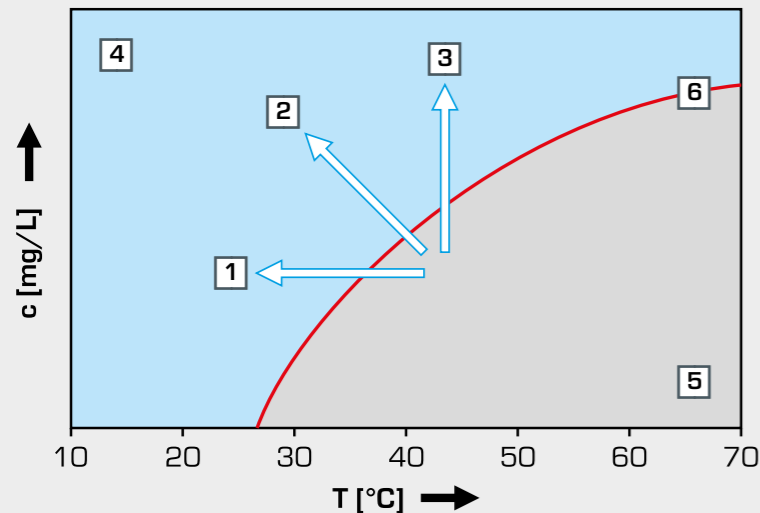


## Basic knowledge

## Crystallisation

Crystallisation is a unit operation in thermal process engineering, and is mainly used for separation and cleaning but also for shaping substances. A characteristic feature of crystallisation is the formation of a new solid phase (crystallisate). The crystallisate can develop from a solution, a liquefied material or vapour. In industrial process and chemical engineering, the main focus is on technical mass crystallisation from liquid phases, particularly solutions. Crystallisation plays a crucial role in the production of crystalline bulk goods such as sugar, cooking salt and fertilisers from aqueous solutions.

A solvent (e.g. water) is able to dissolve a certain quantity of a material (salt) at a fixed temperature. As long as the solvent's maximum capacity to absorb the dissolved substance (saturation concentration) is not reached, there is only a single liquid phase. If the saturation concentration is exceeded, the dissolved substance begins to crystallise. This results in a second, solid phase – the crystallisate.



Simplified illustration of crystallisation unit operations in temperature/solubility diagram:

- T temperature  
c dissolved material  
1 cooling crystallisation  
2 vacuum crystallisation  
3 evaporation crystallisation  
4 oversaturated solution  
5 undersaturated solution  
6 solubility curve

Crystallisation can be achieved using three unit operations:

#### ■ Cooling crystallisation

If solubility is highly dependent on temperature, the saturation concentration of the solute can be exceeded by cooling.

#### ■ Evaporation crystallisation

Part of the solvent is evaporated until the dissolved quantity of material in the remaining solution exceeds the saturation concentration. This unit operation is used if solubility is only slightly dependent on temperature.

#### ■ Vacuum crystallisation

This unit operation uses a combination of the effects described before. Relaxation in a vacuum evaporates part of the solution. The removal of the latent heat of evaporation has a cooling effect on the solution. This unit operation is particularly beneficial for temperature-sensitive substances as evaporation in a vacuum occurs at lower temperatures.

## Basic knowledge

## Membrane separation processes

Compared to filtration, membrane separation processes remove much smaller substances, such as viruses and dissolved ions, from the water. The driving forces of the separation process are differences in concentration or pressure between the two sides of the membrane. The following membrane separation processes are used in water treatment:

Microfiltration

Ultrafiltration

Nanofiltration

Reverse osmosis

The pressure difference – the so-called transmembrane pressure – increases in the sequence indicated above. At the same time the separation limit – that is, the size of the smallest separable substances – decreases. The treated water is termed permeate, and the retained portion of the raw water is retentate.

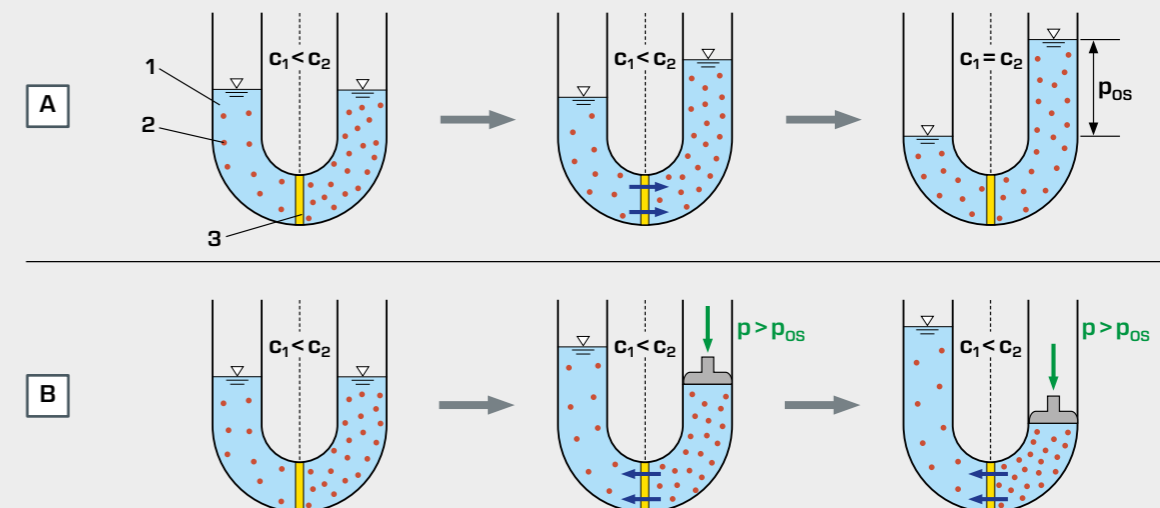
## Reverse osmosis

Reverse osmosis is particularly important. This unit operation enables high purity water to be produced. It is widely used for many different processes in industry and for desalination of sea water.

To understand the reverse osmosis, the osmosis first has to be explained by an example (figure). Two salt solutions with differing concentrations are separated by a semi-permeable membrane. The membrane is only permeable to water molecules. In trying to equalise concentrations on either side, water flows from left to right through the membrane. The water level rises on the right side until a state of equilibrium is established, the – so called – osmotic equilibrium. The same salt concentration now

prevails on both sides of the membrane. The resultant hydrostatic pressure difference between the two sides of the membrane is termed the osmotic pressure.

To reverse the direction of flow of the water (reverse osmosis), the osmotic pressure must be overcome. To do so, a pressure greater than the osmotic pressure is applied to the right side of the membrane. The water then flows from right to left through the membrane. The retentate is produced on the right hand side, and the permeate on the left. In the applications mentioned transmembrane pressures up to 100 bars can be required.



Fundamental principle of osmosis (A) and reverse osmosis (B):

- 1 water, 2 salt ions, 3 semi-permeable membrane;  
p pressure,  $p_{os}$  osmotic pressure,  $c_1$  salt concentration on the left side of the membrane,  $c_2$  salt concentration on the right side of the membrane