

100 年度「園區廠商節水節能減碳輔導計畫」-節水教育訓練

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## 高科技產業廢水回收及用水管理

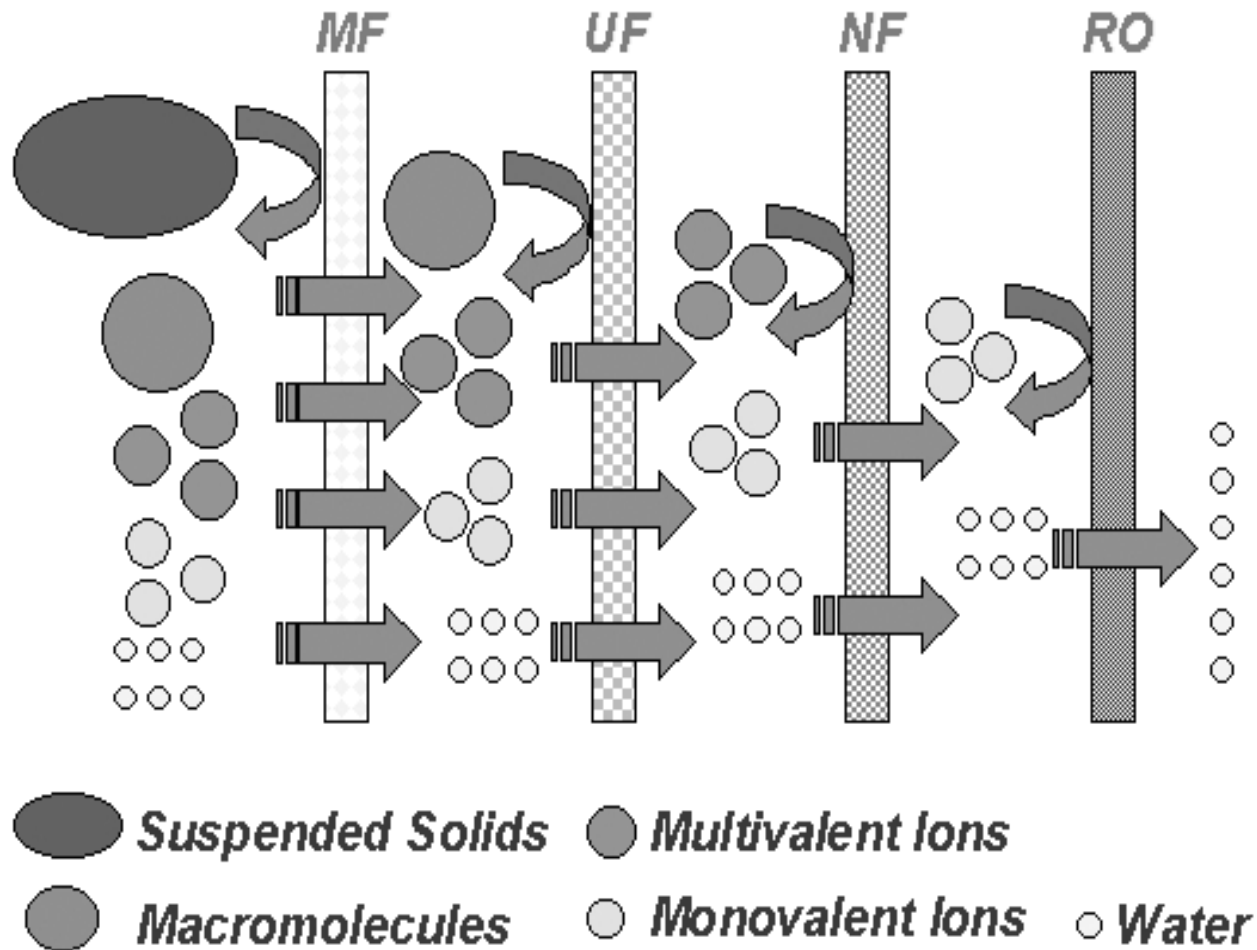
報告人：梁德明

工研院能環所

水科技組

100年10月21日

# 各種薄膜分離物質的比較



## NF、RO、ED比較

Factor	Membrane process		
	Nanofiltration	Reverse osmosis	Electrodialysis
Membrane driving force	Hydrostatic pressure difference	Hydrostatic pressure difference	Electromotive force
Typical separation mechanism	Sieve, solution/diffusion, and exclusion	Solution/diffusion and exclusion	Ion selective membrane
Typical pore size	Micropores (<2 nm)	Dense (<2 nm)	na
Typical operating range, $\mu\text{m}$	0.001–0.01	0.0001–0.001	na
Molecular weight cut-off	300–1000	<300	na
Permeate description	Water, very small molecules, ionic solutes	Water, very small molecules, ionic solutes	Water, ionic solutes
Typical constituents removed	Small molecules, color, some hardness, bacteria, viruses, proteins	Very small molecules, color, hardness, sulfates, nitrate, sodium, other ions	Charged ionic solutes
Operating pressure <sup>b</sup>	350–550 kPa 3.5–5.5 bar (50–80 lb/in. <sup>2</sup> )	1200–1800 kPa 12–18 bar (175–260 lb/in. <sup>2</sup> )	na
Energy consumption <sup>b</sup>	0.6–1.2 kWh/m <sup>3</sup>	1.5–2.5 kWh/m <sup>3</sup>	1.1–2.6 kWh/m <sup>3</sup>
Material	Cellulosic, aromatic polyamide, thin film composite <sup>c</sup>	Cellulosic, aromatic polyamide, thin film composite <sup>c</sup>	Ion exchange resin cast as a sheet
Configuration	Spiral wound, hollow fiber	Spiral wound, hollow fiber	Sheets

<sup>a</sup>Adapted from Tchobanoglous et al. (2003).

<sup>b</sup>Based on treating reclaimed water with a TDS concentration in the range from 1000 to 2500 mg/L (see also Table 9-11). Significantly higher operating pressures are required for seawater.

<sup>c</sup>With surface layer formed from different types of polyamide compounds. Support structure usually made of polysulfone.

Note:  $\text{kPa} \times 10^{-2} = \text{bar}$ , (1 bar = 100 kPa =  $10^5 \text{ N/m}^2$ ).

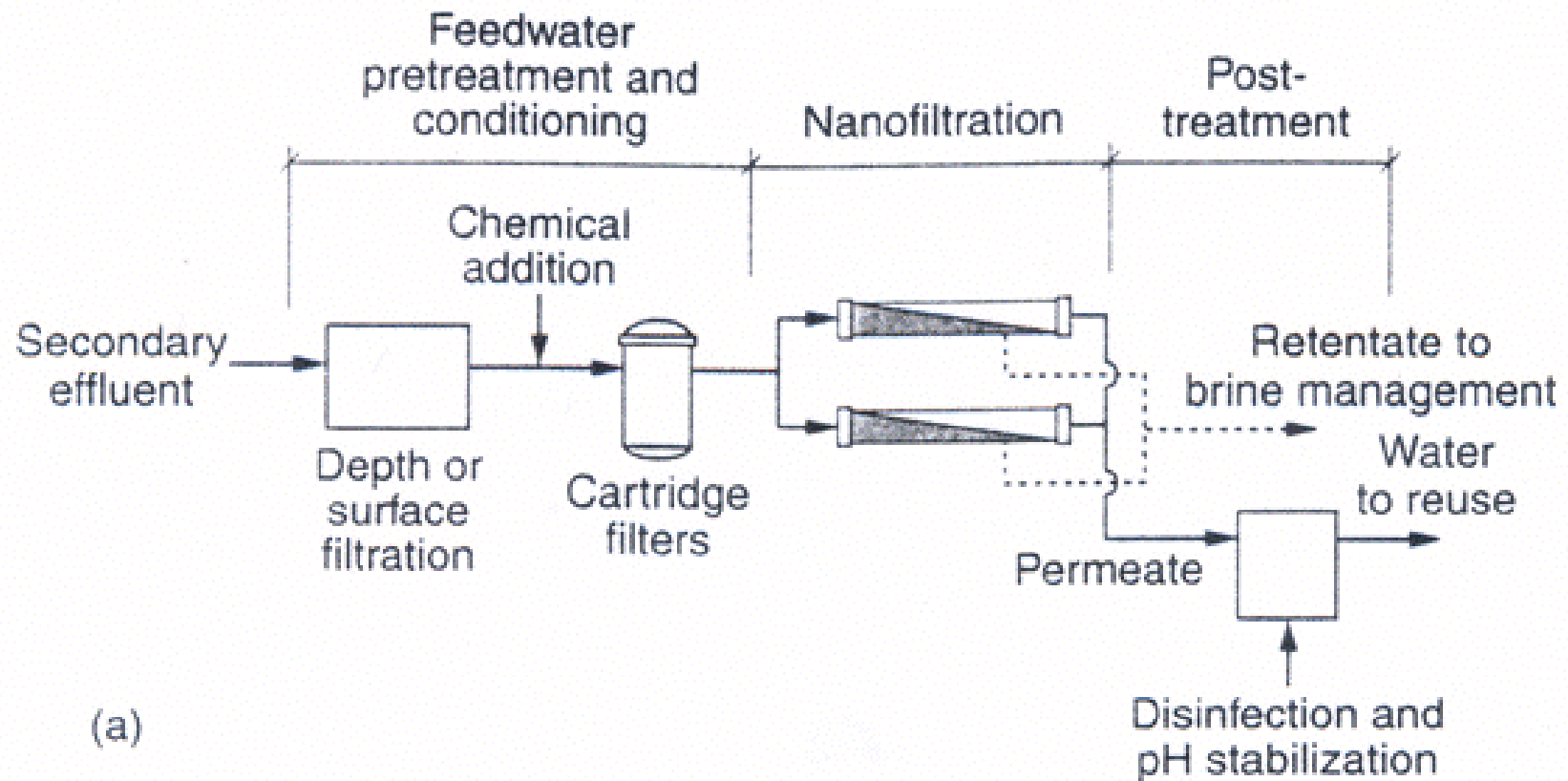
$\text{kPa} \times 0.145 = \text{lb/in.}^2$ .

na = not applicable.

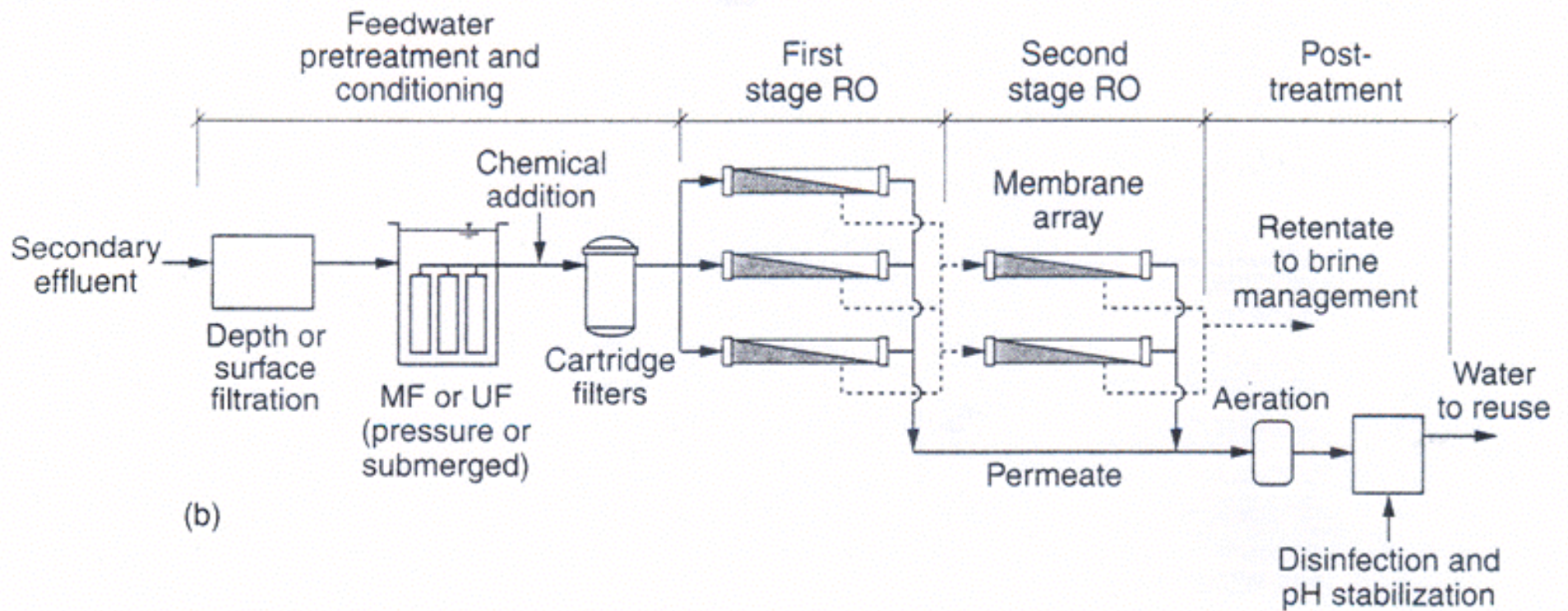
## NF、RO、ED應用

Applications	Process and process function
<b>Nanofiltration (NF)</b>	
Water softening	Used to reduce the concentration of multivalent ions contributing to hardness for specific water reuse applications.
Water reuse	Used to reduce the TDS concentration of reclaimed water for specific applications. Also used in conjunction with reverse osmosis (see Fig. 9-6).
Water reuse	Used to treat prefiltered effluent (typically with MF or UF) for indirect potable reuse applications such as groundwater injection.
<b>Reverse osmosis (RO)</b>	
Desalination (desalting)	Used to remove dissolved constituents from both brackish and sea water.
Water reuse	Used to treat prefiltered effluent (typically with cartridge filtration, MF, or UF) for indirect potable reuse applications such as groundwater injection.
Two-stage treatment for boiler use	Two stages of RO are used to produce water suitable for high pressure boilers in industrial reuse applications.
<b>Electrodialysis (ED) and electrodialysis reversal (EDR)</b>	
Desalination (desalting)	Used to remove dissolved charged ionic constituents from brackish water.
Water reuse	Used to treat prefiltered (usually with cartridge filters) brackish water with a low TDS concentration. ED/EDR removes only ionized compounds; dissolved organic compounds pass through ED/EDR systems and must be removed by other means.
Water softening	Used to reduce the concentration of multivalent ions contributing to hardness for specific water reuse applications.

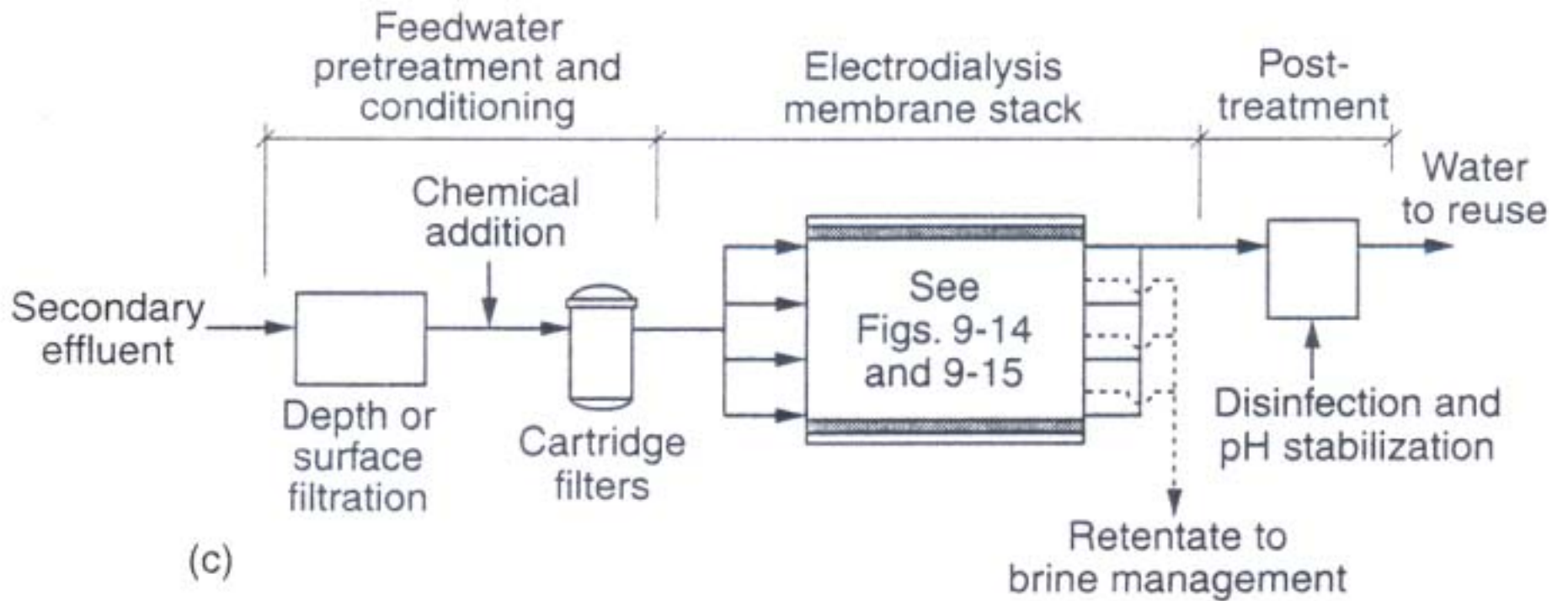
# 水再生回收程序



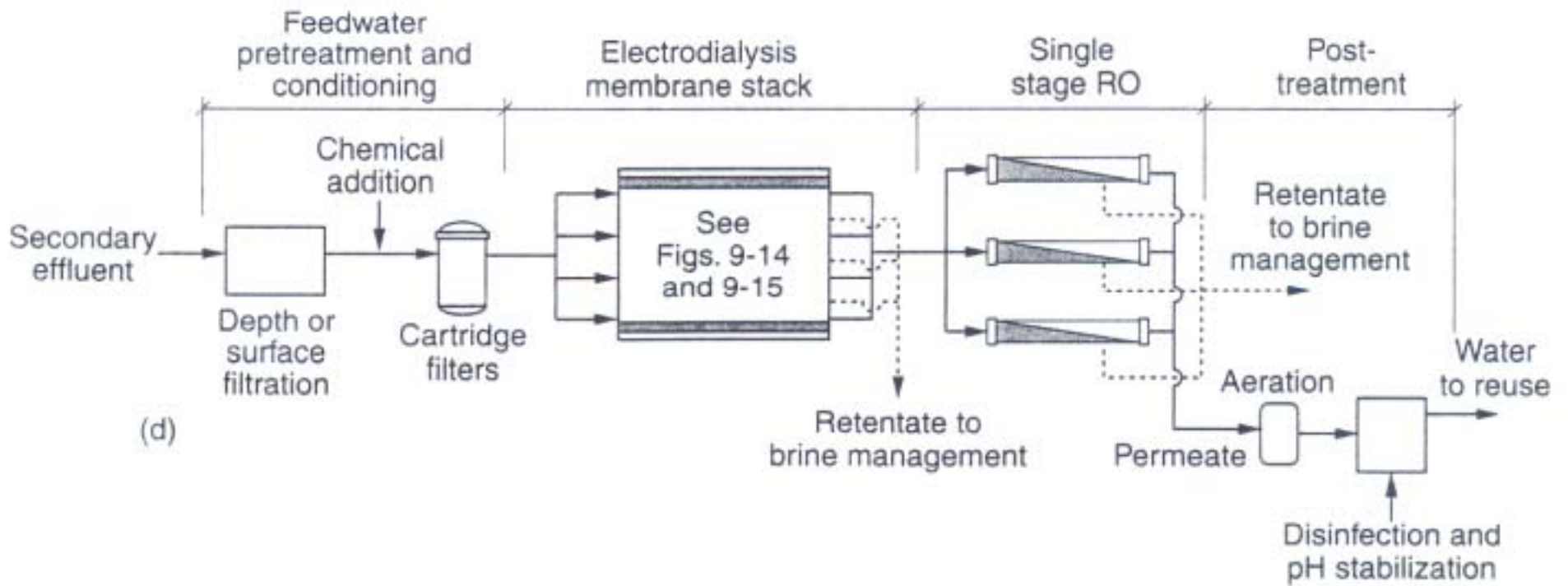
# 水再生回收程序



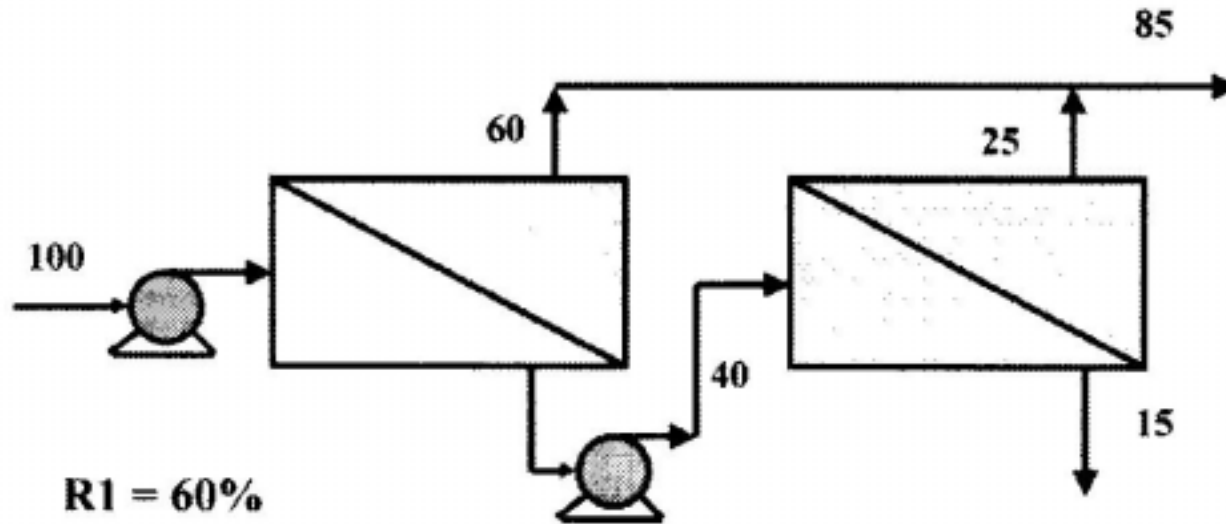
# 水再生回收程序



# 水再生回收程序



# 逆滲透操作型式



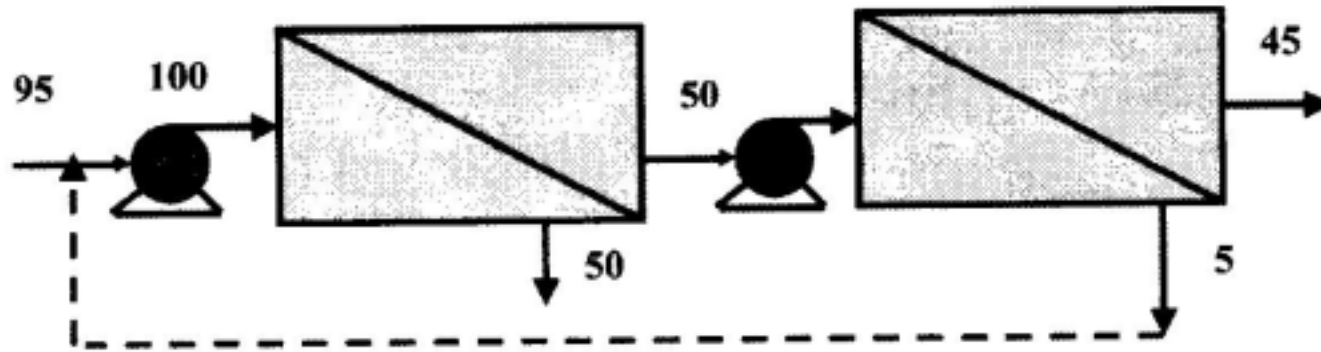
**R1 = 60%**

**R2 = 62%**

**Rt = 85%**

- Configuration of two stage RO unit with interstage booster pump.

# 逆滲透操作型式



$$R1 = 50.0 \%$$

$$R2 = 90.0 \%$$

$$Rt = 45.0\% \text{ (w/o recirculation)}$$

$$Rt = 47.3\% \text{ (w recirculation)}$$

Recovery rate in a two pass RO unit.

# 薄膜壓力

## List of Applied Pressure for Typical Membrane Filtration Processes

Membrane processes	Pressure (atm)
RO – Seawater	54.4–68.0
RO – Waste and process	20.4–40.8
RO – Water purification	13.6–23.8
RO – Undersink (home)	3.4
NF	6.8–13.6
UF	1.7–10.2
MF (crossflow)	0.7–1.7

# 進水水質

**Table 2.7 Feed water requirements to minimise fouling**

<b>Parameter</b>	<b>Value</b>
SDI <sub>15</sub>	≤4
Turbidity	< 1*
Iron**	< 0.05 mg/l
Manganese	< 0.5 mg/l
Hydrogen sulphide	< 0.1 mg/l
Organics (TOC)	< 10 mg/l

\* Some membrane manufacturers recommend that turbidity be < 0.2 NTU

\*\* At pH > 7.0 and 5–10 mg/l dissolved oxygen; at lower pH and lower oxygen levels, slightly higher iron levels can be tolerated

# 冷卻水塔



冷卻水塔所須補充水量，可由設置所須供應面積推估所需冷卻能力 (RT)後，依所需總冷卻能力 $\times 0.12$ 計算需補充水量。

# 冷卻系統

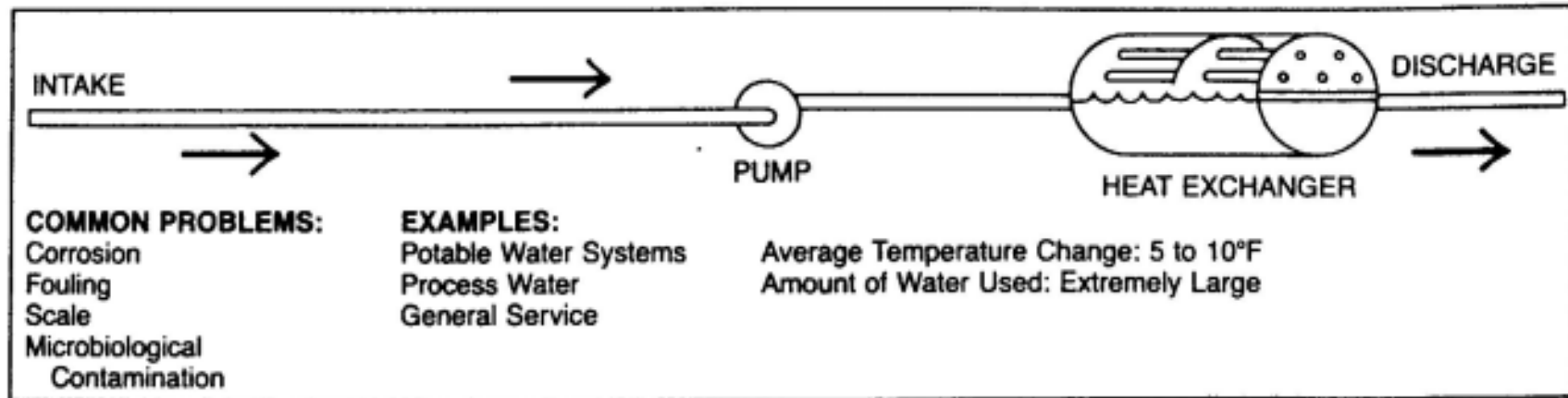
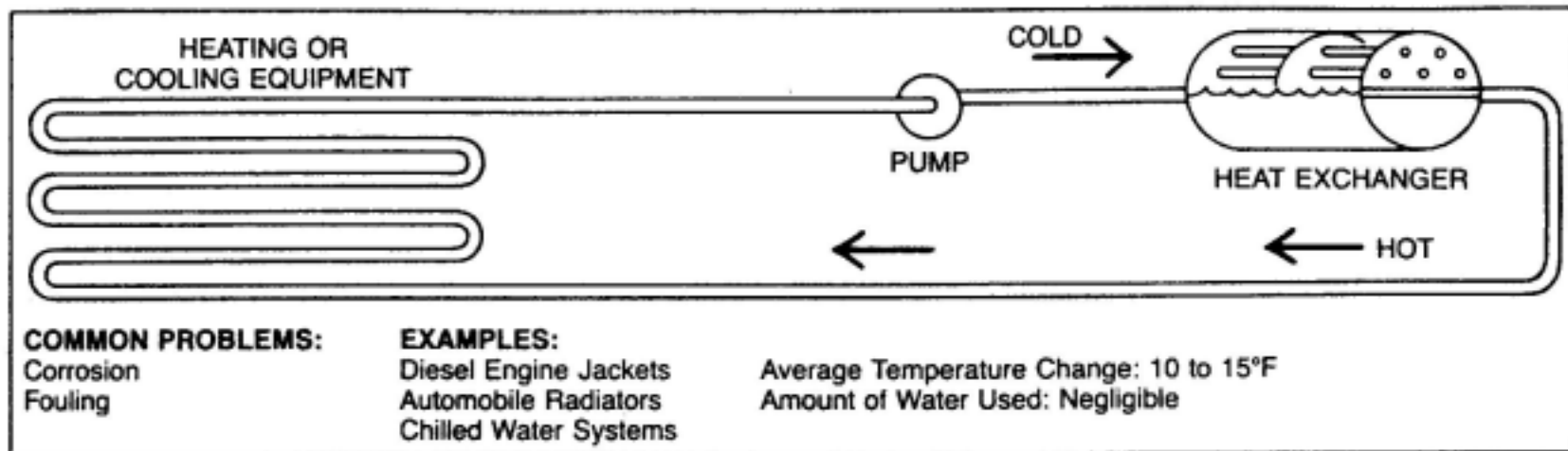


Figure 1.1 Schematic of once-through cooling system.

# 冷卻系統



**Figure 1.2** Schematic of closed recirculating cooling system.

# 冷卻系統

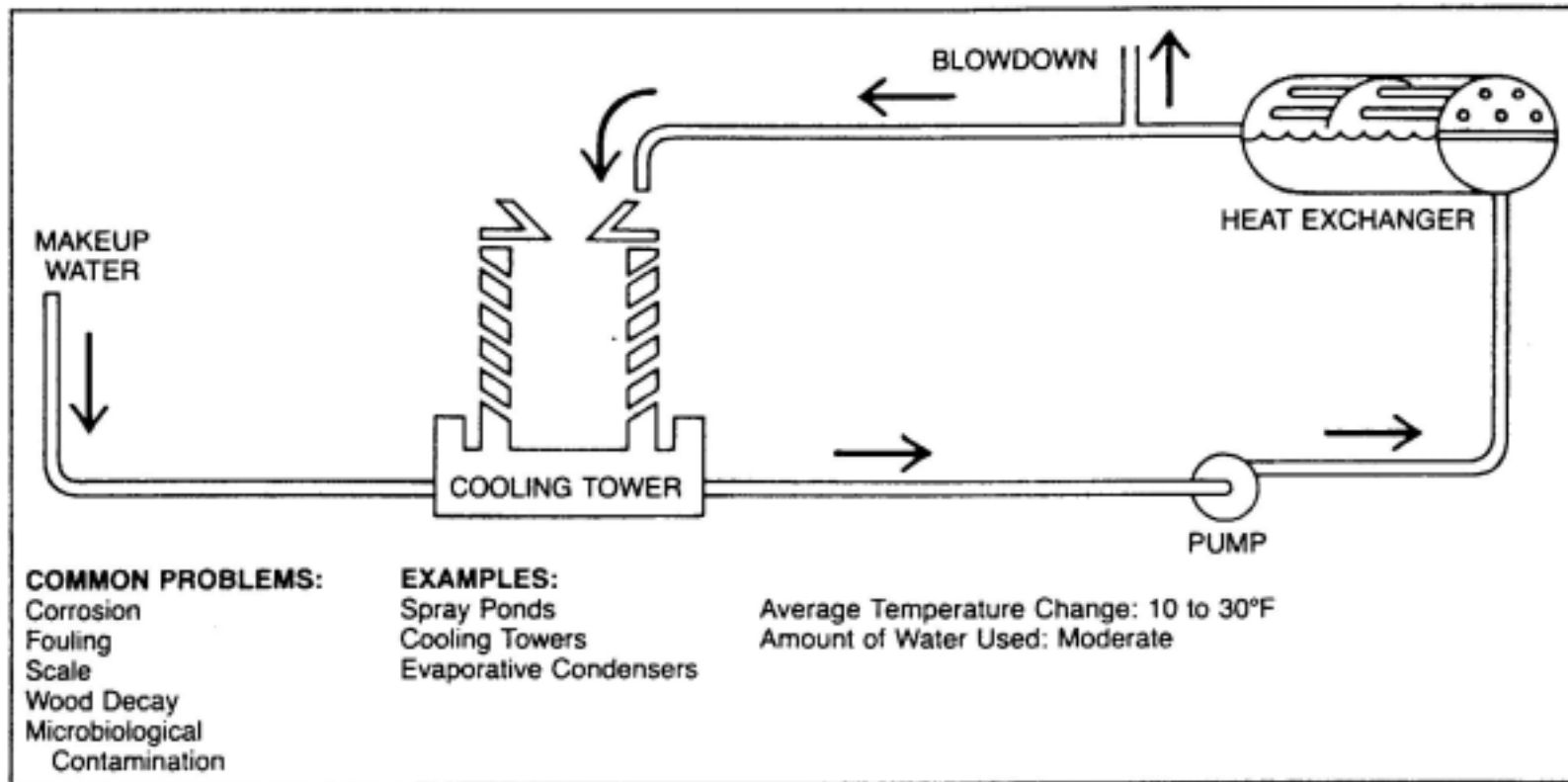


Figure 1.3 Schematic of open recirculating cooling system.

# 冷卻系統

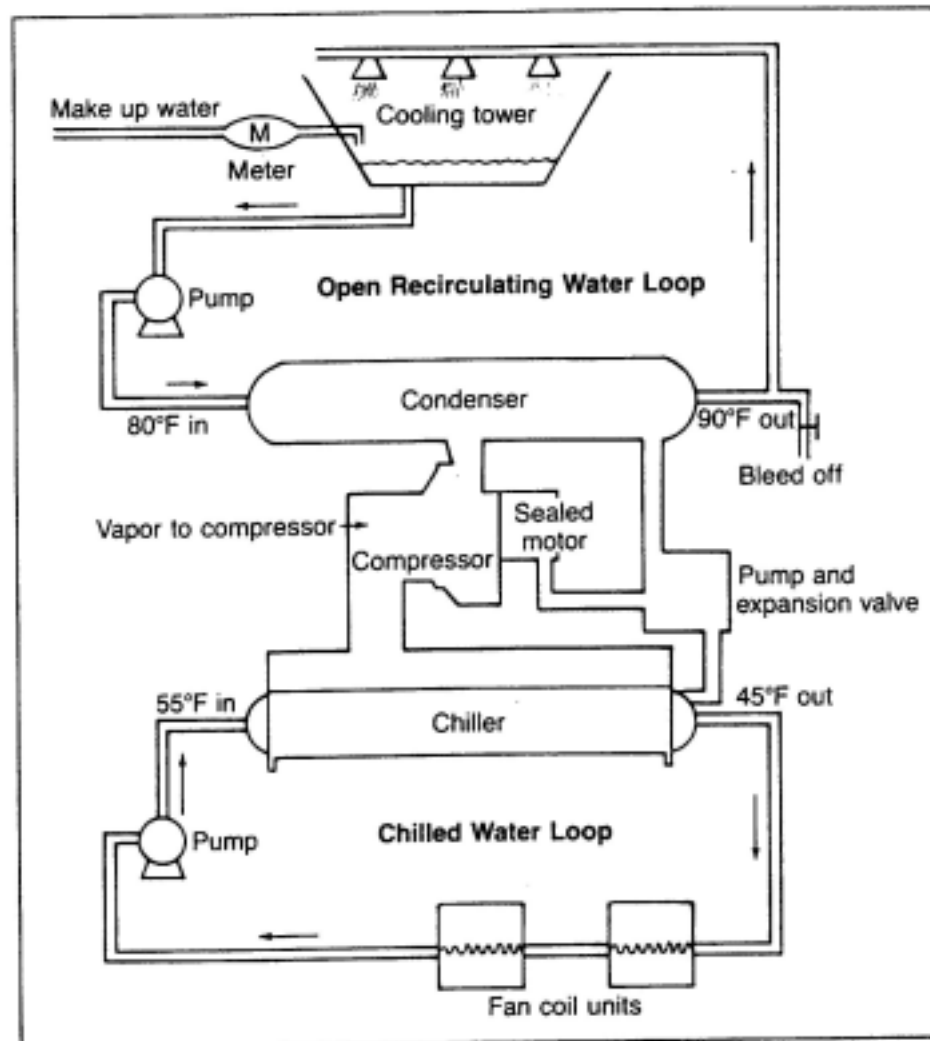
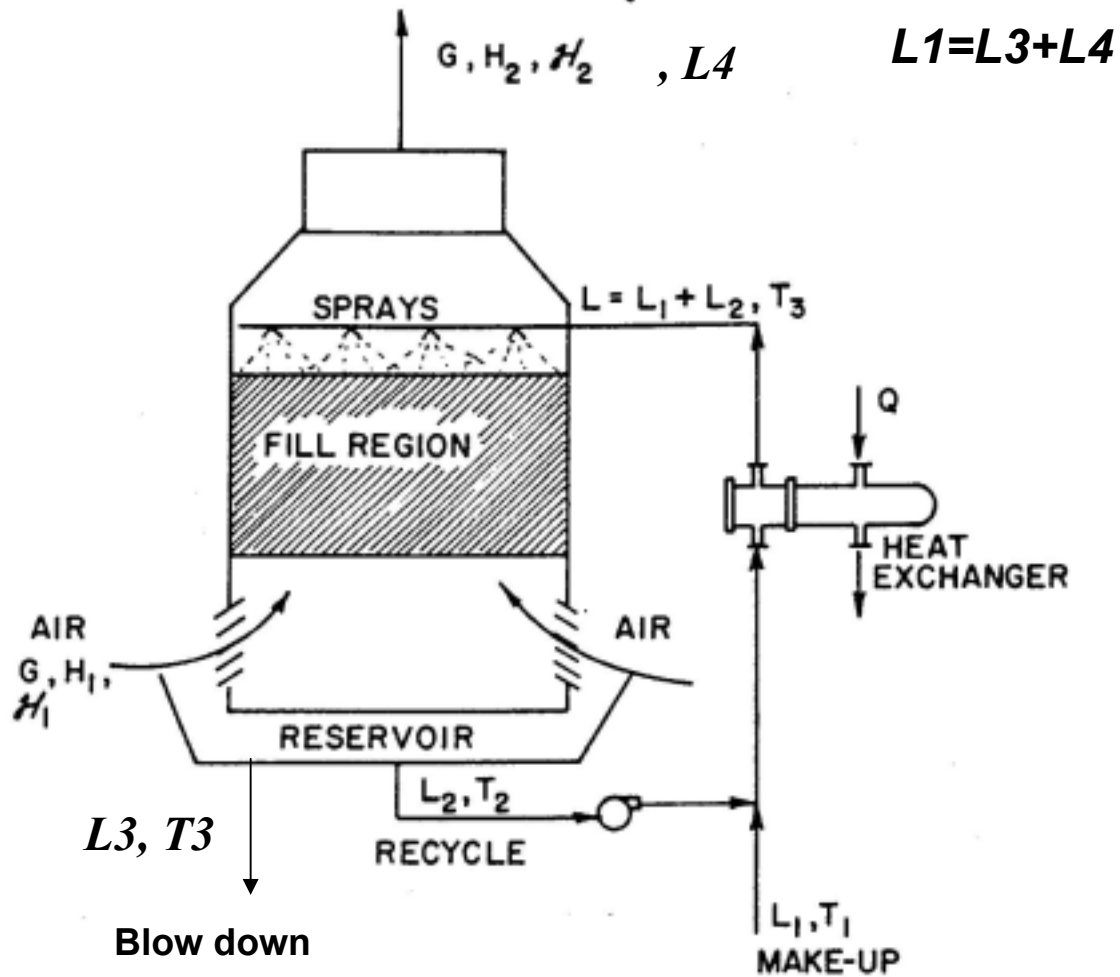


Figure 1.4 Schematic of all components of a complete air-conditioning system. [Fig. 37.8, *The Nalco Water Handbook*, 1st ed. (1979), reprinted with permission from McGraw-Hill, Inc.]

# 冷卻水塔氣體與液體平衡

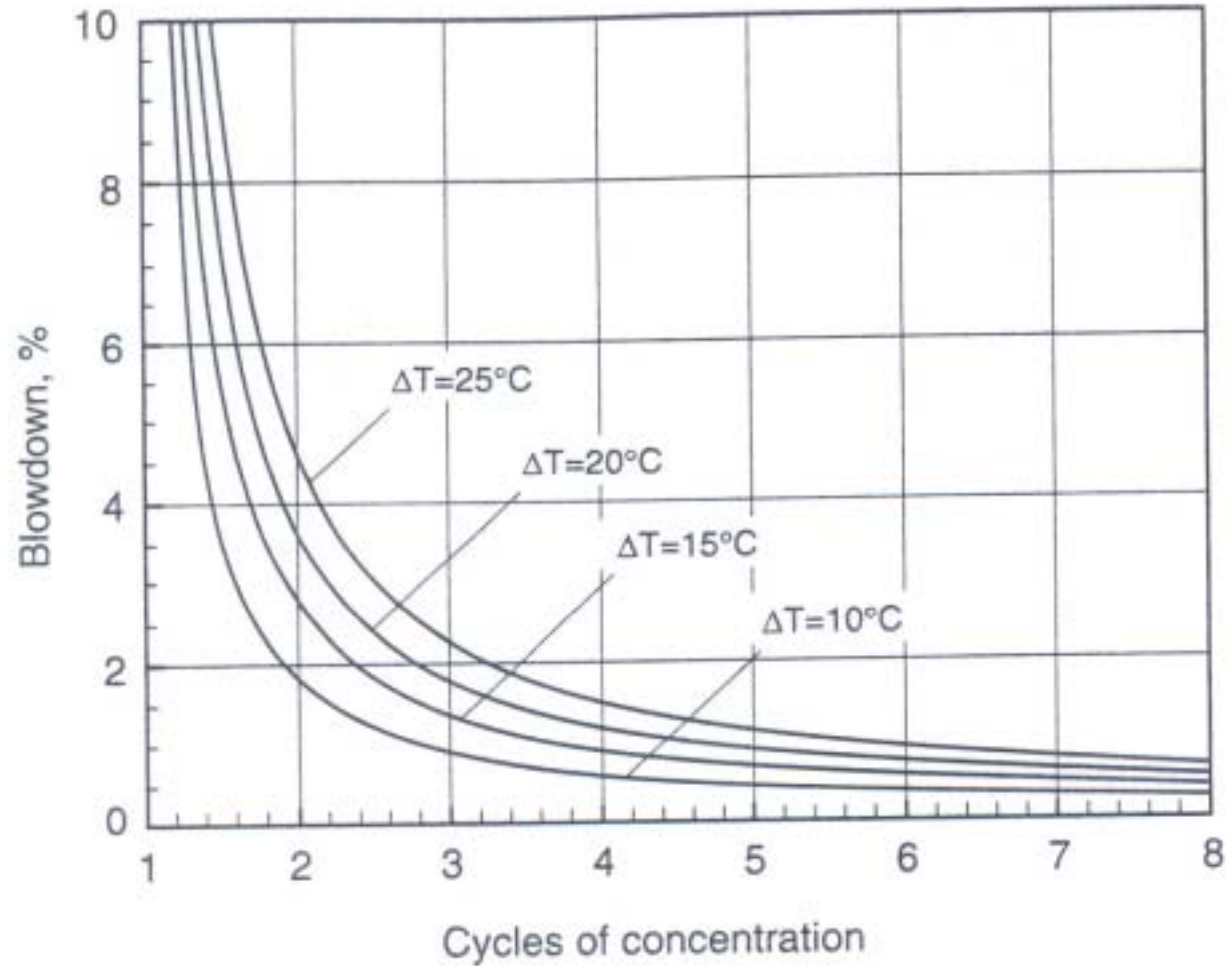


$L_1/L_3$ : 濃縮比

Cooling tower heat, air, water flow

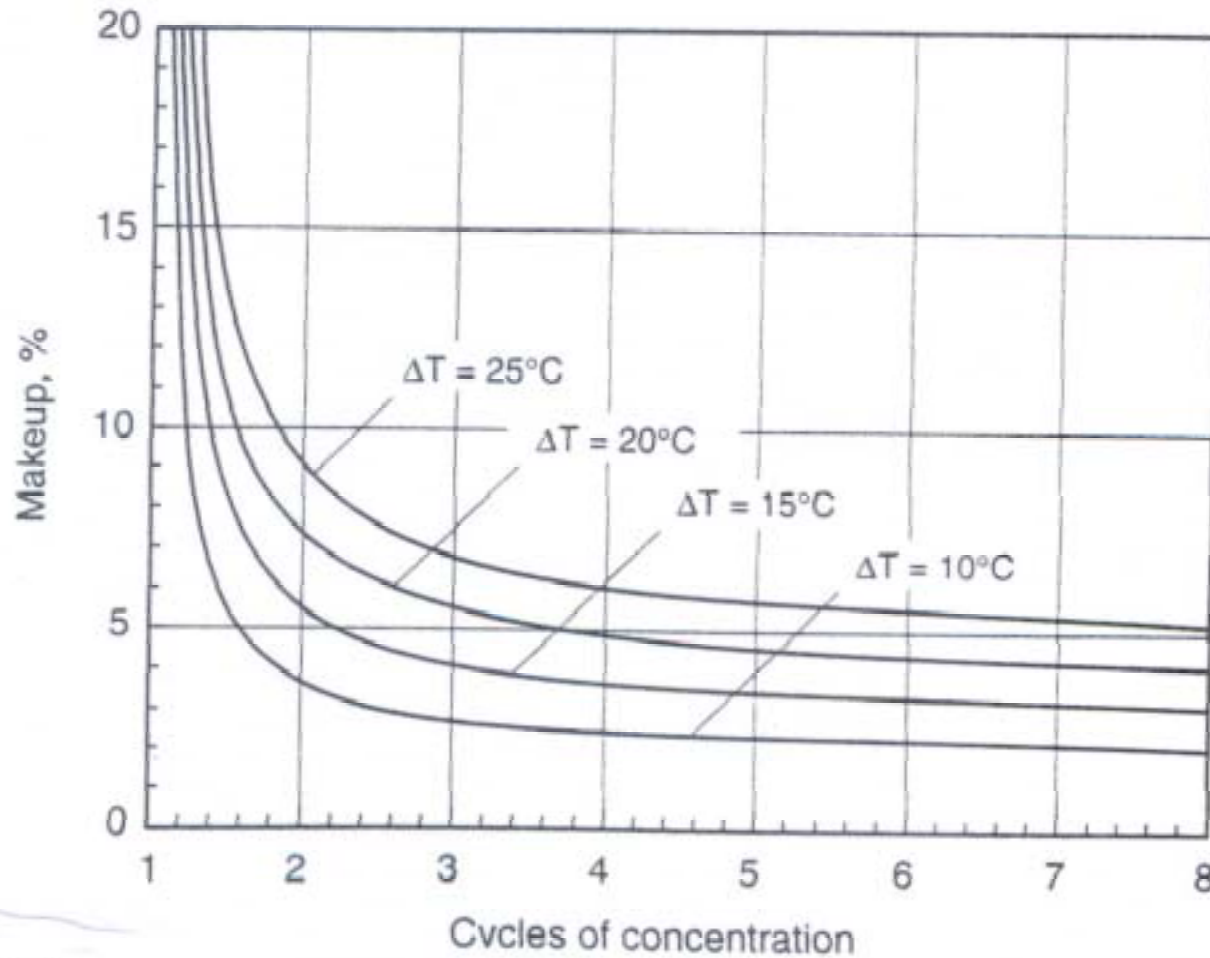
# 冷卻水塔排水比例 (%循環水量)

Blowdown requirements for a cooling tower.  
Assumption: water loss from drift = 0.1 percent.



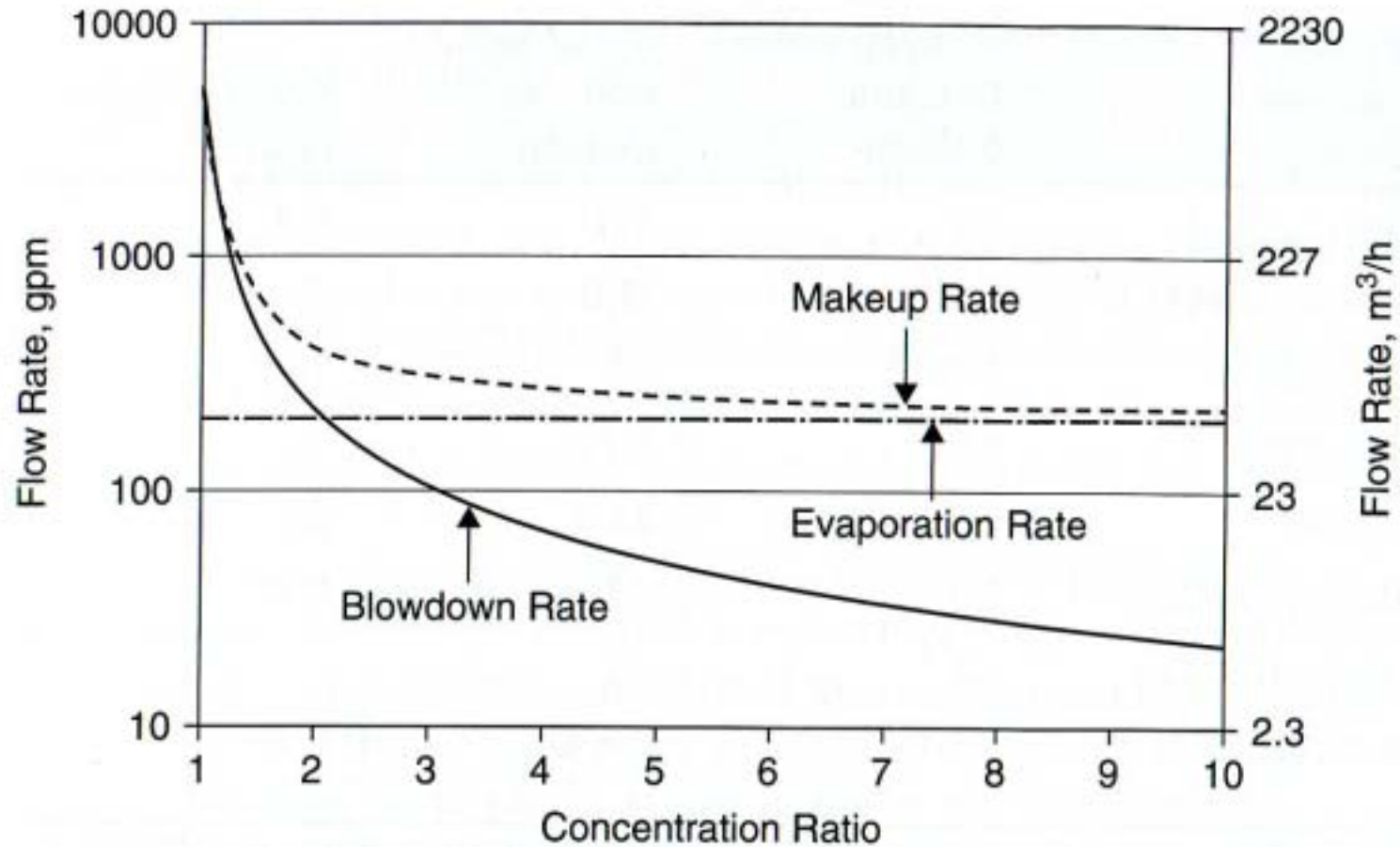
# 冷卻水塔補水比例

(%循環水量)



Makeup water requirements for a cooling tower.

# 冷卻水塔補水與排水



**FIGURE 14.27** Reduction of makeup and blowdown rate as concentration ratio increases in a cooling tower.

# 常見水質造成的問題

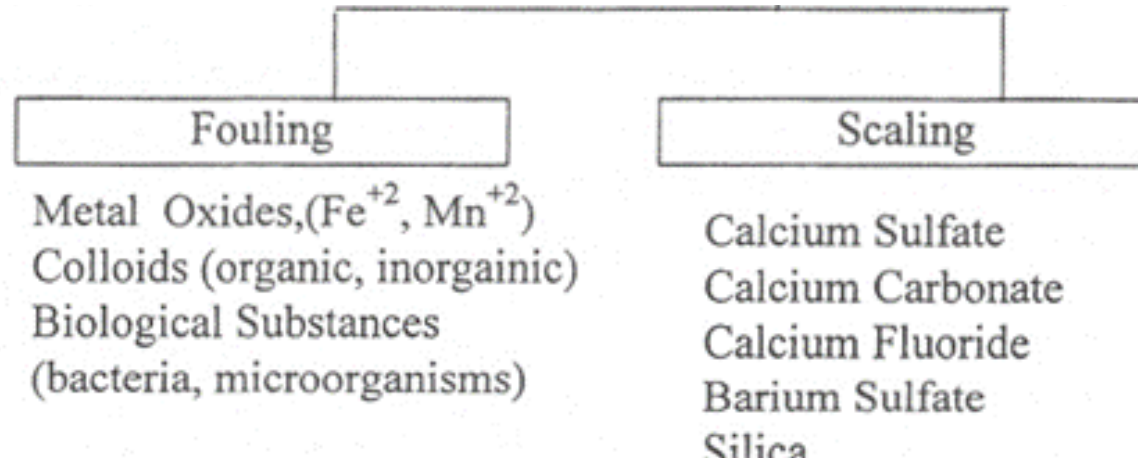


Table 8.2 Typical cooling water particle size distribution.

Size (micron)	Particle Count		
	Per 100ml	Percent of Particles in this Size	Cumulative Percent of all Particles
0.5 - < 1.0	30,277,895	97.7	97.7
1.0 - < 5.0	614,664	2.0	99.7
5.0 - < 10	72,178	0.2	99.9
10 - < 15	21,561	0.1	100.0
15 - < 20	8,186	0.0	100.0
>20	5,765	0.0	100.0
Total	31,000,249	100.0	100.0

# 常見水質造成的問題

Parameter	Optimum Range	Rationale
Alkalinity	Consistency	Variations in alkalinity can influence formation of metal-carbonate complexes and result in increased metal release.
Ammonia	Not present	Ammonia can form complexes with metals, resulting in increased solubility and metal release. Can promote biological growth and microbiologically induced corrosion. Corrosive to Cu and Cu alloys.
Calcium	Consistency	Calcium can form calcite on pipe walls, possibly preventing release of copper. Variations in water quality will promote dissolution of pipe film and promote metal release.
Chloride	Consistency	Chloride can increase corrosion rates under conditions of low dissolved oxygen. Can form complexes with metals increasing solubility and metal release.
Dissolved oxygen	Consistency	Dissolved oxygen can serve as an electron acceptor for corrosion reactions; however, it also reacts to form protective oxide layers that prevent corrosion. Localized differences in dissolved oxygen can promote corrosion.
Magnesium	Consistency	Magnesium can interfere with the deposition of calcium complexes on the pipe wall.
Total organic carbon (TOC)	Consistency	Organic carbon can coat pipe surfaces and prevent metal release. It can also form metal complexes and increase metal release. Can promote biological growth and microbiologically induced corrosion.
Orthophosphate	0.5–5 mg/L as PO <sub>4</sub>	Orthophosphate can react with copper to form copper phosphate complexes that coat the interior pipe wall
pH	7.3 to 7.8	pH influences metal solubility and reactions with carbonates. pH may be locally higher at the pipe surface due to OH <sup>-</sup> generation.
Sulfate	Consistency	Sulfate can interfere with formation of cupric hydroxide scales, thus increasing the potential for metal release.
Temperature	Consistency	Corrosion rates increase with increasing temperature. Temperature influences solubility, rates of microbiological activity, water density, and associated mixing efficiency.

## 水質與腐蝕指標

Parameter	Rationale	Optimum range
Aggressiveness index (AI)	Empirical relationship of pH, alkalinity and hardness developed for assessing corrosion of asbestos/cement pipes.	>12
Buffer capacity	Measure of the ability of water to resist a change in pH. Higher buffer capacity allows for more consistent pH at the pipe wall and in the bulk water, thus preventing localized metal release.	>0.5 meq/L·pH unit
Calcium carbonate precipitation potential (CCPP)	Estimate of the mass of calcite ( $\text{CaCO}_3$ ) that can deposit or dissolve from pipe walls.	4–10 mg/L as $\text{CaCO}_3$
Langelier saturation index (LSI)	Estimate of the potential for calcite ( $\text{CaCO}_3$ ) to either deposit or dissolve from pipe walls (no information on mass available).	0 to $\pm 0.2$ pH unit
Ryznar stability index (RSI)	Empirical variation on the LSI that gives more weighting to the saturation pH.	>6.2 pH unit
Alkalinity to chloride + sulfate ratio	Comparison of availability of anions to react with metals.	>1 eq/eq
Chloride to bicarbonate ratio	Comparison of the potential for chloride and bicarbonate to form metal complexes. Increases in steel corrosion have been observed at values over 0.3.	>0.2 eq/eq
Chloride to sulfate ratio	Measure of potential competitive reactions between anions and released metals.	<0.6 mg/mg

# 結垢物對熱傳的影響

**Table 5.1** Thermal Data Regarding Heat Transfer Coefficients Across Scale Layers

Scale type	Thermal conductivity $\lambda_0$ in W/m °K	For an average $\lambda_0$ value of	And a layer thickness of	Gives an efficiency loss of*:
CaCO <sub>3</sub>	1.5 to 1.8	1.7 W/m – °K	0.1 mm	7%
			0.25 mm	15%
			0.5 mm	26%
			1 mm	41%
CaSO <sub>4</sub>	0.6 to 2.3	1.2 W/m – °K	0.1 mm	9%
			0.25 mm	20%
			0.5 mm	33%
			1 mm	50%
SiO <sub>2</sub>	0.08 to 0.18	0.12 W/m – °K	0.1 mm	50%
			0.25 mm	71%
			0.5 mm	83%
			1 mm	91%
For comparison Cu	340			

\*For a power transfer of 1200 W/m<sup>2</sup> – °K

Source Weber and Knopf (52).

# 結垢物對熱傳的影響

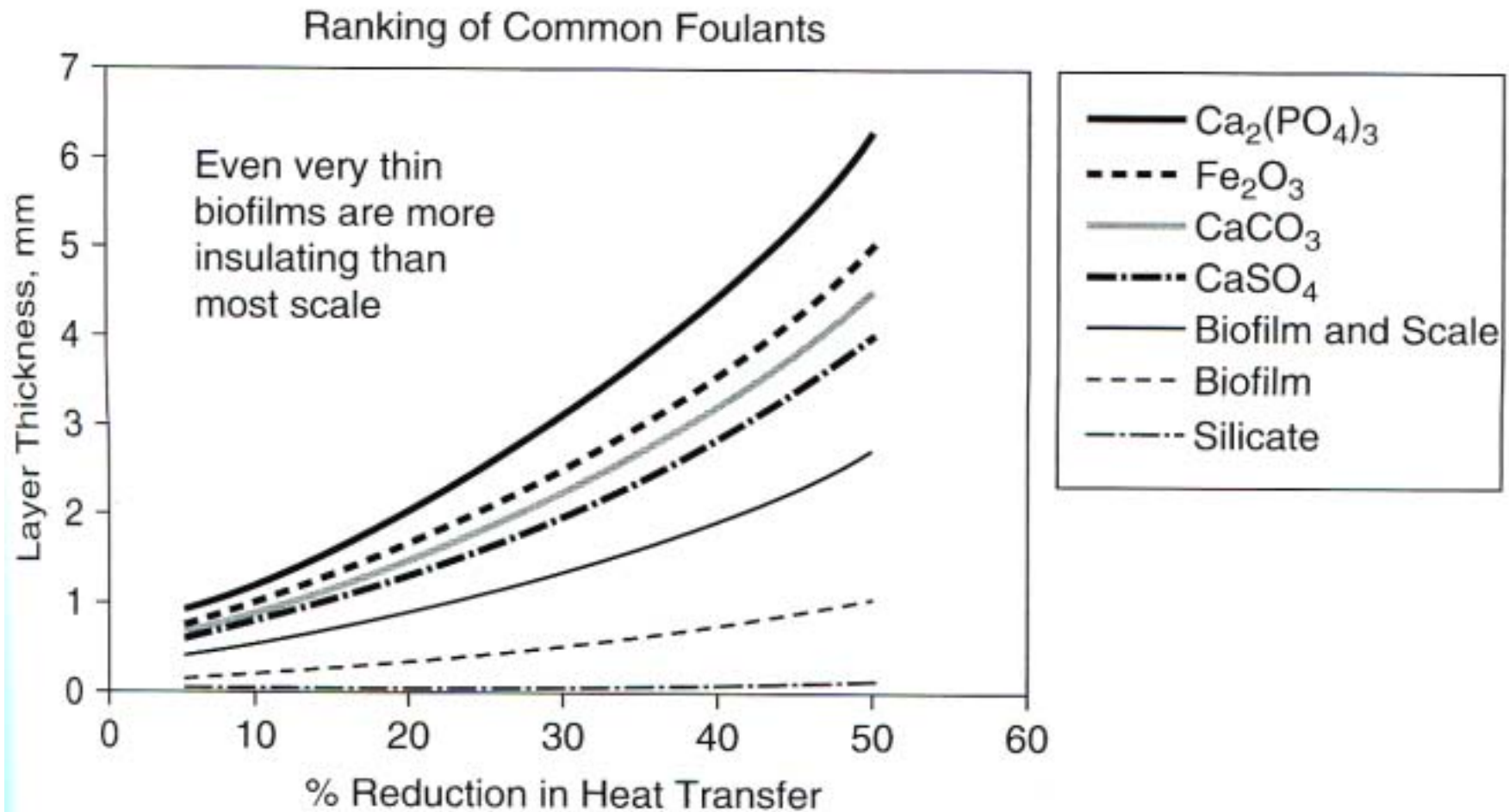


FIGURE 14.5 Insulating power of common foulants in heat exchangers.

## 冷卻水補充水水質

**Table 2.13** Recommended Cooling Water Quality Criteria for Make-Up Water to Recirculating Systems

Parameter <sup>a</sup>	Recommended limit <sup>b</sup>
Cl	500
TDS	500
Hardness	650
Alkalinity	350
pH <sup>c</sup>	6.9–9.0
COD	75
TSS	100
Turbidity	50
BOD <sup>c</sup>	25
Organics <sup>c</sup>	1.0
NH <sub>4</sub> -N <sup>c</sup>	1.0
PO <sub>4</sub> <sup>c</sup>	4
SiO <sub>2</sub>	50
Al	0.1
Fe	0.5
Mn	0.5
Ca	50
Mg	0.5
HCO <sub>3</sub>	24
SO <sub>4</sub>	200

<sup>a</sup> All values in mg/L except pH and turbidity.

<sup>b</sup> Water Pollution Control Federation, 1989.

<sup>c</sup> Methylene blue active substances.

Compiled from Reference 13.

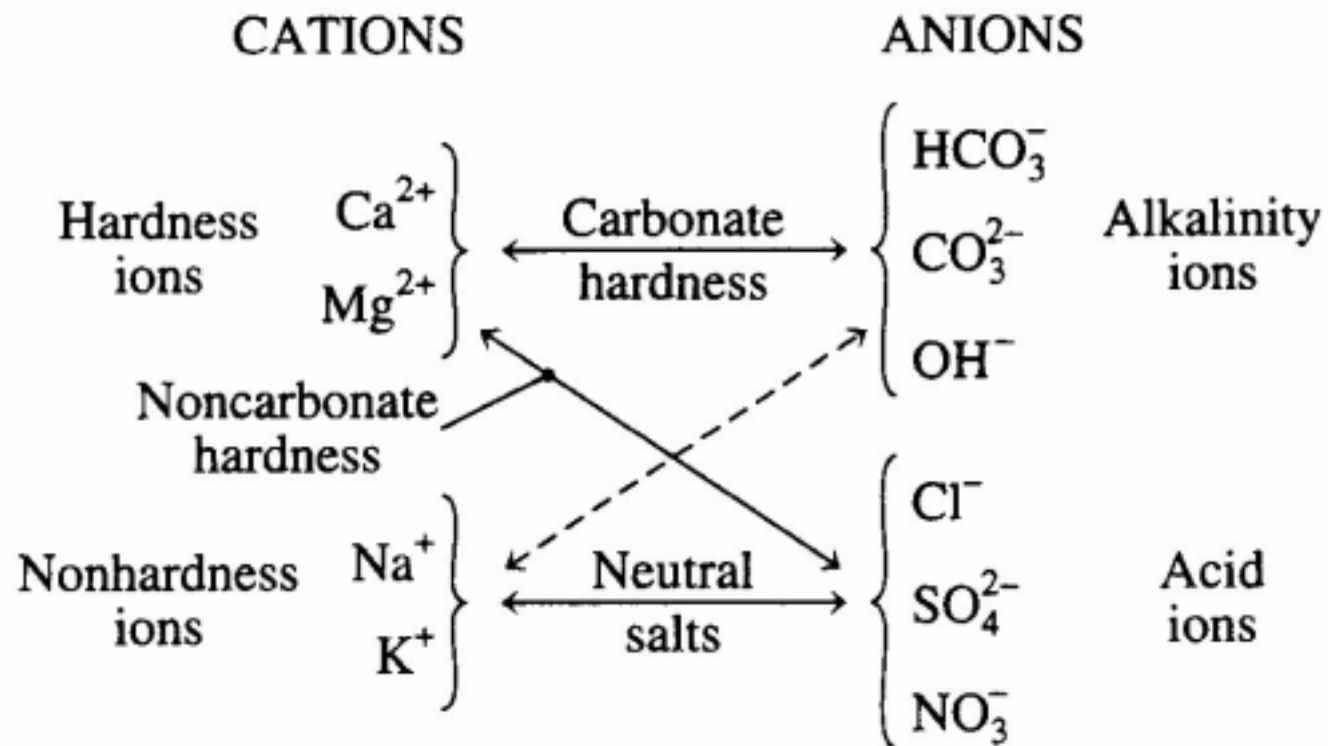
## 鍋爐與冷卻水水質

Characteristics	Boiler Feedwater (psig)				Cooling Water			
					Once-Through		Makeup for Recirculation	
	0-150	150-700	700-1500	1500-5000	Fresh	Brackish	Fresh	Brackish
Silica (SiO <sub>2</sub> )	30	10	1.0	0.01	50	25	50	25
Aluminum (Al)	5	0.1	0.01	0.01	—	—	0.1	—
Iron (Fe)	1	0.3	0.05	0.01	—	—	0.5	—
Manganese (Mn)	0.3	0.01	0.01	—	—	—	0.5	—
Copper (Cu)	0.5	0.05	0.05	0.01	—	—	—	—
Calcium (Ca)	—	0	0	"	200	420	50	420
Magnesium (Mg)	—	0	0	"	—	—	—	—
Sodium and potassium	—	—	—	—	—	—	—	—
Ammonia (NH <sub>3</sub> )	0.1	0.1	0.1	0.7	—	—	—	—
Bicarbonate (HCO <sub>3</sub> )	170	120	50	"	600	—	25	—
Sulfate (SO <sub>4</sub> )	—	—	—	—	680	2,700	200	2,700
Chloride (Cl)	—	—	—	—	600	—	500	—
Fluoride (F)	—	—	—	—	600	19,000	500	19,000
Nitrate (NO <sub>3</sub> )	—	—	—	—	—	—	—	—

# 鍋爐與冷卻水水質

Characteristics	Boiler Feedwater (psig)				Cooling Water			
					Once-Through		Makeup for Recirculation	
	0-150	150-700	700-1500	1500-5000	Fresh	Brackish	Fresh	Brackish
Phosphate (PO <sub>4</sub> )	—	—	—	—	—	—	—	—
Dissolved solids	700	500	200	0.5	1,000	35,000	500	35,000
Suspended solids	10	5	0	0	5,000	2,500	100	100
Hardness (CaCO <sub>3</sub> )	20	1.0	0.1	0.07	850	6,250	130	6,250
Alkalinity (CaCO <sub>3</sub> )	140	100	40	0	500	115	20	115
Acidity (CaCO <sub>3</sub> )	—	—	—	—	—	—	—	—
pH (units)	8.0-10.0	8.0-10.0	8.2-9.2	8.8-9.2	5.0-8.3	—	—	—
Color (units)	—	—	—	—	—	—	—	—
Organics								
MBAS	—	—	—	—	—	—	1	—
CCl <sub>4</sub>	—	—	—	—	—	—	1	—
COD	5	5	0.5	0	75	75	75	75
Dissolved oxygen	<0.03	<0.03	<0.03	<0.005	—	—	—	—
Temperature, °F	120	120	120	120	100	120	100	120
Turbidity (JTU)	10	5	0.5	0.05	5,000	100	—	—

# 常見水中沉澱化合物



**Figure 15.1** Major cations and associated anions in a typical water.

# 常見水中化合物的溶解度積

**TABLE 3.6 Solubility Products at 25°C of Typical Hydroxides and Carbonates**

Reaction	Solubility product, $K_{sp}^*$
$\text{Fe(OH)}_2 \rightleftharpoons \text{Fe}^{+2} + 2\text{OH}^-$	$1 \times 10^{-14}$
$\text{Fe(OH)}_3 \rightleftharpoons \text{Fe}^{+3} + 3\text{OH}^-$	$2 \times 10^{-39}$
$\text{Al(OH)}_3 + 3\text{H}^+ \rightleftharpoons \text{Al}^{+3} + 3\text{H}_2\text{O}$	$1 \times 10^{-9}$
$\text{ZnO} + 2\text{H} \rightleftharpoons \text{Zn}^{+2} + \text{H}_2\text{O}$	$6.7 \times 10^{-12}$
$\text{Mn(OH)}_2 \rightleftharpoons \text{Mn}^{+2} + 2\text{OH}^-$	$1.6 \times 10^{-13}$
$\text{Ca(OH)}_2 \rightleftharpoons \text{Ca}^{+2} + 2\text{OH}^-$	$3.7 \times 10^{-6}$
$\text{CaCO}_3 \rightleftharpoons \text{Ca}^{+2} + \text{CO}_3^{-2}$	$5 \times 10^{-9}$
$\text{Mg(OH)}_2 \rightleftharpoons \text{Mg}^{+2} + 2\text{OH}^-$	$1 \times 10^{-11}$
$\text{MgCO}_3 \rightleftharpoons \text{Mg}^{+2} + \text{CO}_3^{-2}$	$1 \times 10^{-5}$

From "Aquatic Chemistry," Stumm & Morgan.

\* From concentrations in moles/liter.

# 常見水中化合物的溶解度積

Table 5.7 Solubility product of sparingly soluble salts

Substance	Formula	Temperature (°C)	Solubility product ( $K_{sp}$ )
Aluminium hydroxide	$Al(OH)_3$	20	$1.9 \times 10^{-33}$
Barium carbonate	$BaCO_3$	16	$7 \times 10^{-9}$
Barium sulphate	$BaSO_4$	25	$1.08 \times 10^{-10}$
Calcium carbonate	$CaCO_3$	25	$8.7 \times 10^{-9}$
Calcium fluoride	$CaF_2$	26	$3.95 \times 10^{-11}$
Calcium sulphate	$CaSO_4$	10	$6.1 \times 10^{-5}$
Cupric sulphide	$CuS$	18	$3.5 \times 10^{-45}$
Ferric hydroxide	$Fe(OH)_3$	18	$1.1 \times 10^{-36}$
Ferrous hydroxide	$Fe(OH)_2$	18	$1.64 \times 10^{-14}$
Magnesium ammonium phosphate	$MgNH_4PO_4$	25	$2.5 \times 10^{-13}$
Magnesium carbonate	$MgCO_3$	12	$2.6 \times 10^{-5}$
Magnesium hydroxide	$Mg(OH)_2$	18	$1.2 \times 10^{-11}$
Manganese hydroxide	$Mn(OH)_2$	18	$4 \times 10^{-14}$
Strontium carbonate	$SrCO_3$	25	$1.6 \times 10^{-9}$
Strontium sulphate	$SrCO_4$	17.4	$2.81 \times 10^{-7}$
Zinc hydroxide	$Zn(OH)_2$	20	$1.8 \times 10^{-14}$

Source: IISFilter

# 常見水中化合物的溶解度積

**Table 17-3**

Typical limiting salts and their solubility products

Salt	Equation	Solubility Product <sup>a</sup> (pK <sub>sp</sub> at 25°C)
Calcium carbonate (aragonite)	$\text{CaCO}_3(\text{s}) \rightleftharpoons \text{Ca}^{2+} + \text{CO}_3^{2-}$	8.2
Calcium fluoride	$\text{CaF}_2(\text{s}) \rightleftharpoons \text{Ca}^{2+} + 2\text{F}^-$	10.3
Calcium orthophosphate	$\text{CaHPO}_4(\text{s}) \rightleftharpoons \text{Ca}^{2+} + \text{HPO}_4^{2-}$	6.6
Calcium sulfate (gypsum)	$\text{CaSO}_4(\text{s}) \rightleftharpoons \text{Ca}^{2+} + \text{SO}_4^{2-}$	4.6
Strontium sulfate	$\text{SrSO}_4(\text{s}) \rightleftharpoons \text{Sr}^{2+} + \text{SO}_4^{2-}$	6.2
Barium sulfate	$\text{BaSO}_4(\text{s}) \rightleftharpoons \text{Ba}^{2+} + \text{SO}_4^{2-}$	9.7
Silica, amorphous	$\text{SiO}_2(\text{s}) + 2\text{H}_2\text{O} \rightleftharpoons \text{Si}(\text{OH})_4(\text{aq})$	2.7

<sup>a</sup> From Stumm and Morgan (1981).

# 常見水中化合物的溶解度

The NALCO Water Handbook

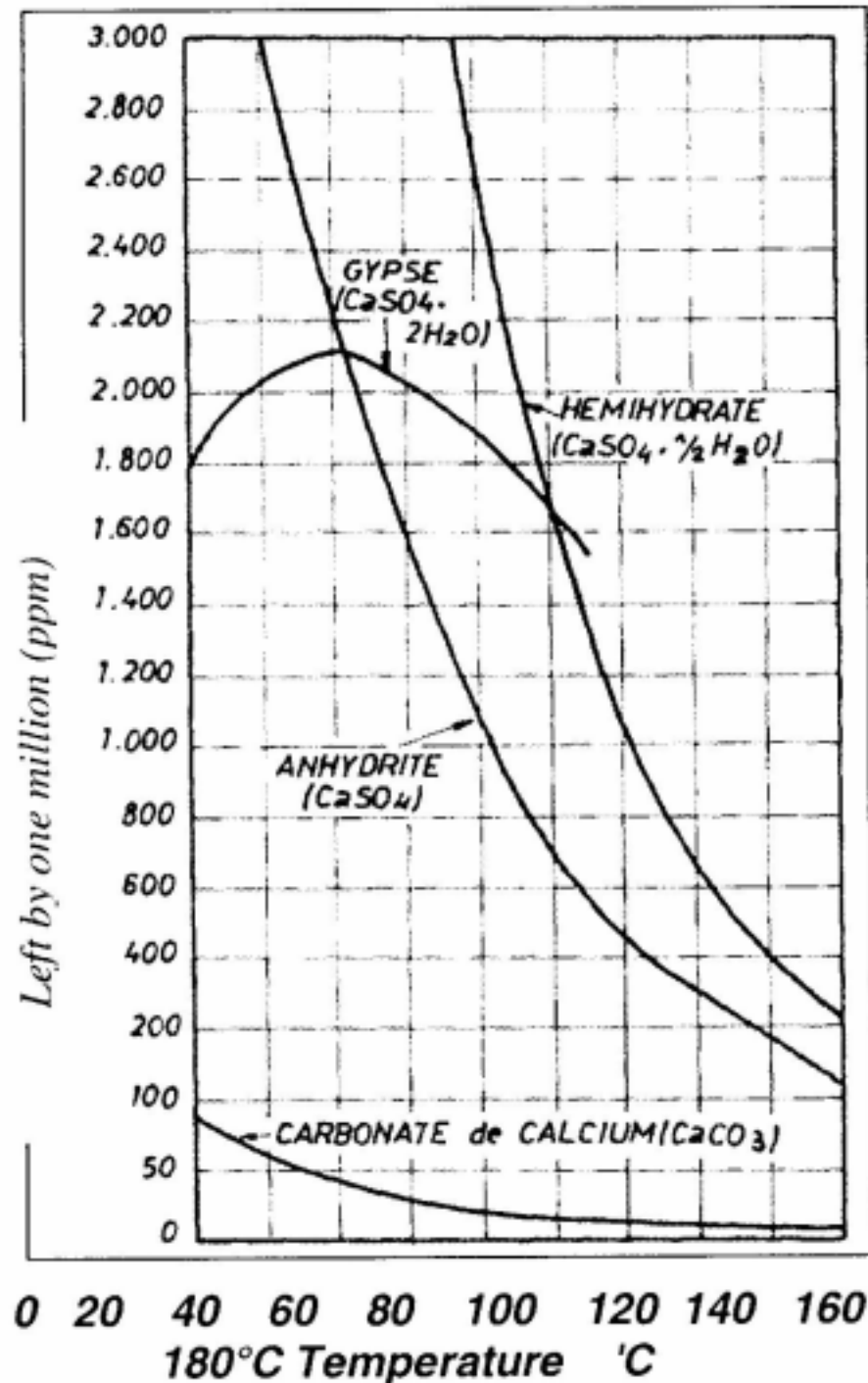
**TABLE 3.3 Solubility of Some Inorganic Compounds in Water at 20°C**

Cation	Compound (solid phase in parenthesis)	Solubility, wt %
Mg <sup>+2</sup>	MgCl <sub>2</sub> (·6H <sub>2</sub> O)	35.3
	Mg(OH) <sub>2</sub>	Nil
	MgCO <sub>3</sub>	Nil
	MgSO <sub>4</sub> (·7H <sub>2</sub> O)	26.2
Ca <sup>+2</sup>	CaCl <sub>2</sub> (·6H <sub>2</sub> O)	42.7
	Ca(OH) <sub>2</sub>	0.17
	CaCO <sub>3</sub>	Nil
	CaSO <sub>4</sub> (·2H <sub>2</sub> O)	0.20
	Ca <sub>3</sub> (PO <sub>4</sub> ) <sub>2</sub>	Nil
Fe <sup>+2</sup>	FeCl <sub>2</sub> (·4H <sub>2</sub> O)	40.8
	Fe(OH) <sub>2</sub>	Nil
Fe <sup>+3</sup>	FeCl <sub>3</sub>	47.9
	Fe(OH) <sub>3</sub>	Nil

\* Infinitely soluble.

# Calcium

Comparison between solubilities of scale-forming calcium salts



# Calcium

**TABLE 15.1** Solubilities of Possible Compounds Related to Water Hardness

Compound	Solubility, mg/L		$K_{sp}$
	Cold	Hot (25°C)	
CaCO <sub>3</sub>	14	18	$5 \times 10^{-9}$
CaCl <sub>2</sub>		745 000	1 590 000
Ca(OH) <sub>2</sub>	1 850	770	$8 \times 10^{-6}$
CaSO <sub>4</sub>	2 090	1 620	$2 \times 10^{-5}$
MgCO <sub>3</sub>	542 500	727 000	—
Mg(OH) <sub>2</sub>	9	40	$9 \times 10^{-12}$
MgSO <sub>4</sub>	260 000	738 000	—
Sr(OH) <sub>2</sub>	4 100	218 300	—
SrCO <sub>3</sub>	11	650	—

## 結垢控制指標

結 垢	控制参数	控 制 指 标
$\text{CaCO}_3$	$\text{pH}_s$	$\text{pH}_a < \text{pH}_s + (0.5 \sim 2.5)$ (16-16)
$\text{CaSO}_4$	溶解度	$(\text{Ca}^{2+}) \times (\text{SO}_4^{2-}) < 50000 \sim 750000$ (16-17)
$\text{Ca}_3(\text{PO}_4)_2$	$\text{pH}_p$	$\text{pH}_a < \text{pH}_p + 1.5$ (16-18)
$\text{MgSiO}_3$	溶解度	$(\text{Mg}^{2+}) \times (\text{SiO}_2) < 3500 \sim 7000$ (16-19)

注： $\text{pH}_a$  和  $\text{pH}_s$  分别为循环水的实际 pH 值和  $\text{CaCO}_3$  饱和平衡时的 pH 值。

$$LI = pH - pH_s$$

$$pH_s = pCa + pAlk + TDS$$

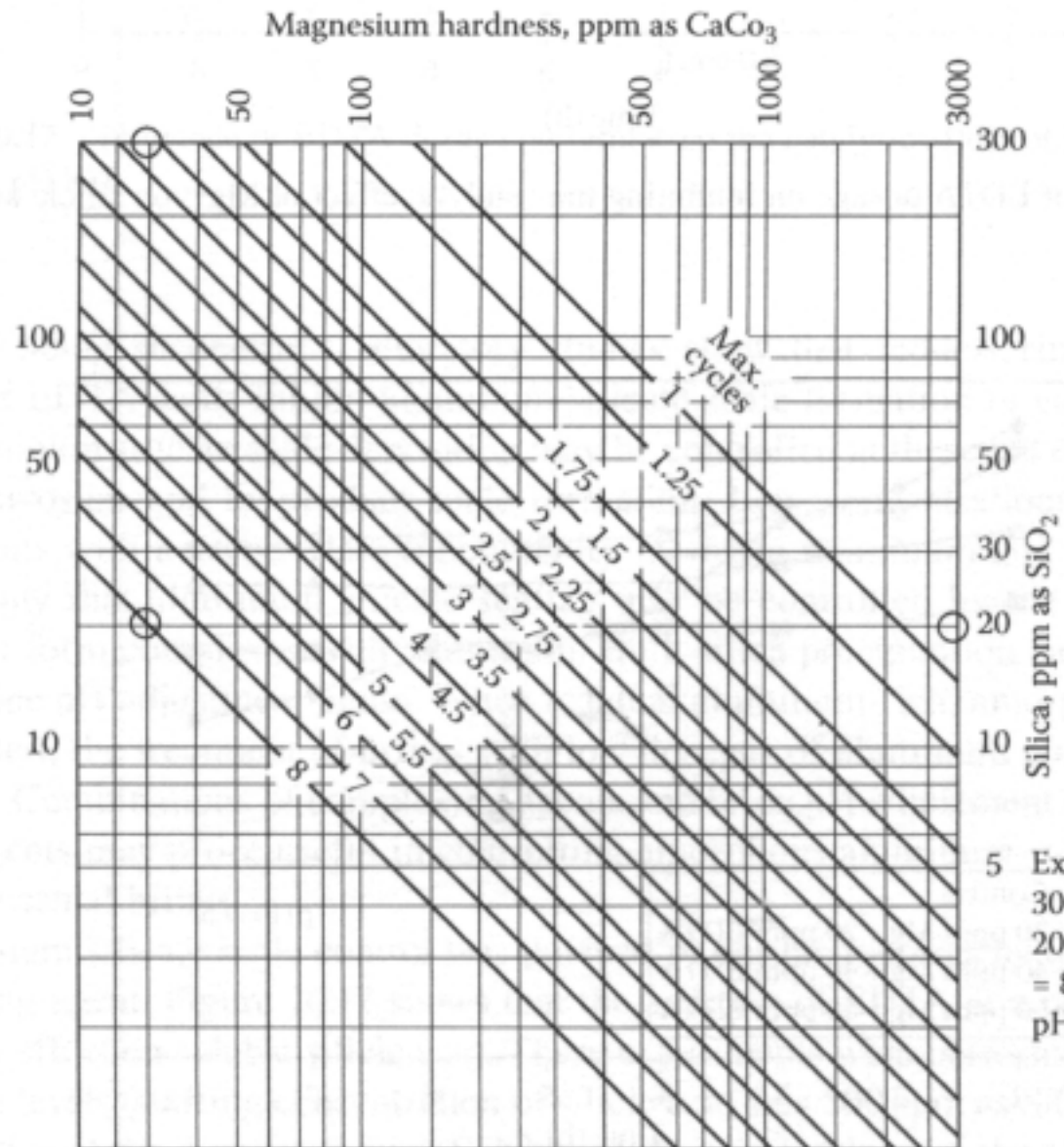
$$RSI = 2pH_s - pH$$

**TABLE 3.1**  
**Values of the LI and the Respective Meaning**  
**for Water Used in Industrial Processes**

Value of LI	Water Characteristics
+2.0	Scale-forming—noncorrosive
+0.5	Slightly scaling and noncorrosive
0.0	Balanced but pitting corrosion possible
-0.5	Slightly corrosive and non-scale-forming
-2.0	Highly corrosive

**TABLE 3.2**  
**Values of the RSI and the Respective Meaning**  
**for Water Used in Industrial Processes**

Value of RSI	Water Characteristics
4.0–5.0	Significant scale formation
5.0–6.0	Scaling to small extent
6.0–7.0	Little scaling, slightly corrosive
7.0–7.5	Corrosive
7.5–9.0	Intensively corroding
9.0 and higher	Destructive corrosion



5 Example:  
 30 ppm magnesium,  
 20 ppm silica  
 = 8.0 cycles  
 pH = 7-9

**FIGURE 10.20** Correlation between magnesium hardness and silica in process waters in calculated maximum cycles of concentration.

# silica

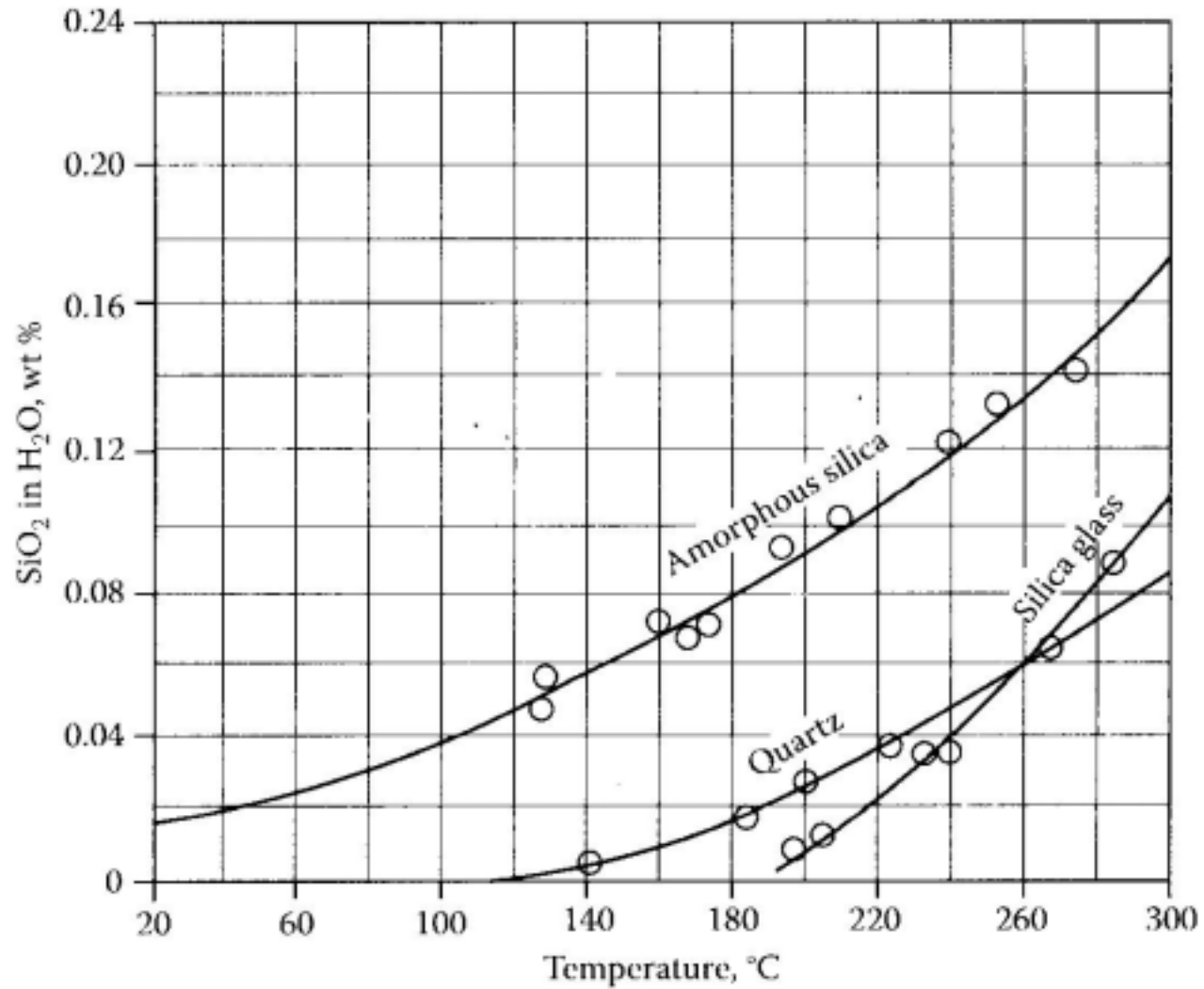
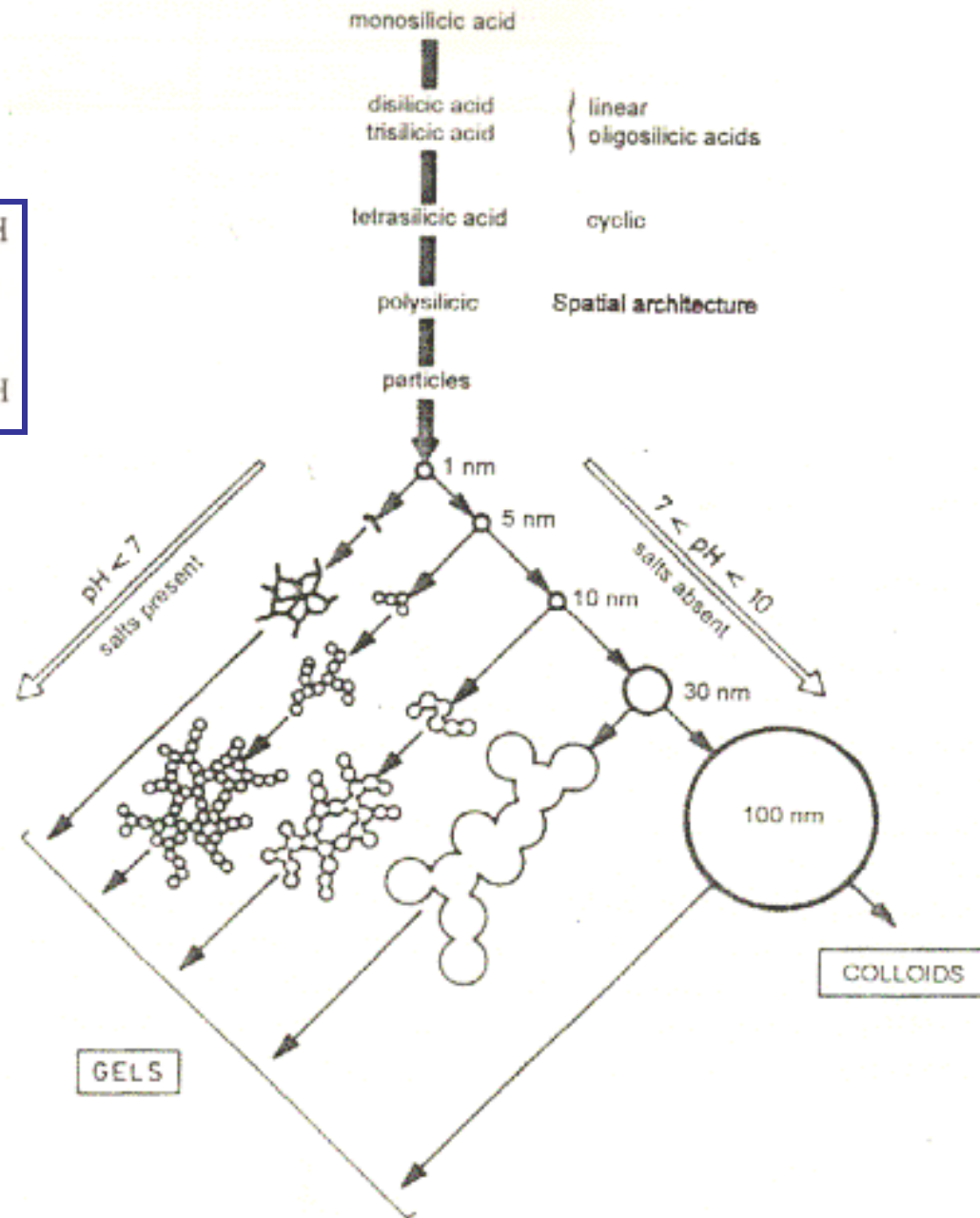
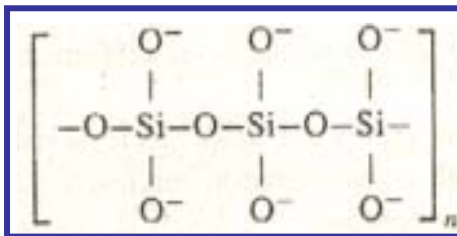
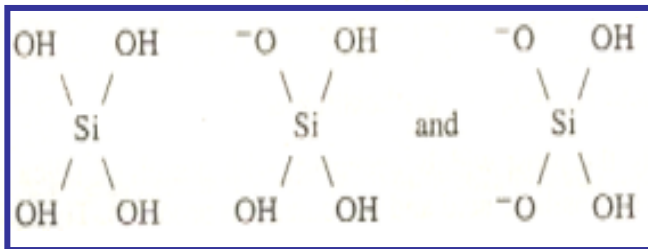


FIGURE 10.3 Dependence of different forms of silica solubility on temperature.

# silica



# silica

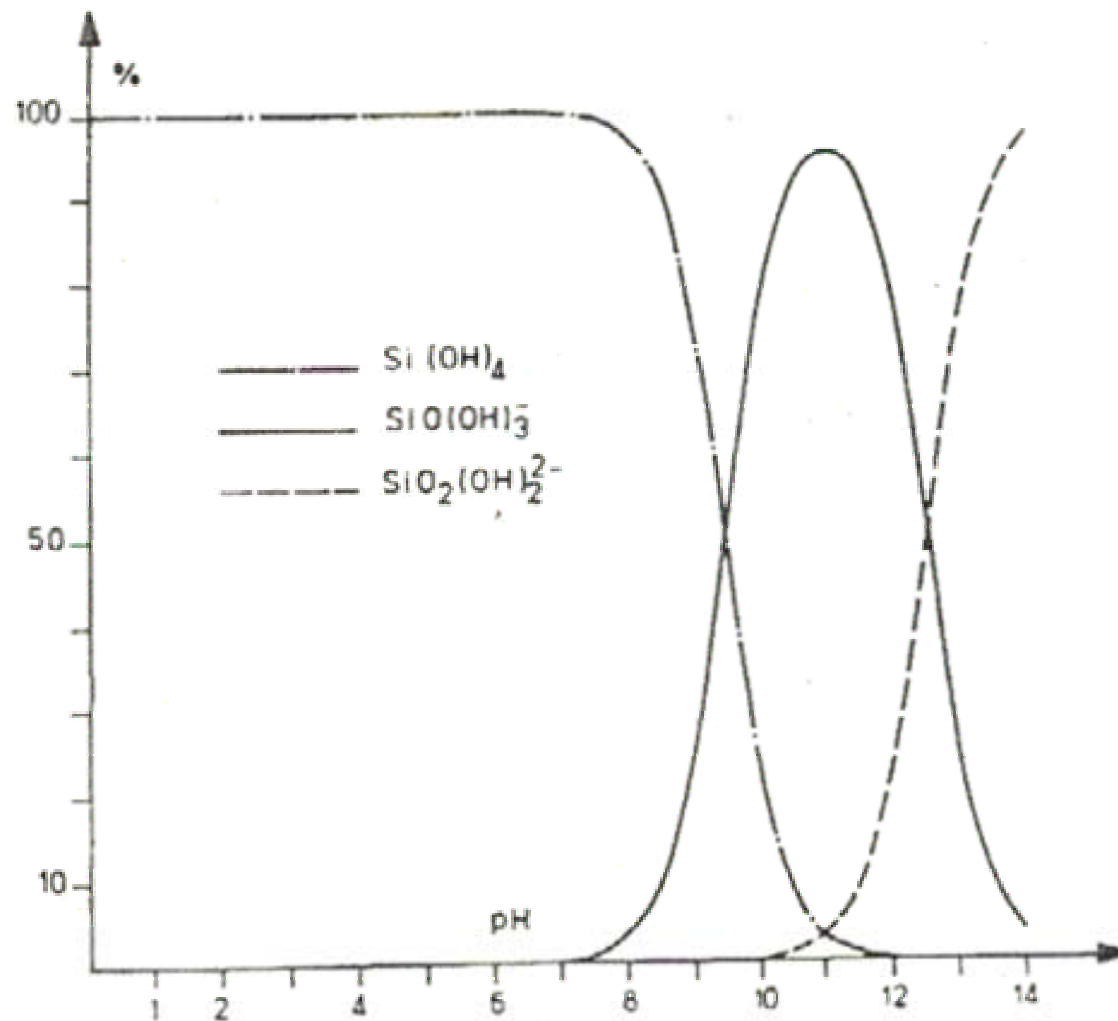


Figure 8.3 Silicon partitioning as a function of pH among orthosilicic acid and its various ionization products.

# silica

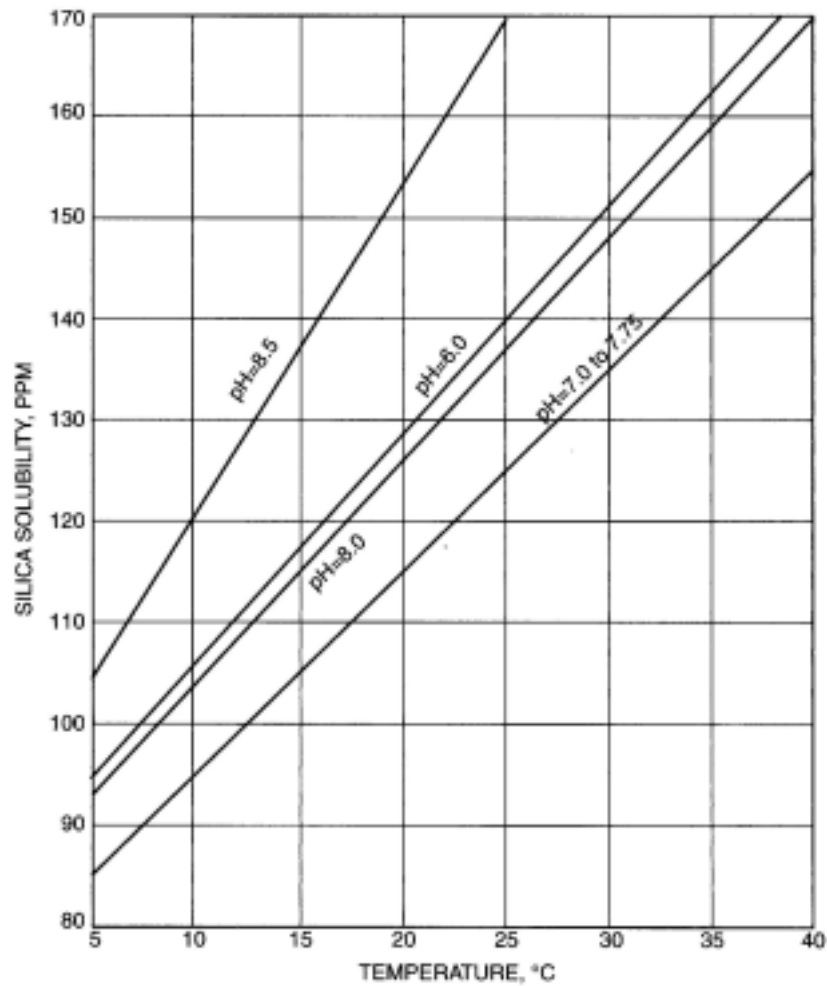


Figure 5.13 Silica solubility plot. Source: Amjad, Reverse Osmosis, 1993

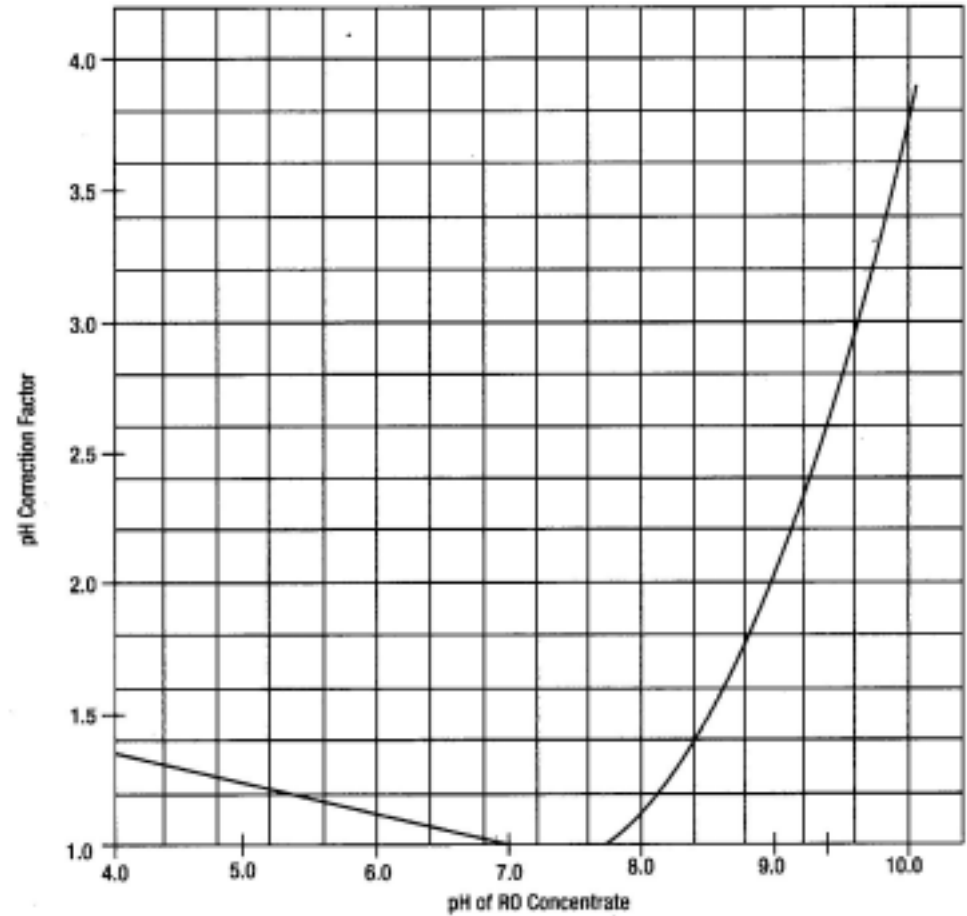


Figure 7.2 Silica solubility as a function of pH. To determine silica solubility at a given pH, multiply the solubility as a function of temperature by the pH correction factor of the given pH of the concentrate solution.

# Fe

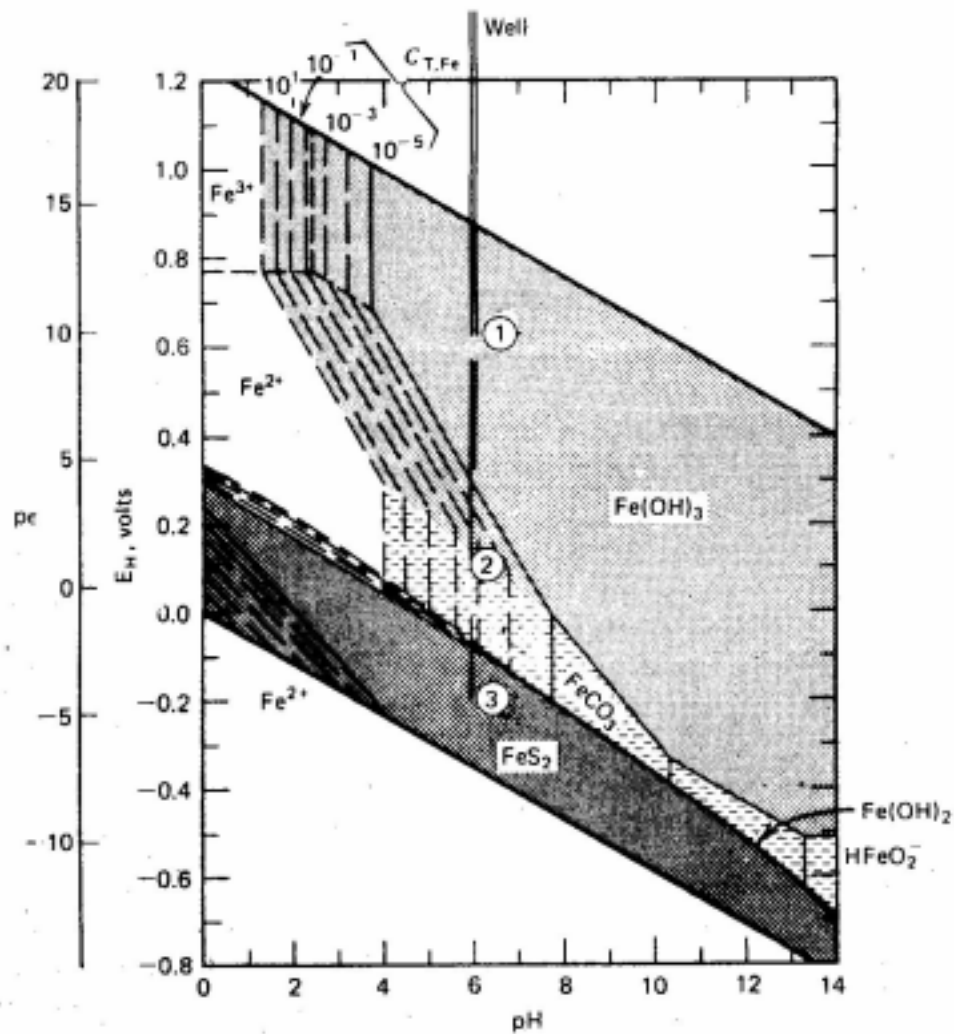
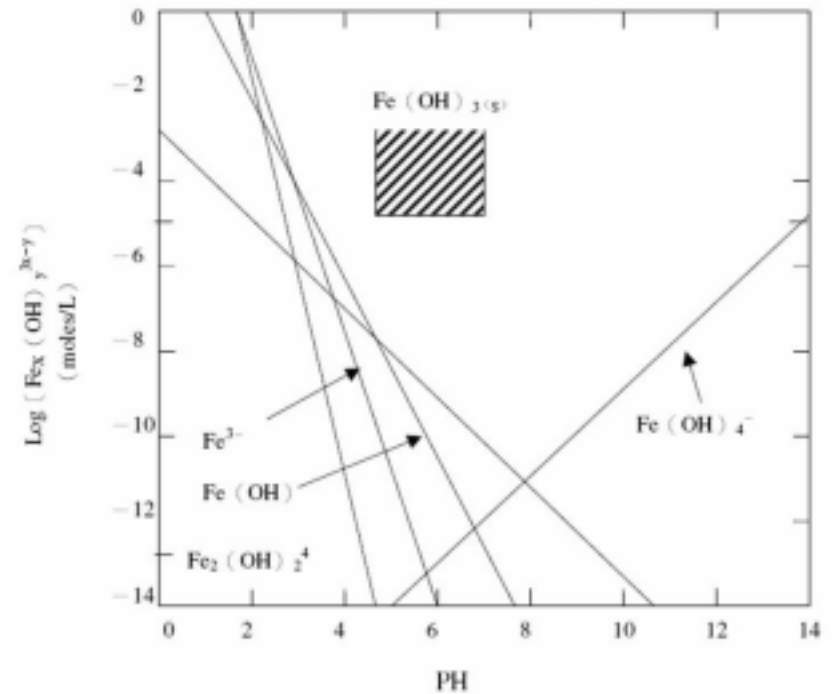
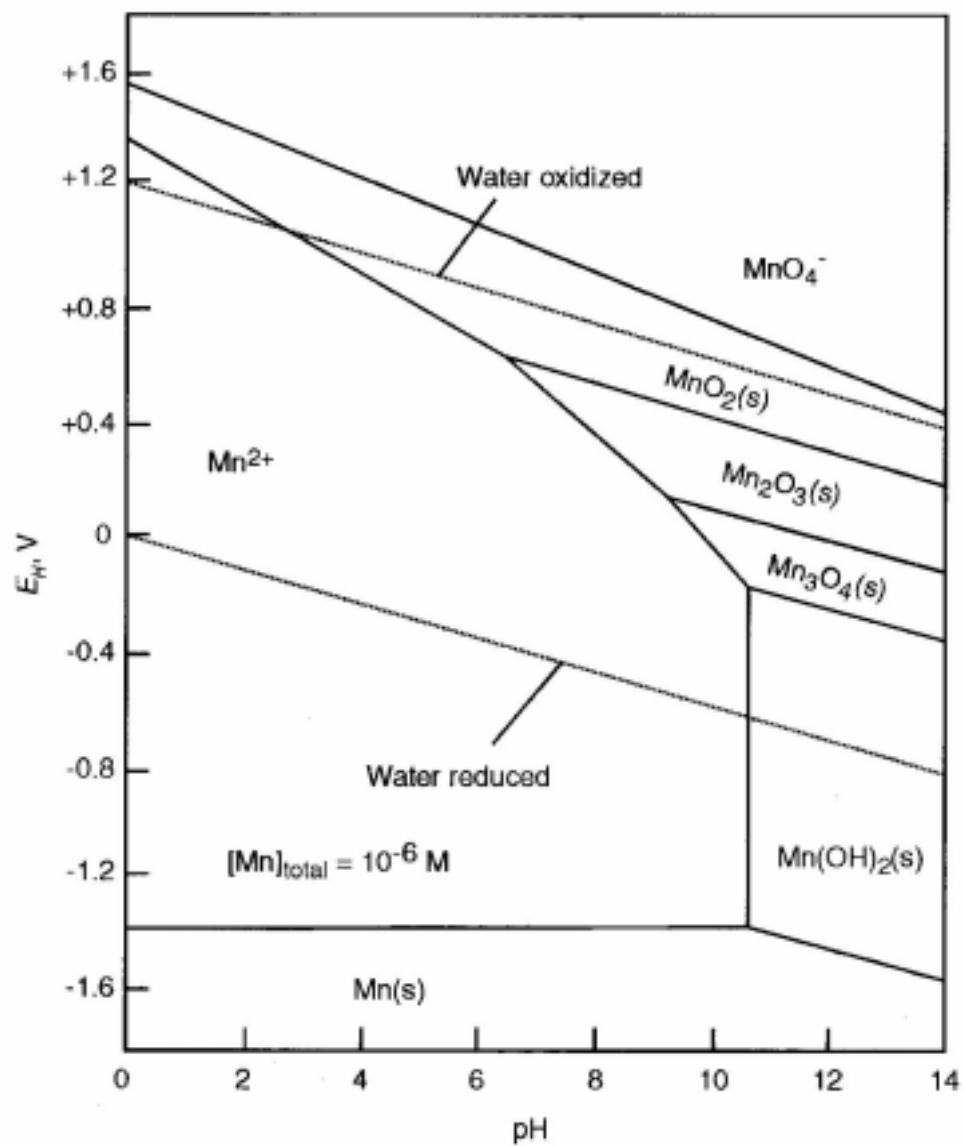


Fig. 7-18. Solubility of iron in relation to pH and pe at 25°C and 1 atm.  $C_{T,S} = 10^{-4}$  M;  $C_{T,CO_2} = 10^{-3}$  M. After J. D. Hem. "Some Chemical Relationships Among Sulfur Species and Dissolved Ferrous Iron," U.S. Geological Service Water Supply Paper, Washington, D.C., 1960.



Fe(III) 平衡

# Mn



**Figure 19-6**  
Forms of manganese in water as function of redox potential versus pH at a water temperature of 25°C (adapted from Pourbaix, 1966, 1974).

# 重金屬

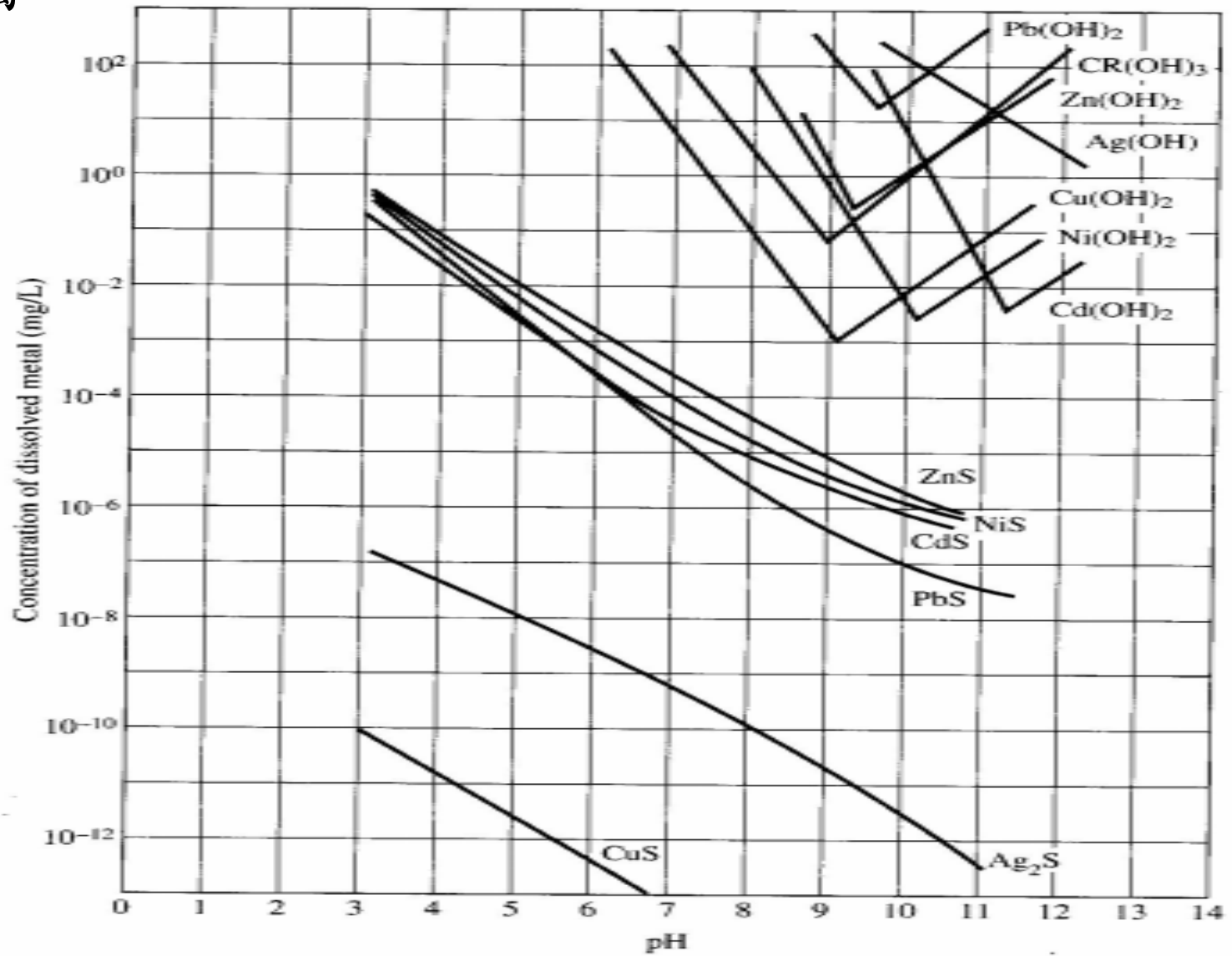
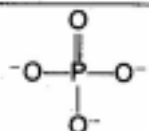
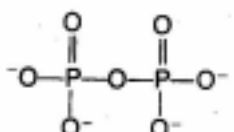
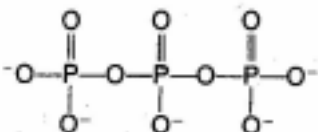
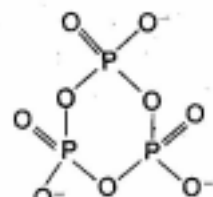
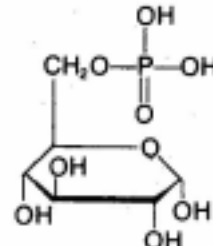


FIGURE 4.8 Heavy metals precipitation as the hydroxide and the sulfide.

# Phosphate

TABLE 6-3 Classes of Phosphorus-Containing Compounds of Importance in Aquatic Systems

Group	Structural Representation (Typical)	Species of Importance	Acid Ionization Constants (25°C)
Orthophosphate		$H_3PO_4$ , $H_2PO_4^-$ , $HPO_4^{2-}$ , $PO_4^{3-}$ , $HPO_4^{2-}$ complexes	$pK_{a,1} = 2.1$ , $pK_{a,2} = 7.2$ , $pK_{a,3} = 12.3$
Polyphosphates		$H_4P_2O_7$ , $H_3P_2O_7^-$ , $H_2P_2O_7^{2-}$ , $HP_2O_7^{3-}$ , $P_2O_7^{4-}$ , $HP_2O_7^{3-}$ complexes	$pK_{a,1} = 1.52$ , $pK_{a,2} = 2.4$ , $pK_{a,3} = 6.6$ , $pK_{a,4} = 9.3$
	pyrophosphate		
		$H_3P_3O_{10}^{2-}$ , $H_2P_3O_{10}^{3-}$ , $HP_3O_{10}^{4-}$ , $P_3O_{10}^{5-}$ , $HP_3O_{10}^{4-}$ complexes	$pK_{a,3} = 2.3$ , $pK_{a,4} = 6.5$ , $pK_{a,5} = 9.2$
	tripolyphosphate		
Metaphosphates		$HP_3O_6^{2-}$ , $P_3O_6^{3-}$	$pK_{a,1} = 2.1$
	trimetaphosphate		
Organic phosphates		Very many types, including phospholipids, sugar phosphates, nucleotides, phosphoamides, etc.	
	glucose 6-phosphate		

# Phosphate

**Table 5.4** Summary of the Inhibitory Effects of Certain Organic Phosphorus Compounds

---

Glycerophosphate	$10^{-3}$ to $10^{-4}$ mol/L
ADP	$10^{-4}$ to $10^{-5}$ mol/L
ATP	$10^{-4}$ to $10^{-5}$ mol/L
Trimetaphosphate	$10^{-4}$ to $10^{-5}$ mol/L
Pyrophosphate	$10^{-5}$ to $10^{-6}$ mol/L
Thiamine pyrophosphate	$10^{-6}$ to $10^{-7}$ mol/L
Triphosphosphate	$10^{-6}$ to $10^{-7}$ mol/L
Hexametaphosphate	Less than $10^{-7}$ mol/L
Long-chained polyphosphates ( $11 < n < 27$ )	Less than $10^{-7}$ mol/L

---

Source Fleish and Neuman (11).

# Phosphate

**Table 6.4** Comparative Data Concerning the Sequestering Capacities and Toxicities of Various Potential Polyphosphate Substitutes

Product	Type of action	Complexing power (*)		Toxicity DL 50 (g/kg)	% biodegradability (30 day)
		20°C	90°C		
<p>Tripolyphosphate</p> $\begin{array}{c} \text{O} \quad \text{O} \quad \text{O} \\ \uparrow \quad \uparrow \quad \uparrow \\ \text{NaO}-\text{P}-\text{O}-\text{P}-\text{O}-\text{P}-\text{O} \text{Na} \\   \quad   \quad   \\ \text{O} \quad \text{O} \quad \text{O} \\   \quad   \quad   \\ \text{Na} \quad \text{Na} \quad \text{Na} \end{array}$	Scale inhibitor	158	113	4.1	
<p>Hydroxy-Ethylidene Diphosphonic Acid (HEDP)</p> $\begin{array}{c} \text{CH}_3 \quad \text{PO}_3\text{H}_2 \\ \backslash \quad / \\ \text{C} \\ / \quad \backslash \\ \text{OH} \quad \text{PO}_3\text{H}_2 \end{array}$	—	394	378	1.8	2-21
<p>Nitrilotriacetic acid (NTA) Citric acid</p>	Complexant	285	202	1.1-1.6	3-74
$\begin{array}{c} \text{OH} \\   \\ \text{CH}_2 - \text{C} - \text{CH}_2 \\   \quad   \quad   \\ \text{COOH} \text{ COOH} \text{ COOH} \\ \text{2-OXA-1-3-4} \end{array}$	Complexant	195	30	1.05	85-93

# EDTA

If we evaluate the complexation aptitude of a molecule in terms of the number of coordination bonds it is capable of forming, EDTA is seen to offer a maximum number

**Table 6.1** Values for  $\log K_S$  at 20°C

Cation	Ba <sup>++</sup>	Ca <sup>++</sup>	Cd <sup>++</sup>	Co <sup>++</sup>	Cu <sup>++</sup>	Fe <sup>++</sup>	Fe <sup>3+</sup>	Hg <sup>++</sup>	Ni <sup>++</sup>
NTA	4.82	6.41	9.54	10.6	12.68	8.84	15.87	—	11.26
EDTA	7.76	10.70	16.59	16.21	18.79	14.33	25.1	21.8	18.36
DCyTA	7.99	12.50						24.3	
Cation	Mg <sup>++</sup>	Mn <sup>++</sup>	Pb <sup>++</sup>	Sr <sup>++</sup>	Zn <sup>++</sup>	Li <sup>++</sup>	Na <sup>+</sup>	H <sup>+</sup>	
NTA	5.41	7.44	11.8	4.98	10.45	3.28	2.1	—	
EDTA	8.69	13.50	18.3	8.63	16.26	2.79	1.66	10.22	
DCyTA	10.32							11.70	

*Source* From data given in Metcalf and Moore (19), Freedman (8), Prakash and Choksi (20), and Schwarzenbach et al. (24).

\* Certain acid functional groups of these molecules are very weak acids. A pH above the highest  $pK_a$  must therefore be used to ensure near total dissociation.

## 回收水用途及其處理方式

回收水用途	處理方式
景觀用水	二級處理+過濾+消毒
非製程洗滌水	二級處理+過濾+消毒
冷卻水塔補充水 (低電導度)	二級處理+高級處理+過濾+離子交換樹脂+消毒
冷卻水塔補充水 (高電導度)	二級處理+高級處理+過濾+電透析(ED)+消毒
製程冷卻及洗滌水	二級處理+高級處理+過濾+消毒
製程用水	二級處理+高級處理+過濾+活性炭+薄膜過濾+消毒
其他(消防用水)	過濾(雨水)

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