1.85 WATER AND WASTEWATER TREATMENT ENGINEERING
HOMEWORK 5

Question 1 (4 points)

The water defined by the analysis given below is to be softened by excess-lime (and soda ash) treatment.

a. Sketch an meq/L bar graph (1 point).
b. Calculate the softening chemicals required (3 points).
c. Draw a bar graph for the softened water after recarbonation and filtration, assuming that 80% of the alkalinity is in the bicarbonate form (1 point).

CO_2	8.8 mg/L		
Ca^{2+}	40.0 mg/L	ALK (HCO_3^-)	135 mg/L
Mg^{2+}	14.7 mg/L	SO_4^{2-}	29.0 mg/L
Na^+	13.7 mg/L	Cl^-	17.8 mg/L

ANSWER – See solution to follow

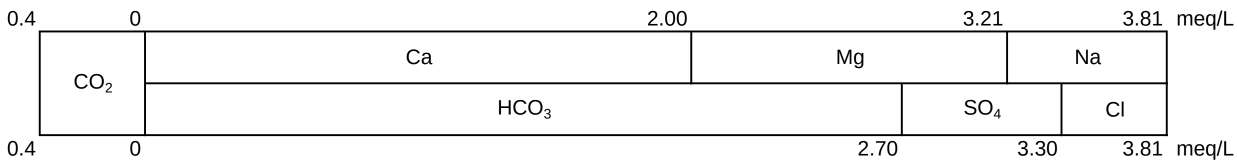
Solution for Homework 5, Problem 1

Cations					Anions				
Ion	MW	Charge	Conc (mg/L)	Equiv. (meq/L)	Ion	MW		Conc (mg/L)	Equiv. (meq/L)
CO_2	44	2	8.8	0.40					
Ca^{2+}	40	2	40	2.00	Alk (HCO_3^-)	50	1	135	2.70
Mg^{2+}	24.3	2	14.7	1.21	SO_4^{2-}	96	2	29	0.60
Na^+	23	1	13.7	0.60	Cl^-	35.5	1	17.8	0.50

Check charge balance:

Total cations: 3.81 Total anions: 3.81

a. Sketch an meq/L bar graph



Note: scale is approximate but numbers are accurate to two digits.

Hardness =	3.21	meq/L	160	mg/L as $CaCO_3$
Strong bases =	3.81	meq/L	190	mg/L as $CaCO_3$
Strong acids =	1.11	meq/L	55	mg/L as $CaCO_3$
Alk =	2.70	meq/L	135	mg/L as $CaCO_3$
Carb hardness =	2.70	meq/L	135	mg/L as $CaCO_3$
Ca carb hardness =	2.00	meq/L	100	mg/L as $CaCO_3$
Mg carb hardness =	0.71	meq/L	36	mg/L as $CaCO_3$
Non-carb hardness =	0.51	meq/L	25	mg/L as $CaCO_3$
Mg NCH =	0.51	meq/L	25	mg/L as $CaCO_3$

b. Calculate the softening chemicals required

Lime requirement:

Component		mg/L as $CaCO_3$	meq/L	Lime as $CaCO_3$	
Lime for CO_2	CO_2	20	0.40	20	
Lime for Ca CH	$Ca(HCO_3)_2$	100	2.00	100	
Lime for Mg CH	$Mg(HCO_3)_2$	36	0.71	71	*
Lime for non-carb hardness	NCH	25	0.51	25	
Total lime needed	Total	181	3.62	216	

Total lime as CaO	121	mg/L as CaO
Plus excess lime	35	mg/L as CaO
Total lime including excess	156	mg/L as CaO

* Note Mg carbonate hardness requires double lime dose

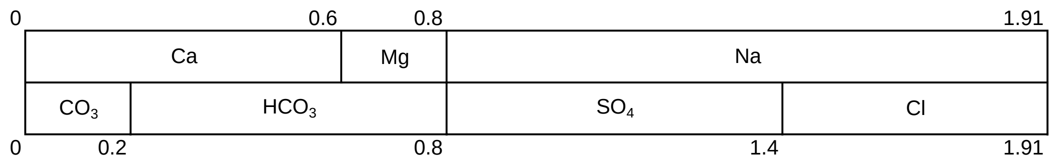
Solution for Homework 5, Problem 1

Soda ash requirement:

Component		mg/L as $CaCO_3$	meq/L	Soda as $CaCO_3$
Soda for non-carb hardness	NCH	25	0.51	25
Total soda ash needed	Total	25	0.51	25

Total soda ash as Na_2CO_3 27 mg/L as Na_2CO_3

c. Draw a bar graph for the softened water after recarbonation and filtration, assuming that 80% of the alkalinity is in the bicarbonate form



Question 2 (2 points)

A small community has used an unchlorinated ground-water supply containing approximately 0.3 mg/L of iron and manganese for several years without any apparent iron and manganese problems. A health official suggested that the town install chlorination equipment to disinfect the water and provide a chlorine residual in the distribution system. After initiating chlorination, consumers complained about water staining washed clothes and bathroom fixtures. Explain what is occurring due to chlorination.

ANSWER: Chlorine is a strong oxidizer and is oxidizing the iron and the manganese. The oxidized iron and manganese is relatively insoluble and forms precipitates. These precipitates cause the stains on fixtures and laundry. Apparently, before chlorination, the iron and manganese remained dissolved or as fine colloids and passed through the system without causing problems.

Question 3 (2 points)

A wastewater containing phenol at a concentration of 0.4 mg/L is to be treated by granular activated carbon. Batch tests have been performed in the laboratory to determine the relative adsorption of phenol by GAC. Testing entails adding a mass of carbon to V = 1 liter of the 0.4 mg/L-solution, allowing the solution to reach equilibrium over 6 days, and then measuring the resulting equilibrium concentration of phenol. Results are shown in the table below. Develop a Freundlich isotherm to fit these data.

Mass of carbon, M (gm)	Initial conc., C_0 (mg/L)	Equilibrium conc C_e (mg/L)
0.52	0.400	0.322
2.32	0.400	0.117
3.46	0.400	0.051
3.84	0.400	0.039
4.50	0.400	0.023
5.40	0.400	0.012
6.67	0.400	0.0061
7.60	0.400	0.0042
8.82	0.400	0.0023

Answer: From spreadsheet calculation:

Data tabulation:

Mass of carbon, M	Initial conc. C_0	Equil. conc C_A	C_0-C_A	V * (C_0 - C_A)	q_A = V (C_0 - C_A) / M	log C_A	log q_A
(g)	(mg/L)	(mg/L)	(mg/L)	(mg)	(mg/g)		
0.52	0.4	0.322	0.078	0.078	0.150	-0.492	-0.824
2.32	0.4	0.117	0.283	0.283	0.122	-0.932	-0.914
3.46	0.4	0.051	0.349	0.349	0.101	-1.292	-0.996
3.84	0.4	0.039	0.361	0.361	0.094	-1.409	-1.027
4.5	0.4	0.023	0.377	0.377	0.084	-1.638	-1.077
5.4	0.4	0.012	0.388	0.388	0.072	-1.921	-1.144
6.67	0.4	0.0061	0.3939	0.3939	0.059	-2.215	-1.229
7.6	0.4	0.0042	0.3958	0.3958	0.052	-2.377	-1.283
8.82	0.4	0.0023	0.3977	0.3977	0.045	-2.638	-1.346
Mass of adsorbent		Liquid phase concentration	Change in conc. in water	Mass adsorbed to carbon	Solid phase concentration		

Data are plotted below and fall more or less on a straight line. Determine approximate slope from first and last points on line: (Note that linear regression would be more accurate.)

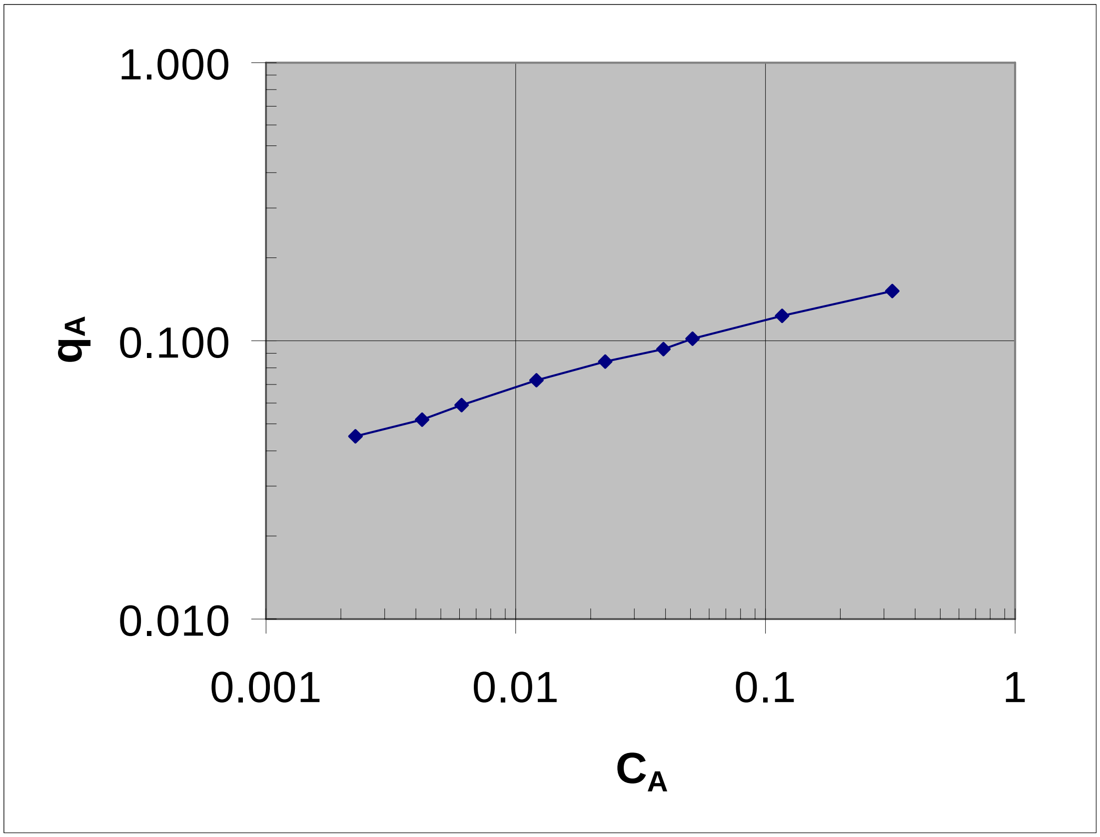
Slope = 1/n = [(log $q_{A,max}$) - log ($q_{A,min}$)]/[log($C_{A,max}$)-log($C_{A,min}$)]

1/n = 0.243

Next determine $K_F = q_A / C_A^{/n}$ for each data point and find average K_F value:

Mass of carbon, M	Equil. conc C_A	q_A = V(C_0-C_A)/M	$K_F = q_A/C_A^{1/n}$
(g)	(mg/L)	(mg/g)	
0.52	0.322	0.150	0.198
2.32	0.117	0.122	0.206
3.46	0.051	0.101	0.208
3.84	0.039	0.094	0.207
4.5	0.023	0.084	0.210
5.4	0.012	0.072	0.211
6.67	0.0061	0.059	0.204
7.6	0.0042	0.052	0.197
8.82	0.0023	0.045	0.198
		Average =	0.204

Data plot:



Question 4 (2 points)

An ion exchange resin is used to remove nitrate from a water supply with the ionic concentrations shown below. The total resin capacity is 1.5 equivalents per liter of resin.

Cations	meq/L
Ca^{2+}	1.4
Mg^{2+}	0.8
Na^{+}	2.6

Anions	meq/L
SO_4^{2-}	0.0
Cl^{-}	3.0
NO_3^{-}	1.8

d. Do the anions and cations balance? (1 point).

e. What volume of water can be treated with each liter of resin? (2 points)

f. Qualitatively, how would your answer differ if the concentrations of Cl^{-} and SO_4^{-} were reversed? (1 point).

Answer:

a. Σcations = 4.8 meq/L
Σanions = 4.8 meq/L Charges balance!.

b. Each liter of resin can remove 1.5 equivalents. Only chloride is present in quantity and nitrate is well above chloride in ion exchanger preference series shown in lecture, therefore can ignore exchange of ions other than nitrate:

Concentration of nitrate = 1.8×10^{-3} eq/L

Volume treated = 1.5 eq / 1.8×10^{-3} eq/L = 833 liters

c. Since SO_4 is above NO_3 in the preference series, if SO_4 were present rather than Cl, SO_4 would be adsorbed instead of NO_3. There were would be far less, if any, NO_3 adsorption. Another resin or much greater amount of resin would be needed.