Reverse Osmosis (6)

Lecture 9

8.RO Pretreatment

- **Proper pretreatment** using both **mechanical and chemical treatments** is critical for an RO system to prevent fouling, scaling and costly premature RO membrane failure and frequent cleaning requirements.

8.1. Need for Pretreatment Processes in RO

- The RO feed water may contain various concentrations of **suspended solids** and **dissolved matter**.
- **Suspended solids** may consist of the following:
- Inorganic particles.
- Colloids.
- Biological matter, which includes microorganisms and algae.
- **Dissolved matter** may consist of:
- highly soluble salts, such as chlorides, and
- sparingly soluble salts, such as carbonates, sulfates, and silica.

8.1. Need for Pretreatment Processes in RO

- **<u>Settling</u>** of the suspended particles or scale formation from the sparingly soluble salts would result in the following:

1. **<u>Blocking of the flow channels</u>** that would increase the pressure drop in the feed channels in the membrane module. This would require increasing the pumping power.

- 2. **<u>Reducing the permeation rate</u>** across the membrane and increase in the amount of salt passage through the membrane. This is caused by scale formation on the membrane surface.

8.1. Need for Pretreatment Processes in RO

- **3. In addition to blockage of the membrane module**, membrane damage can be caused by system operation at excessively low pH values, high chlorine concentration, or presence of other aggressive chemical compounds that would react and destruct the membrane material.

8.1. Need for Pretreatment Processes in RO

- Depending on the raw water quality, the pretreatment process may consists of all or some of the following treatment steps:
- Removal of large particles using a coarse strainer.
- Water disinfection with chlorine or other biocides.
- Media filtration.
- Reduction of alkalinity by pH adjustment.
- Addition of scale inhibitor.
- Reduction of free chlorine using sodium bisulfite or activated carbon filters.
- Final removal of suspended particles using cartridge filters.

8.2. Raw water quality in RO

Is the feed water is a surface water or a well water? It is a very important question

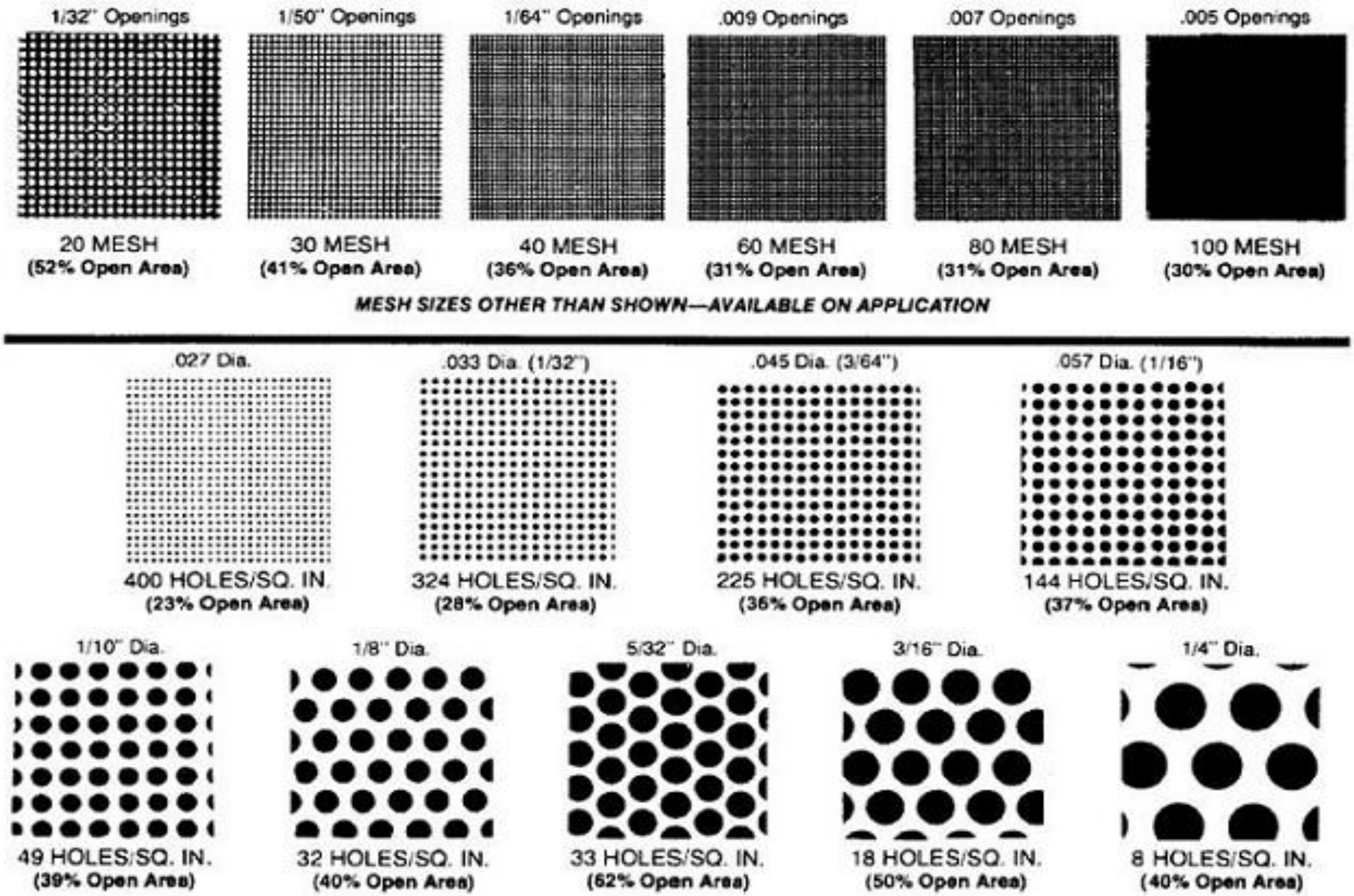
Surface water is the feed water that taken from sea or ocean by certain intake facilities.

Well water is the feed water that taken from aquifers and the intake facilities are different from that used in case of surface water.

8.2. Raw water quality in RO

- **Large particles** are removed from the feed water using **mesh strainers or traveling screens**.
- **Mesh strainers** are used in well water supply systems to stop and remove **sand particles**, which may be pumped from the well.
- **Traveling screens** are used mainly for **surface water** sources, which typically have large concentrations of biological debris.

Mesh strainers



8.2. Raw water quality in RO

- It is common practice to **disinfect surface feed water** in order to control biological activity.
- **Biological activity** in **well water** is usually **very low**, and in majority of cases, well water does not require chlorination.
- In some cases, chlorination is used to oxidize iron and manganese in the well water before filtration.
- Well water containing hydrogen sulfide should not be chlorinated or exposed to air.
- In presence of an oxidant, the sulfide ion can oxidize to sulfur, which eventually may plug membrane elements.

8.2. Raw water quality in RO

- **Settling** of surface water in a **detention tank** results in some **reduction** of **suspended particles**.
- Addition of **flocculants**, such as iron or aluminum salts, results in formation of **corresponding hydroxides**; these hydroxides **neutralize** surface charges of colloidal particles, **aggregate**, and adsorb to **floating particles** before **settling** at the lower part of the clarifier.

8.2. Raw water quality in RO

- To increase the size and strength of the flock, a **long chain organic polymer** can be added to the water **to bind flock particles** together.
- Use of **lime** results in **increase of pH**, **formation of calcium carbonate** and **magnesium hydroxide** particles.
- **Lime clarification** results in **reduction of hardness** and alkalinity, and the clarification of treated water.

8.2. Raw water quality in RO

- **Well water** usually contains **low concentrations of suspended particles,** due to the filtration effect of the aquifer.
- The **pretreatment** of well water is usually limited to **screening of sand**, **addition of scale inhibitor** to the feed water, and **cartridge filtration**.

8.2. Raw water quality in RO

- Some surface water may contain high concentrations of **dissolved organics**.
- Those can be removed by passing feed water through an **activated carbon filter**.
- Depending on composition of the water, **acidification** and **addition scale inh**ibitor may be required.

8.3.Testing Methods

- Testing methods of feed water include the following:
- - Ionic constituents.
- - Turbidity.
- - Total suspended solids (TSS).
- - Total organic carbon (TOC).
- - Silt Density Index (SDI).
- - Dissolved gases such as CO_2, O_2, and Cl_2.
- - PH.
- - Temperature.

8.3.Testing Methods

- **Silt Density Index (SDI)**
- It is an important **empirical test** used to characterize the fouling potential of a reverse osmosis **feed water stream**.
- The SDI test is based on measuring the rate of plugging a 45 micron filter using a constant 30 psig feed pressure for a specified period of time.
- SDI 15 refers to a silt density index test which was run for 15 minutes.
- **Typically:**
- Spiral wound reverse osmosis systems require an SDI < 5
- Hollow fiber reverse osmosis systems require an SDI < 3
- Most deep well waters have an SDI of 3 and most surface waters have SDI's greater than 6.

Silt Density Index (SDI)

8.3.Testing Methods

- The RO operators use the SDI test as measure of the feed quality and operation ease.
- The guidelines for RO operation using the SDI test is as follows:
- SDI < 1, implies high quality feed water that would provide trouble free operation for years.
- 1 < SDI < 3, implies moderate to low quality feed water that would allow for few months of operation before need for membrane cleaning.
- 3 < SDI < 5 implies low quality feed water, which would require frequent cleaning.
- SDI > 5 implies very poor water quality and operation at these conditions is not acceptable.

8.4. Suspended Solids and Silt Reduction

- Typical examples of suspended solids include the following:
- Mud and silt
- Organic colloids
- Iron corrosion products
- Precipitated iron
- Algae
- Bacteria
- Rocks
- Silica/Sand
- Precipitated Manganese
- Precipitated Hardness
- Aluminum hydroxide flock

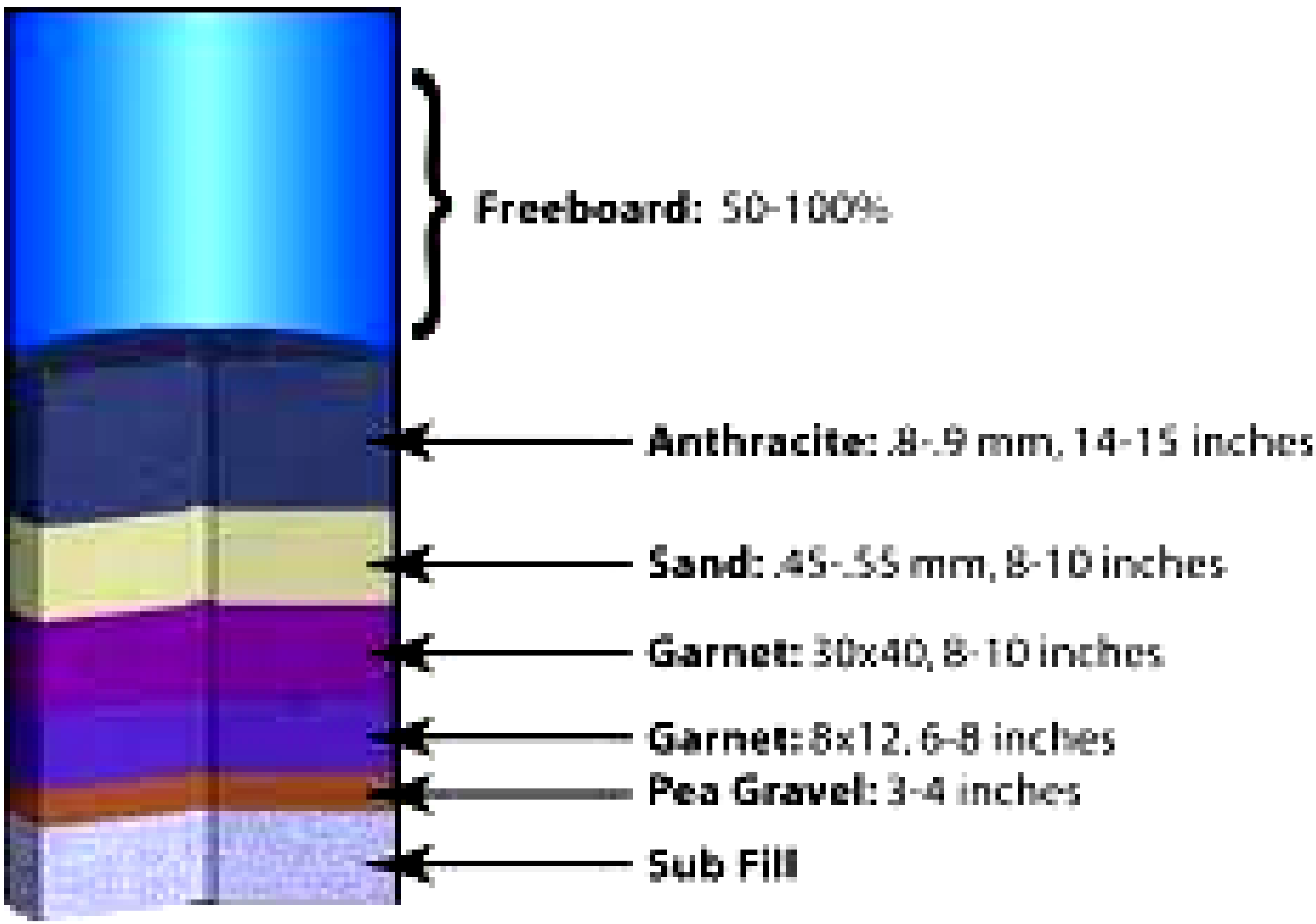
8.4.1. Multi-Media Filter (MMF)

- A Multi-Media Filter is used to help prevent fouling of an RO system.
- A MMF typically contains **three layers of media consisting** of **anthracite coal**, **sand and garnet**, with a supporting layer of **gravel** at the bottom.
- These are the medias of choice because of the differences in size and density.
- The **larger (but lighter) anthracite coal will be on top** and the **heavier (but smaller) garnet will remain on the bottom.**

8.4.1. Multi-Media Filter (MMF)

- Features of media filters include the following:
- The layers contain gravel, activated carbon or anthracite.
- The top layer of the bed consists of coarsely graded material, whereas the finely graded material is layered on the bottom
- The thickness of the filter layer is about 1-3 m.
- Compressed air or water is used for back-flushing.
- The particle size of the filter material is 0.5 - 3 mm.
- Most of the filtration process takes place in the top layer of the bed.

8.4.1. Multi-Media Filter (MMF)



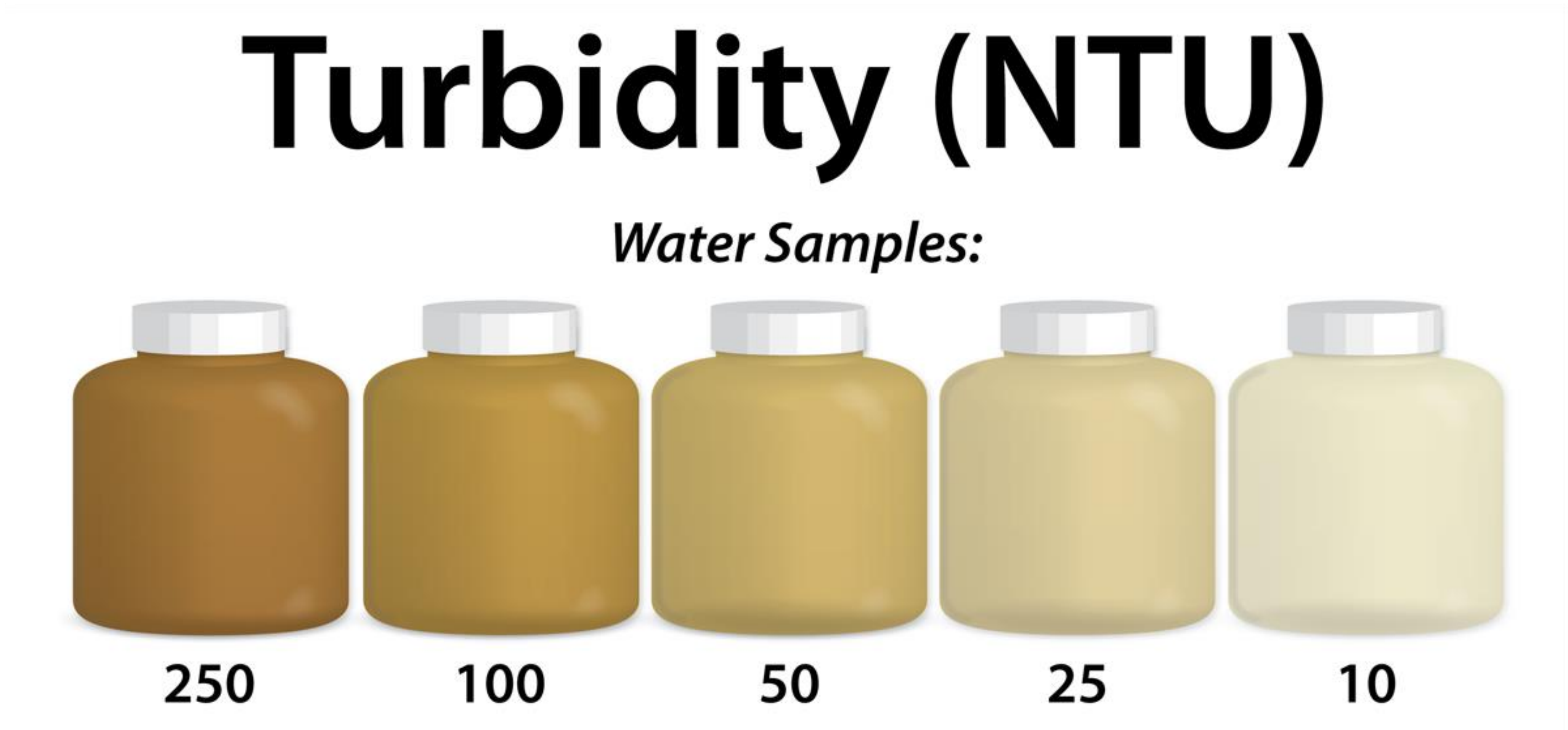
8.4.1. Multi-Media Filter (MMF)

- The filter media arrangement allows the **largest dirt** particles to be **removed near the top** of the media bed with the **smaller dirt particles** being retained **deeper and deeper in the media**.
- This allows the entire bed to act as a filter allowing much longer filter run times between backwash and more efficient particulate removal.
- A well-operated **Multi-Media Filter** can remove particulates down to **15-20 microns**.

8.4.1. Multi-Media Filter (MMF)

- A MMF that **<u>uses a coagulant</u>** addition (which induces tiny particles to join together to form particles large enough to be filtered) can remove particulates down to **<u>5-10 microns</u>**.
- To put this in perspective, the width of a human hair is around 50 microns.
- A multi media filter is suggested when the Silt Density Index (SDI) value is greater than 3 or when the turbidity is greater than 0.2 **Nephelometric Turbidity Unit (NTU)**.
- There is no exact rule, but the above guidelines should be followed to prevent premature fouling of RO membranes.

8.4.1. Multi-Media Filter (MMF)



8.4.2. Cartridge Filters

- Features of cartridge filters include the following:
- Cartridge filters are used in various RO configurations.
- The last pretreatment step prior to the RO process.
- The most common size is the 5 µm filter.
- The separation media can be made of polymer materials, such as polypropylene.
- Combination of media and cartridge filters may be the most optimum and economic solution for particle removal.

8.4.2. Cartridge Filters

8.4.2. Cartridge Filters

- Cartridge filters, almost universally used in all RO systems **prior to the high pressure pump**, serve as the final barrier to water born particles.
- The nominal rating commonly used in RO applications is in the range of **5 - 15 microns**.
- **Some** systems use **cartridges** with micron ratings as low as **1 micron**.
- There seems to be little benefit from lower micron rated filters as **such filters require a high replacement rate** with relatively small improvement in the final feed water quality.

8.4.2. Cartridge Filters

- Recently, **new pretreatment** equipment has been introduced to the RO market.
- It consists of backwashable **microfiltration** and **ultrafiltration** membrane modules.
- This new equipment can operate reliably at a **very high recovery rates and low feed pressure**.
- The new systems can provide **better feed water quality** than a number of conventional filtration steps operating in series.
- The **cost of this new equipment is still very high** compared to the cost of an RO unit.

8.6. Fouling and Scale Control

- Scale forming compounds, in order of occurrence, include the following:
- Calcium carbonate
- Calcium sulfate
- Silica complexes
- Barium sulfate
- Strontium sulfate
- Calcium fluoride
- It should be stressed that the formed scale is made of several compounds.
- This is because that the first compound being precipitated would provide nucleation sites for other compounds.

8.6.1 Calcium Carbonate

- The calcium carbonate equilibrium reaction is given by:
- $Ca^{+2} + 2\ HCO^{-3} \longrightarrow CaCO_3 + CO_2 + H_2O$
- Precipitation of calcium carbonate is favored by:
- Increasing calcium or bicarbonate concentration.
- Increasing the temperature.
- Increasing the pH (more alkaline solution).

8.6.1 Calcium Carbonate

- Common methods to prevent calcium carbonate scaling include the following:
- **Removal** of all or some of the **bicarbonate** alkalinity by **feeding acid**.
- Use of **scale-control agents**.

The choice between acid dosing and anti-scale control depends on:

- Type of membrane, especially compatibility for long-term operation at low pH.
- Process economics, which would optimize the purchasing cost of antiscalent and acid as well as the capital of handling and dosing equipment for the acid and the antiscalent.

8.6.1 Calcium Carbonate

- In this regard, **sulfuric acid is very inexpensive** when compared to other acids or antiscalent compounds.
- However, its use should be handled properly.
- Otherwise, the **presence of the sulfate group** in the acid may enhance formation of the **calcium, barium, or strontium sulfate scale.**
- Final selection would depend on the feed salinity and product quality, which may call for use of each method separately or the combined use of both techniques.
- For example, **seawater** desalination would call for **simultaneous use of acid and antiscalent dosing**.

8.6.1 Calcium Carbonate

- Another problem related to acid dosing is the generation of large amounts of CO_2.
- As a result, the CO_2 concentration increases in the permeate water because of its high permeability of CO_2 across various types of RO membranes.
- This reduces the permeate pH and imposes an overload on ion exchange units used for polishing of the RO makeup water.

8.6.2 Calcium Sulfate

- Various forms $CaSO_4$ crystals include the following:
- Hydrate calcium sulfate, $CaSO_4.2\ H_2O$.
- Anhydrous calcium sulfate, $CaSO_4$.
- Hemihydrate calcium sulfate, $CaSO_4.1/2\ H_2O$.
- All of these compounds have **reverse solubility**, where it **precipitates at high temperature**.
- However, increase in the ionic concentration of Ca^{+2} and $SO_4{}^{2-}$ beyond the solubility limit ions in the brine stream may result in severe scaling.

8.6.2 Calcium Sulfate

- Prevention of $CaSO_4$ scaling in RO includes the following:
- 1. Addition of anti-scaling agents, which includes polyphosphates, polycarboxylates or sodium hexametaphosphate to prevent precipitation of $CaSO_4$.
- 2. Proper dosing would allow for safe operation even if the brine stream has higher concentration than the saturation limit.
- 3. Lowering the permeate recovery rate to prevent increase in the concentration beyond the saturation limit.

8.6.3 Silica

- Silica scaling has the following features:
- - The solubility of silica depends on the system pH and temperature.
- - **Low temperature operation, i.e., below 10°C, and silica saturation below 120 ppm** allows for operation with brine solutions supersaturated in silica with **little or no silica scaling.**
- - Operation at **higher concentrations or temperature enhances the silica scaling process**.
- - Silica forms complex precipitates with iron, aluminum, and magnesium hydroxides.
- - The most effective method to prevent silica scaling is to **maintain its concentration below the saturation limit**, which is strongly affected by the **system temperature**.

8.6.3 Silica

8.7. Anti-scalants/Scale Inhibitors

- **Anti-scalants** and scale inhibitors, as their name suggests, are chemicals that can be added to feed water before an RO unit to help **reduce the scaling potential** of the feed water.
- Anti-scalants and scale inhibitors **increase the solubility limits** of troublesome inorganic compounds.
- By increasing the solubility limits, you are able to concentrate the salts further than otherwise would be possible and therefore achieve a higher recovery rate and run at a higher concentration factor.

8.7. Anti-scalants/Scale Inhibitors

- Anti-scalants and scale inhibitors work by **interfering with scale formation and crystal growth.**
- The choice of anti-scalant or scale inhibitor to use and the correct dosage depends on the feed water chemistry and RO system design.

8.7. Anti-scalants/Scale Inhibitors

8.7. Anti-scalants/Scale Inhibitors

Polyphosphates

Questions:

- **Complete the following statements with the proper word (s):**
- 1. Settling of the suspended particles can cause ---------- of the flow channels of the membranes.
- 2. Large particles are removed from the feed water using ------ or ---------.
- 3. Biological activity in well water is usually very -----.
- 4. In presence of an oxidant, the sulfide ion can oxidize to --------, which eventually may plug membrane elements.
- 5. To increase the size and strength of the flock, a ----- can be added to the water to bind flock particles together.

Questions:

- 6. The solubility of silica depends on the system ------- and -----------.
- 7. The structure of hemihydrate calcium sulfate is --------.
- 8. The most common size of cartridge filter is --------.
- 9. A multi media filter is suggested when the Silt Density Index (SDI) value is greater than ----------.
- 10. A MMF typically contains three layers of media consisting of ---------, ------------ and ------------.