Dow
Liquid Separations

FILMTEC
Membranes
and
DOWEX
Ion Exchange Resins

ENGINEERING INFORMATION

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DOWEX and FILMTEC Engineering Information

1. Particle Size Distribution

Test methods to establish and/or express the size distribution of DOWEX* standard ion exchange resins are based an “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 ±µm	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	0.5 80
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	0.05 3
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 ±50 microns
Uniformity Coefficient, max.	1.1
Greater than 840 microns (20 mesh), max.	5%
Less than 300 microns (50 mesh), max.	0.5%

Table 3. Conversion of Common Units

From ! to ¡	to from	multiply by divide by
LENGTH		
inch (in.)	metre (m)	0.0254
foot (ft)	metre (m)	0.3048
yard (yd)	metre (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}	litre (l)	0.01639
ft^3	litre (l)	28.32
yd^3	litre (l)	764.6
Imp. Gallon (U.K.)	litre (l)	4.546
U.S. Gallon (gal.)	litre (l)	3.785
MASS		
grain (gr)	gram (g)	0.0648
Ounce	gram (g)	28.35
pound (Ib)	gram (g)	453.6
PRESSURE		
Atmosphere (atm)	kilo Pascal	101.3
Bar	kPa	100.0
Ib/ft^2	kPa	0.04788
Ib/in.^{2} = psi	bar	0.069
Ib/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
gal./day = gpd	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		
901/ft^3	l/l	0.134
CHEMICAL DOSAGE		
Ib/ftl	g/l	103

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.

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 litre (g/l) into equivalent per litre (eq/l) or of gram of $CaCO_3$ equivalents per litre (g $CaCO_3$/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 (mg = 10^{-6} g) of the (ionic) species per litre (l) or cubic metre (m^3) of water.
- As equivalents (eq) or milliequivalents (meq = 10^{-3} eq) of the ionic species per litre (l) or cubic metre (m^3) of water.

Still widely used concentration units are:

- Kilograins of $CaCO_3$ per cubic foot (kgr/ft^3)
- 1 French degree = 1 part $CaCO_3$ per 100.000 parts of water
- 1 German degree = 1 part CaO per 100.000 parts of water
- Grains $CaCO_3$/gallon (U. S.)
- ppm $CaCO_3$
- 1 English degree (Clark) = 1 grain $CaCO_3$ per (British) Imperial gallon of water

Table 5 gives the conversion factors for commonly encountered units to milliequivalents/litre (meq/l) and mg $CaCO_3$/l. Multiply by the conversion factor to obtain mg $CaCO_3$/l or meq/l. Divide by the conversion factor to obtain the different units from numbers expressed as mg $CaCO_3$/l or meq/l.

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	Conversion to 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)	$H_2PO_4^-$	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 an conversion to monovalent neutral species.

Table 5. Conversion Factors

	mg $CaCO_3$/l	meq/l
kgr/ft^3	2288	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 ($CaCO_3$) Equivalent of Common Substances

Compounds	Formula	Molecular Weight	Equivalent Weight	Substance to $CaCO_3$ equivalent multiply by	$CaCO_3$ equivalent to Substance multiply by
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_2O_3	101.9	17.0	2.94	0.34
Sodium Aluminate	$Na_2Al_2O_4$	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)	$CaSO_4 \bullet 2H_2O$	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)	$MgSO_4$ - $7H_2O$	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	AgCI	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_2CO_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	$Na_3PO_4 \bullet 12H_2O$	380.2	126.7	0.40	2.53
Tri-sodium Phos. (anhydrous)	Na_3PO_4	164.0	54.7	0.91	1.09
Disodium Phoshate	$Na_2HPO_4 \bullet 12H_2O$	358.2	119.4	0.42	2.39
Disodium Phos. (anhydrous)	Na_2HPO_4	142.0	47.3	1.06	0.95
Monosodium Phosphate	NaH_2PO4 - H_20	138.1	46.0	1.09	0.92
Monosodium Phos. (anhydrous)	NaH_2PO4	120.0	40.0	1.25	0.80
Sodium Metaphosphate	$NaPO_3$	102.0	34.0	1.47	0.68
Sodium Sulfate	Na_2SO_4	142.1	71.0	0.70	1.42
Sodium Sulfite	Na_2SO_4	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 following equations:

°C to °F: (9/5 x °C) + 32 = °F

°F to °C: 5/9 (°F – 32) = °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:

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

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

10^{-6} S/cm = 1 µS/cm ~ 1 MΩcm = 106 Ωcm

10^{-3} S/cm = 1 mS/cm ~ 1 kΩcm = 103 Ωcm

Figure 1. Conversion of Temperature Units

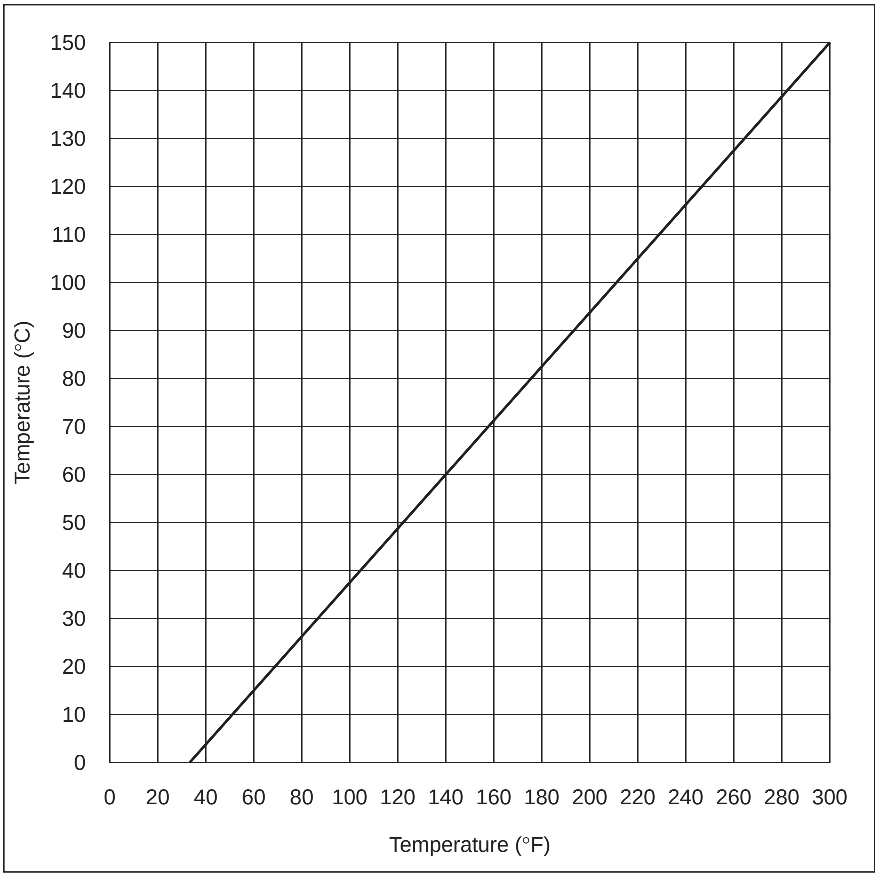
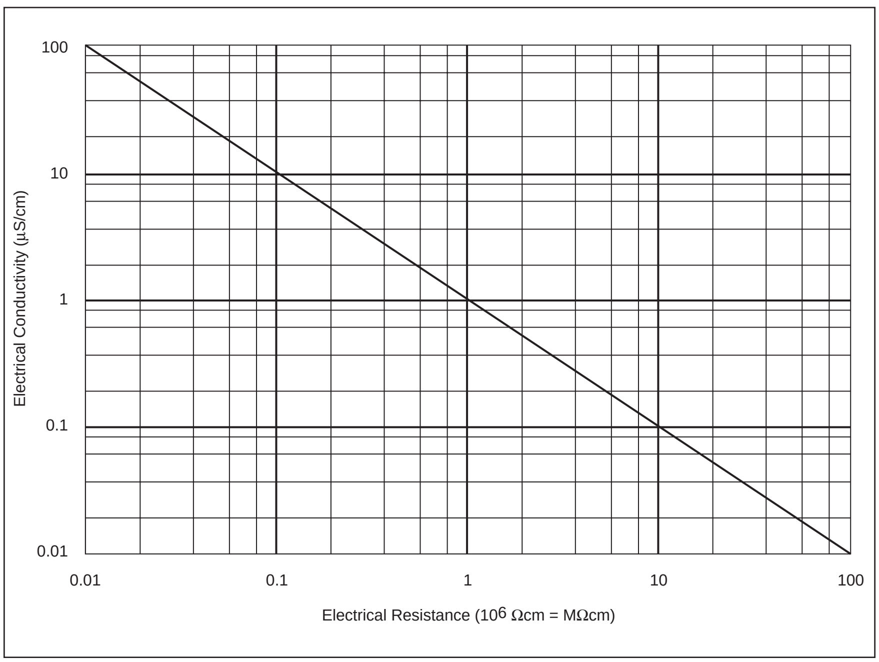


Figure 2. Conversion of Conductivity to Resistance



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°C (77°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

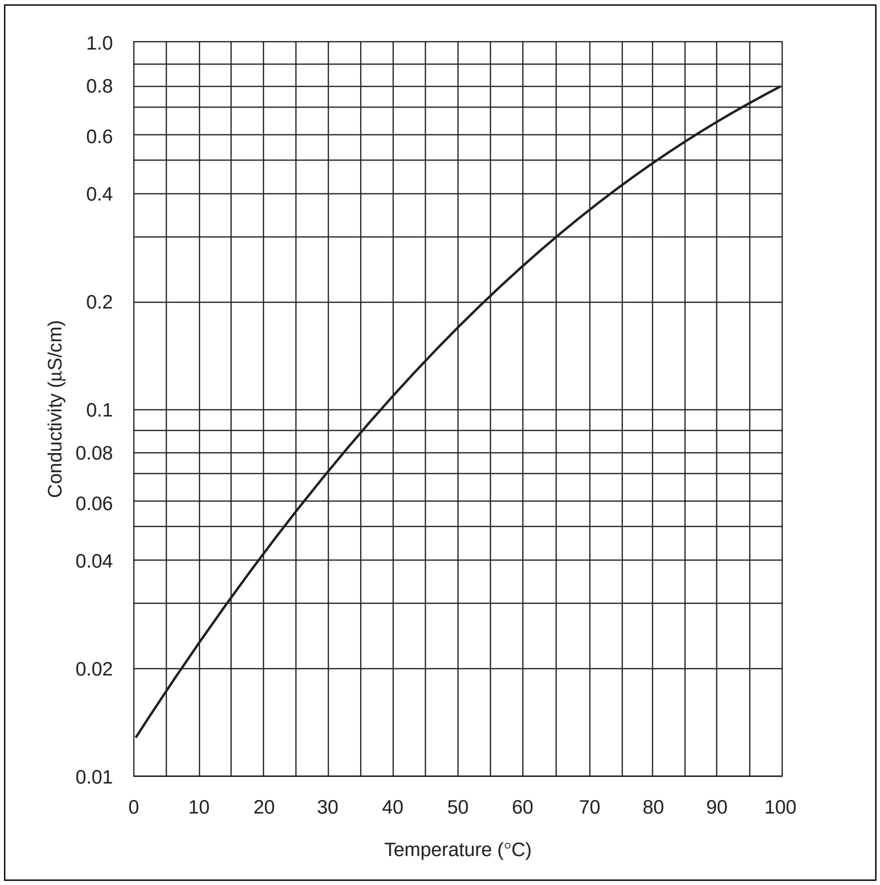


Figure 4. Conductivity vs. Concentration for Ionic Solutions at 25°C

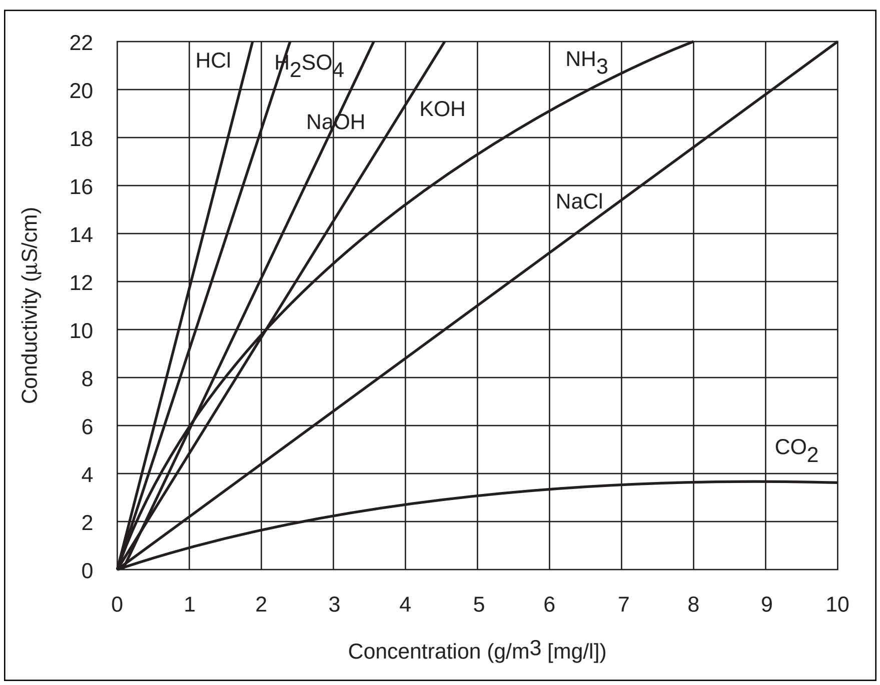


Table 7. Conductivity of Solutions at Other Temperatures

	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_2SO_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. Concentrations for Ionic Solutions at 25°C

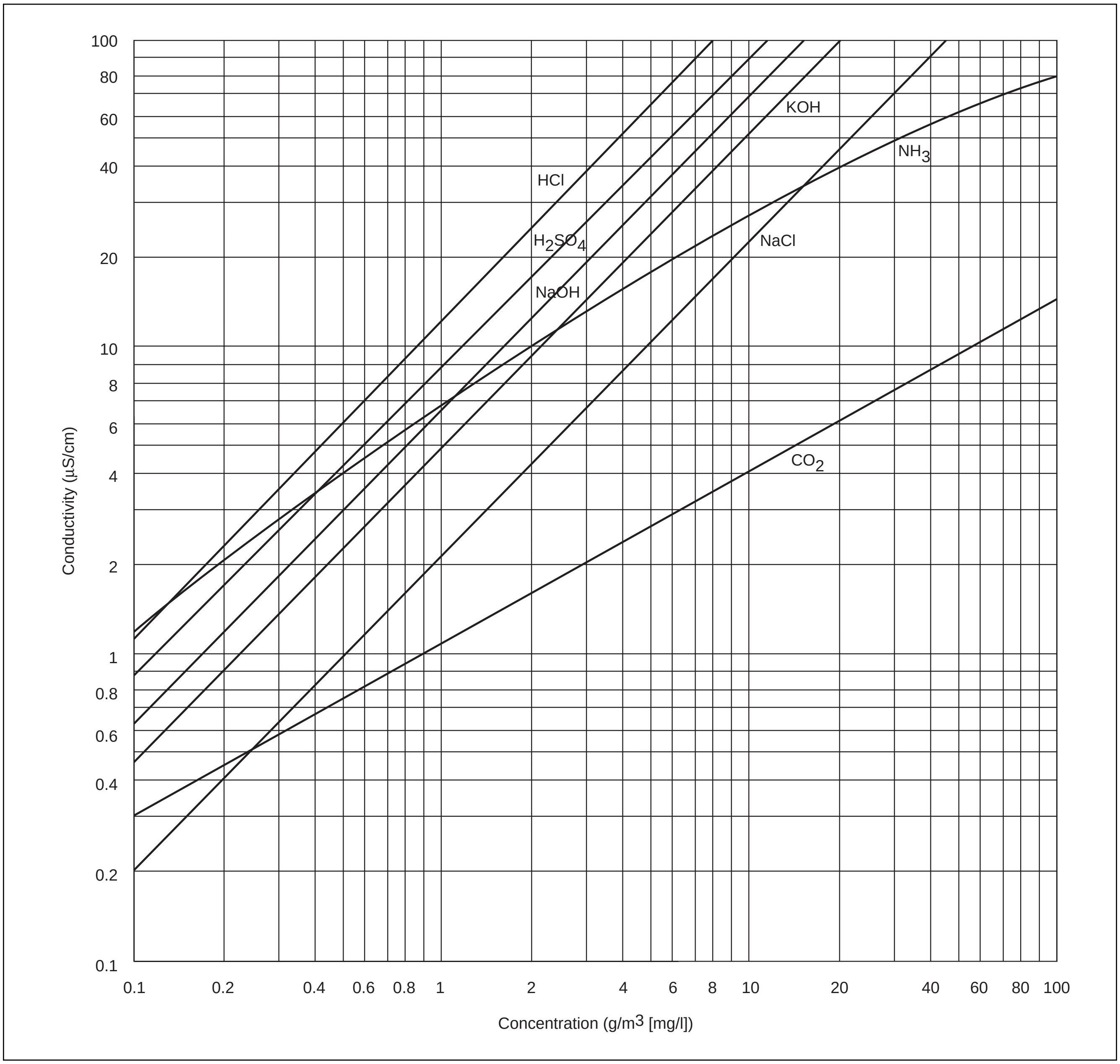


Table 8. Conductivity of Solutions, Acids, Alkalis and Salts at 25°C Expressed as μS/cm per meq/l

Component	Concentration in meg/l infin. 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_2SO_4	430	424	412	407	390	380	346	317
H_3PO_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_4OH	271	109	49	36	17	12	5.6	3.9
NaCl	126	126	124	124	121	118	111	107
Na_2SO_4	130	128	126	124	117	113	97.7	90.0
Na_2CO_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

Source: Landolt Börnstein 6° edition Band II/7.

Table 9. Conductivity of Ions Expressed as μS/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
$H_2PO_4^-$	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	-

Figure 6. Conductance vs. Total Dissolved Solids

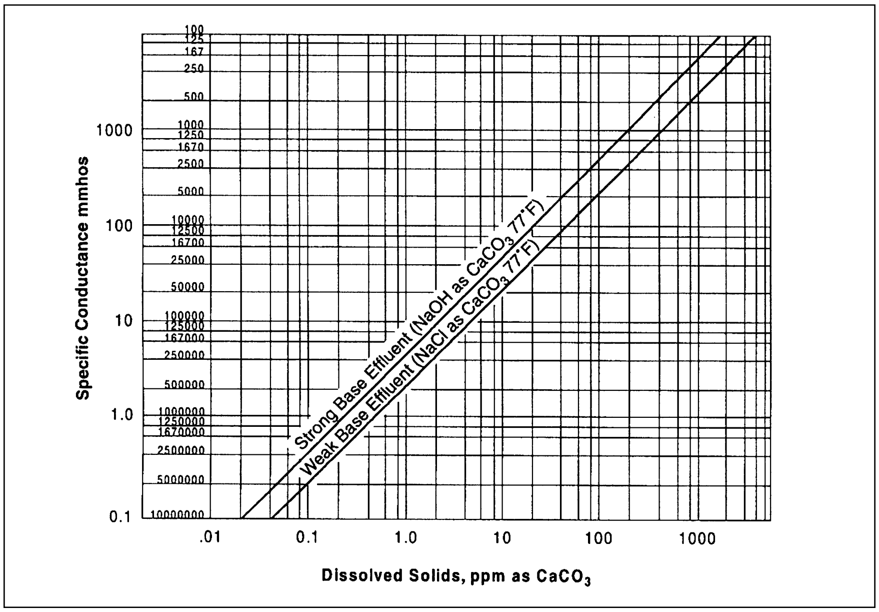


Figure 7. Relationship Between Dissolved Solids and Conductance in Demineralization Operations

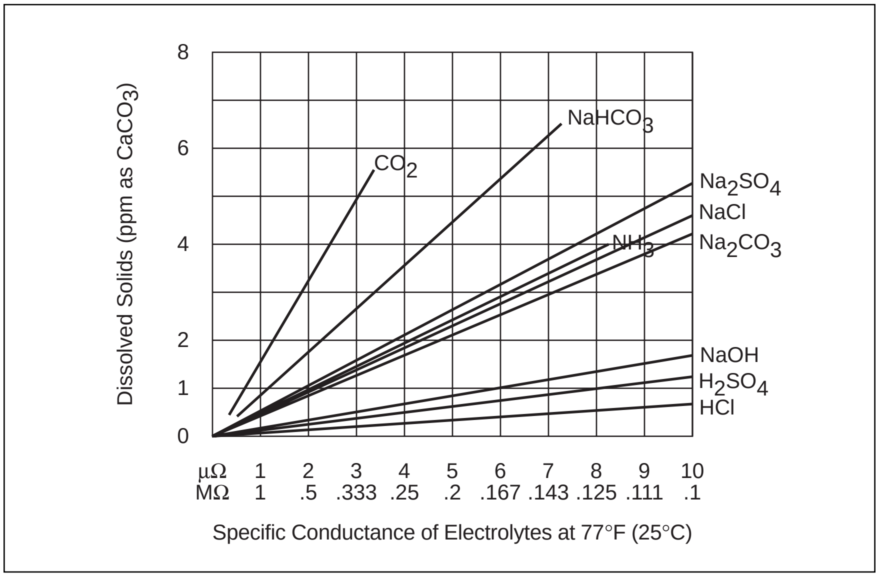


Table 10. Specific Conductance of Sodium Chloride

µmhos/cm	ppm	µmhos/cm	ppm	µmhos/cm	ppm	µmhos/cm	ppm	µmhos/cm	ppm	µmhos/cm	ppm	µmhos/cm	ppm
10	5	620	307	1440	723	3350	1726	8600	4654	20000	11476	50000	30425
20	9	630	312	1460	733	3400	1753	8700	4710	20250	11630	51000	31103
30	14	640	317	1480	743	3450	1781	8800	4767	20500	11784	52000	31781
40	19	650	323	1500	754	3500	1808	8900	4823	20750	11937	53000	32459
60	28	660	328	1525	766	3550	1835	9000	4879	21000	12091	54000	33137
70	33	670	333	1550	770	3600	1863	9100	4935	21250	12245	55000	33815
80	38	680	338	1575	792	3650	1899	9200	4991	21500	12399	56000	34493
90	42	690	343	1600	805	3700	1917	9216	5000	21750	12552	57000	35171
100	47	700	348	1625	817	3750	1945	9300	5047	22000	12705	58000	35849
110	52	710	353	1650	830	3800	1972	9400	5103	22250	12860	59000	36527
120	57	720	358	1675	843	3850	1999	9500	5159	22500	13013	60000	37205
130	61	730	363	1700	856	3900	2027	9600	5215	22750	13167	61000	37883
140	66	740	368	1725	868	3950	2054	9700	5271	23000	13321	62000	38561
150	71	750	373	1750	881	4000	2081	9800	5327	23250	13474	63000	39239
160	75	760	378	1775	894	4100	2136	9900	5383	23500	13628	64000	39917
170	80	770	383	1800	907	4200	2191	10000	5439	23750	13782	65000	40595
180	85	780	388	1825	920	4300	2245	10200	5551	24000	13936	66000	41273
190	90	790	393	1850	932	4400	2300	10400	5664	24250	14089	67000	41961
200	95	800	399	1875	945	4500	2356	10600	5776	24500	14243	68000	42629
210	100	810	404	1900	958	4600	2412	10800	5888	24750	14397	69000	3307
220	105	820	409	1925	971	4700	2468	11000	6000	25000	14550	70000	43985
230	110	830	414	1950	983	4800	2524	11200	6122	25500	14858	71000	44663
240	115	840	419	1975	996	4900	2580	11400	6243	26000	15165	72000	45341
250	120	850	424	2000	1000	5000	2636	11600	364	26500	15473	73000	46091
260	125	860	429	2025	1022	5100	2692	11800	6485	27000	15780	74000	46697
270	130	870	434	2050	1034	5200	2748	12000	6607	27500	16087	76000	48053
280	135	880	439	2075	1047	5300	2805	12200	6728	28000	16395	77000	48731
290	140	890	444	2125	1073	5400	2861	12400	6843	28500	16702	78000	49409
300	145	900	449	2150	1085	5500	2917	12600	6970	29000	17010	79000	50087
310	150	910	454	2175	1098	5600	2973	12800	7091	29500	17317	80000	50765
320	155	920	459	2200	1111	5700	3029	13000	7213	30000	17624	81000	51443
330	160	930	464	2225	1124	5800	3085	13200	7334	30500	17932	82000	52121
340	165	940	469	2250	1137	5900	3141	13400	7455	31000	18239	83000	52799
350	171	950	474	2275	1140	6000	3197	13600	7576	31500	18547	84000	53477
360	176	960	480	2300	1162	6100	3253	13800	7898	32000	18854	85000	54155
370	181	970	485	2325	1175	6200	3309	14000	7819	32500	19161	86000	54833
380	186	980	490	2350	1188	6300	3365	14200	7940	33000	19469	87000	55511
390	191	990	495	2375	1200	6400	3421	14400	8061	34000	20084	88000	56130
400	196	1000	500	2400	1213	6500	3477	14600	8182	34500	20391	89000	56867
410	201	1020	510	2425	1226	6600	3533	14800	8304	35000	20698	90000	57545
420	206	1040	520	2450	1239	6700	3589	15000	8425	35500	21006	91000	58223
430	211	1080	540	2475	1251	6800	3645	15250	8576	36000	21313	92000	58901
440	216	1100	550	2500	1264	6900	3701	15500	8728	36500	21621	93000	59579
450	221	1120	561	2550	1290	7000	3758	15750	8879	37000	21928	94000	60257
460	226	1140	571	2600	1315	7100	3814	16000	9031	37500	22235	95000	60935
470	231	1160	581	2650	1344	7200	3870	16250	9182	38000	22543	96000	61613
480	236	1180	591	2700	1371	7300	3926	16500	9334	38500	22850	97000	62291
490	241	1200	601	2750	1398	7400	3982	16750	9486	39000	23158	98000	62969
500	247	1220	611	2800	1426	7500	4038	17000	9637	39500	23465	99000	63647
510	252	1240	621	285	1453	7600	4094	17500	9940	40000	23773	100000	64325
520	257	1260	632	2900	1480	7700	4150	1775	10092	41000	24387		
530	262	1280	642	2950	1508	7800	4206	18000	10247	42000	25002		
550	272	1300	652	3000	1535	7900	4262	18250	10400	43000	25679		
560	277	1320	662	3050	1562	8000	4318	18500	10554	44000	26357		
570	282	1340	672	3100	1589	8100	4374	18750	10708	45000	27035		
580	87	1360	682	3150	1617	8200	4430	19000	10852	46000	27713		
590	292	1380	692	3200	1644	8300	4486	19250	11015	47000	28391		
600	297	1400	702	3250	1671	8400	4542	19500	11169	48000	29069		
610	302	1420	713	3300	1699	8500	4598	19750	11323	49000	29747		

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 µS/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).

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.

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).

CO_2 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 CO_2. Accounting for this contribution to conductivity, it is then possible to establish the leakage level of NaCl.

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

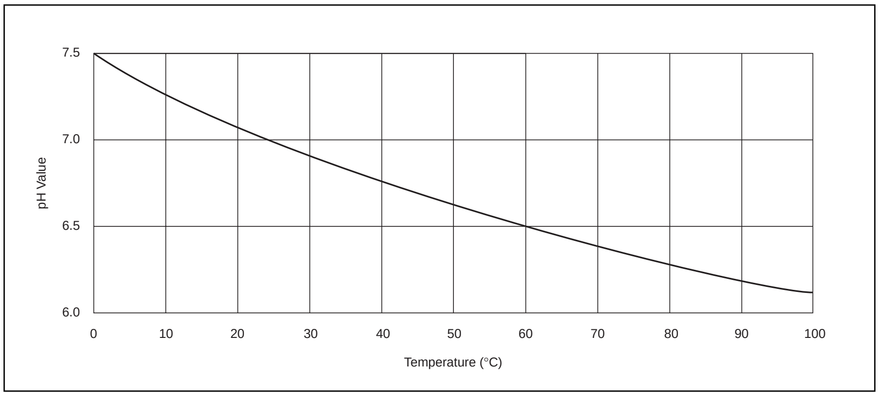


Figure 9. The pH of Basic Solutions at 25°C (77°F)

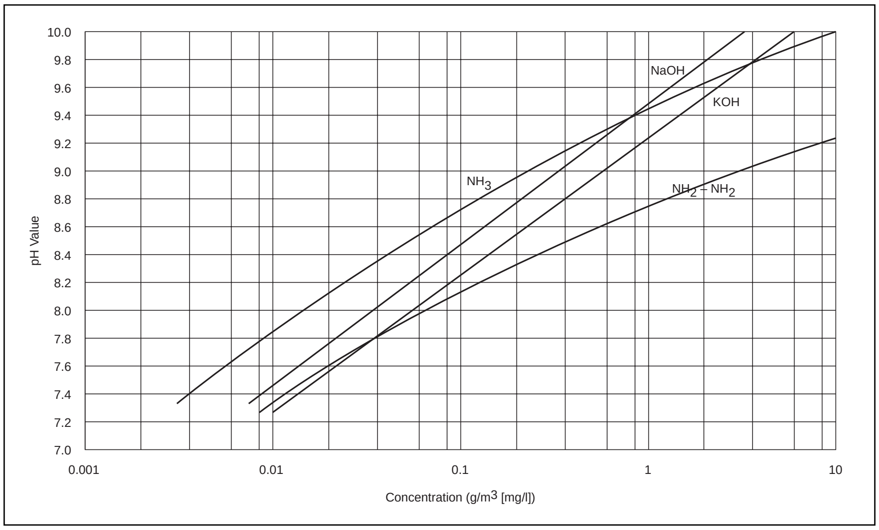
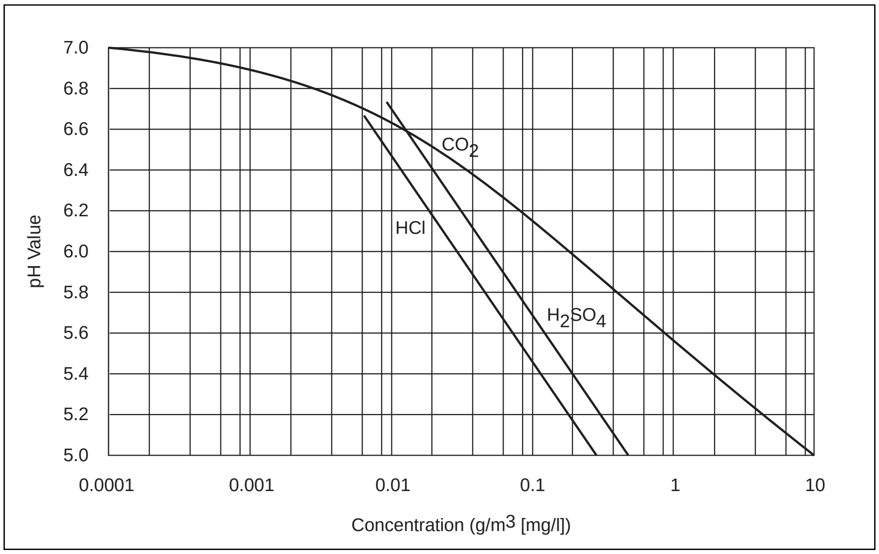


Figure 10. The pH of Acid Solutions at 25°C (77°F)



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 colour change of the indicator is reported as alkalinity; therefore:

1 ml acid = 1 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 (HCO_3^-) and carbonate (CO_3^{--}) 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

! carbonate = 1.0 meq/l

! bicarbonate = 2.0 meq/l

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 an the purity of the regenerant chemicals have to assure a trouble-free operation of the ion exchange resin after regeneration. The chemicals have therefore to be free of suspended materials, or other materials that may be precipitated an 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 rotes can affect the efficiency of the operation.

Recommendations an 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 eventually waste chemicals from process streams. Figures for impurity levels are the basis of a 100 percent regeneration chemical.

1. Hydrochloric Acid: HCl (Muriatic Acid) Both as a gas and in solution, HCl is very corrosive and can cause severe burns an contact. Mucous membranes of the eyes and of the upper respiratory tract are especially susceptible to high atmospheric concentrations. Avoid inhalation of

Table 11. Calculating Concentrations for P- and M-Alkalinity

P and M alkalinity	Hydroxyl (OH)	Carbonate (CO_3)	Bicarbonate (HCO_3)
P = O	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

Table 12. Recommended Maximum Impurity Levels for HCl

	Recommended Max. 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

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 bv 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.

2. Sulfuric Acid: H_2SO_4 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 H_2SO_4 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).

3. Sodium Hydroxide: NaOH (Caustic Soda) Sodium hydroxide or caustic soda can cause severe burns an contact with skin or 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 percent NaOH or as a 30 to 50 percent liquid (see Table 14).

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 percent NaCl and over 0.1 percent (1000 mg/l) $NaClO_3$.

Sodium hydroxide solutions are mostly diluted to between 2 and 5 percent for the regeneration of weakly or strongly basic resins.

Regeneration of strongly basic resins can eventually be carried out with NaOH containing higher NaCl concentrations at the expense

Table 13. Recommended Maximum Impurity Levels for H_2SO_4

	Recommended Max. 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

Table 14. Recommended Maximum Impurity Levels for NaOH

	Recommended Max. Impurity Levels
NaCl	0.6%
$NaClO_3$	30 mg/l
Na_3CO_3	0.75%
Fe	10 mg/l
Heavy metals (total)	5 mg/l
SiO_3	50 mg/l
Na_2SO_4	0.2%

Table 15. 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_2CO_3	0.02%	0.2%	0.2%	0.5-1%
$NaClO_3$	1 mg/l	2 mg/l	0.5%l	2 mg/l
NaCl	0.002%	0.2-.05%	1-2%	0.4-1.5%
$NaSO_4$	10 mg/l	0.1%l	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

however, of efficiency (2 percent NaCl will cause about 10 percent reduction in efficiency). $NaClO_3$ levels of 500 mg/l can be allowed for strongly basic resins in single beds.

Weakly basic resins will suffer mostly from high $NaClO_3$ levels as conversion to $HClO_3$ can create a strong oxidizing agent. Therefore, mixed bed anion exchangers should be regenerated with regular grade diaphragm cell caustic soda. On the other hand, regeneration of weakly basic resins will not suffer from high NaCl, Na_2SO_4 or $NaCO_3$ levels. If very low chloride levels are required, mercury grade NaOH should be used.

Typical analyses for different caustic qualities are given in Table 15.

4. Ammonia: NH_3 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 NH_3. 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.

5. Sodium Carbonate: $NaCO_3$ (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 Na_2SO_4 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.

6. 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.

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 SO_4^{--} in solutions happens, however, only in more diluted solutions. Figures 11 and 12 give the proportions of non-ionized H_2SO_4, the partially ionized acid (HSO_4^-) and proportions of the fully ionized acid (SO_4^{--}) as functions of the acid concentration.

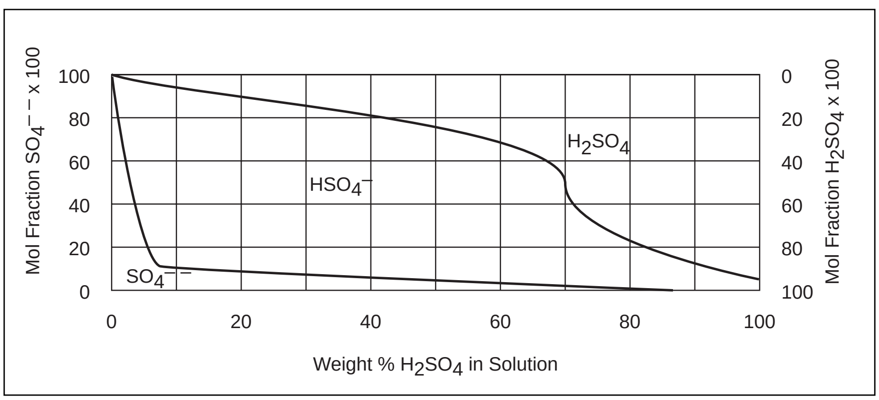
Table 16. Recommended Maximum Impurity Levels for NaCl

	Recommended Max. Impurity Levels
SO_4^{--}	1%
$Mg^{+++}Ca^{++}$	0.5%

Table 17. Concentration of NaCl and Process Used

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

Figure 11. Ionization of Sulfuric Acid



1. 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).

2. 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.

3. 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^{--}) in the solution. The proportions of the different species at different pH values can be established from Figure 15.

Figure 12. Ionization of Diluted H_2SO_4 Solutions at 25°C (77°F)

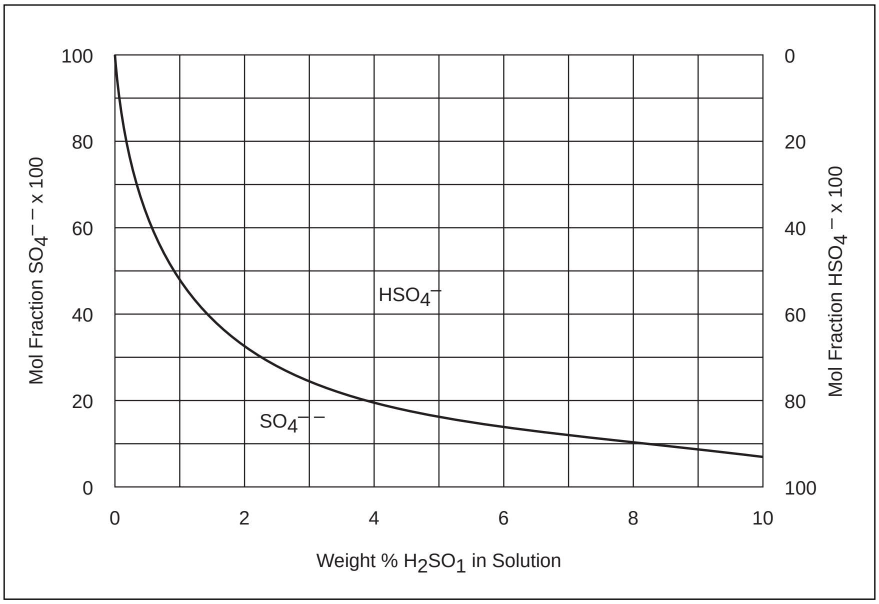


Figure 13. Sulfate/Bisulfate Equilibrium as Function of pH at 25°C (77°F)

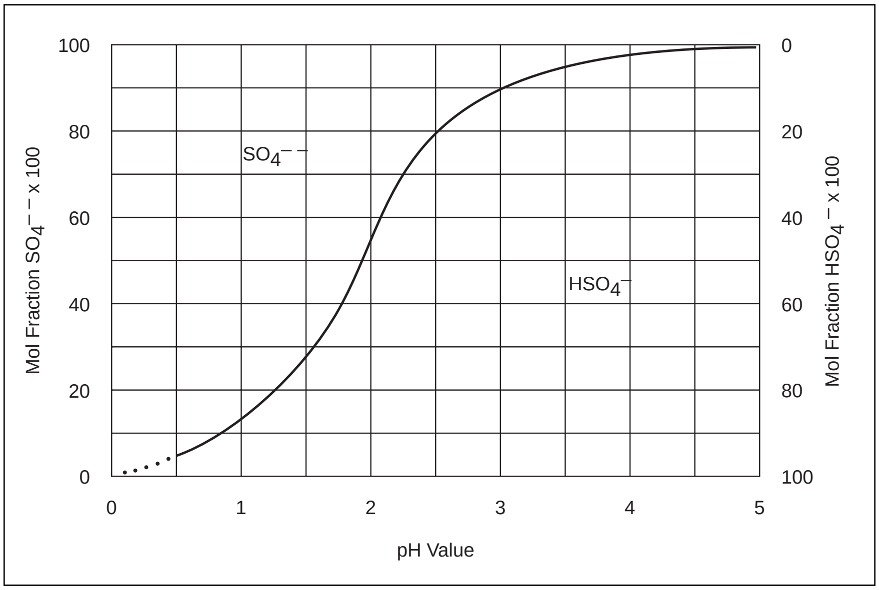


Figure 14. Ionization of Diluted Ammonia Solutions as Function of the pH at 25°C (77°F)

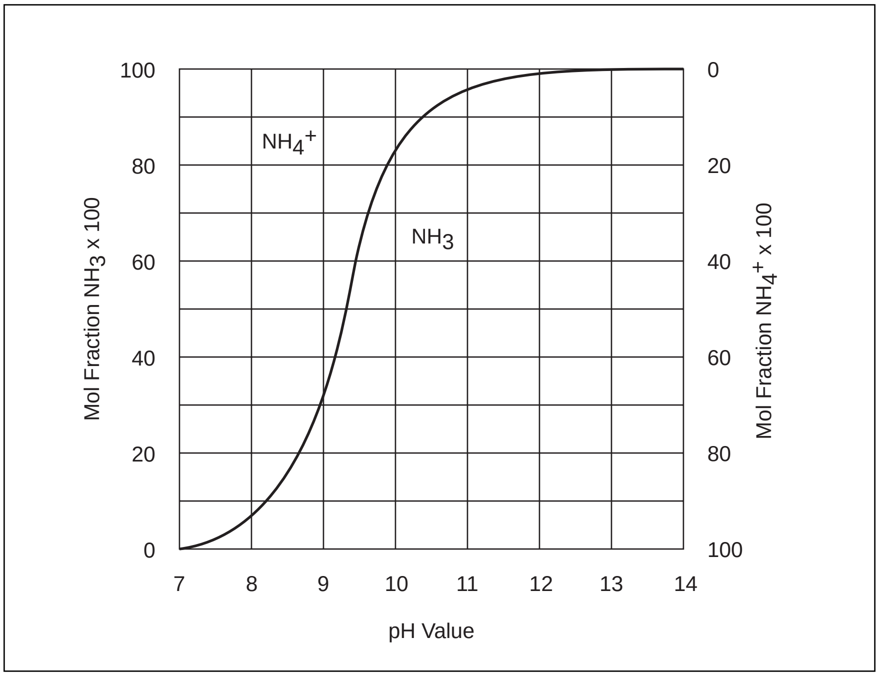
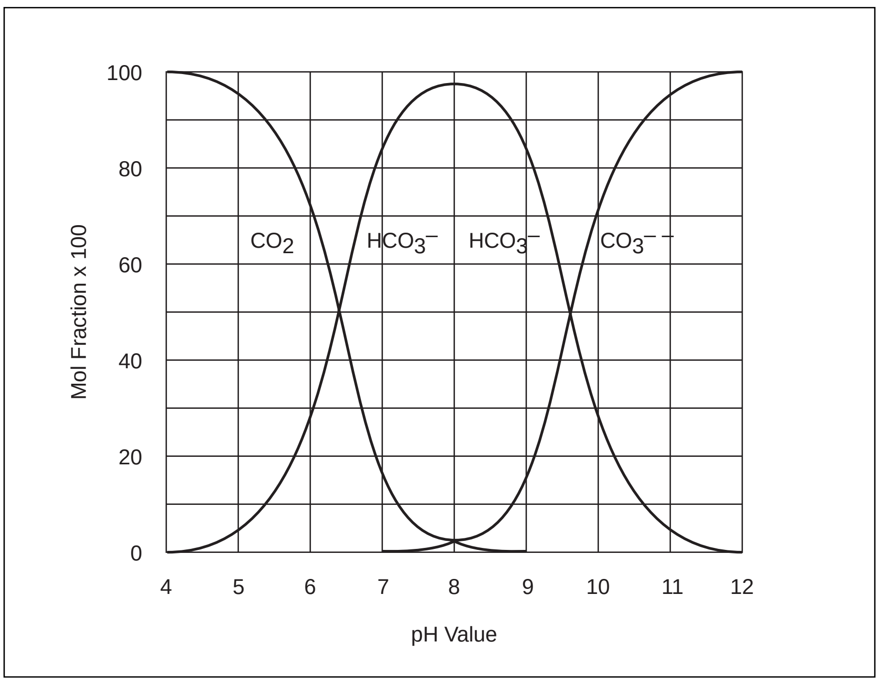


Figure 15. Ionization of Carbon Dioxide Solutions as Function of the pH at 25°C (77°F)



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

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	0.5
1	10.03	0.274	0.084	1.003	0.7
1.5	15.09	0.413	0.13	1.006	1.0
2	20.16	0.552	0.17	1.008	1.3
2.5	25.28	0.692	0.22	1.01 1	1.7
3	30.39	0.833	0.25	1.013	2.0
3.5	35.53	0.973	0.30	1.015	2.3
4	40.72	1.12	0.34	1.018	2.7
5	51.15	1.40	0.43	1.023	3.3
6	61.68	1.69	0.50	1.028	4.0
7	72.31	1.98	0.60	1.033	4.7
8	83.04	2.28	0.69	1.038	5.4
9	93.87	2.57	0.78	1.043	1
10	104.8	2.87	0.87	1.048	7
12	127.0	3.48	1.04	1.058	8.0
14	149.5	4.10	1.22	1.068	9.3
16	172.5	4.73	1.46	1.078	10.5
18	195.8	5.37	1.65	1.088	1 1.8
20	219.6	02	1.83	1.098	13.0
22	243.8	68	2.0	1.108	14.2
24	268.6	7.36	2.2	1.1 19	15.4
26	293.5	8.04	2.5	1.129	15
28	318.9	8.74	2.68	1.139	17.7
30	344.7	9.44	2.88	1.149	18.7
32	370.9	10.16	3.07	1.159	19.8
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 H_2SO_4 Solutions

Concentration g H_2SO_4/100 g solution weight %	Concentration g H_2SO_4/l	Concentration eq/l	Concentration lbs/gal.	Density kg/l	Density ° Baumé
0.5	5.01	0.102	0.042	1.002	0.6
1	10.05	0. 205	0.084	1.005	0.9
1.5	15.12	0.309	126	1.008	1.3
2	20.24	0.413	0.169	1.012	1.9
3	30.54	0.623	0.255	1.018	2.8
4	41.00	0.837	0.342	1.025	3.6
5	51.60	1.05	0.43	1.03 2	4.6
6	62.34	1.27	0.52	1.039	5.5
7	73.15	1.49	0.61	1.045	5
8	84.16	1.72	0.70	1.052	7.3
9	95. 31	1.95	0.796	1:059	8.1
10	106	2.18	0.89	1.066	9.0
12	129.6	2.64	1.07	1.080	10.8
14	153.3	3.13	1.24	1.095	12.6
16	177.4	3.62	1.52	1.109	14.3
18	202.5	4.13	1.71	1.125	10
20	228.0	4.65	1.90	1.140	17.7
30	365.7	7.46	2.9	1.219	20
35	439.6	8.97	4.2	1.256	29.7
40	521.2	10.6	5.0	1.303	33.5
45	607.1	12.4	5.8	1.349	37.4
50	697.5	14.2	6.5	1.395	41.1
55	794.8	12	7.5	1.445	44.5
60	899.4	18.4	8.4	1.499	48.1
65	1010	20.6	9.2	1.553	51.4
70	1127	23.0	9.9	1.610	54.7
75	1252	25.5	11.1	1.669	57.9
80	1382	28.2	11.9	1.727	60.8
85	1511	30.8	12.6	1.777	63.4
90	1634	33.3	13.3	1.815	64.9
92	1678	34.2	14.0	1.824	65.3
94	1720	35.1	14.4	1.830	65.6
96	1763	30	14.7	1.836	66
98	1799	37	15.0	1.836	66
100	1831	374	15.3	1 831	65.6

Table 20. Concentration and Density of NaOH Solutions

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	126	0.042	1.004	0. 8
1	10.10	0.253	0.084	1.010	1.5
1.5	15.2	0.381	0.13	1.015	2.3
2	20.4	0.510	0.17	1.021	3.0
2.5	25.7	0.641	0.22	1.026	3.7
3	31.0	0.774	0.26	1.03 2	4.6
3.5	33	0.907	0.30	1.038	5.4
4	41.7	1.04	0.35	1.043	5.9
5	52.7	1.32	0.44	1.054	7.3
6	63.9	1.60	0.53	1.065	8.9
7	75.3	1.88	0.63	1.076	10.1
8	89	2.17	0.73	1.087	11.5
9	98. 8	2.47	0.825	1.098	12.9
10	110.9	2.77	0.925	1.109	14.2
12	135.7	3.39	1.1	1.131	17
14	161.4	4.03	1.4	1.153	19.2
16	188.0	4.70	1.65	1.175	21.6
18	215.5	5.39	1.9	1.197	23.9
20	243.8	09	2.1	1.219	20
30	398.3	9.96	3.65	1.328	35.8
40	571.9	14.3	5.0	1.430	43.5
50	762.7	19.1	6.37	1.525	49.8

Table 21. Concentration and Density of NH_3 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	0.95 8	12
12	114.0	70	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	1 1.5
14	154.1	2.64	1.29	1.101	13.4
16	178.6	3.06	1.49	1.1 16	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 Na_2CO_3 Solutions

Concentration g Na_2CO_3/100 g solution weight %	Concentration g Na_2CO_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	5 2.5	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	1 1.0
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-H_2O Solution (0 to 100°C) in g/ml

Table 24 shows the specific gravity of NaOH-H_2O solution.

13. Solubility of $CaSO_4$

$CaSO_4$ is only very slightly soluble in water. Its solubility is increased in diluted sulfuric acid; however, $CaSO_4$ 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).

Table 24. Specific Gravity NaOH-H_2O Solution (0 to 100°C) in g/ml

Concentration NaOH g/100 g solution	Temperature °C										
	0	10	20	30	40	50	60	70	80	90	100
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	1.01 15
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	1.075 8	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	1.1 195	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

Figure 16. Solubility of $CaSO_4$ in Solutions of Sulfuric Acid in Water

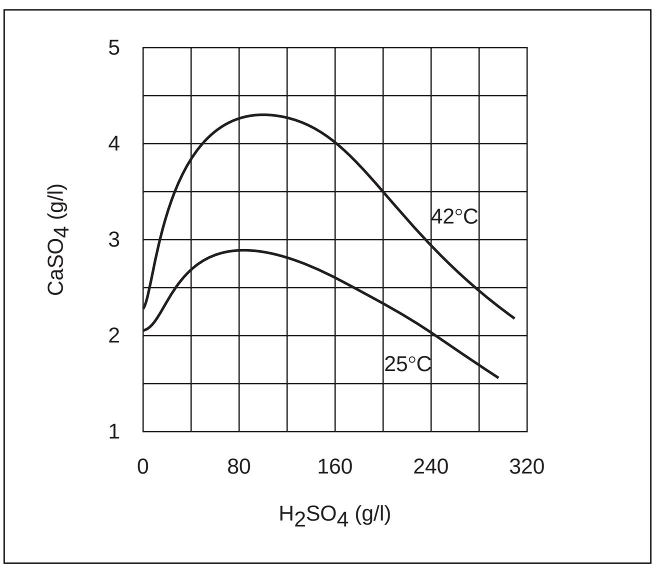
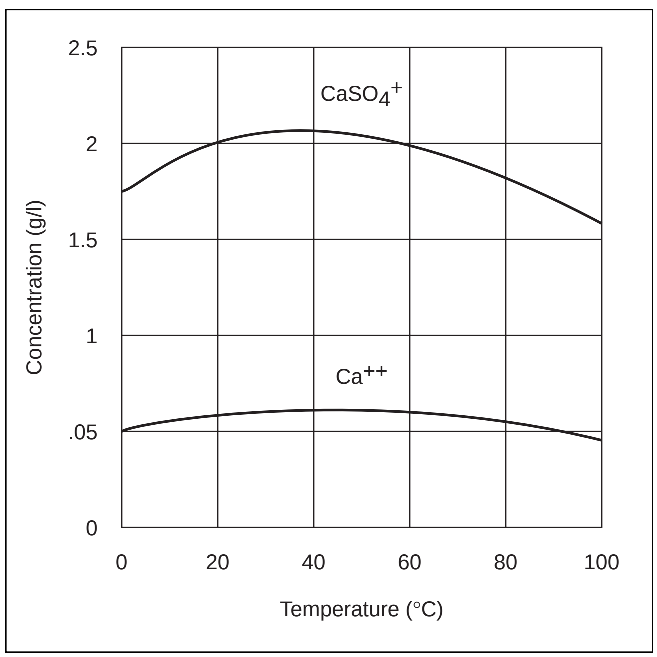


Figure 17. Solubility of $CaSO_4$ at Different Temperatures in Water



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:

$2\ Na_2SO_3 + O_2$! $2Na_2SO_4$

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.

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:

$Na_2SO_3 + Cl_2 + H_2O$! $2HCl + Na_2SO_4$

$SO_2 + Cl_2 + H_2O$! $2HCl + H_2SO_4$

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

This leads to following amounts of reducing agents to add per 1000 liter of water for the given chlorine levels in Table 26.

Figure 18. Solubility of Oxygen in Water

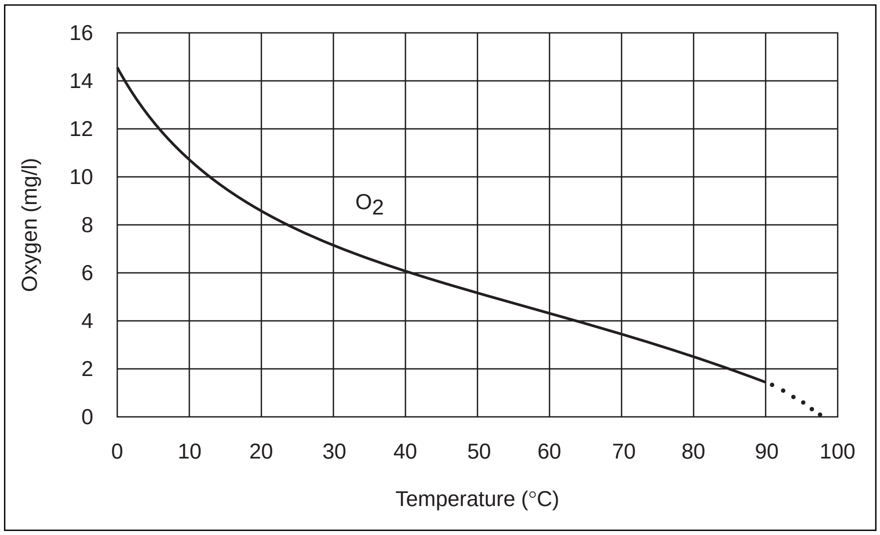


Table 25. Levels Required to Remove Dissolved Oxygen

Dissolved Oxygen		Sodium Sulfite (theoretical amount)	
cc/liter[1]	mg/l	mg/l	lbs/1000 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.

Table 26. Levels Required for Removal of Chlorine

Cl_2	Na_2SO_3 (theoretical amount)		SO_2 (theoretical amount)	
mg/l	g/1000 l	lbs/1000 gal.	g/1000 l	lbs/1000 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.

17. Osmotic Pressure of Solutions

Figure 20 shows the osmotic pressure of solutions.

Figure 19. Osmotic Pressure of Sodium Chloride

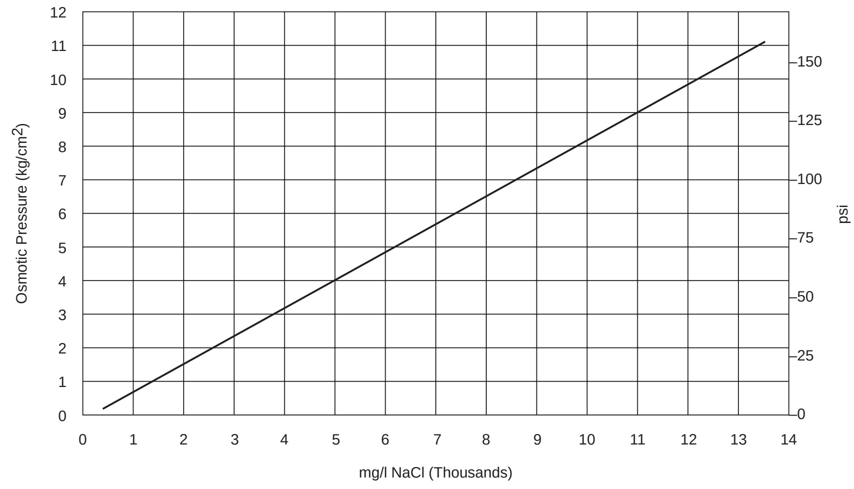
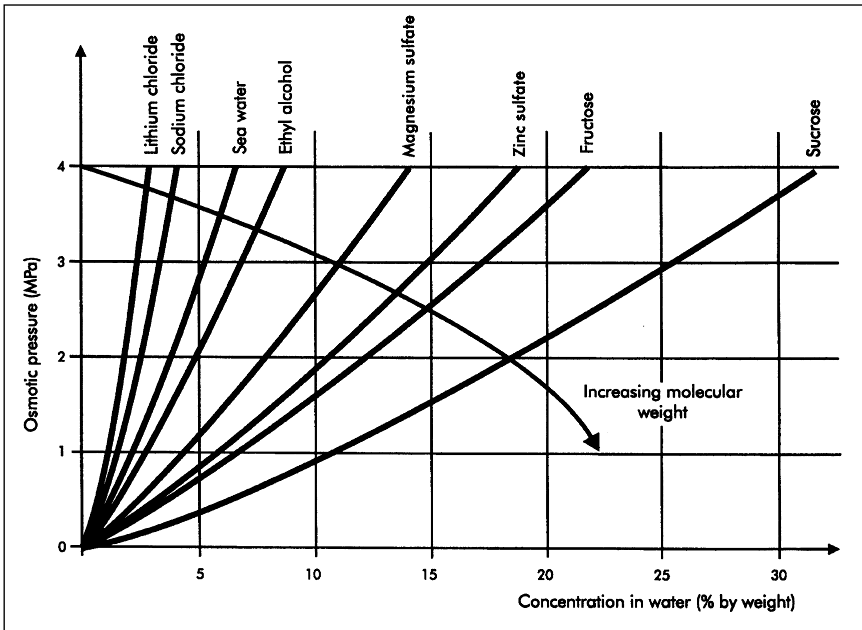


Figure 20. Osmotic Pressure of Solutions



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	1071	4.6	16.6
14'0"	153.9	1152	4.8	18.1
14'6"	165.1	1235	5.0	19.6
15'0"	176.7	1322	5.2	21.2

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WARNING: Oxidizing agents such as nitric acid attack organic ion exchange resins under certain conditions. This could lead to anything from slight resin degradation to a violent exothermic reaction (explosion). Before using strong oxidizing agents, consult sources knowledgeable in handling such materials.

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