

Lecture 17

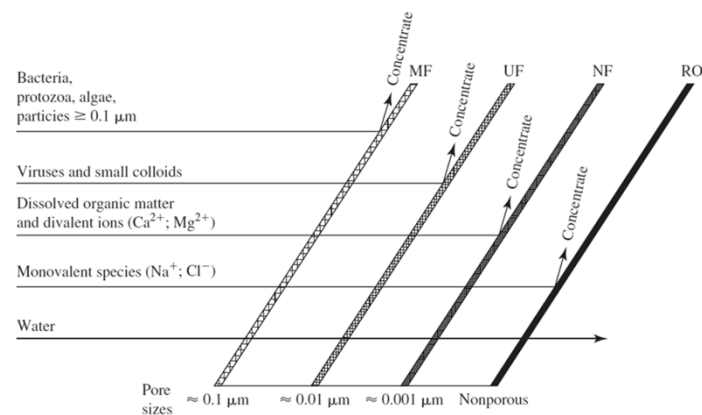
DISSOLVED SOLIDS REMOVAL (1)

Course: Water Reuse
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Dissolved matter

- For many water reuse applications, the removal of residual particulate matter by methods already described provide an appropriate level of treatment.
- Where increased removal of dissolved organic and inorganic constituents is required, other technologies are required for their removal. Dissolved solids are little affected by the treatment operations discussed previously.
- With the increased use of reclaimed water for applications where quality and reliability are critical (i.e. potable reuse and some industrial uses) the removal of dissolved solids and trace constituents may be required.

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Nanofiltration separation mechanism

- Nanofiltration membranes have pore sizes ranging from less than 0.001 to 0.003 μm , and they reject on two levels of selectivity.
- First, noncharged soluble organics are rejected on size and shape; the molecules are too large to pass through the pores.
- Second, charged soluble salts smaller than the membrane pores are rejected because the water is more soluble in the membrane than is a specific salt.
- In RO the second mechanism (known as solution diffusion) is dominant.

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Nanofiltration

- In concept and operation, NF is very similar to RO; the key difference is the degree of removal of **monovalent ions** such as sodium and chlorides.
- Reverse osmosis usually removes 98+% of monovalent ions while NF varies between 10-50%, depending on the material and manufacture of the membrane.
- Nanofiltration has been called “loose RO” as well.
- NF and RO membranes are usually manufactured in the “spiral wound” configuration

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NF Rejection

Constituent	Unit	Rejection rate
		Nanofiltration
Total dissolved solids	%	40–60
Total organic carbon	%	90–98
Color	%	90–96
Hardness	%	80–85
Sodium chloride	%	10–50
Sodium sulfate	%	80–95
Calcium chloride	%	10–50
Magnesium sulfate	%	80–95
Nitrate	%	10–30
Fluoride	%	10–50
Arsenic (+5)	%	<40
Atrazine	%	85–90
Proteins	log	3–5
Bacteria ^b	log	3–6
Protozoa ^b	log	>6
Viruses ^b	log	3–5

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Osmosis

- When two solutions with different solute concentrations are separated by a semipermeable membrane, a difference in chemical potential will exist across the membrane.
- Water will tend to diffuse through the membrane from the lower-concentration (higher-potential) side to the higher-concentration (lower-potential) side. The water passing through the membrane is trying to dilute the higher ionic concentration solution to equalize the concentrations on both sides of the membrane.
- The countering pressure required to stop this transfer is called **osmotic pressure** and is a function of the solute characteristics and concentration and temperature.

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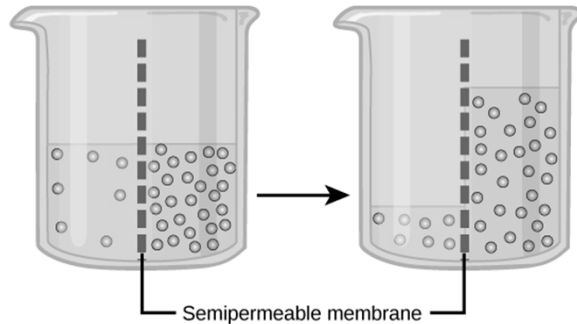
اسمز

• اسمز به معنای عبور خودکار یک حلال (به عنوان مثال آب) از یک غشاء نیمه تراوا از محلولی رقیقتر به محلولی غلیظتر است به صورتی که غشاء نیمه تراوا از عبور محلول (مثلا نمک) جلوگیری کرده ولی از عبور حلال جلوگیری نکند.

• عبور خودکار به دلیل اختلاف غلظت محلول در دو طرف غشاء است و تمایل طبیعی محلول برای ایجاد تعادل در غلظت طرفین

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Osmosis / Reverse Osmosis



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Osmotic pressure

$$\pi = i\varphi CRT$$

i = number of ions produced during dissociation of solute

φ = osmotic coefficient, unitless

C = concentration of all solutes, moles/L

R = universal gas constant, $8.314 \text{ kPa} \cdot \text{m}^3/\text{kg mole} \cdot \text{K}$

T = absolute temperature, K

The number of ions per mole, i , for example would be 2 for NaCl. The osmotic coefficient, φ , depends on the nature of the substance and its concentration. For NaCl it ranges from 0.93 to 1.03 over a concentration range of 10 to 120 g/L of salt. Seawater has an osmotic coefficient that varies from 0.85 to 0.95 for the same concentration range.

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فشار

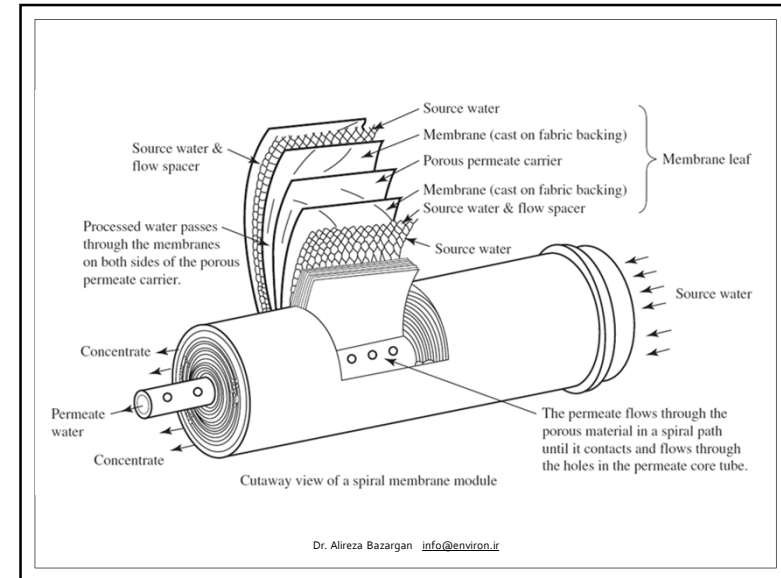
فشار (kPa)	فرایند
350-1000	NF
1000-4000	Brackish RO
5500-8000	Seawater RO

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معایب	محاسن	جنس غشاء
-عدم مقاومت در برابر دمای بالای 30 درجه -تجزیه در محیط های اسیدی و بازی -عدم مقاومت در برابر تجزیه بیولوژیک	-مقاوم در برابر کلر آزاد	Cellulose Acetate (CA)
-fouling بیشتر -عدم مقاومت در برابر کلر آزاد	-مقاوم در برابر pH -مقاوم در برابر تجزیه بیولوژیک -شار بیشتر و کیفیت آب بالاتر	Polyamide (PA)

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Video clip inserted



پیش تصفیه

- با تنظیم pH و اضافه کردن ماده ضد رسوب (پلیمر و ترکیبات مخصوص) تا حدودی از گرفتگی غشاء جلوگیری میشود
- غشاء اسمز معکوس backwash نمی شود پس قبل از رسیدن آب به غشاء ها حتما باید تصفیه شده باشند
- به طوری که ذرات معلق بزرگتر از 5 میکرون کاملا حذف شده باشند. کدورت نباید بالاتر از 1 باشد، و ترجیحا زیر 0.2 NTU
- با ضد عفونی کردن، از رشد بیولوژیک جلوگیری می شود

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Factors that should be considered in designing NF and RO systems include the following (EPRI, 1999):

- A method of particle filtration. Because NF and RO are intended mainly to remove dissolved salts, they should, ideally, have turbidity levels less than 0.5 NTU in the influent.
- Presence and level of oxidants in the feedwater. Many thin film composite membranes are less tolerant of free chlorine or other oxidants such as ozone in the feedwater. Generally, membrane manufacturers recommend less than 1000 mg/L·h with free chlorine; membranes are warranted for up to 1000 h of contact with water containing 1 mg/L of free chlorine, or 200 h with 5 mg/L. Membranes made of polyvinylidene fluoride, which have a high resistance to ozone, are becoming available.
- Biological contamination. Biological contamination and large organic molecules should also be removed in a pretreatment system as they tend to accumulate and foul the membrane surface and cause a decline in performance. To prevent biological fouling, in addition to particle filtration, an appropriate level of disinfection should be provided in accordance with recommendations of the membrane manufacturer.
- Membrane protection by chemical addition. Generally, only a few chemicals are needed to enhance membrane performance. Acid addition may be needed to adjust the feed pH to control scale formation if cellulose acetate membranes are used. Antiscalants may be required to prevent precipitation of slightly soluble salts.

Pretreatment options

Material to be removed	Method of pretreatment	Description or discussion
Scale formation	pH adjustment	To inhibit scale formation, pH adjustment of the feedwater within the range from 4.0 to 7.5 is required. A low pH enhances conversion of carbonate into bicarbonate species, which are much more soluble. Cellulose acetate RO membranes have an optimum pH range of 5 to 7, as they are prone to hydrolysis below a pH of 5. Newer polyamide RO membranes can be used over a broader pH range of 2 to 11 (Paranjape et al., 2003).
	Antiscalants	Antiscalants are polymeric compounds that either prevent scale formation entirely or permit formation of scales that can be removed easily during cleaning. Certain antiscalants, however, may increase the fouling of humic acids on RO membranes (Richard et al., 2001).
Sparingly soluble salts	Chemical treatment	Sparingly soluble salts such as silica can be removed by chemical treatment where reclaimed water is to be used for industrial purposes, i.e., removal of silica may be required to prevent precipitation on heat exchangers.

Material to be removed	Method of pretreatment	Description or discussion
Iron and manganese	Ion exchange or chemical treatment	Removal of iron and manganese will decrease scaling potential.
Microorganisms	Disinfection	Disinfection of the feedwater may be accomplished using either chlorine, ozone, or UV irradiation to limit bacterial activity. Ultrafiltration can also be used to reduce the number of microorganisms.
Particulate matter	Depth or surface filtration, microfiltration, or ultrafiltration	Particulate matter can be removed by various methods of filtration (see Chap. 8). Fouling agents may pass through these filtration systems, thus the potential for membrane fouling should be verified by pilot-testing.
Particulate and colloidal matter	Cartridge filter (also ultrafiltration)	Cartridge filters are pressure-driven filters with pore sizes varying from 5 to 15 μm and are installed commonly ahead of RO membranes. Cartridge filters provide a final level of protection against the intrusion of relatively large solids into the RO system. The filters do not remove dissolved substances. Most cartridge filters are polypropylene wound cartridges from 800 to 1000 mm in length housed inside a vertical or horizontal stainless steel or fiberglass vessel. Generally, the pressure drop across a clean cartridge filter is between 0 and 35 kPa. As the solids accumulate and the pressure drop reaches a threshold range of 70 to 80 kPa, the cartridge has to be removed and replaced (Paranjape et al., 2003).

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Cartridge filter pretreatment

- Cartridge filters, are almost always used as a further pre-treatment step, both with reclaimed water as well as untreated seawater, following one or more of the pretreatment options discussed. They have two important functions:
 - (1) as an inexpensive secondary barrier in the event of a failure in the pre-treatment system
 - (2) to remove any particulate impurities originating from the other pretreatment processes or chemicals which have been added

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How do we measure fouling potential?

- The sample to be tested is passed through a 0.45 μm millipore filter with a 47-mm internal diameter at a constant pressure of 207 kPa (30 lb/in², psi) gauge and various measurements are made.
- Silt Density Index (SDI)

$$\text{SDI} = \frac{\%P_{207}}{t} = \frac{100 [1 - (t_i/t_f)]}{t}$$

$\%P_{207}$ = percent plugging at 207 kPa (30 lb/in.²) feed pressure

t = total time for running the test

t_i = time to collect the initial sample of 500 mL

t_f = time to collect final sample of 500 mL

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Example

- After pretreatment prior to RO skids, the following measurements are made for the SDI test. Has the pretreatment been adequate?

Test run time = 30 min
Initial 500 mL = 2 min
Final 500 mL = 10 min

Solution

- Calculate the SDI using Eq. (9-1).

$$SDI = \frac{100[1 - (t/t_i)]}{t}$$

$$SDI = \frac{100[1 - (2/10)]}{30} = 2.67$$

Modified fouling index

- The MFI is determined using the same equipment and procedure used for the SDI, but the volume is recorded every 30s over a 15-min filtration period.
- The value of the MFI is obtained as the slope of the straight-line portion of the curve obtained by plotting the inverse flow versus the cumulative volume.

$$\frac{1}{Q} = (MFI) V + b$$

where Q = average flow, L/s

MFI = modified fouling index, s/L²

V = volume, L

b = constant (intercept of linear portion of curve)

Mini Plugging Factor Index

- A measure of the change in flowrate as a function of time, defined as the slope of the linear portion of the flowrate versus time curve

$$Q = (MPFI) t + a$$

where Q = average flow at 30 s intervals, L/s

MPFI = mini plugging factor index, L/s²

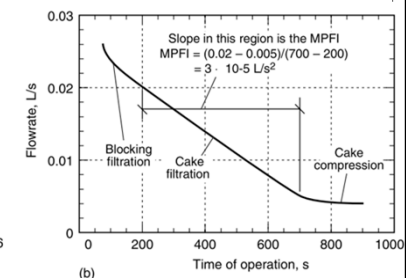
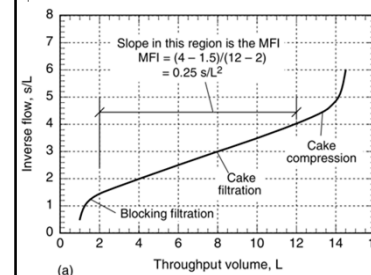
t = time, s

a = constant (intercept of linear portion of curve)

- The shortcoming of all 3 tests is that they use a 0.45 μm filter which doesn't capture the effect of smaller colloids

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Fouling indices



Suitable fouling index values before water reaches the membrane

Membrane process	SDI	MFI, s/L ²	MPFI, L/s ²
Nanofiltration	0-3	0-10	0-1.5 × 10 ⁻⁴
Reverse osmosis	0-3	0-2	0-3 × 10 ⁻⁵