



Dow
Water Solutions

DOWEX™ Ion Exchange Resins

and

FILMTEC™ Membranes

Engineering Information

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1. Particle Size Distribution

Test methods to establish and/or express the size distribution of DOWEX™ standard ion exchange resins are based on "U.S.A. Standard Series" of sieves. Table 1 gives the main characteristics of sieves of interest to the analysis of bead size distributions.

Due to the narrow particle size distribution of DOWEX uniform particle sized resins, the conventional method of using U.S.A. Standard Sieves does not provide sufficiently detailed information to describe the particle distribution effectively.

The particle distribution for DOWEX uniform particle sized resins is therefore given as a mean particle size covering a specified range and a uniformity coefficient which is < 1.1. In addition, upper and/or lower maximum limits may be given, which are expressed as a percentage. This is illustrated in Table 2.

This resin therefore has a mean particle size between 600 and 700 microns with 90 percent of the beads within ± 100 microns of the mean. No more than 0.2 percent of the bead population is below 300 microns.

Table 1. Main characteristics of sieves

Sieve mesh number	Nominal sieve opening (mm)	Opening tolerance ($\pm\mu\text{m}$)	Nominal wire diameter (mm)
10	2.00	70	0.900
12	1.68	60	0.810
14	1.41	50	0.725
16	1.19	45	0.650
18	1.00	40	0.580
20	0.841	35	0.510
25	0.707	30	0.450
30	0.595	25	0.390
35	0.500	20	0.340
40	0.420	19	0.290
45	0.354	16	0.247
50	0.297	14	0.215
60	0.250	12	0.180
70	0.210	10	0.152
80	0.178	9	0.131
100	0.150	8	0.110
120	0.125	7	0.091
140	0.104	6	0.076
170	0.089	5	0.064
200	0.074	5	0.053
230	0.064	4	0.044
270	0.053	4	0.037
325	0.043	3	0.030
400	0.038	3	0.025

Table 2. Particle distribution of DOWEX MONOSPHERE™ 650C

Resin	DOWEX MONOSPHERE 650C
Mean particle size	650 \pm 50 microns
Uniformity coefficient, max.	1.1
Greater than 840 microns (20 mesh), max.	5%
Less than 300 microns (50 mesh), max.	0.5%

2. Conversion of Common Units

To convert non-metric units to the metric/S.I. units, multiply by the factors given; to convert S.I./metric units to the non-metric unit, divide by the factor given in Table 3. A unit converter is also available.

Table 3. Conversion of common units

From To	→ ←	To From	Multiply by Divide by
LENGTH			
inch (in)		meter (m)	0.0254
foot (ft)		meter (m)	0.3048
yard (yd)		meter (m)	0.9144
AREA			
in ²		m ²	0.0006452
ft ²		m ²	0.0929
yd ²		m ²	0.8361
VOLUME			
in ³		liter (L)	0.01639
ft ³		liter (L)	28.32
yd ³		liter (L)	764.6
Imp. gallon (U.K.)		liter (L)	4.546
U.S. gallon (gal)		liter (L)	3.785
MASS			
grain (gr)		gram (g)	0.0648
ounce		gram (g)	28.35
pound (lb)		gram (g)	453.6
PRESSURE			
atmosphere (atm)		kilo Pascal	101.3
bar		kPa	100.0
lb/ft ²		kPa	0.04788
lb/in ² = psi		bar	0.069
lb/in ² = psi		kPa	6.895
PRESSURE DROP			
psi/ft		kPa/m	22.62
VISCOSITY			
poise		Pascal-second (Pa s)	0.1
FLOW RATE			
gal/min = gpm		m ³ /hr	0.227
gal/min = gpm		L/sec	0.063
gal/day = gpd		m ³ /day	0.003785
gal/day = gpd		L/hr	0.158
million gal/day = mgd		m ³ /hr	157.73
million gal/day = mgd		m ³ /day	3785
Imp. gpm		m ³ /hr	0.273
FLOW VELOCITY			
gpm/ft ²		m/h	2.445
gpd/ft ²		L/m ² hr	1.70
SERVICE FLOW RATE			
gpm/ft ³		(m ³ /h)/m ³	8.02
RINSE VOLUME			
gal/ft ³		l/l	0.134
CHEMICAL DOSAGE			
lb/ft ³		g/L	16.0

3. Concentration of Ionic Species

Table 4 gives multiplication factors for the conversion of concentration units of ionic species given as gram of the ion per liter (g/L) into equivalent per liter (eq/L) or of gram of CaCO₃ equivalents per liter (g CaCO₃/L).

Concentrations of ionic species in water have been expressed in different units in different countries. Concentrations should normally be expressed in one of the following ways:

- As grams (g), milligrams (mg = 10⁻³ g) or micrograms (μg = 10⁻⁶ g) of the (ionic) species per liter (L) or cubic meter (m³) of water.
- As equivalents (eq) or milliequivalents (meq = 10⁻³ eq) of the ionic species per liter (L) or cubic meter (m³) of water.

Still widely used concentration units are:

- Kilograins of CaCO₃ per cubic foot (kgr/ft³)
- 1 French degree = 1 part CaCO₃ per 100,000 parts of water
- 1 German degree = 1 part CaO per 100,000 parts of water
- Grains CaCO₃/gallon (U. S.)
- ppm CaCO₃
- 1 English degree (Clark) = 1 grain CaCO₃ per (British) Imperial gallon of water

Table 4. Multiplication factors for the conversion of concentration units of ionic species

Compound	Formula	Ionic weight	Equivalent weight	Conversion to	
				g CaCO ₃ /L	eq/L
POSITIVE IONS					
Aluminum	Al ⁺⁺⁺	27.0	9.0	5.56	0.111
Ammonium	NH ₄ ⁺	18.0	18.0	2.78	0.0556
Barium	Ba ⁺⁺	137.4	68.7	0.73	0.0146
Calcium	Ca ⁺⁺	40.1	20.0	2.50	0.0500
Copper	Cu ⁺⁺	63.6	31.8	1.57	0.0314
Hydrogen	H ⁺	1.0	1.0	50.0	1.0000
Ferrous iron	Fe ⁺⁺	55.8	27.9	1.79	0.0358
Ferric iron	Fe ⁺⁺⁺	55.8	18.6	2.69	0.0538
Magnesium	Mg ⁺⁺	24.3	12.2	4.10	0.0820
Manganese	Mn ⁺⁺	54.9	27.5	1.82	0.0364
Potassium	K ⁺	39.1	39.1	1.28	0.0256
Sodium	Na ⁺	23.0	23.0	2.18	0.0435
NEGATIVE IONS					
Bicarbonate	HCO ₃ ⁻	61.0	61.0	0.82	0.0164
Carbonate	CO ₃ ⁻	60.0	30.0	1.67	0.0333
Chloride	Cl ⁻	35.5	35.5	1.41	0.0282
Fluoride	F ⁻	19.0	19.0	2.63	0.0526
Iodide	I ⁻	129	129	0.39	0.0079
Hydroxide	OH ⁻	17.0	17.0	2.94	0.0588
Nitrate	NO ₃ ⁻	62.0	62.0	0.81	0.0161
Phosphate (tribasic)	PO ₄ ⁻	95.0	31.7	1.58	0.0315
Phosphate (dibasic)	HPO ₄ ⁻	90	48.0	1.04	0.0208
Phosphate (monobasic)	H ₂ PO ₄ ⁻	97.0	97.0	0.52	0.0103
Sulfate	SO ₄ ⁻	91	48.0	1.04	0.0208
Bisulfate	HSO ₄ ⁻	97.1	97.1	0.52	0.0103
Sulfite	SO ₃ ⁻	80.1	40.0	1.25	0.0250
Bisulfite	HSO ₃ ⁻	81.1	81.1	0.62	0.0123
Sulfide	S ⁻	32.1	10	3.13	0.0625
NEUTRAL					
Carbon dioxide	CO ₂	44.0	44.0	1.14	0.0227
Silica	SiO ₂	60.0	60.0	0.83	0.0167
Ammonia	NH ₃	17.0	17.0	2.94	0.0588

Note: Calculations based on conversion to monovalent neutral species.

Table 5 gives the conversion factors for commonly encountered units to milliequivalents/liter (meq/L) and mg CaCO₃/L. Multiply by the conversion factor to obtain mg CaCO₃/L or meq/L. Divide by the conversion factor to obtain the different units from numbers expressed as mg CaCO₃/L or meq/L.

Table 5. Conversion factors

	mg CaCO ₃ /L	meq/L
kg/ft ³	2,288	45.8
1 grain/U.S. gallon	17.1	0.342
ppm CaCO ₃	1.0	0.020
1 English degree	14.3	0.285
1 French degree	10.0	0.200
1 German degree	17.9	0.357

Table 6. Calcium carbonate (CaCO₃) equivalent of common substances

Compounds	Formula	Molecular weight	Equivalent weight	Substance to CaCO ₃ equivalent to substance multiply by	
				CaCO ₃ equivalent	CaCO ₃ equivalent
Aluminum sulfate (anhydrous)	Al ₂ (SO ₄) ₃	342.1	57.0	0.88	1.14
Aluminum hydroxide	Al(OH) ₃	78.0	26.0	1.92	0.52
Aluminum oxide (alumina)	Al ₂ O ₃	101.9	17.0	2.94	0.34
Sodium aluminate	Na ₂ Al ₂ O ₄	163.9	27.3	1.83	0.55
Barium sulfate	BaSO ₄	233.4	116.7	0.43	2.33
Calcium bicarbonate	Ca(HCO ₃) ₂	162.1	81.1	0.62	1.62
Calcium carbonate	CaCO ₃	100.1	50.0	1.00	1.00
Calcium chloride	CaCl ₂	111.0	55.5	0.90	1.11
Calcium hydroxide	Ca(OH) ₂	74.1	37.1	1.35	0.74
Calcium oxide	CaO	56.1	28.0	1.79	0.56
Calcium sulfate (anhydrous)	CaSO ₄	136.1	68.1	0.74	1.36
Calcium sulfate (gypsum)	CaSO ₄ · 2H ₂ O	172.2	86.1	0.58	1.72
Calcium phosphate	Ca ₃ (PO ₄) ₂	310.3	51.7	0.97	1.03
Ferrous sulfate (anhydrous)	FeSO ₄	151.9	76.0	0.66	1.52
Ferric sulfate	Fe ₂ (SO ₄) ₃	399.9	66.7	0.75	1.33
Magnesium oxide	MgO	40.3	20.2	2.48	0.40
Magnesium bicarbonate	Mg(HCO ₃) ₂	146.3	73.2	0.68	1.46
Magnesium carbonate	MgCO ₃	84.3	42.2	1.19	0.84
Magnesium chloride	MgCl ₂	95.2	47.6	1.05	0.95
Magnesium hydroxide	Mg(OH) ₂	58.3	29.2	1.71	0.58
Magnesium phosphate	Mg ₃ (PO ₄) ₂	262.9	43.8	1.14	0.88
Magnesium sulfate (anhydrous)	MgSO ₄	120.4	60.2	0.83	1.20
Magnesium sulfate (Epsom salts)	MgSO ₄ · 7H ₂ O	246.5	123.3	0.41	2.47
Manganese chloride	MnCl ₂	125.8	62.9	0.80	1.26
Manganese hydroxide	Mn(OH) ₂	89.0	44.4	1.13	0.89
Potassium iodine	KI	166.0	166.0	0.30	3.32
Silver chloride	AgCl	143.3	143.3	0.35	2.87
Silver nitrate	AgNO ₃	169.9	169.9	0.29	3.40
Silica	SiO ₂	60.1	30.0	1.67	0.60
Sodium bicarbonate	NaHCO ₃	84.0	84.0	0.60	1.68
Sodium carbonate	Na ₂ CO ₃	106.0	53.0	0.94	1.06
Sodium chloride	NaCl	58.5	58.5	0.85	1.17
Sodium hydroxide	NaOH	40.0	40.0	1.25	0.80
Sodium nitrate	NaNO ₃	85.0	85.0	0.59	1.70
Tri-sodium phosphate	Na ₃ PO ₄ · 12H ₂ O	380.2	126.7	0.40	2.53
Tri-sodium phosphate (anhydrous)	Na ₃ PO ₄	164.0	54.7	0.91	1.09
Disodium phosphate	Na ₂ HPO ₄ · 12H ₂ O	358.2	119.4	0.42	2.39
Disodium phosphate (anhydrous)	Na ₂ HPO ₄	142.0	47.3	1.06	0.95
Monosodium phosphate	NaH ₂ PO ₄ · H ₂ O	138.1	46.0	1.09	0.92
Monosodium phosphate (anhydrous)	NaH ₂ PO ₄	120.0	40.0	1.25	0.80
Sodium metaphosphate	NaPO ₃	102.0	34.0	1.47	0.68
Sodium sulfate	Na ₂ SO ₄	142.1	71.0	0.70	1.42
Sodium sulfite	Na ₂ SO ₃	126.1	63.0	0.79	1.26

4. Conversion of Temperature Units

Conversions of temperature units between °C and °F can be made graphically using the grid in Figure 1 or by mathematical conversion using the following equations:

$$^{\circ}\text{C to } ^{\circ}\text{F: } (9/5 \times ^{\circ}\text{C}) + 32 = ^{\circ}\text{F}$$

$$^{\circ}\text{F to } ^{\circ}\text{C: } 5/9 (^{\circ}\text{F} - 32) = ^{\circ}\text{C}$$

The S.I. unit is °C.

5. Conversion of Conductivity to Resistance

The salt content of a water or the impurities left after ion exchange are commonly expressed in terms of conductivity, expressed as Siemens per centimeter (S/cm) for a standard measuring cell with a cell constant of 1 cm (see Figure 2).

As the conductivity is the reciprocal of the resistance, such characteristics can alternatively be expressed in Ohm multiplied by centimeter (Ωcm) whereby:

$$\text{Scm}^{-1} = \frac{\text{S}}{\text{cm}} = \frac{1}{\Omega\text{cm}} = \Omega^{-1}\text{cm}^{-1}$$

Consequently, the following units of conductivity and resistance are different expressions relating to the same situation:

$$10^{-6} \text{ S/cm} = 1 \mu\text{S/cm} \sim 1 \text{ M}\Omega\text{cm} = 10^6 \Omega\text{cm}$$

$$10^{-3} \text{ S/cm} = 1 \text{ mS/cm} \sim 1 \text{ k}\Omega\text{cm} = 10^3 \Omega\text{cm}$$

Figure 1. Conversion of temperature units

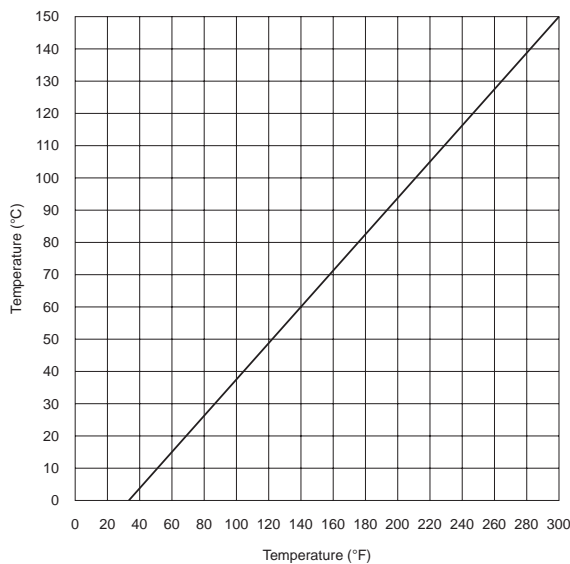
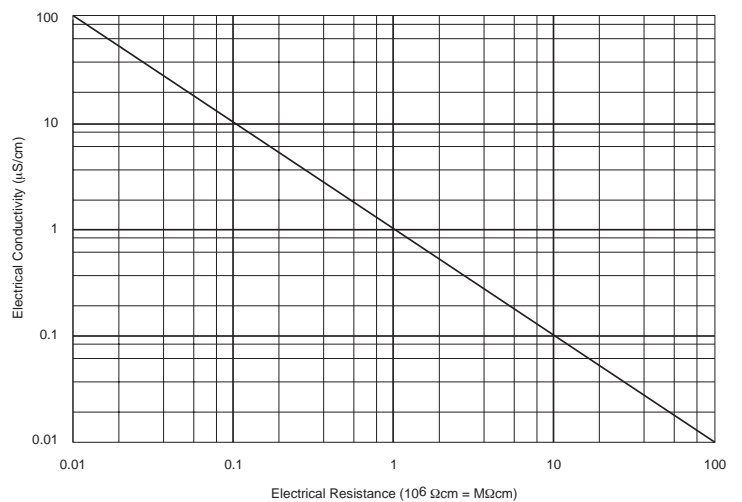


Figure 2. Conversion of conductivity to resistance



6. Conductivity of Water as Function of the Temperature

The conductivity of water, free of any impurities, will vary with temperature as presented in Figure 3 in accordance with its changing degree of auto-dissociation into H^+ and OH^- and the different mobilities of these ions at different temperatures.

7. Conductivity of Ionic Solutions

Figures 4 through 7 show the relationship of the conductivity of a solution containing one given chemical, to the concentration of this chemical.

The conductivity of solutions at other temperatures can be calculated by multiplying conductivities at $25^\circ C$ ($77^\circ F$) with the correction factors in Table 7. These factors are only valid for diluted solutions as they suppose total ionic dissociation of the chemical.

Figure 3. Conductivity of water as function of the temperature

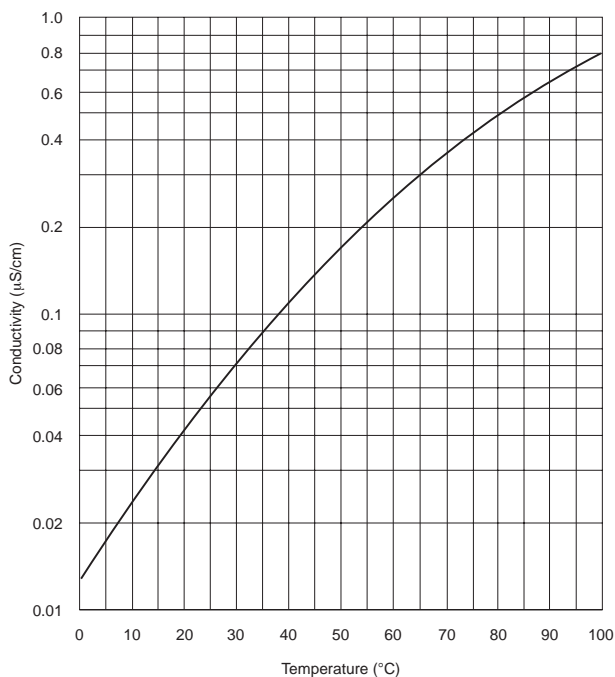


Figure 4. Conductivity vs. concentration for ionic solutions at $25^\circ C$ ($77^\circ F$)

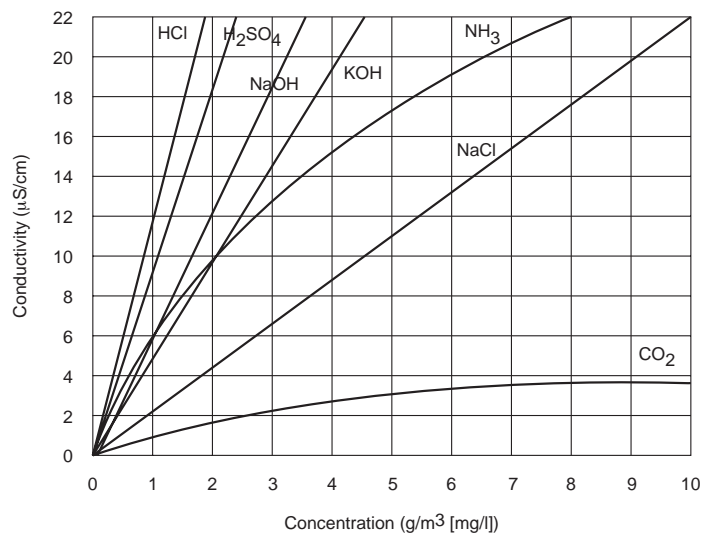


Table 7. Conductivity of solutions at other temperatures

	0°C (32°F)	18°C (64°F)	25°C (77°F)	50°C (122°F)
HCl	0.66	0.89	1.00	1.37
H ₂ SO ₄	0.66	0.87	1.00	1.38
NaCl	0.53	0.86	1.00	1.57
NaOH	0.54	0.89	1.00	1.51
KOH	0.55	0.89	1.00	1.50

Figure 5. Conductivity vs. concentration for ionic solutions at 25°C (77°F)

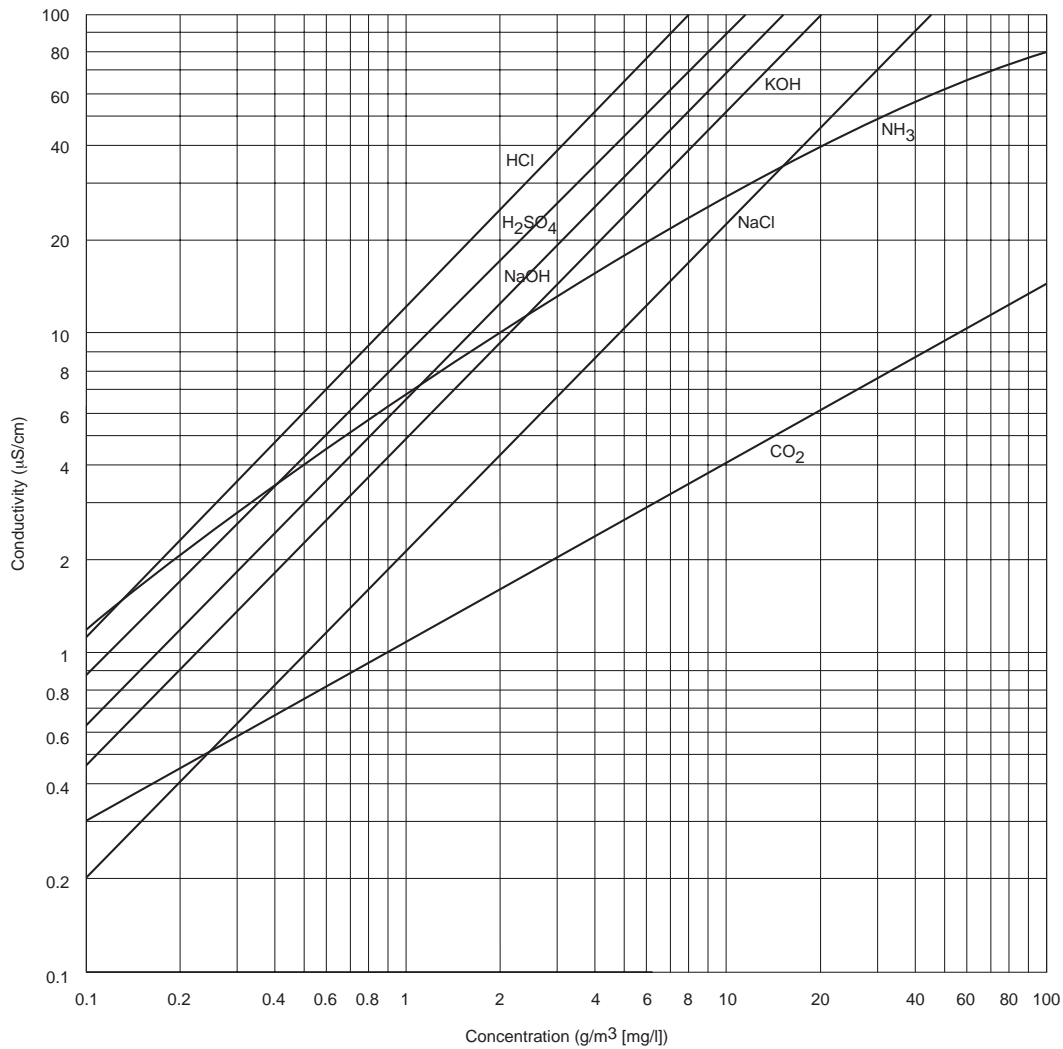


Figure 6. Conductance vs. total dissolved solids

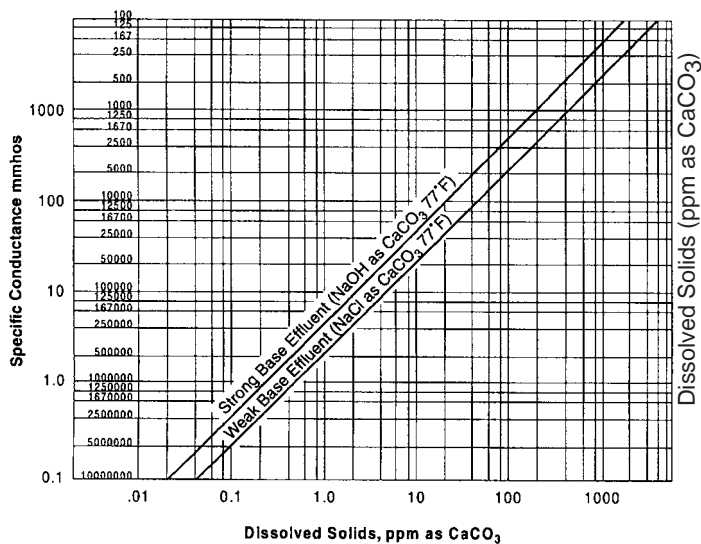


Figure 7. Relationship between dissolved solids and conductance in demineralization operations

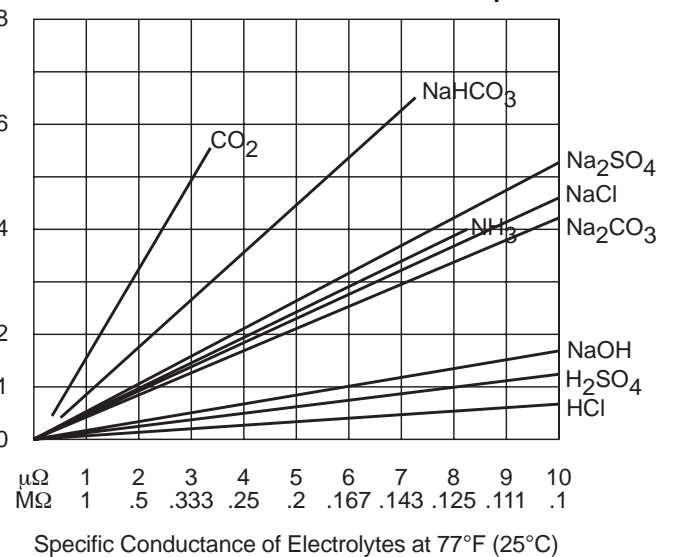


Table 8. Conductivity of solutions, acids, alkalis and salts at 25°C (77°F), expressed as $\mu\text{S}/\text{cm}$ per meq/L

Component	Concentration in meq/L							
	infinitely diluted	0.1	0.5	1.0	5.0	10.0	50.0	100.0
HCl	426	425	423	421	415	412	399	392
HNO ₃	421	420	417	416	410	407	394	386
H ₂ SO ₄	430	424	412	407	390	380	346	317
H ₃ PO ₄	419	394	359	336	264	223	133	104
NaOH	248	247	246	245	241	238	227	221
KOH	271	270	269	268	264	261	251	246
NH ₄ OH	271	109	49	36	17	12	5.6	3.9
NaCl	126	126	124	124	121	118	111	107
Na ₂ SO ₄	130	128	126	124	117	113	97.7	90.0
Na ₂ CO ₃	124	122	120	119	112	108	93.2	86.3
NaHCO ₃	96.0	95.2	94.2	93.5	90.5	88.4	80.6	76.0
KCl	150	149	148	141	144	141	133	129

Table 9. Conductivity of ions expressed as $\mu\text{S}/\text{cm}$ per meq/L, infinitely diluted

Ion	20°C (68°F)	25°C (77°F)	100°C (212°F)
H ⁺	328	350	646
Na ⁺	45	50.1	155
K ⁺	67	73.5	200
NH ₄ ⁺	67	73.5	200
Mg ⁺⁺	47	53.1	170
Ca ⁺⁺	53.7	59.5	191
OH ⁻	179	197	446
Cl ⁻	69.0	76.3	207
HCO ₃ ⁻	36.5	44.5	—
NO ₃ ⁻	65.2	71.4	178
H ₂ PO ₄ ⁻	30.1	36.0	—
CO ₃ ⁻	63.0	72.0	—
HPO ₄ ⁻	—	53.4	—
SO ₄ ⁻	71.8	79.8	234
PO ₄ ⁼⁼	—	69.0	—

Table 10. Specific conductance of sodium chloride

µmhos/cm	ppm	µmhos/cm	ppm	µmhos/cm	ppm	µmhos/cm	ppm	µmhos/cm	ppm	µmhos/cm	ppm	µmhos/cm	ppm
10	5	630	312	1,480	743	3,500	1,808	9,000	4,879	21,250	12,245	56,000	34,493
20	9	640	317	1,500	754	3,550	1,835	9,100	4,935	21,500	12,399	57,000	35,171
30	14	650	323	1,525	766	3,600	1,863	9,200	4,991	21,750	12,552	58,000	35,849
40	19	660	328	1,550	770	3,650	1,899	9,216	5,000	22,000	12,705	59,000	36,527
60	28	670	333	1,575	792	3,700	1,917	9,300	5,047	22,250	12,860	60,000	37,205
70	33	680	338	1,600	805	3,750	1,945	9,400	5,103	22,500	13,013	61,000	37,883
80	38	690	343	1,625	817	3,800	1,972	9,500	5,159	22,750	13,167	62,000	38,561
90	42	700	348	1,650	830	3,850	1,999	9,600	5,215	23,000	13,321	63,000	39,239
100	47	710	353	1,675	843	3,900	2,027	9,700	5,271	23,250	13,474	64,000	39,917
110	52	720	358	1,700	856	3,950	2,054	9,800	5,327	23,500	13,628	65,000	40,595
120	57	730	363	1,725	868	4,000	2,081	9,900	5,383	23,750	13,782	66,000	41,273
130	61	740	368	1,750	881	4,100	2,136	10,000	5,439	24,000	13,936	67,000	41,961
140	66	750	373	1,775	894	4,200	2,191	10,200	5,551	24,250	14,089	68,000	42,629
150	71	760	378	1,800	907	4,300	2,245	10,400	5,664	24,500	14,243	69,000	43,307
160	75	770	383	1,825	920	4,400	2,300	10,600	5,776	24,750	14,397	70,000	43,985
170	80	780	388	1,850	932	4,500	2,356	10,800	5,888	25,000	14,550	71,000	44,663
180	85	790	393	1,875	945	4,600	2,412	11,000	6,000	25,500	14,858	72,000	45,341
190	90	800	399	1,900	958	4,700	2,468	11,200	6,122	26,000	15,165	73,000	46,019
200	95	810	404	1,925	971	4,800	2,524	11,400	6,243	26,500	15,473	74,000	46,697
210	100	820	409	1,950	983	4,900	2,580	11,600	6,364	27,000	15,780	76,000	48,053
220	105	830	414	1,975	996	5,000	2,636	11,800	6,485	27,500	16,087	77,000	48,731
230	110	840	419	2,000	1,000	5,100	2,692	12,000	6,607	28,000	16,395	78,000	49,409
240	115	850	424	2,025	1,022	5,200	2,748	12,200	6,728	28,500	16,702	79,000	50,087
250	120	860	429	2,050	1,034	5,300	2,805	12,400	6,843	29,000	17,010	80,000	50,765
260	125	870	434	2,075	1,047	5,400	2,861	12,600	6,970	29,500	17,317	81,000	51,443
270	130	880	439	2,125	1,073	5,500	2,917	12,800	7,091	30,000	17,624	82,000	52,121
280	135	890	444	2,150	1,085	5,600	2,973	13,000	7,213	30,500	17,932	83,000	52,799
290	140	900	449	2,175	1,098	5,700	3,029	13,200	7,334	31,000	18,239	84,000	53,477
300	145	910	454	2,200	1,111	5,800	3,085	13,400	7,455	31,500	18,547	85,000	54,155
310	150	920	459	2,225	1,124	5,900	3,141	13,600	7,576	32,000	18,854	86,000	54,833
320	155	930	464	2,250	1,137	6,000	3,197	13,800	7,698	32,500	19,161	87,000	55,511
330	160	940	469	2,275	1,140	6,100	3,253	14,000	7,819	33,000	19,469	88,000	56,130
340	165	950	474	2,300	1,162	6,200	3,309	14,200	7,940	34,000	20,084	89,000	56,867
350	171	960	480	2,325	1,175	6,300	3,365	14,400	8,061	34,500	20,391	90,000	57,545
360	176	970	485	2,350	1,188	6,400	3,421	14,600	8,182	35,000	20,698	91,000	58,223
370	181	980	490	2,375	1,200	6,500	3,477	14,800	8,304	35,500	21,006	92,000	58,901
380	186	990	495	2,400	1,213	6,600	3,533	15,000	8,425	36,000	21,313	93,000	59,579
390	191	1,000	500	2,425	1,226	6,700	3,589	15,250	8,576	36,500	21,621	94,000	60,257
400	196	1,020	510	2,450	1,239	6,800	3,645	15,500	8,728	37,000	21,928	95,000	60,935
410	201	1,040	520	2,475	1,251	6,900	3,701	15,750	8,879	37,500	22,235	96,000	61,613
420	206	1,080	540	2,500	1,264	7,000	3,758	16,000	9,031	38,000	22,543	97,000	62,291
430	211	1,100	550	2,550	1,290	7,100	3,814	16,250	9,182	38,500	22,850	98,000	62,969
440	216	1,120	561	2,600	1,315	7,200	3,870	16,500	9,334	39,000	23,158	99,000	63,647
450	221	1,140	571	2,650	1,344	7,300	3,926	16,750	9,486	39,500	23,465	100,000	64,325
460	226	1,160	581	2,700	1,371	7,400	3,982	17,000	9,637	40,000	23,773		
470	231	1,180	591	2,750	1,398	7,500	4,038	17,500	9,940	41,000	24,387		
480	236	1,200	601	2,800	1,426	7,600	4,094	17,750	10,092	42,000	25,002		
490	241	1,220	611	2,850	1,453	7,700	4,150	18,000	10,247	43,000	25,679		
500	247	1,240	621	2,900	1,480	7,800	4,206	18,250	10,400	44,000	26,357		
510	252	1,260	632	2,950	1,508	7,900	4,262	18,500	10,554	45,000	27,035		
520	257	1,280	642	3,000	1,535	8,000	4,318	18,750	10,708	46,000	27,713		
530	262	1,300	652	3,050	1,562	8,100	4,374	19,000	10,852	47,000	28,391		
550	272	1,320	662	3,100	1,589	8,200	4,430	19,250	11,015	48,000	29,069		
560	277	1,340	672	3,150	1,617	8,300	4,486	19,500	11,169	49,000	29,747		
570	282	1,360	682	3,200	1,644	8,400	4,542	19,750	11,323	50,000	30,425		
580	287	1,380	692	3,250	1,671	8,500	4,598	20,000	11,476	51,000	31,103		
590	292	1,400	702	3,300	1,699	8,600	4,654	20,250	11,630	52,000	31,781		
600	297	1,420	713	3,350	1,726	8,700	4,710	20,500	11,784	53,000	32,459		
610	302	1,440	723	3,400	1,753	8,800	4,767	20,750	11,937	54,000	33,137		
620	307	1,460	733	3,450	1,781	8,900	4,823	21,000	12,091	55,000	33,815		

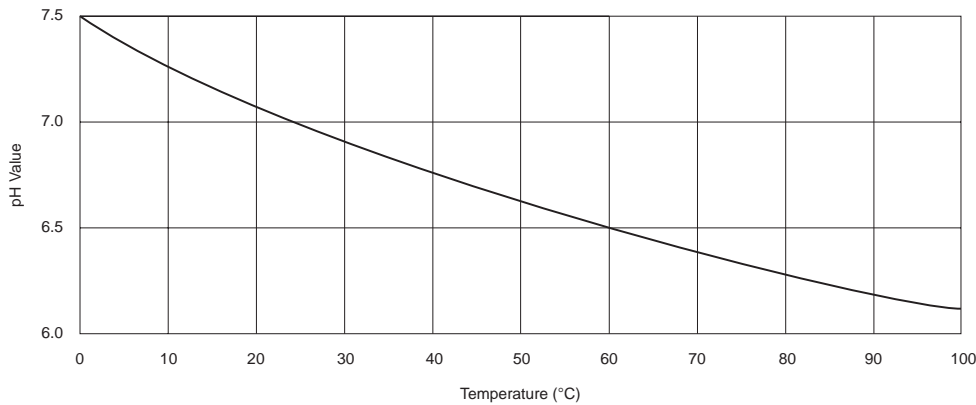
8. The pH of Pure Water as a Function of Temperature

The pH of pure water is 7.0 at 25°C (77°F). Deviations at other temperatures are due to the changing degree of auto-dissociation of water (see Figure 8).

The pH measurements in water of high purity become very difficult. The pH values registered with normal pH meters in water with conductivities below 0.2 $\mu\text{S}/\text{cm}$ should therefore be considered unreliable.

The pH meters will often have an internal temperature compensation; values measured at other temperatures will thereby be corrected to the value at 25°C (77°F).

Figure 8. The pH of pure water as a function of temperature



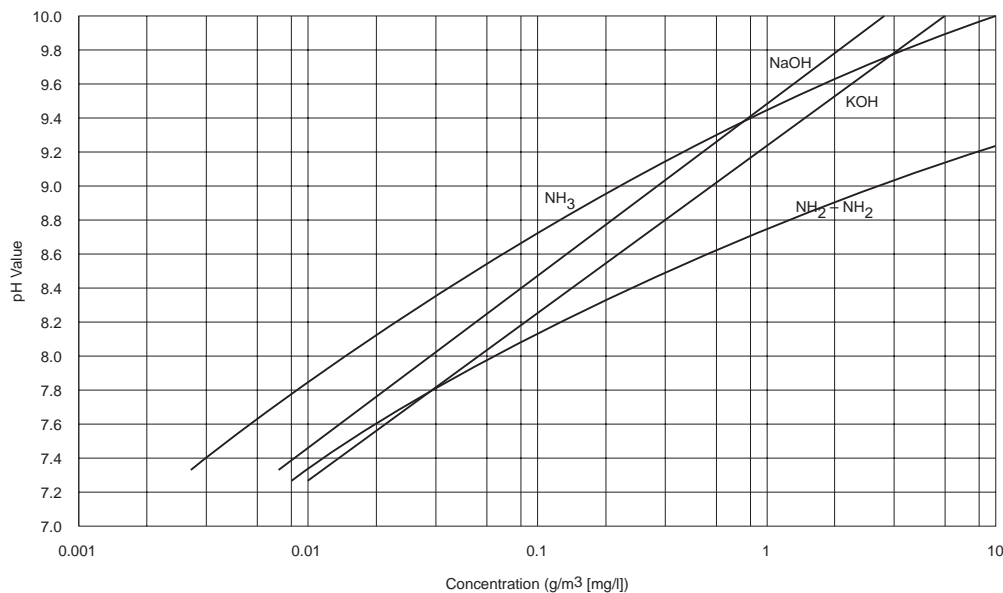
9. The pH of Basic Solutions at 25°C (77°F)

The pH-values are a valuable tool to measure the concentration of ammonia (NH_3) or hydrazine (N_2H_4) in condensate circuits, freed of other impurities (see Figure 9).

NaOH and KOH concentrations can be monitored by pH measurements or conductivity measurements during the rinsing cycle of anion exchange resins, or to establish the Na leakage from the cation exchanger in a running unit.

Increments of conductivity over the value accounted for by pH can indicate the presence of neutral salts.

Figure 9. The pH of Basic Solutions at 25°C (77°F)

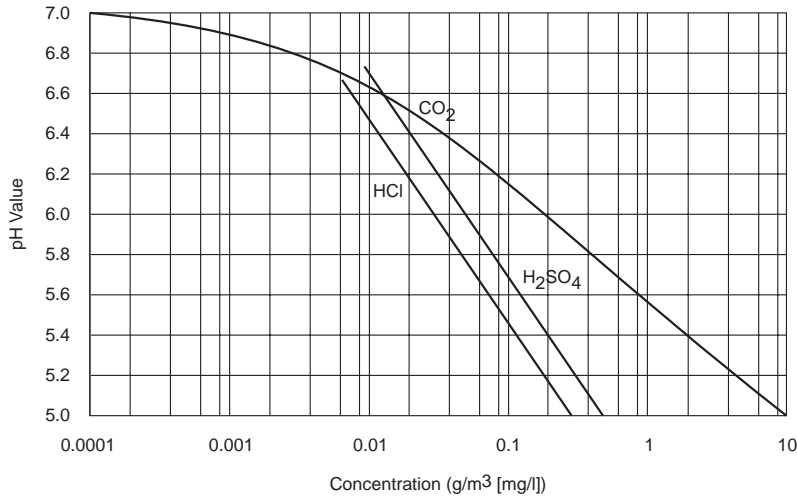


10. The pH of Acid Solutions at 25°C (77°F)

Analogous to the case of basic solutions, pH measurements can establish the concentration of acids during the rinsing cycle of cation exchange resins (see Figure 10).

CO₂ will be present in the effluent from a demineralizer consisting of a strongly acidic cation exchanger and a weakly basic anion exchanger. The pH measurements can establish the concentration of CO₂. Accounting for this contribution to conductivity, it is then possible to establish the leakage level of NaCl.

Figure 10. The pH of acid solutions at 25°C (77°F)



11. P- and M-Alkalinity

Alkalinity titrations are carried out using an acid solution of 0.1 N and a 100 mL water sample, or using a 1 N solution and a 1 L water sample. The volume of acid, expressed in mL of acid added to cause color change of the indicator is reported as alkalinity; therefore:

$$1 \text{ mL acid} = 1 \text{ meq/L alkalinity}$$

If phenolphthalein is used as indicator, P-alkalinity is measured. If methylorange is used, M-alkalinity is measured.

Although alkalinity numbers as such are interesting, it is also necessary to know the concentrations of the species making up this alkalinity; the main contributors are hydroxyl (OH⁻), bicarbonate (HCO₃⁻) and carbonate (CO₃⁻²) ions. Their concentrations can be calculated from P- and M-alkalinity assuming:

1. P-alkalinity determines all hydroxyl and half of the carbonate alkalinity.
2. M-alkalinity determines the total of carbonate, bicarbonate and hydroxyl alkalinity.

Table 11 can then be used to calculate the concentrations of the different species for different cases of P- and M-alkalinity. Results are obtained in meq/L.

Example: If P-alkalinity is 0.5 mL and M-alkalinity is 3 mL, then P < 1/2 M applies

$$\begin{aligned} \text{carbonate} &= 1.0 \text{ meq/L} \\ \text{bicarbonate} &= 2.0 \text{ meq/L} \end{aligned}$$

Table 11. Calculating concentrations for P- and M-alkalinity

P- and M-Alkalinity	Hydroxyl (OH)	Carbonate (CO ₃)	Bicarbonate (HCO ₃)
P = 0	0	0	M
P < 1/2 M	0	2P	M - 2p
P = 1/2 M	0	M	0
P > 1/2 M	2P - M	2(M - P)	0
P = M	M	0	0

12. Information on Regenerant Chemicals

12.1 Properties, Impurities and Concentrations

General

Sufficient precautions should be taken when handling, transporting or disposing of acidic or basic regenerants. Even after dilution to their operational concentrations or in the waste after regeneration, sufficient acid or base can be present to cause severe damage to mankind. Adequate protection for all parts of the body should therefore be provided whenever using these chemicals and the manufacturer's guidelines for handling these products should be carefully followed.

The specifications and the purity of the regenerant chemicals have to assure a trouble-free operation of the ion exchange resin after regeneration. Therefore, the chemicals have to be free of suspended materials, or other materials that may be precipitated and/or absorbed by the resin. They should also be free of ionic species other than the active regeneration agents, as this will decrease the regeneration efficiency and/or increase the leakage of this species during the operational cycle. For example, sodium hydroxide containing 2 percent NaCl will reduce the efficiency by 5 to 10 percent and cause a higher Cl-leakage from the strongly basic anion exchange resin.

In counter-current operations where low leakage levels are especially aimed for, regenerants should contain minimal levels of impurities.

Different processes and technologies and different requirements as to the quality of the treated effluent will therefore impose different restrictions on the impurity levels in the regeneration chemicals and the dilution water. In the same way, regenerant concentrations and flow rates can affect the efficiency of the operation.

Recommendations and the quality of regeneration chemicals are given in the following sections. The recommended qualities should prove sufficient for all ion exchange resin applications, and under certain conditions lesser qualities can be used, including eventual waste chemicals from process streams. Figures for impurity levels are the basis of a 100 percent regeneration chemical.

Hydrochloric acid: HCl (muriatic acid)

Both as a gas and in solution, HCl is very corrosive and can cause severe burns on contact. Mucous membranes of the eyes and of the upper respiratory tract are especially susceptible to high atmospheric concentrations. Avoid inhalation of the fumes and provide adequate ventilation when handling the acid. The acid is commercially offered as a colorless to light yellow/green liquid in concentrations of about 28 to 36 weight to weight percent HCl (see Table 12).

Hydrochloric acid from hydrolysis of chlorinated organic materials is not suitable for use as regenerant. Acid from the salt-acid process or by the hydrogen-chlorine process is satisfactory.

Hydrochloric acid solutions are most diluted to 4 to 5 percent for the regeneration of strongly acidic ion exchangers, and from 1 to 5 percent for weakly acidic resins in water demineralization applications. Higher concentrations using 8 to 10 percent HCl are sometimes preferred in other applications.

Table 12. Recommended maximum impurity levels for HCl

	Recommended maximum impurity levels
Fe	0.01%
Other metals, total	10 mg/L
Organic matter	0.01%
Sulfuric acid, as SO ₃	0.4%
Oxidants (HNO ₃ , Cl ₂)	5 mg/L
Suspended matter as turbidity	~ 0
Inhibitors	None

Sulfuric acid: H₂SO₄

Sulfuric acid is dangerous when improperly handled. Concentrated solutions are rapidly destructive to tissues they contact, producing severe burns. Contact with eyes will cause severe damage and blindness. Inhaling vapors from hot acid or oleum may be harmful. Swallowing may cause severe injury or death. One should be well aware of the strong exothermicity of the dilution of H₂SO₄ with water, which can raise the temperature very high and very fast. The acid is supplied as a colorless to yellow/brown liquid in concentrations of about 93 weight percent.

Sulfuric acid solutions are mostly diluted to 1 to 6 percent for the regeneration of strongly acidic ion exchangers and to 0.5 to 1 percent for weakly acidic ion exchangers in water demineralization applications. Stepwise increase of the acid concentration may be preferred under circumstances of high-hardness waters (see Table 13).

Table 13. Recommended maximum impurity levels for H₂SO₄

	Recommended maximum impurity levels
Fe	50 mg/L
Nitrogen compounds	20 mg/L
As	0.2 mg/L
Organic matter	0.01%
Suspended matter as turbidity	~ 0
Inhibitors	None
Other heavy metals	20 mg/L

Sodium hydroxide: NaOH (caustic soda)

Sodium hydroxide or caustic soda can cause severe burns on contact with skin, eyes or when taken internally. Great care must be taken when handling the anhydrous material or when preparing or handling caustic soda solutions.

Caustic soda is offered as solid flakes or pellets of about 98% NaOH or as a 30 to 50% liquid. It is mostly diluted to between 2 and 5% for the regeneration of weakly or strongly basic resins.

Typical analyses for different caustic qualities are given in the following table:

Table 14. Typical analyses for different caustic qualities

Compound	Mercury1 grade	Rayon1 grade	Regular diaphragm grade	Regular technical flake
NaOH	51%	50.1%	50.4%	98%
Na ₂ CO ₃	0.02%	0.2%	0.2%	0.5 - 1%
NaClO ₃	1 mg/L	2 mg/L	0.5%	2 mg/L
NaCl	0.002%	0.2 - 0.5%	1 - 2%	0.4 - 1.5%
NaSO ₄	10 mg/L	0.1%	0.03%	0.3%
Fe	1 mg/L	10 mg/L	15 mg/L	10 mg/L
Heavy metals (total)	2 mg/L	4 mg/L	N.S.	2 mg/L
SiO ₂	10 mg/L	40 mg/L	N.S.	500 mg/L

Regeneration of strongly basic anion exchangers is influenced by the quality of caustic available. Chloride, chlorate and ferrate ions are potential contaminants in caustic that may affect resin regeneration efficiency and stability. Sodium chlorate itself has very little oxidative properties in neutral or alkaline solutions, but in acid conditions (i.e. during resin exhaustion), chloric acid is generated which is a powerful oxidizing agent.

Chlorates have a strong affinity for the resin and will tend to be exchanged on the resin. It is suspected that the chlorate will be eluted from the column with other anions during exhaustion and when low pH solution contacts the bed, oxidation will result.

The recommended caustic quality for ion exchangers is as follows:

Table 15. Recommended maximum impurity levels for NaOH

	Recommended maximum impurity levels
NaOH	49 - 51%
NaCl	1.0%
NaClO ₃	1,000 mg/L
Na ₂ CO ₃	0.2%
Fe	5 mg/L
Heavy metals (total)	5 mg/L
SiO ₃	50 mg/L
Na ₂ SO ₄	250 mg/L

Mercury cell or purified diaphragm cell (rayon) quality sodium hydroxide will normally meet such specifications. Regular diaphragm cell quality caustic soda can contain over 2% NaCl and over 0.1% (1,000 mg/L) NaClO₃.

For high water quality applications with counter-current regeneration systems (such as UPCORE™ packed bed systems), mixed beds, condensate polishers and where low chlorides are required, mercury or rayon grades should be used.

Weakly basic resins will suffer mostly from high NaClO₃ levels as conversion to HClO₃ can create a strong oxidizing agent. Therefore, weak base anion exchangers should not be regenerated with regular grade diaphragm cell caustic soda. As long as chlorate and ferrate levels are low, regeneration of weakly basic resins will not suffer from high NaCl, Na₂SO₄ or Na₂CO₃ levels.

Regeneration of strongly basic resins can eventually be carried out with NaOH containing higher NaCl concentrations at the expense however, of efficiency (1% NaCl will cause about 10% reduction in efficiency). This reduction will not be noticed if a demineralizer train that is simultaneously regenerated is cation resin limited (i.e., breaks on sodium) or throughput is based on time and not leakage. Even if the anion resin breaks first, this reduction may go unnoticed since there can be other factors in a production environment that limit throughput. NaClO₃ levels of 1,000 mg/l can be allowed for strongly basic resins in single beds.

Studies¹ comparing the performance of DOWEX™ strong base anion resins regenerated with mercury cell caustic and regular diaphragm grade caustic in a co-flow system showed no differences in the rinse requirements or water quality produced by either caustic type. There was however a 3-6% reduction in the operating capacity of strong base resins regenerated with regular grade caustic. Subsequent field trials showed no measurable difference in resin performance and supported the fact that regular-grade caustic can be used in most co-current demineralizer systems. Many co-flow units operate today with regular grade caustic.

Ammonia: NH₃

Ammonia gas or fumes from concentrated solutions can cause serious irritation to eyes and the respiratory tract. Avoid inhalation and provide adequate ventilation when handling ammonia solutions.

Ammonia is mostly offered as a solution in water, containing 20 to 30 weight percent NH₃. Impurities are normally minimal and cause no potential problem in ion exchange regeneration.

Ammonia is mostly used in concentrations between 3 and 5 percent for regeneration of weakly to medium basic anion exchange resins.

Sodium carbonate: NaCO₃ (soda ash)

Sodium carbonate does not require special handling precautions. It is supplied as a white, anhydrous powder with over 98 percent purity. Impurity levels are thus minimal and cause no potential problem in ion exchange regeneration. Moreover, higher levels of NaCl or Na₂SO₄ will not adversely affect the regeneration efficiency, although they will of course not contribute as regeneration chemicals.

Sodium carbonate is mostly diluted to between 5 and 8 percent for the regeneration of weakly to medium basic ion exchange resins.

Sodium chloride: NaCl (salt)

Sodium chloride does not require special handling precautions. It is offered as a white powdered, granulated or pelleted solid of 98 to 99 percent (see Table 16).

Sodium chloride is used for regeneration in different processes. Concentrations will differ depending upon the process, as is illustrated in Table 17.

Table 16. Recommended maximum impurity levels for NaCl

	Recommended maximum impurity levels
SO ₄ ⁻	1%
Mg ⁺⁺⁺ Ca ⁺⁺	0.5%

Table 17. Concentration of NaCl and process used

Process	Resin	Concentration
Softening	DOWEX™ MARATHON™ C	8 - 26% NaCl
Dealkalization	DOWEX MARATHON A2	5 - 10% NaCl
Organic screen	DOWEX MARATHON 11	10% NaCl + 1% NaOH

12.2 Ionization and Equilibrium Data

Sulfuric acid has two acidic protons (H⁺). The first H⁺ is very acidic and will appear as an ion in all but very concentrated solutions. Ionization of the second H⁺, leaving free SO₄⁻ in solutions happens, however, only in more diluted solutions. Figures 11 and 12 give the proportions of nonionized H₂SO₄, the partially ionized acid (HSO₄⁻) and proportions of the fully ionized acid (SO₄⁻) as functions of the acid concentration.

Figure 11. Ionization of sulfuric acid

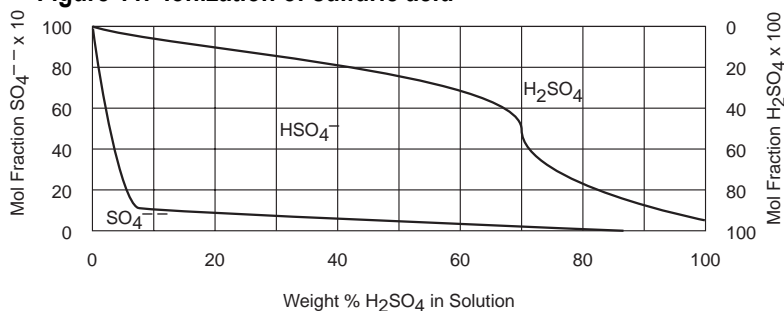
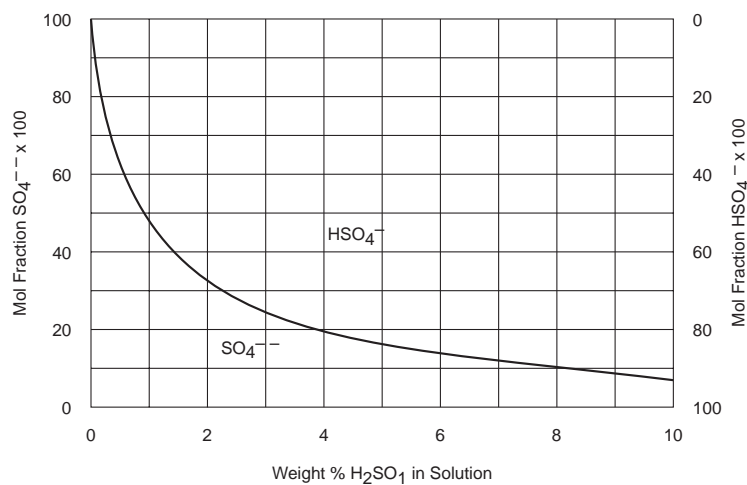


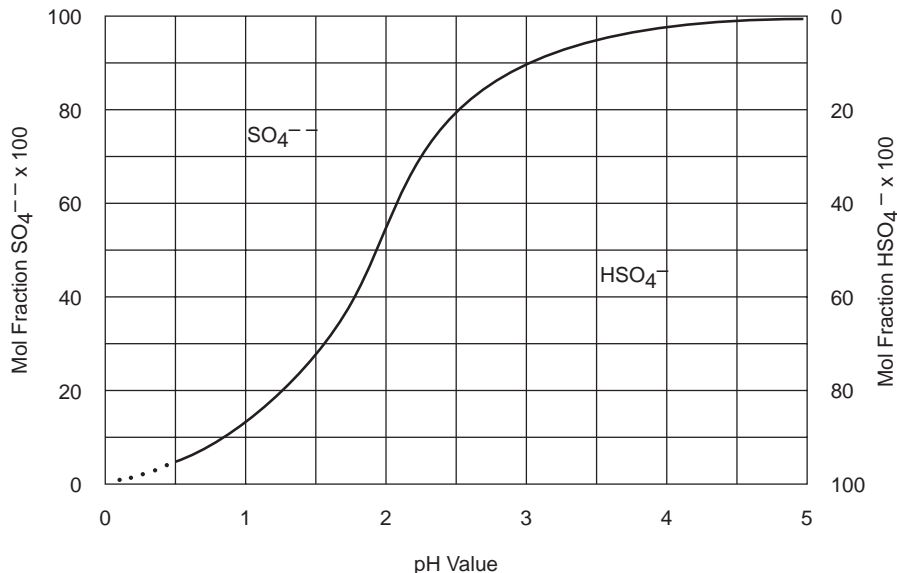
Figure 12. Ionization of diluted H₂SO₄ solutions at 25°C (77°F)



Sulfate/bisulfate equilibrium as function of pH at 25°C (77°F)

In the presence of other acids/bases the equilibrium between bisulfate (HSO_4^-) and sulfate (SO_4^{--}) will be shifted as a function of the overall pH of the solution. Figure 13 shows the proportions of HSO_4^- and SO_4^{--} for diluted solution at 25°C (77°F).

Figure 13. Sulfate/bisulfate equilibrium as function of pH at 25°C (77°F)

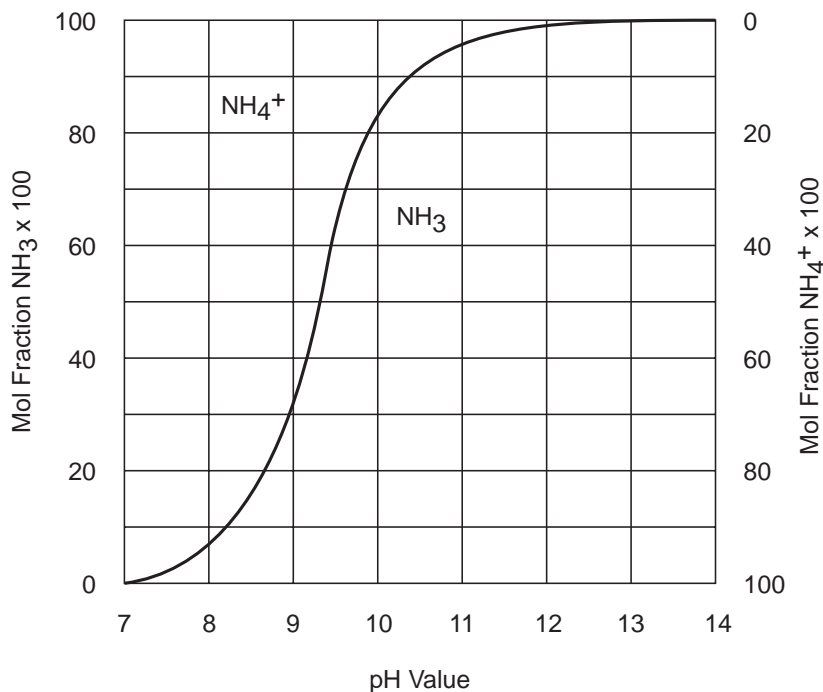


Ionization of diluted ammonia solutions as function of the pH at 25°C (77°F)

Ammonia (NH_3) is a weak base, accepting H^+ in acidic and weakly basic media, but not in strongly basic solutions.

Figure 14 allows to establish the proportion of protonated ammonia, appearing as an ammonium ion (NH_4^+), and free ammonia (NH_3) at different pH values. At pH 7 or lower, all ammonia will be present as NH_4^+ ; at pH 12 or higher, only free ammonia will be present.

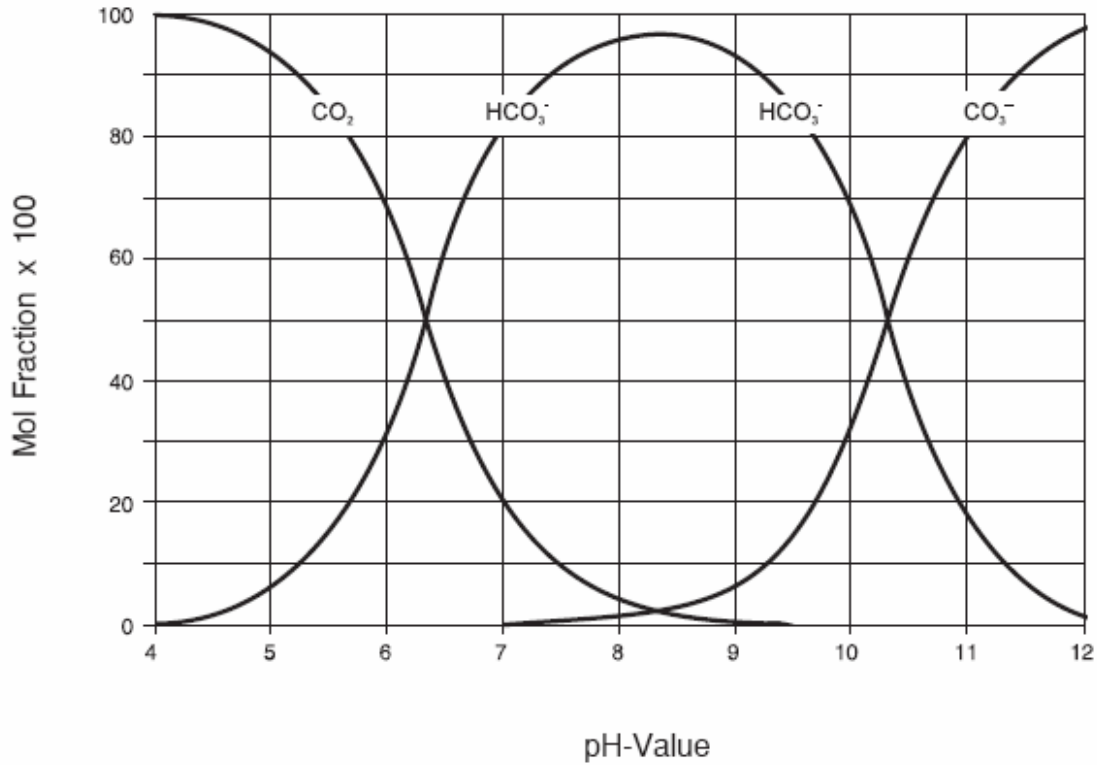
Figure 14. Ionization of diluted ammonia solutions as function of the pH at 25°C (77°F)



Ionization of carbon dioxide solutions as function of the pH at 25°C (77°F)

Carbon dioxide (CO_2), also present as carbonic acid (H_2CO_3), is a weak acid with two weakly acidic protons. Depending upon the pH of the solution, the acid will be present as free acid (CO_2), partially ionized, leaving bicarbonate (HCO_3^-) in the solution, or fully ionized, leaving carbonate (CO_3^{2-}) in the solution. The proportions of the different species at different pH values can be established from Figure 15.

Figure 15. Ionization of carbon dioxide solutions as function of the pH at 25°C (77°F)



12.3 Concentration and Density of Solutions

Tables 18 through 23 show the concentration and density of solutions.

Table 18. Concentration and density of HCl solution @ 20°C (68°F)

Concentration g HCl/100 g solution weight %	Concentration g HCl/L	Concentration eq/L	Concentration lbs/gal.	Density kg/L	Density ° Baumé
0.5	5.01	0.137	0.042	1.001	0.1
1	10.03	0.274	0.084	1.003	0.4
1.5	15.09	0.413	0.13	1.006	0.9
2	20.16	0.552	0.17	1.008	1.2
2.5	25.28	0.692	0.22	1.011	1.6
3	30.39	0.833	0.25	1.013	1.9
3.5	35.53	0.973	0.30	1.015	2.1
4	40.72	1.12	0.34	1.018	2.6
5	51.15	1.40	0.43	1.023	3.3
6	61.68	1.69	0.50	1.028	3.9
7	72.31	1.98	0.60	1.033	4.6
8	83.04	2.28	0.69	1.038	5.3
9	93.87	2.57	0.78	1.043	6.0
10	104.8	2.87	0.87	1.048	6.6
12	127.0	3.48	1.04	1.058	7.9
14	149.5	4.10	1.22	1.068	9.2
16	172.5	4.73	1.46	1.078	10.5
18	195.8	5.37	1.65	1.088	11.7
20	219.6	6.02	1.83	1.098	12.9
22	243.8	6.68	2.03	1.108	14.1
24	268.6	7.36	2.24	1.119	15.4
26	293.5	8.04	2.45	1.129	16.6
28	318.9	8.74	2.68	1.139	17.7
30	344.7	9.44	2.88	1.149	18.8
32	370.9	10.16	3.07	1.159	19.9
34	397.5	10.89	3.26	1.169	21.0
36	424.4	11.63	3.45	1.179	22.0
38	451.8	12.38	3.63	1.189	23.0
40	479.2	13.13	3.8	1.198	24.0

Table 19. Concentration and density of H₂SO₄ solutions @ 20°C (68°F)

Concentration g H ₂ SO ₄ /100 g solution weight %	Concentration g H ₂ SO ₄ /L	Concentration eq/L	Concentration lbs/gal.	Density kg/L	Density ° Baumé
0.5	5.01	0.102	0.042	1.002	0.3
1	10.05	0.205	0.084	1.005	0.7
1.5	15.12	0.309	0.126	1.008	1.3
2	20.24	0.413	0.169	1.012	1.7
3	30.54	0.623	0.255	1.018	2.6
4	41.00	0.837	0.342	1.025	3.5
5	51.60	1.05	0.43	1.032	4.5
6	62.34	1.27	0.52	1.039	5.4
7	73.15	1.49	0.61	1.045	6.3
8	84.16	1.72	0.70	1.052	7.2
9	95.31	1.95	0.80	1.059	8.1
10	106.00	2.18	0.88	1.066	9.0
12	129.6	2.64	1.07	1.080	10.8
14	153.3	3.13	1.24	1.095	12.5
16	177.4	3.62	1.52	1.109	14.3
18	202.5	4.13	1.71	1.124	16.0
20	228.0	4.65	1.90	1.139	17.7
30	365.7	7.46	3.05	1.219	26.0
35	439.6	8.97	3.66	1.260	29.9
40	521.2	10.6	4.35	1.303	33.7
45	607.1	12.4	5.06	1.348	37.4
50	697.5	14.2	5.82	1.395	41.1
55	794.8	16.2	6.63	1.445	44.7
60	899.4	18.4	7.50	1.498	48.2
65	1010	20.6	8.42	1.553	51.7
70	1127	23.0	9.40	1.611	55.0
75	1252	25.5	10.44	1.669	58.1
80	1382	28.2	11.52	1.727	61.1
85	1511	30.8	12.60	1.779	63.5
90	1634	33.3	13.62	1.814	65.1
92	1678	34.2	13.99	1.824	65.5
94	1720	35.1	14.34	1.831	65.8
96	1763	35.9	14.70	1.836	66.0
98	1799	36.7	15.00	1.836	66.0
100	1831	37.4	15.27	1.831	65.8

Table 20. Concentration and density of NaOH solutions @ 20°C (68°F)

Concentration g NaOH/100 g solution weight %	Concentration g NaOH/L	Concentration eq/L	Concentration lbs/gal.	Density kg/L	Density ° Baumé
0.5	5.02	0.126	0.04	1.004	0.8
1	10.10	0.253	0.08	1.010	1.4
1.5	15.2	0.381	0.13	1.015	2.3
2	20.4	0.510	0.17	1.021	2.9
2.5	25.7	0.641	0.22	1.026	3.7
3	31.0	0.774	0.26	1.032	4.5
3.5	33	0.907	0.30	1.038	5.4
4	41.8	1.04	0.34	1.043	6.0
5	52.8	1.32	0.44	1.054	7.4
6	63.9	1.60	0.53	1.065	8.8
7	75.3	1.88	0.63	1.076	10.2
8	86.9	2.17	0.72	1.087	11.6
9	98.8	2.47	0.82	1.098	12.9
10	110.9	2.77	0.92	1.109	14.2
12	135.7	3.39	1.13	1.131	16.8
14	161.4	4.03	1.34	1.153	19.2
16	188.0	4.70	1.57	1.175	21.6
18	215.5	5.39	1.79	1.197	23.9
20	243.8	6.10	2.03	1.219	26.1
30	398.4	9.96	3.32	1.328	36.6
40	572.0	14.3	4.76	1.430	43.8
50	762.7	19.1	6.35	1.525	49.9

Table 21. Concentration and density of NH₃ solutions

Concentration g NH ₃ /100 g solution weight %	Concentration g NH ₃ /L	Concentration eq/L	Concentration lbs/gal.	Density kg/L	Density ° Baumé
1	9.94	0.58	0.083	0.994	10.9
2	19.8	1.16	0.17	0.990	11.5
3	29.6	1.74	0.25	0.985	12.2
4	39.2	2.30	0.33	0.981	12.8
5	48.8	2.87	0.41	0.977	13.3
6	58.4	3.43	0.49	0.973	13.9
7	67.8	3.98	0.57	0.969	14.4
8	77.2	4.53	0.64	0.965	15.1
9	85	5.08	0.73	0.961	15.7
10	95.8	5.62	0.82	0.958	16.2
12	114.0	7.00	1.0	0.950	17.3
14	132.0	7.75	1.25	0.943	18.5
16	149.8	8.80	1.3	0.936	19.5
18	167.3	9.82	1.5	0.929	20.6
20	184.6	10.8	1.7	0.923	21.7
24	218.4	12.8	1.9	0.910	23.9
28	251.4	14.8	2.1	0.898	25.3
32	282.6	16	2.4	0.883	28.6

Table 22. Concentration and density of NaCl solutions

Concentration g NaCl/100 g solution weight %	Concentration g NaCl/L	Concentration eq/L	Concentration lbs/gal.	Density kg/L	Density ° Baumé
1	10.1	0.172	0.08	1.005	0.9
2	20.2	0.346	0.17	1.013	2.0
3	30.6	0.523	0.25	1.020	3.0
4	41.1	0.703	0.34	1.027	3.9
5	51.7	0.885	0.44	1.034	4.8
6	62.5	1.07	0.53	1.041	5.8
7	73.4	1.26	0.62	1.049	9
8	84.5	1.45	0.71	1.056	7.7
9	95.7	1.64	0.80	1.063	8.6
10	107.1	1.83	0.89	1.071	9.6
12	130.3	2.23	1.09	1.086	11.5
14	154.1	2.64	1.29	1.101	13.4
16	178.6	3.06	1.49	1.116	15.2
18	203.7	3.49	1.70	1.132	19
20	229.6	3.93	1.92	1.148	18.6
22	251	4.38	2.1	1.164	20.5
24	283.3	4.85	2.35	1.180	22.1
26	311.3	5.33	2.59	1.197	23.8

Table 23. Concentration and density of Na₂CO₃ solutions

Concentration g Na ₂ CO ₃ /100 g solution weight %	Concentration g Na ₂ CO ₃ /L	Concentration eq/L	Concentration lbs/gal.	Density kg/L	Density ° Baumé
1	10.1	0.191	0.084	1.009	1.4
2	20.4	0.385	0.17	1.019	2.8
3	30.9	0.583	0.26	1.029	4.3
4	41.6	0.785	0.35	1.040	5.6
5	52.5	0.991	0.44	1.050	7.0
6	63.6	1.20	0.53	1.061	8.4
7	75.0	1.42	0.63	1.071	9.8
8	85	1.63	0.72	1.082	11.0
9	98.3	1.85	0.82	1.092	12.4
10	110.3	2.08	0.92	1.103	13.6
12	134.9	2.55	1.13	1.124	10
14	160.5	3.03	1.34	1.146	18.4
16	187.0	3.53	1.53	1.169	21.0
18	214.7	4.05	1.70	1.193	23.4

12.4 Specific Gravity NaOH-H₂O Solution (0 to 100°C) in g/mL

Table 24 shows the specific gravity of NaOH-H₂O solution.

Table 24. Specific gravity NaOH-H₂O solution (0 to 100°C) in g/mL

Concentration NaOH g/100 g solution	0°C (32°F)	10°C (50°F)	20°C (68°F)	30°C (86°F)	40°C (104°F)	50°C (122°F)	60°C (140°F)	70°C (158°F)	80°C (176°F)	90°C (194°F)	100°C (212°F)
1	1.0124	1.0115	1.0095	1.0069	1.0033	0.9990	0.9941	0.9884	0.9824	0.9760	0.9693
2	1.0244	1.0230	1.0207	1.0177	1.0139	1.0095	1.0045	0.9989	0.9929	0.9865	0.9797
3	1.0364	1.0345	1.0318	1.0285	1.0246	1.0201	1.0150	1.0094	1.0035	0.9970	0.9903
4	1.0482	1.0459	1.0428	1.0393	1.0352	1.0305	1.0254	1.0198	1.0139	1.0075	1.0009
5	1.0598	1.0571	1.0538	1.0501	1.0458	1.0412	1.0359	1.0302	1.0243	1.0179	1.0115
6	1.0713	1.0683	1.0648	1.0609	1.0564	1.0517	1.0463	1.0407	1.0347	1.0284	1.0220
7	1.0828	1.0795	1.0758	1.0717	1.0672	1.0623	1.0569	1.0513	1.0453	1.0390	1.0326
8	1.0943	1.0908	1.0869	1.0826	1.0780	1.0730	1.0676	1.0619	1.0560	1.0497	1.0432
9	1.1057	1.1020	1.0979	1.0934	1.0887	1.0836	1.0782	1.0725	1.0665	1.0602	1.0537
10	1.1171	1.1132	1.1089	1.1043	1.0995	1.0942	1.0889	1.0831	1.0771	1.0708	1.0643
12	1.1399	1.1355	1.1309	1.1261	1.1210	1.1157	1.1101	1.1043	1.0983	1.0920	1.0855
14	1.1624	1.1578	1.1530	1.1480	1.1428	1.1373	1.1316	1.1257	1.1195	1.1132	1.1066
16	1.1849	1.1801	1.1751	1.1699	1.1645	1.1588	1.1531	1.1471	1.1408	1.1343	1.1277
18	1.2073	1.2023	1.1972	1.1918	1.1863	1.1805	1.1746	1.1685	1.1621	1.1556	1.1489

13. Solubility of CaSO₄

CaSO₄ is only very slightly soluble in water. Its solubility is increased in diluted sulfuric acid; however, CaSO₄ precipitation should be prevented in an ion exchange bed, where it may occur when sulfuric acid is used to regenerate a cation exchange resin (see Figures 16 and 17).

Figure 16. Solubility of CaSO₄ in solutions of sulfuric acid in water

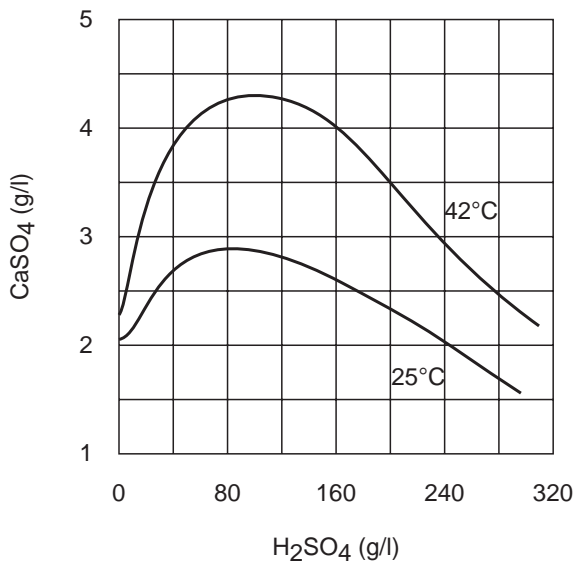
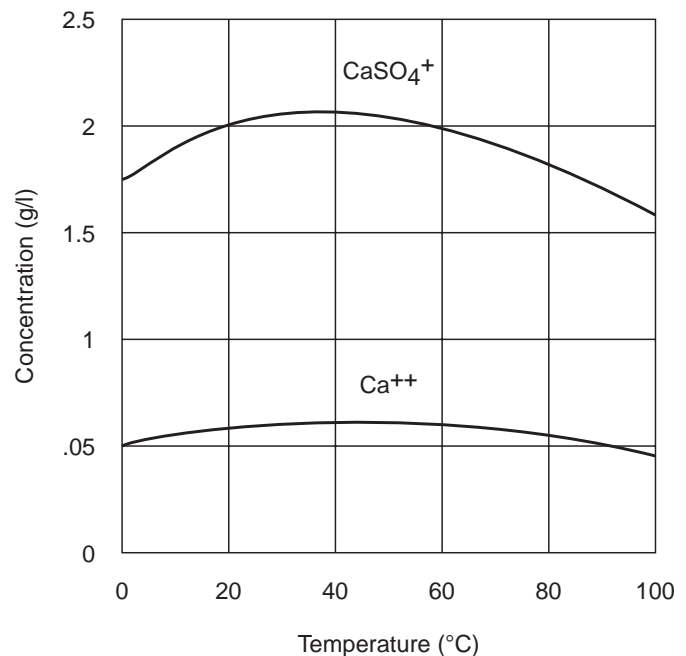


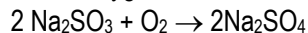
Figure 17. Solubility of CaSO₄ at different temperatures in water



14. The Removal of Oxygen

Figure 18 shows the solubility of oxygen in water as a function of temperature.

Dissolved oxygen can be reduced by using sodium sulfite according to following reaction:



Based on this equation, a minimum of 7.87 mg Na_2SO_3 is necessary per mg dissolved O_2 . Table 25 shows levels required to remove different amounts of dissolved oxygen.

Figure 18. Solubility of oxygen in water

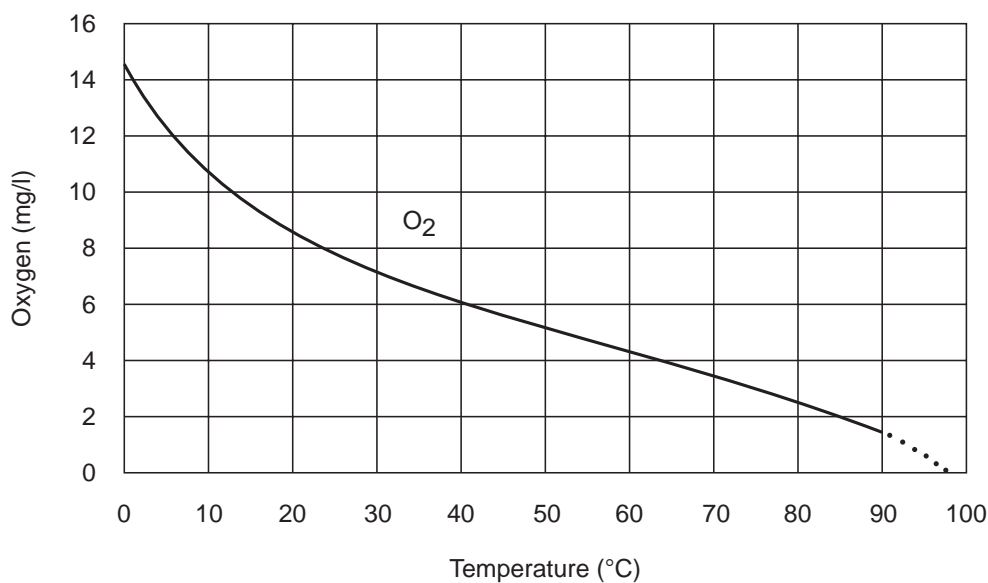


Table 25. Levels required to remove dissolved oxygen

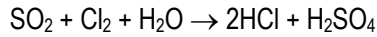
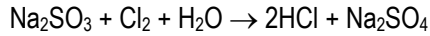
Dissolved oxygen		Sodium sulfite (theoretical amount)	
cc/liter ¹	mg/L	mg/L	lbs/1,000 gal
0.1	0.14	1.1	0.0094
0.2	0.29	2.3	0.019
0.3	0.43	3.4	0.028
0.4	0.57	4.5	0.038
0.5	0.72	5.6	0.047
1.0	1.4	11.3	0.094
2.0	2.9	22.5	0.19
5.0	7.2	56.3	0.47
10.0	14.3	112.5	0.94

¹ 1 cc dissolved oxygen per liter = 1.43 mg/L.

1 mg/L dissolved oxygen = 0.698 cc/liter.

15. The Removal of Chlorine

Chlorine is a strong oxidant and may readily degrade ion exchange resins. Chlorine levels in water can be reduced using sulfur dioxide or sodium sulfite according to following reactions:



Per gram of chlorine to remove, one needs to add a minimum of 0.91 grams of SO_2 or 1.78 grams of Na_2SO_3 .

This leads to following amounts of reducing agents to add per 1,000 liters of water for the given chlorine levels in Table 26.

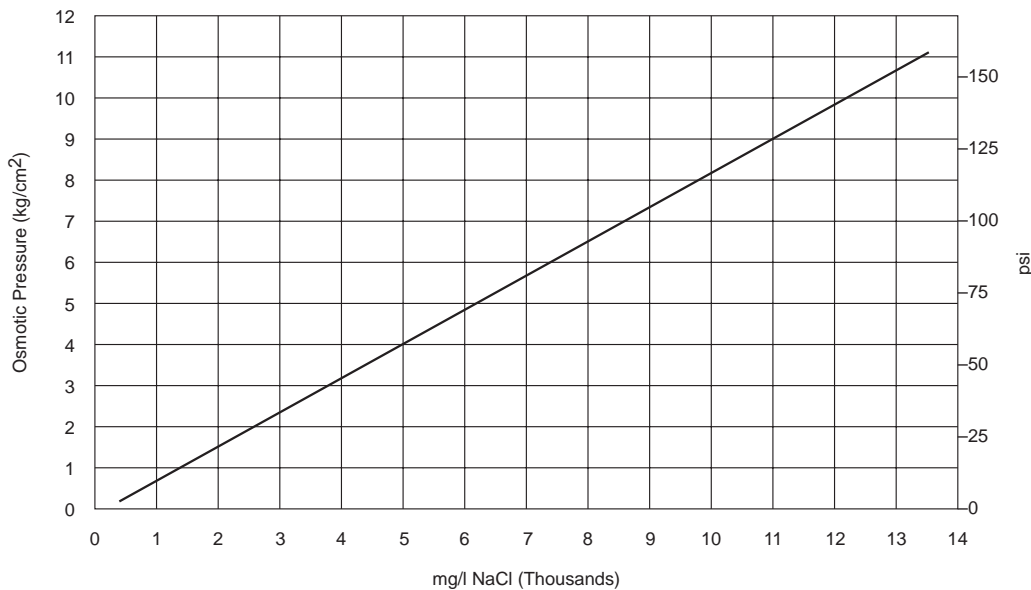
Table 26. Levels required for removal of chlorine

Cl ₂ mg/L	Na ₂ SO ₃ (theoretical amount)		SO ₂ (theoretical amount)	
	g/1,000 L	lbs/1,000 gal	g/1,000 L	lbs/1,000 gal
0.1	0.18	0.0015	0.09	0.00075
0.5	0.89	0.0075	0.45	0.0038
1	1.78	0.015	0.91	0.0075
2	3.56	0.030	1.82	0.015
3	5.34	0.045	2.73	0.0225
4	7.12	0.06	3.64	0.03
5	8.90	0.075	4.55	0.038
10	17.80	0.15	9.10	0.075

16. Osmotic Pressure of Sodium Chloride

Figure 19 shows the osmotic pressure of sodium chloride.

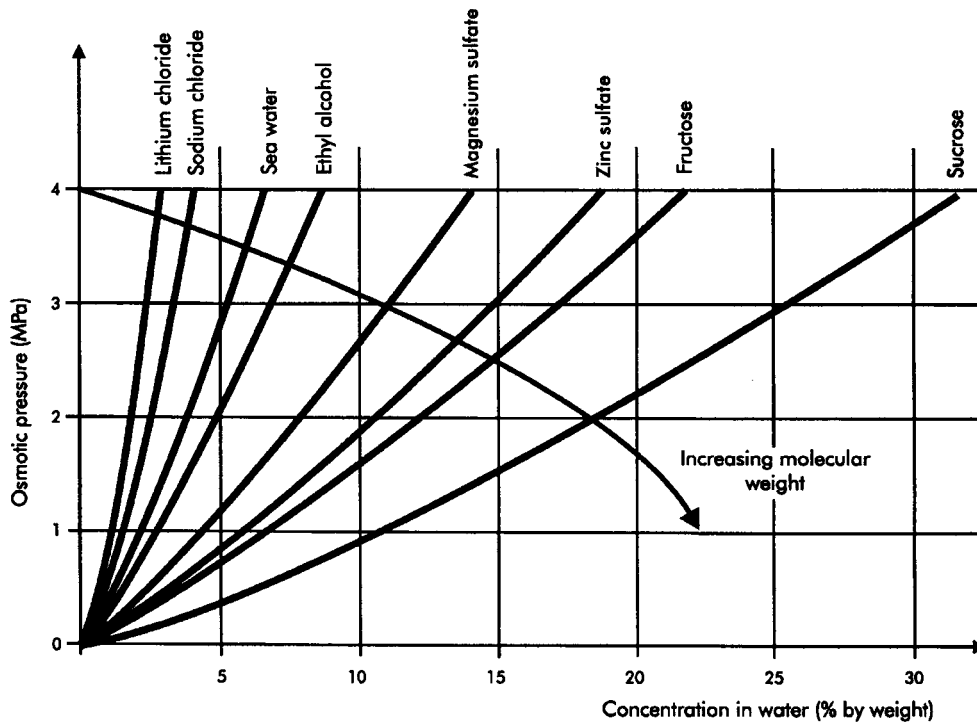
Figure 19. Osmotic pressure of sodium chloride



17. Osmotic Pressure of Solutions

Figure 20 shows the osmotic pressure of solutions.

Figure 20. Osmotic pressure of solutions



18. Tank Capacities, Vertical Cylindrical, in U.S. and Metric Units

Table 27 shows tank capacities, vertical cylindrical, in U.S. and metric units.

Table 27. Tank capacities, vertical cylindrical, in U.S. and metric units

Diameter in ft.	Cubic feet per foot depth or area in ft ²	U.S. gal. per foot of depth	Diameter in m	m per m depth or area in m ²
1' 0"	0.79	5.87	0.3	0.07
1' 1"	0.92	6.89	0.4	0.13
1' 2"	1.07	8.00	0.5	0.2
1' 3"	1.23	9.18	0.6	0.28
1' 4"	1.40	10.44	0.7	0.39
1' 5"	1.58	11.79	0.8	0.50
1' 6"	1.77	13.22	0.9	0.64
1' 7"	1.97	14.73	1.0	0.79
1' 8"	2.18	16.32	1.1	0.95
1' 9"	2.41	17.99	1.2	1.13
1' 10"	2.64	19.75	1.3	1.33
1' 11"	2.89	21.58	1.4	1.54
2' 0"	3.14	23.50	1.5	1.77
2' 6"	4.91	36.72	1.6	2.01
3' 0"	7.07	52.88	1.7	2.27
3' 6"	9.62	71.97	1.8	2.54
4' 0"	12.57	94.0	1.9	2.84
4' 6"	15.90	119.0	2.0	3.14
5' 0"	19.63	146.9	2.1	3.46
5' 6"	23.76	177.7	2.2	3.80
6' 0"	28.27	211.5	2.3	4.16
6' 6"	33.18	248.2	2.4	4.52
7' 0"	38.48	287.9	2.5	4.91
7' 6"	44.18	330.5	2.6	5.31
8' 0"	50.27	376.0	2.7	5.73
8' 6"	56.75	424.5	2.8	6.16
9' 0"	63.62	475.9	2.9	6.61
9' 6"	70.88	530.2	3.0	7.07
10' 0"	78.54	587.5	3.2	8.04
10' 6"	86.59	647.7	3.4	9.08
11' 0"	95.03	710.9	3.6	10.2
11' 6"	103.9	777.0	3.8	11.3
12' 0"	113.1	846.0	4.0	12.6
12' 6"	122.7	918.0	4.2	13.9
13' 0"	132.7	992.9	4.4	15.2
13' 6"	143.1	1,071	4.6	16.6
14' 0"	153.9	1,152	4.8	18.1
14' 6"	165.1	1,235	5.0	19.6
15' 0"	176.7	1,322	5.2	21.2

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