

# Seneca College BES 706

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## 1 – Municipal Water Supply and Waste Water Treatment

### SAQ 1.1: pH and hydrogen ion concentration

- 1.) What is the concentration of hydrogen ions in moles/L when the pH is 5?
- 2.) How many times more acidic is a solution with pH 5 than a solution with pH 8?
- 3.) Basic or alkaline solutions have a pH greater than what number?

*Solution:*

1. pH is  $-\log[H^+]$  where  $[H^+]$  is the hydrogen ion concentration in moles/L. Therefore, when pH = 5,  $[H^+] = \log^{-1}(5) = 10^{-5}$  moles/L or 0.00001 moles/L.
2. It follows that  $[H^+] = 10^{-8}$  when the pH is 8. Therefore the ratio of  $[H^+]$  at pH 5 to that at pH 8 is  $10^{-5}/10^{-8} = 10^3$  or 1,000. That is the pH 5 solution is 1,000 times as acidic as the pH 8 solution.
3. A solution is basic or alkaline when its pH is greater than 7.

### SAQ 1.2: Some Basic Chemistry

- 1.) Give a few examples of common inorganic compounds and common organic compounds.
- 2.) How would you expect inorganic and organic compounds to compare to each other in terms of their solubility in water?
- 3.) If Calcium (Ca) is a positive ion in water, what would you expect its electrical charge to be?
- 4.) What does the formula  $CaCO_3$  mean?

*Solution:*

- 1.) Inorganic compounds are comprised of metallic and non-metallic ions. Some examples are:
  - common salt, sodium chloride  $NaCl$
  - calcium chloride, sometimes used to melt road ice in the winter,  $CaCl_2$
  - hydrogen chloride gas, which in solution is hydrochloric acid,  $HCl$
  - caustic soda or sodium hydroxide,  $NaOH$ .

Organic compounds are covalently bonded compounds based on a carbon skeleton. Some examples are

- sugar or sucrose,  $C_{12}H_{22}O_{11}$
- ethanol,  $C_2H_5OH$
- methyl alcohol or methanol,  $CH_3OH$
- phenol,  $C_6H_5OH$
- urea,  $NH_2CONH_2$

- 2.) The general rule is “like dissolves like”; that is water, having an ionic character, tends to dissolve inorganic compounds that are ionic in character, but tends not to dissolve most organic compounds (a notable exception being the alcohols because of their OH groups).

3.) Ca is doubly positive as an ion, that is  $\text{Ca}^{++}$ .

4.) The formula  $\text{CaCO}_3$  indicates that one  $\text{Ca}^{++}$  ion is combined with one  $\text{CO}_3^{-2}$  (or carbonate) ion, which has a charge of -2.

### SAQ 1.3: Alkalinity Calculation

A given water has alkalinity measured as  $P = 300$  ppm and  $M = 400$  ppm. What are the hydroxide alkalinity, the carbonate alkalinity and the bicarbonate alkalinity in this water?

*Solution:*

Based on Table 1.3, we see that  $P > \frac{1}{2} M$ , and therefore:

Relationship between P and M	Hydroxide ( $\text{OH}^-$ ) Alkalinity is	Carbonate ( $\text{CO}_3^{-2}$ ) Alkalinity is	Bicarbonate ( $\text{HCO}_3^-$ ) Alkalinity is
When $P = 0$	0	0	M
When $P = M$	M	0	0
When $P = \frac{1}{2} M$	0	$> 2 \times P$	0
When $P < \frac{1}{2} M$	0	$2 \times P$	$M - 2 \times P$
When $P > \frac{1}{2} M$	$2 \times P - M$	$2 \times (M - P)$	0

$$\text{OH}^- = 2P - M = 2 \times 300 - 400 = 200 \text{ ppm}$$

$$\text{CO}_3^{-2} = 2(M - P) = 2 \times 100 = 200 \text{ ppm}$$

$$\text{HCO}_3^{-1} = 0$$

## 2 – The Effects of Water Contaminants

### SAQ 2.1: Atoms, Elements and Compounds

- 1.) What are the main components of an atom?
- 2.) What is the Periodic Table of the elements, and how is it organized?
- 3.) Define the term “chemical compound”.
- 4.) What is an ion? How are the two main types of ions distinguished from one another?

*Solution:*

1.) An atom consists of a positive nucleus, containing electrically positive protons and electrically neutral neutrons, surrounded by negatively charged electrons.

2.) The Periodic Table of the elements is a listing of all the chemical elements in order of their atomic numbers, which is equal to the number of protons in their nuclei. The table is organized in columns of elements (called “groups”) that are chemically similar due to the similarity in the structure of their

outermost electrons; and in rows (called “periods”) which are elements that from left to right have their outer electron orbitals filled.

3.) A chemical compound is a substance comprised of two or more chemically bonded elements in a fixed proportion that determines the composition of the substance.

4.) An ion is an atom or chemically bonded group of atoms that has lost or gained one or more electrons, so that there is an excess of negative charge (in the case of negative “anions”) or deficiency (in the case of positive “cations”).

### SAQ 2.2: Metal loss in corrosion

1.) What are the essential components of a corrosion cell?

2.) At which electrode in a corrosion cell is metal lost or destroyed? Why?

3.) What is the direction of electron flow in a corrosion cell?

*Solution:*

1.) A corrosion cell must have:

- an **anode**

- a **cathode**

- and a conductive path between the anode and the cathode in the metal and external to the metal through an electrolyte.

2.) Metal is lost or destroyed at the anode, at which metal atoms lose electrons to go into solution as positive ions (cations) in a reaction called **oxidation**

3.) Electrons flow through the metal from the anode to the cathode.

### SAQ 2.3: Effect of dissolved solids

Why do you suppose more dissolved solids would tend to increase the rate of corrosion?

*Solution:*

The rate of corrosion is controlled by a number of factors, including the conductivity of the electrolyte. The more ions in solution, the greater is the conductivity. Therefore, more dissolved solids, since they contribute more ions in solution, increases the conductivity of the electrolyte and therefore the rate of corrosion.

### SAQ 2.4: Unit Conversion

Given that one imperial gallon of water weighs 10.0 pounds, what is 1 grain per imperial gallon in ppm?

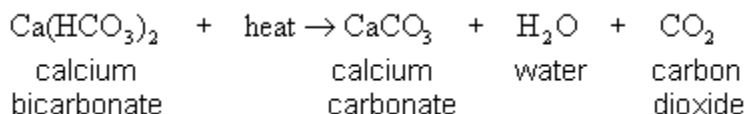
*Solution:*

7000 grains = 1 lb.

$$\begin{aligned} 1 \frac{\text{grain}}{\text{imperial gallon}} &= \frac{1 \text{ grain}}{1 \text{ gal}} \times \frac{1 \text{ gal}}{10 \text{ lb.}} \times \frac{1 \text{ lb.}}{7000 \text{ grains}} = 1 \text{ grain per } 70,000 \text{ grains} \times \frac{1,000,000}{70,000} \\ &= 14.29 \text{ grains per million grains} = 14.29 \text{ ppm} \end{aligned}$$

### 3 – External Water Treatment Processes

#### SAQ 3.1: Reducing calcium concentration



Based on the above chemical equation why, since calcium is present in equal amounts on both sides of the equation, is the calcium concentration in solution reduced by the application of heat?

*Solution:*

Based on the equation  $\text{Ca(HCO}_3\text{)}_2 + \text{heat} \rightarrow \text{CaCO}_3 + \text{H}_2\text{O} + \text{CO}_2$  we see that heat drives the reaction from left to right. Calcium bicarbonate on the left is in solution, but calcium carbonate on the right precipitates out of solution. Therefore, in going from left to right, calcium comes out of solution thereby reducing its concentration.

#### SAQ 3.2: Anions and Cations

- 1.) In general terms, what is a cation? Similarly, what is an anion?
- 2.) What is the charge on a calcium ion? On a chloride ion?
- 3.) What does the term “valence” mean?

*Solution:*

- 1.) A cation is a positively charged ion, whereas an anion is negatively charged.
- 2.) Calcium has a charge of +2, and chloride is -1.
- 3.) Valence is the relative charge on the ion, e.g. +2 and -1 for calcium and chloride respectively.

#### SAQ 3.3: Resin Structure

- 1.) What is a polymer? Briefly explain this in terms of the kind of molecular structure exhibited.
- 2.) What is “crosslinking”? Briefly explain this in terms of the kind of molecular structure exhibited.

*Solution:*

- 1.) A polymer is a substance comprised of a large number of repeating units of the same chemical molecular structure joined together by covalent bonds, often forming a chain structure.
- 2.) “Crosslinking” is the joining together of multiple long chain polymer molecules by means of a chemical element or compound that serves as the crosslinking agent. Crosslinked polymers have very high molecular weights, and take the form of a web of long chains that are joined together side by side.

### SAQ 3.4: Transition Metals

What are “transition metals”? Give a couple of examples.

*Solution:*

The “transition metals” are the Group IB through VIIIB elements in the periodic table, consisting of metals starting in Period 4 that are having their inner electron orbitals filled. Common examples of transition metals are iron (Fe), nickel (Ni), copper (Cu) and zinc (Zn).

### SAQ 3.5: Polystyrene and Phenolic Resins

- 1.) What is polystyrene? What is the generic formula for this material?
- 2.) What is a phenolic material? What is the generic formula for this material?

*Solution:*

1. Polystyrene is a common polymer or plastic for which the basic building block is the cyclic styrene molecule,  $C_6H_5CH=CH_2$ .
2. A phenolic material is one based on the phenol molecule, which is the six carbon benzene ring with an OH group replacing one of the H atoms:  $C_6H_5OH$ .

### SAQ 3.6: Capacity Calculations

Given that US Gal.  $\times 0.833$  = Imperial Gal., calculate the total capacity for a duplex water softening system such as the one discussed above for the following:

*Solution:*

Total exchangeable ions  
= grains per imp. Gallon  
=  $200/14.3 = 13.99$  grains per imp. Gallon

Number of imperial gallons per hour =  $50 \times 60 = 3,000$  imp. Gal/hr  
Number of gallons per 4 hours =  $3,000 \times 4 = 12,000$  imp. Gallons/4 hours  
Total capacity to be exchanged between regenerations  
=  $13.99$  grains/imp. Gallon  $\times 12,000$  imp. Gallons/regeneration  
=  $167,880$  grains per regeneration  
=  $167.88$  kilograins per regeneration

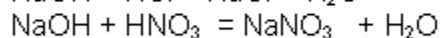
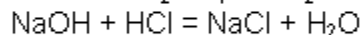
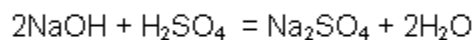
Since this is a duplex water softening system, the total capacity for the system is twice that of the one unit, or  $335.76$  kgr.

### SAQ 3.7: Neutralization

What is the neutralization reaction that occurs when caustic is used to post-treat the effluent from a hydrogen cycle softener? Answer this for all three acids discussed.

*Solution:*

The three acids in question are sulphuric,  $\text{H}_2\text{SO}_4$ , hydrochloric,  $\text{HCl}$ , and nitric  $\text{HNO}_3$ . Their neutralization reactions with caustic,  $\text{NaOH}$ , are respectively:



In each case we see a salt plus water as the products of reaction.

### SAQ 3.8: Solvents, solutes and solutions

What do the terms solvent, solute, and solution mean?

*Solution:*

A solution is a mixture of two or more substances having the same concentration throughout and consisting of a single phase (for example, and usually, a liquid). The solvent is the substance present in the larger amount, having the same state (i.e. liquid) as does the solution. The solute is the substance present in the smaller amount, which may or may not have the same state as the solution (i.e. solids and gases may be solutes, but liquids may also be the solute, as in a solution of alcohol in water).

### SAQ 3.9: Recovery rate in RO

Feedwater flow = product water flow + waste water flow

$$\% \text{ recovery} = \frac{\text{product water flow}}{\text{feed water flow}} \times 100$$

Product water = 800 L/day

As an exercise, use the same data given above except for the waste water flow. Calculate the recovery rate for a value of 600L/day.

*Solution:*

$$\% \text{ recovery} = 800/1,400 \times 100 = 57\%.$$

## 4 – Internal Water Treatment Processes

### SAQ 4.1: Anodes and Cathodes

- 1.) What type of chemical process occurs at an anode? At a cathode?
- 2.) Where does metal loss occur in a corrosion cell?
- 3.) In a single metal, what circumstances can cause an area to become anodic?
- 4.) Where there are two metals in electrical contact, which one will be anodic?

*Solution:*

- 1.) Oxidation, or the loss of electrons, occurs at an anode, and reduction, or gain of electrons, at a cathode.
- 2.) Metal loss occurs at the anode.
- 3.) Single metal corrosion occurs because some areas become anodic, due to differences in aeration within the electrolyte, the deposition of dirt, scale or other deposits on some parts of the surface, openings in protective coatings that have been applied to the metal, surface imperfections in the metal, and other causes.
- 4.) The more active metal in the galvanic series will be the anode.

### **SAQ 4.2: Concentration Calculation**

A 2,000 gallon system has been determined to have a thermofluid concentration of 35%. The desired concentration is 45%. In order to bring the system up to the desired concentration, a stock thermofluid mixture that is 75% thermofluid is available. Determine the amounts of depleted system fluid and stock thermofluid that need to be mixed together to give the required 2,000 gallons of 45% solution.

*Solution:*

Let the amount of stock thermofluid used be T gallons; therefore the amount of system fluid to be used is 2,000 – T gallons.

The amount of thermofluid in the mixture = the amount in the system fluid + the amount in the stock fluid.

$$\begin{aligned}0.45(2,000) &= 0.35(2,000 - T) + 0.75T \\900 &= 700 - 0.35T + 0.75T \\200 &= 0.4T \text{ and } T \text{ therefore} = 200/0.4 = 500 \text{ gallons.}\end{aligned}$$

That is, 1,500 gallons of depleted system fluid need to be mixed with 500 gallons of stock thermofluid.

### **SAQ 4.3: Latent and Sensible Heat**

Distinguish between latent and sensible heat. What latent heat is involved in the operation of cooling towers?

*Solution:*

Latent heat is the energy gained or lost when a substance undergoes a change in state at a constant temperature, as from liquid to solid or vapour to liquid. Sensible heat is the energy gained or lost when a substance changes its temperature.

Cooling towers cool water by partial evaporation of the water into an air stream. The energy removed from the liquid is mainly the latent heat of vaporization resulting from that partial evaporation.

#### SAQ 4.4: Turnover time

Calculate the turnover time (Tt) for a recirculation rate of 6,000 USGPM and a total water volume of 10,000 US gallons.

*Solution:*

The turnover time (Tt) is the time to recirculate the system water through the entire system, and is obtained by dividing the system volume by the total recirculation rate.

Here,  $Tt = 10,000/6,000 = 1.67$  minutes.

#### SAQ 4.5: Passivation

What do we mean by “passivation” in regard to a metal that is susceptible to corrosive attack?

*Solution:*

Passive metals are resistant to corrosive attack. Metals that are ordinarily active (i.e. relatively high in the galvanic series) can be made passive by changing the nature of the exposed surface of the metal; for example, the active metal aluminum is made passive by the closely adhering, invisible aluminum oxide coating that forms on its surface under the right conditions. Other metals may require the addition of other substances to the electrolyte to cause a passive coating to form.

### 5 – Steam Boiler and Distribution systems

#### SAQ 5.1: Boiler Capacity

How much steam would be produced per hour if a steam boiler had the following operating conditions?

100 Bhp

80% operating efficiency

50% operating load.

*Solution:*

**Steam rate (E) = Bhp x 34.5 lb/hr/Bhp x % efficiency x % load**

Here, the steam rate =  $100 \text{ Bhp} \times 34.5 \text{ lb/hr/Bhp} \times 0.80 \times 0.50 = 1,380 \text{ lb./hr.}$

#### SAQ 5.2: Heat transfer and scale

What characteristic of scale is it that results in the heat transfer efficiency of a boiler tube being reduced?

*Solution:*

Scale tends to have a low thermal conductivity, and so creates an additional resistance to heat transfer.



### **SAQ 5.3 Steam losses from malfunctioning traps**

An on-line calculator for estimating steam loss and the cost of that loss is posted at <http://appserver.ittind.com/software/HSapps/trapsizes/trap.htm>.

For example, what would be the steam loss rate in lb/hr and the annual cost, assuming a cost of production of \$7.75 per 1000 lb, in a plant operating 24/7 for 40 weeks per year?

*Solution:*

Unfortunately this calculator is no longer available.

## **6 – Humidification Systems**

## **7 – Potable and Domestic Water Treatment**

## **8 – Water Treatment Control Systems**

### **SAQ 8.1: Conductivity**

What is the “conductivity” that is being used to control chemical feed and bleed-off?

*Solution:*

It is electrical conductivity that is being measured; the solution is more conductive when it has a higher concentration of dissolved solids.

### **SAQ 8.2: Boiler blowdown**

What is “blowdown”, and why is it necessary?

*Solution:*

Blowdown is the periodic discharge of liquid from the boiler. This is necessary because, as the boiler causes the evaporation of water into steam, dissolved substances do not exit from the boiler with the steam (which is essentially pure water) but rather accumulate in the liquid. As a result, the concentration of these substances—including treatment chemicals and other impurities—increases over time and must be removed periodically to maintain the desired concentration in the boiler.

## 9 – Water Efficiency

### SAQ 9.1: Water Consumption Calculation

Table 9.2: Sample Device Inventory  
LOCATION: 2nd Floor, ACME Corporation, Men's Washroom

Type of Device	Make and Model	Number of Devices	Unit Flow*
Urinal, Manual	Waltec, Wastrel	10	6 L/flush
Toilet, Tank-type	American Standard, Squanderer	5	13 L/flush
Sink, hand-wash, two-valve faucet, aerated	Delta Aquarius	10	1 L/25 seconds
Shower, two-valve	Water Pik Prodigal 1000	1	10 L/40 seconds
Washing Machine, Top Load	Kenmore Servicemaster	1	140 L/load
Urinal, Waterless	Crane P-U	1	0 L/flush

The ACME Corporation has 100 employees on site at any time, 75 men and 25 women, in a two-shift (8 hours each) 5 day per week operation. Using reasonable assumptions (make sure you state them) and the device inventory in Table 9.2, estimate water consumption per week resulting from employee washroom use.

*Solution:*

In this sample exercise, we have 75 male and 25 female employees per shift in a two-shift, 5 days/week operation. Without inquiring too deeply into the ablution habits of your colleagues, you can make some realistic assumptions about washroom use. My analysis follows:

Assume an average 3 washroom uses per person per shift, with, for male employees (if this isn't too indelicate) using urinals twice and a toilet once in those three excursions. Further, let's assume the female employees use a toilet on each visit, and that both male and female employees use the sink for hand wash for 25 seconds per visit.

So, this adds up to the following volumes:

Males: 2 urinal uses @ 6 L./use:

75 persons x 2 shifts/day x 5 days/week x 2 uses/shift x 6 L./use = 9,000 L./wk

1 toilet use per shift @ 13 L./flush

75 persons x 2 shifts/day x 5 days/week x 1 use/shift x 13 L./use = 9,750 L./wk

3 hand wash @ 1 L./use

75 persons x 2 shifts/day x 5 days/week x 3 uses/shift x 1 L./use = 2,250 L./wk

Females: 3 toilet uses @ 13 L./use plus hand wash @ 1 L./use:

25 persons x 2 shifts/day x 5 days/week x 3 uses/shift x 14 L./use  
= 10,500 L./wk

The total washroom use, then, is 31,500 L./week

### SAQ 9.2: Cooling Towers

Consider a cooling tower of rated capacity 150 tons, with total dissolved solids concentration of 1,000 mg/L in blowdown water, and a makeup water concentration of 200 mg/L. Calculate the total consumption of water (i.e. the make-up water rate) in L/min. It is proposed that blowdown be decreased to maintain a total dissolved solids concentration in the tower at 2,000 mg/L. What will be the reduction in water consumption?

*Solution:*

To answer this question, we need to calculate the water consumption under the current conditions and that under the proposed conditions, using the three relationships

$$M = B + E$$

$$CR = M/B$$

$$B = E/(CR - 1)$$

plus the “rule of thumb” between cooling load and evaporation rate, that is 11.4 L/minute per 100 tons of cooling capacity (this rule of thumb is derived from the latent heat of vaporization at typical conditions, since it is the evaporation of water that achieves the cooling effect).

Under current conditions, then:

$$\text{Evaporation rate} = 1710 \text{ L/min}$$

$$\text{Concentration ratio} = 1000/200 = 5.0$$

$$\text{Blowdown (+ drift)} = E/(CR - 1) = 1710/(5 - 1) = 427.5 \text{ L/min}$$

$$\text{Total consumption} = \text{makeup water} = 1710 + 427.5 = 2137.5 \text{ L/min.}$$

Under the proposed conditions:

$$\text{Evaporation rate is the same} = 1710 \text{ L/min}$$

$$\text{Concentration ratio} = 2000/200 = 10$$

$$\text{Blowdown (+ drift)} = E/(CR - 1) = 1710/(10 - 1) = 190 \text{ L/min}$$

$$\text{Total consumption} = \text{makeup water} = 1710 + 190 = 1900 \text{ L/min}$$

Therefore, increasing the solids concentration in the tower will result in a savings of 237.5 L/min of water. Whether or not this is a good strategy will depend on the nature of the tower and the chemicals used for treatment.

### SAQ 9.3: Cycles of Concentration

At 3 cycles of concentration, what percentage of the open recirculating system water is evaporated, and what percentage of the system water leaves the system via the bleed-off?

*Solution:*

$$BD\% = E/(C - 1) = 66.6\%/(3 - 1) = 66.6\%/2 = 33.3\%$$

That is, 33.3% of the system water leaves by bleed-off, and 66.7% by evaporation.

### SAQ 9.4: Heat Loss from Uninsulated Pipe

For a 150 psig steam system, how many million Btu/year would a 100 ft. long uninsulated 8 inch pipe lose assuming 8,760 operating hours per year?

*Solution:*

Table 9.10: Heat Loss from Uninsulated Pipe  
(US Department of Energy Industrial Technologies Program, *Steam Tip Sheets: #2, Insulate Steam Distribution and Condensate Return Lines*)

Distribution Line Diameter, inches	Heat Loss Per 100 Feet of Uninsulated Steam Line, MMBtu/yr			
	Steam Pressure, psig			
	15	150	300	600
1	140	285	375	495
2	235	480	630	840
4	415	850	1,120	1,500
8	740	1,540	2,030	2,725
12	1,055	2,200	2,910	3,920

Based on horizontal steel pipe, 75°F ambient air, no wind velocity, and 8,760 operating hours per year.

Based on the data in Table 9.10, the heat loss would be 1,540 million BTU/yr.

### SAQ 9.5: Cost of Steam Leaks

For a 100 psig steam system in which the cost of steam is \$9.00/1,000 lb., what would you estimate the effect of a ¼ inch orifice steam leak to be in terms of steam wasted per month and the cost of that steam per month?

*Solution:*

Table 9.12: Cost of Steam Leaks for 100 psig Steam @ \$5.00/1000 lb  
(Source: *The Natural Gas Boiler Burner Consortium*,  
[http://www.energysolutionscenter.org/BoilerBurner/Eff\\_Improve/Steam\\_Distribution/Steam\\_Leaks.asp](http://www.energysolutionscenter.org/BoilerBurner/Eff_Improve/Steam_Distribution/Steam_Leaks.asp))

Size of Orifice (in)	Lbs Steam Wasted Per Month	Total Cost Per Month	Total Cost Per Year
1/2	835,000	\$4,175.00	\$50,100.00
7/16	637,000	3,185.00	38,220.00
3/8	470,000	2,350.00	28,200.00
5/16	325,000	1,625.00	19,500.00
1/4	210,000	1,050.00	12,600.00
3/16	117,000	585.00	7,020.00
1/8	52,500	262.50	3,150.00

The steam loss values assume clean, dry steam flowing through a sharp-edged orifice to atmospheric pressure with no condensate present. Condensate would normally reduce these losses due to the flashing effect when a pressure drop is experienced.

According to Table 9.12, the rate of steam loss is 210,000 lb./month. At the given cost of steam, this amounts to the not insignificant sum of \$1,890 per month, for one ¼ inch leak!

**10 – Alternative Technologies**

**11 – Health, Safety and the Indoor Environment**

**S1 – Basic Chemistry**

**S2 – Properties of Steam**

**S3 – Humidity and Psychrometry**

**S4 – Water and Energy**