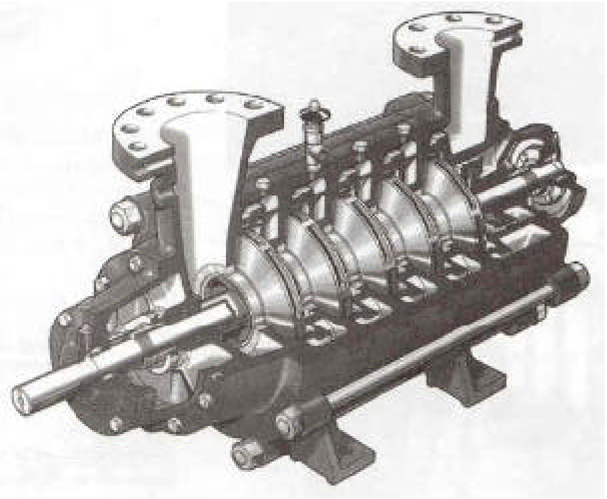

*Fig. 3.12 - Five stage centrifugal pump*

Centrifugal impellors can be open or closed. The picture of the five stage pumps shows closed blades. In figure 3.14 a picture of an open blade in the form af a propellor is shown.

Figure 3.15 gives an example of a cut open pump with an open blade.

*Fig. 3.13 - Ground water pump with two stages*

The axial propellor pumps are best applied for large volume flows and low heads (less than 1 ato or 10 meter). The application for mixed flow pumps is in the range of 3 to 30 meters head and is characterised with a fairly constant efficiency with varying heads.

Centrifugal pumps are used when high heads are required (above 20 meters). With serial or multi stage pumping heads up to 1000 meter can be reached.

### 3.3.4 Specific speed

To classify geometrically similar pumps, the numerical quantity ‘specific speed’ has been adopted. Specific speed is the speed required for delivery of unit flow against unit head; it will vary in accordance with the system of units used

Specific speed

$$Ns = \frac{n\sqrt{Q}}{\sqrt[3]{H^4}}$$

N is the pump impeller speed in rpm; Q is output at maximum efficiency ($m^3/s$); H is delivery head at maximum efficiency (m) as can be read from the efficiency curve. Specific speeds are an indication of what type of impeller pump can be used for a specific application.

Following the definition of specific speed a pump with a low specific speed will generally give a low volume flow with a high pressure. A radial flow pump will be most suited. A high specific

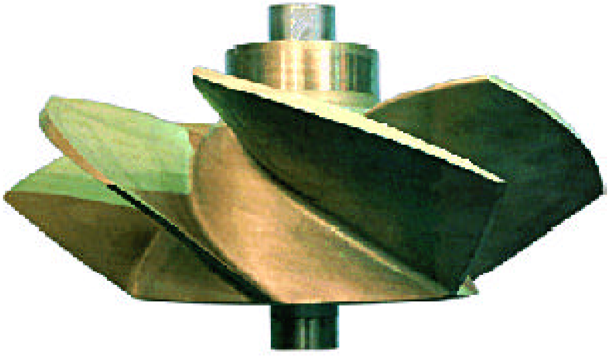

*Fig. 3.14 - Propellor*

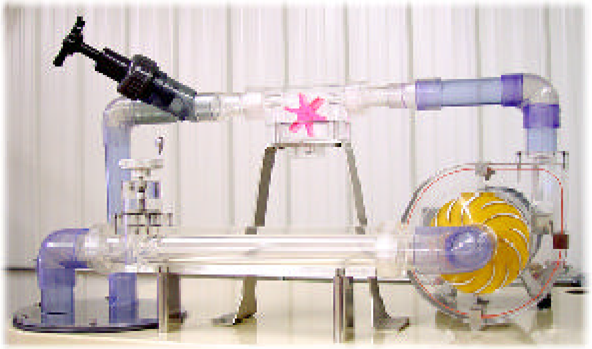

*Fig. 3.15 - Glass pump*

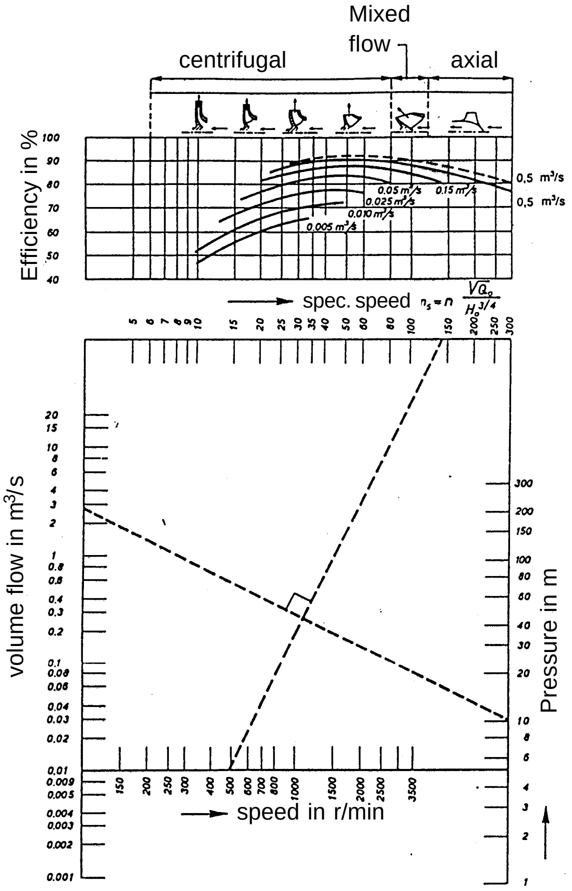

*Fig. 3.16 - Relation between specific and actual speed,*

speed will result in a relative large volume flow at a relative low pressure, resulting in a preference for an axial pump.

Figure 3.16 gives a relation between specific speed, actual speed, pressure, volume flow and efficiency.

### *3.3.5 Working principle impellor pumps*

The rotation of the axle accelerates the fluid adding kinetic energy to the fluid. Within the house or diffuser of the pump this kinetic energy is partly transformed to static pressure, increasing the head of the fluid.
At the suction side of the impellor the fluid accelerates as well and pressure at that point will be lowered, following the laws of Bernoulli. Energy is conserved and at the suction side of the pump the pressure of the fluid will be partly transformed to kinetic energy. This requirement is expressed in the Net Positive Suction Head (NPSH) of a pump. At high volume flows, the NPSH will increase, because the kinetic energy at the suction side will be higher due to the higher fluid velocity.

The form of the blades on the impellor affects the characteristics of the pump. Different shapes of blades are given in figure 3.17. Every blade has its own set of pump curves.

*Fig. 3.17 - Different types of blades*

## 3.4 Application of pumps

### *3.4.1 Pump and network characteristics*

The performance of a pump is described by the Q-H-curve, giving the relation between the volume flow and the head realised by a single pump (figure 3.3).

On the other hand the network served can be characterised with the pipe characteristic. Every set or system of pipes can be virtually represented by a single pipe with equivalent hydraulic features. In the end a complete network can hydraulically be represented by one pipe, called the network characteristic. The hydraulic losses in this characteristic pipe are quadratic proportional to the velocity, and thus volume flow, in that pipe.

$$\Delta H = \lambda \frac{L}{D}\frac{v^2}{2g} = 0{,}0826\frac{\lambda L}{D^5}Q^2$$

The pump is used to compensate the dynamic energy losses in the pipes.

A network characteristic gives the required pressure at the pump that guarantees a minimum pressure at a critical point in the network. The network characteristic represents the hydraulic behaviour of the network between the pumping station and the characteristic pressure point in the network. If a network is represented in one pipe the pipe characteristic can be visualised as is shown in figure 3.18.

In a graph this results in the quadratic curve shown in figure 3.18.

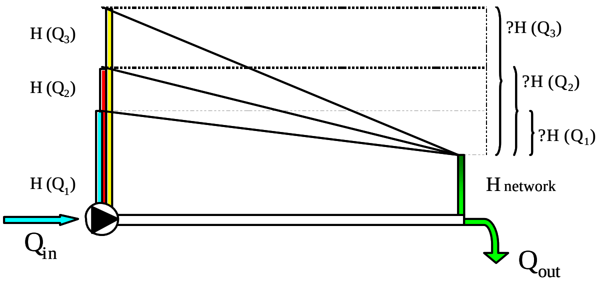

*Fig. 3.18 - Network characteristic*

Combination of the Q-H curve and the pipe characteristic gives the optimal working point of the combination pump-network, which is represented in figure 3.19.
The intersection of the two curves is the working point. At this volume flow the exact minimum pressure is reached in the network attached to this pump.
If another volume flow is demanded in this network, for instance a lower volume flow, than the working

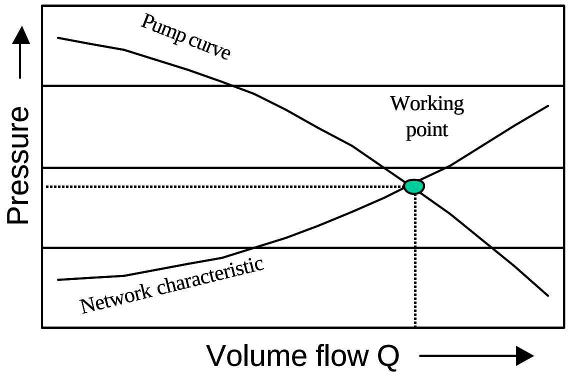

*Fig. 3.19 - Working point*

point will shift on the pump curve. The extra pressure will be the extra pressure in the characteristic point in the network (see figure 3.20). This means that in the network the pressure is higher than the minimum required according to the network characteristic.
The manufacturer of the pump will provide the pump curve as a product specification. One must bear in mind that the pump curve only reflects the pump performance in its own and not the performance within the lay-out of the pumping station, for instance in combination with a non-return valve.
The network characteristic can theoretically be calculated by combing the pipes in the network to one pipe only. Using network models and a calculation program is a more feasible option.

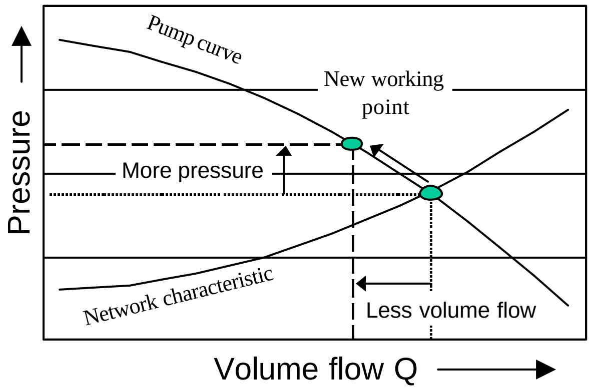

*Fig. 3.20 - New working point*

### 3.4.2 Pump lay out

The volume flow in a network will vary over the hours of the day, the days of the week and even the seasons in a year. Typical demand curves for drinking water are given in figure 3.21.

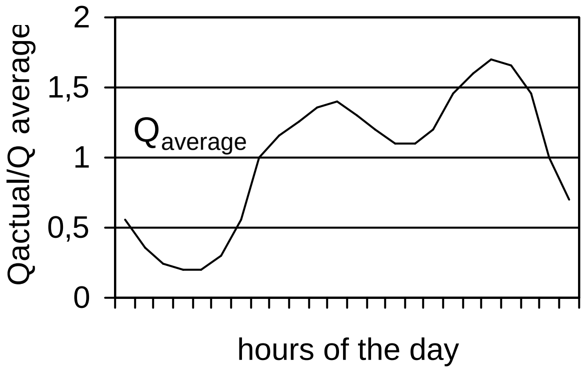

*Fig. 3.21 - Demand curves*

The variation in demand amounts to a factor 5 or higher given the fact that the average demand can vary with a factor 2 over the seasons (see also the lecture notes CT3420). The situation for a pressurised sewer pipes is more or less the same, with an even higher fluctuation as a result of rainwater. In times of heavy rainfall the maximum capacity of the system will be used. Usually this results in a direct waste of diluted sewerage water on surface water.
This varying flow pattern cannot be covered with one pump. Theoretically a pump and a network have only one ideal working point. In reality always more pumps will be installed to cover the pipe characteristic as good as possible with the combination of pumps.

Pumps can be put in parallel as is shown in figure 3.22. Pumps in parallel give a different composite curve as pumps in series as sown in the different pictures. The result of pumps in parallel is more flow with a pressure less than the maximum pressure of a single pump. This is demonstrated in figure 3.22.

A picture of pumps in parade is given in figure 3.23.

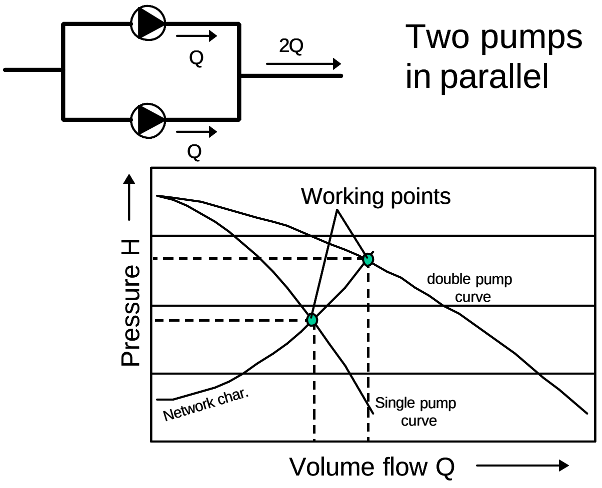

*Fig. 3.22 - Pumps in parallel*

*Fig. 3.23 - Multiple pumps in parallel*

Pumps can also be configured in series. This also gives a composed pump curve as is demonstrated in figure 3.24.

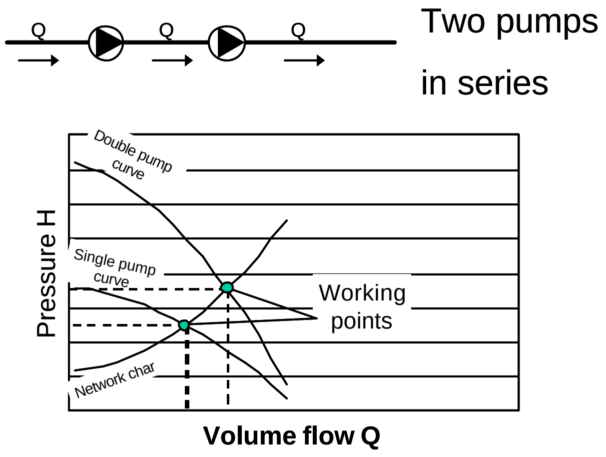

*Fig. 3.24 - Pumps in series*

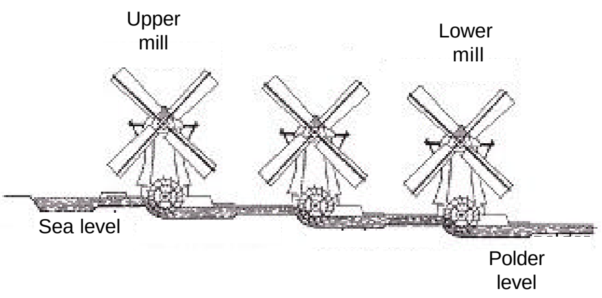

*Fig. 3.25 - Mills in serie*

In series pumps can also be placed, for instance a row of windmills, all pumping the water to a higher level. The result of pumps in series is that pressure is added. This means that higher pressures are possible, but not more flow than from the single pump.

### *3.4.3 Flow control and variable speed pumps*

Because of the varying demands in a drinking water network, a pumping station will consist of several pumps. Switching pumps on and off will make different combinations of pumps possible in series or in parallel, which gives sufficient pressure and volume flow in the network.
As shown in the previous paragraph, pump curves can be constructed using the individual pump curves of the separate pumps. In the network the pressure will vary when pumps are switched on and off. Especially during night hours, when consumption is low, the pressure may rise. Too high pressure may lead to an elevated level of leakage and may cause taps to start dripping. To maintain a constant level of pressure the pump can be throttled at the pumping station, for instance by using a valve. Effectively this means a higher resistance at the beginning of the pipe.

Another way of controlling the flow and pressure in a network is to install variable speed pumps. With a variable speed pump the power of the driving engine can be controlled leading to a pump with a number of pump curves.
In figure 3.26 a set of pump curves of a variable speed pump is drawn, together with a network characteristic.

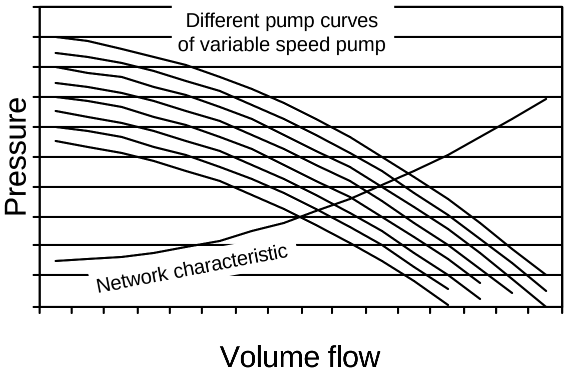

*Fig. 3.26 - Variable speed pump*

### *3.4.4 Pumping station lay out*

For the design of an actual pumping station several input parameters have to be known. At first the variation in volume flows that will have to be dealt with by the pumping station. For typical ‘utility purposes’ like drinking water supply or sewerage water transport a forecast for the volume flows to be expected has to be made. The growth of the area to be served has to be known, for instance the number of drinking water consumers or the paved surface in case of a sewerage water collection. If it is difficult to make a more or less realistic forecast, this will have an effect on the lay out of the pumping station. Modular built up in compartments that can easily be added to the original building is an opportunity. Another way is to have more pumps and pump combinations that can serve the demand.

The next input is the network characteristic of the network to be served. This network characteristic can be determined using measurements or network calculations. With the designed network or a calibrated model of an existing one (see next chapter) the network characteristic can be composed.

The network characteristic together with the demand variations, gives the range of pressures and volume flows to be covered with the pumping lay out.

In the number of pumps to be installed one has to have a certain redundancy. Because of normal maintenance one or two pumps may be in service of can break down for any reason. For maintenance reasons one has to consider whether is it sensible to have the same pumps or pumps with exchangeable parts.

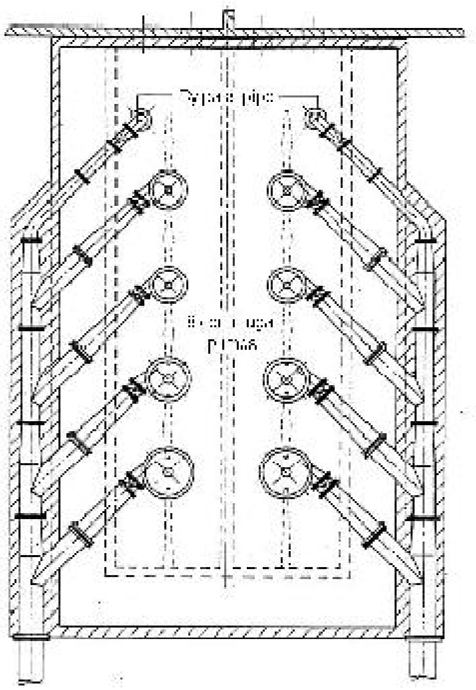

*Fig. 3.27 - Pump layout*

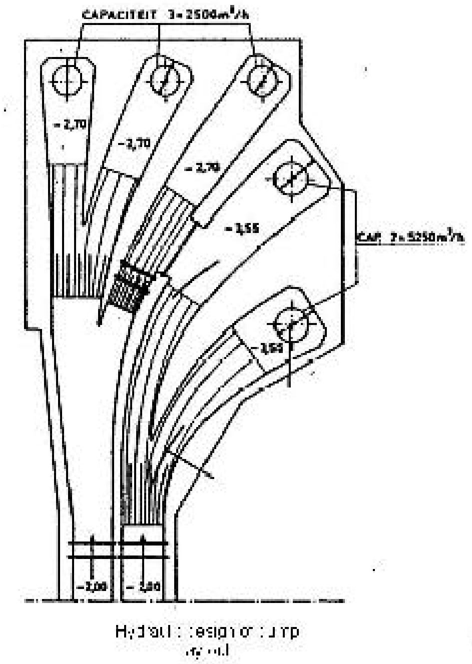

*Fig. 3.28 - Pump layout*

Eventually the pumps have to be installed within a pumping station. A schematic of a pumping station with several pumps in parallel is given in figure 3.27 and 3.28 as an example of how to make a pump lay out.

Hydraulic considerations will have to be made. Avoiding sharp corners is the leading principle. Make constructions that are as smooth as possible. Firstly to prevent energy losses because of release of flow lines and introducing extra resistance in the system. Secondly to prevent ‘dead’ corners in the system that can give rise to water quality problems.

*Fig. 3.29 - Pump with non-return valve*

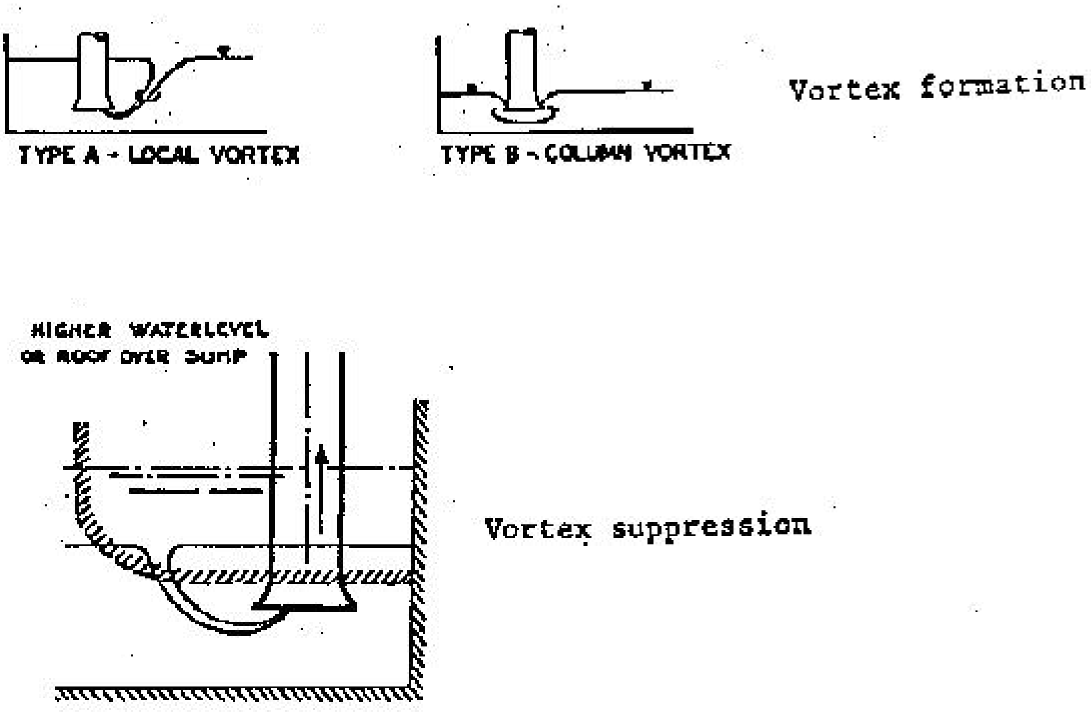

*Fig. 3.30 - Vortexes*

Extra attention should be paid to the suction side of the pumps. Of course the NPSH (net positive suction head) has to be taken into account, but also the risk of air entrapment due to vortexes should be considered. An example of a vortex is given in figure 3.30.

Every pump in a pumping station will be equipped with a non-return valve. This is necessary to prevent water to flow back when the pump is switched of or in the case of parallel pumps to prevent ‘round pumping’. The check valve can be at the suction side or pressure side of the pump. Examples of both are given in figures 3.29 and 3.31.

*Fig. 3.31 - Pump with check valve*