Desalination

Desalination is defined as any process which removes excess salts and minerals from water (or) the chemical process of changing seawater into potable water are called desalination. These processes may be used for municipal, industrial or any commercial uses.

In major desalination methods the feed water is treated and two streams of water are obtained:

- Treated potable fresh water that has less amounts of salt and minerals(treated water or product water)
- Concentrate or brine that has salt and mineral concentrations higher than that of original feed water or saltwater.

The water that is obtained after desalination should be remineralised to be fit for human consumption. The concentrated brine obtained in desalination process must be disposed of in a proper manner.

Desalination technologies

There are two major technologies which are used for desalination. These are-

- Thermal desalination technology
- Membrane desalination technology

Apart from these there are alternative technologies like freezing and ion exchange.

1. Thermal desalination processes

It is generally known as distillation. It is one of the most ancient ways of desalinating sea water and converting them to drinking water. This technology is rarely used for desalinating brackish water since it is expensive.

This technology is based on principles of boiling the saline water and evaporating it and then collecting the condensed vapour to obtain pure water. The salt is left behind and the distillate is collected.

It is subdivided into the following types

1.1. Multi-stage flash distillation (MSF):

—Multistage flash distillation process principle involves the distillation through many (multi-stage) chambers and in each successive stage there is progressively low pressures.

—The feed water is initially heated under high pressure and is passed into the first flash chamber. In first flash chamber the pressure is released causing the water to boil rapidly resulting in quick evaporation or flashing.

— This process continues in each successive stage because the pressure in the next stage is less than the previous stage.

—The vapour that is produced by flashing is converted into fresh water by condensing it on heat exchanger tubing present in each stage. The tubes are then cooled by incoming cooler feed water.

—In the MSF process the feed water (saline water) is heated in a vessel known as the brine heater until it reaches a temperature below the saturation boiling temperature.

—The heated seawater then flows through a series of vessels, in sequence, where the lower atmospheric pressure causes the water to boil quickly and get vaporized. This sudden introduction of hot water into the reduced-pressure chamber is referred to as the 'flashing effect' because the water nearly flashes into steam. A small percentage of this water is converted into water vapour that is converted to fresh water by getting condensed on the tubes of heat exchangers (condenser) that pass through each stage. The incoming feed water going to the brine heater cools the tubes.

Advantages of MSF:

— Relatively simple to construct and easy to operate,

— No moving parts, other than conventional pumps, and contains only some amount of connection tubing,

—A high level of purification.

Disadvantages of MSF

—An energy demanding process.

—MSF plants are prone to corrosion unless stainless steel is used.

—MSF plants are also subjected to erosion and impingement attack.

—Though operating plants at higher temperatures (over 115°C) improves their efficiency but causes scaling problems because the salts such as calcium sulphate precipitate on the tubes surfaces and cause

thermal and mechanical problems like tube clogging.

– Due to presence of more stages in MSF the capital cost increases and it causes operational complexity.

1.2. Multiple effect distillation(MED):

–Multi-effect distillation employs the same principles of multi-stage flash distillation but contrary to it, it occurs in a series of vessels (effects) and uses the principles of evaporation and condensation at reduced ambient pressure.

–In Multi- effect distillation process, a series of evaporator effects produce water at progressively lower pressures.

–As pressure decreases successively water boils at lower temperatures and the water vapour of the first vessel serves as the heating medium for the second, and so on.

–The more the vessels or effects, the higher the performance ratio. The water vapour which is formed during boiling of water is condensed and collected.

Advantages of multi-effect distillation

–It operates at lower temperatures of 70°C. This lessens tube corrosion and the scale formation on the tube surfaces.

–The cost of pre-treatment and operation of this technology is low.

–The power consumption in this technology is lower than that of the MSF and performance is higher than MSF plants.

1.3. Vapour compression evaporation

In the vapour compression distillation (VCD) or vapour compression evaporation process the heat for evaporating the feed water comes from the compression of vapour and not by the direct exchange of heat from steam produced in a boiler.

Two devices are generally used in this process to condense the water vapour to generate adequate heat to evaporate the seawater. Among them one is a mechanical compressor (mechanical vapour compression) and the other a steam jet (thermal vapour compression).

Mechanical compressor creates vacuum in the evaporator and compresses the vapour obtained from the evaporator, condenses it in a tube bundle. The feed water is sprayed outside the heated tube bundle. Here the water boils and gets evaporated partially creating more vapour.

In case of steam jet type of vacuum compression distillation the water vapour is extracted and compressed by the steam jet and condensed on the tube walls to furnish heat of condensation to evaporate the feed water that is being pumped on the other side in the evaporator.

Advantages and disadvantages of vapour compression evaporation

– This method is simple and reliable. So, it is a better option for small-scale desalination units.

– The operating temperature of VC distillation or evaporation is low which makes it energy efficient process.

– Since the operating temperatures are low (below 70°C), the potential for scale formation and tube corrosion is reduced.

1.4. Solar desalination

–In solar desalination method the sun provides heat energy to evaporate freshwater from salt water.

–In solar distillation process, the water vapour generated from the evaporation process condenses on a clear glass or plastic covering and then it is collected as freshwater in a condensate trough.

–The covering is used for dual purposes one to transmit radiant energy and second to allow water vapour to condense on its interior surface. The salt that is left behind and un-evaporated water present in the still basin must be disposed of appropriately.

Solar distillation is mostly used in arid regions where safe freshwater is not available.

1.5. Cogeneration system for power and water desalination:

There is a possibility to use energy for dual purpose or cogeneration systems in which the energy sources can perform various different functions like electric power generation and desalination of water.

Advantages and disadvantages

– It uses very less fuel and the energy costs are less for desalination process.
– In contrary, one of the disadvantages is due to permanent coupling between the desalination plant and the power plant.

2. Membrane processes

Membrane processes uses a relatively permeable membrane to move either water or salt to produce two zones of differing concentrations to produce fresh water.
Membrane technology consists of several processes, but the major difference between them lies in the size of the ions, molecules and suspended particles that are retained or allowed to pass via the membranes.
Major separation processes include nano-filtration, ultra-filtration, microfiltration and filtration used in the pre-treatment stages of desalination that are used to remove large particles, bacteria, ions and for water softening.
The membrane processes are further categorized into

2.1. Reverse osmosis (RO) and nanofiltration (NF)

In RO process a pressure is used as the driving force to push feed water through a semi-permeable membrane into a product water stream and a concentrated brine stream.

Osmosis is a natural phenomenon by which water from a low salt concentration solution flows into a more concentrated solution via semi-permeable membrane. When pressure is applied to the solution of higher salt concentration solution, the water starts flowing in a reverse direction through the semi-permeable membrane, leaving the salt behind. This is known as the reverse osmosis process or RO process. Here the membrane configurations consist of spiral wound, hollow fibre and sheet with spiral. The operating pressures for reverse osmosis and nano-filtration range in between 50 and 1000psig.
–Nano-filtration (NF) is also a similar membrane process which is used for removal of divalent salt ions such as Calcium, Magnesium, and Sulphate.
–RO is also used for removal of Sodium and Chloride ions.
An RO desalination plant mainly comprises of four major systems:

- Pre-treatment system,
- High-pressure pumps,
- Membrane systems and
- Post-treatment.

Advantages

- Problems related to corrosion of metals are very less due to ambient temperature conditions
- Polymeric materials are preferred to metal alloys.

Disadvantages:

In seawater desalination, 40–90 gallons of water are wasted to produce 5 gallons of usable water.

2.2. Electrodialysis (ED)

–Electrodialysis (ED) method is a voltage-driven process which uses electrical potential to remove salts using a membrane, leaving fresh water behind.
–Electrodialysis (ED) process is operated using direct current (DC) in which ions (contrary to water in pressure-driven processes) flow via ion selective membranes to oppositely charged electrodes. In these systems, the polarity of the electrodes is reversed repeatedly.
–Since water contains dissolved salts in the form of ions and these ions get attracted towards oppositely charged electrodes, electrodialysis can be used to separate salts and fresh water-.this method uses suitable membranes to permit passage of selective ions either cations or anions.

2.3. Membrane distillation

–This technology uses the principles of both distillation and membrane based desalination processes.
–In this method temperature difference is created in between the supply solution that is coming in contact with the surface on one side of microporous membrane and the space left on its other side.
–This temperature difference causes difference in vapour pressure, resulting in the transfer of the produced vapour through the

membrane onto the condensation surface.
—The whole process is based on the use of hydrophobic membranes that are permeable only to the vapour, thus excluding liquid phase and dissolved particles.
—The vapour produced then passes through the membrane and gets condensed on the cooling surface producing fresh water.

Advantages

— Membrane distillation utilizes less amount of heat because it is simple and operates at low temperature.
— It operates at a lower pressure than other pressure-driven membrane processes.

Disadvantages

—MD requires more space compared to other membrane processes.
— The feed water should not have any organic pollutants.

3. Alternative processes

Some alternative methods are also used for desalination process. They are

3.1 Freezing

The principle involved in freezing desalination is that, in the process of freezing, the dissolved salts present in the feed water are separated during the formation of ice crystals. Seawater can be desalinated by cooling the water to form crystals under controlled conditions. Before the total amount of feed water has been frozen, the mixture is washed and rinsed to remove the salts present in the remaining water or that is sticking to the ice crystals. The ice is then melted to produce fresh water.

Advantages and disadvantages

—This process uses lower amount of energy and has less chance for corrosion and scaling.
—It produces pure drinking water and also water for irrigation.
— The disadvantage in this process is handling ice and water mixtures which are mechanically complicated to move and to be processed.

3.2 Ion exchange: Solvent process

Ion exchangers are generally organic or inorganic solids which are capable of exchanging one type of cation (or anion) immobilized on the solid surface for another type of cation (or anion) present in solution. For example, Na+ ions in solution can be replaced with H+ by a cation exchanger and Cl− ions can be similarly replaced with OH− by an anion exchanger, resulting in the complete 'demineralization' of a NaCl solution. This process can be reversed by regenerating the cation exchanger with an acid, and the anion exchanger with a base.

Conclusion

The desalination of brackish water and seawater would be a solution for the world's water shortage problem. Desalination processes are normally used to produce drinking water in areas where only seawater or brackish water is the source of water. Though desalination costs seem to be progressively decreasing, but they are still costlier than conventional drinking water processes.