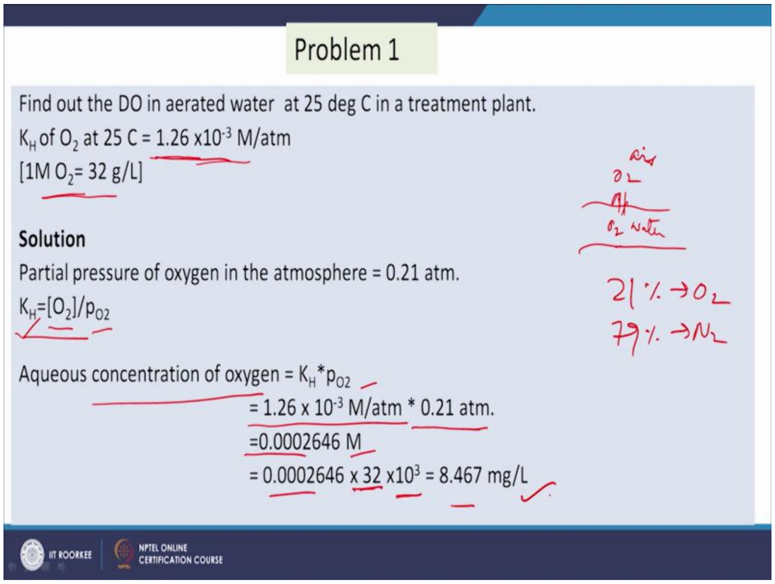
Basic Environmental Engineering and Pollution Abatement
Professor Prasenjit Mondal
Department of Chemical Engineering
Indian Institute of Technology, Roorkee
Lecture 15
Tutorial - 3

Hello everyone. Now, we will discuss on some numerical problems based on our last four classes.

(Refer Slide Time: 0:40)



Problem 1

Find out the DO in aerated water at 25 deg C in a treatment plant.

K_H of O_2 at 25 C = 1.26×10^{-3} M/atm

[1M O_2= 32 g/L]

Solution

Partial pressure of oxygen in the atmosphere = 0.21 atm.

$K_H=[O_2]/p_{O2}$

Aqueous concentration of oxygen = $K_H * p_{O2}$

= 1.26×10^{-3} M/atm * 0.21 atm.

=0.0002646 M

= $0.0002646 \times 32 \times 10^3$ = 8.467 mg/L

air

O_2

K_H

O_2 water

21% → O_2

79% → N_2

So, the first problem, the statement is find out the DO in aerated water at 25 °C in a treatment plant KH of O_2 at 25 °C is $1.26*10^{-3}$ M/atmosphere. So, K_H is the Henry's constant and molecular rate of oxygen is 32 g/L so it is given. So, we have to find out the DO in aerated water and you know that in any river stream or in aerated water so, oxygen present in air and oxygen present in water.

So, these are in equilibrium and what will be the equilibrium concentration of oxygen in water phase that is defined by this formula that is K_H is equal to concentration of oxygen in aqueous phase divided by partial pressure of oxygen in the atmosphere or in the air where the water is in contact with the air. So, this K_H is nothing but Henry's constant so, this value is given here $1.26*10^{-3}$ M/atmosphere pressure.

Therefore, we need to calculate oxygen concentration, so K_H * partial pressure of oxygen. So, we have to get this formula aqueous concentration of oxygen

Partial pressure of oxygen in the atmosphere = 0.21 atm.

$K_H=[O_2]/p_{O2}$

Aqueous concentration of oxygen = K_H*p_{O2}

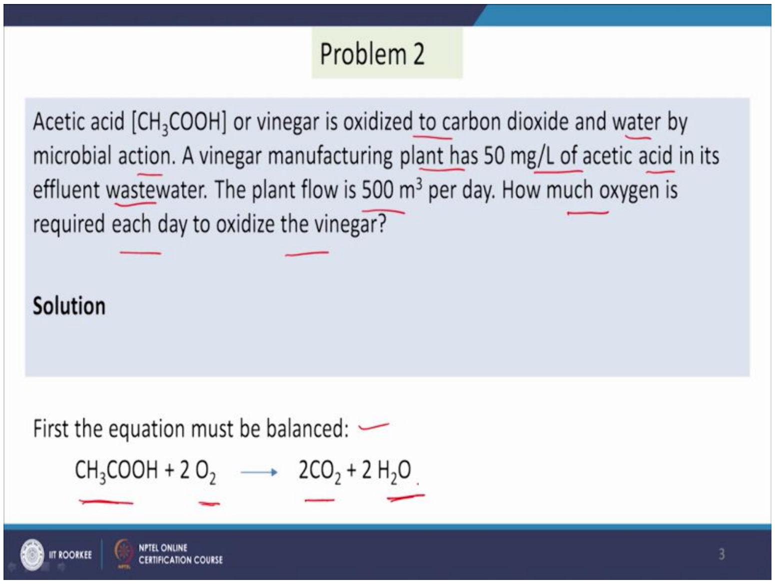
$= 1.26 \times 10^{-3}$ M/atm * 0.21 atm.

=0.0002646 M

$= 0.0002646 \times 32 \times 10^3 = 8.467$ mg/L

So now, the problem 1 is solved.

(Refer Slide Time: 3:51)



Problem 2

Acetic acid [CH_3COOH] or vinegar is oxidized to carbon dioxide and water by microbial action. A vinegar manufacturing plant has 50 mg/L of acetic acid in its effluent wastewater. The plant flow is 500 m^3 per day. How much oxygen is required each day to oxidize the vinegar?

Solution

First the equation must be balanced:

$$CH_3COOH + 2\,O_2 \longrightarrow 2CO_2 + 2\,H_2O$$

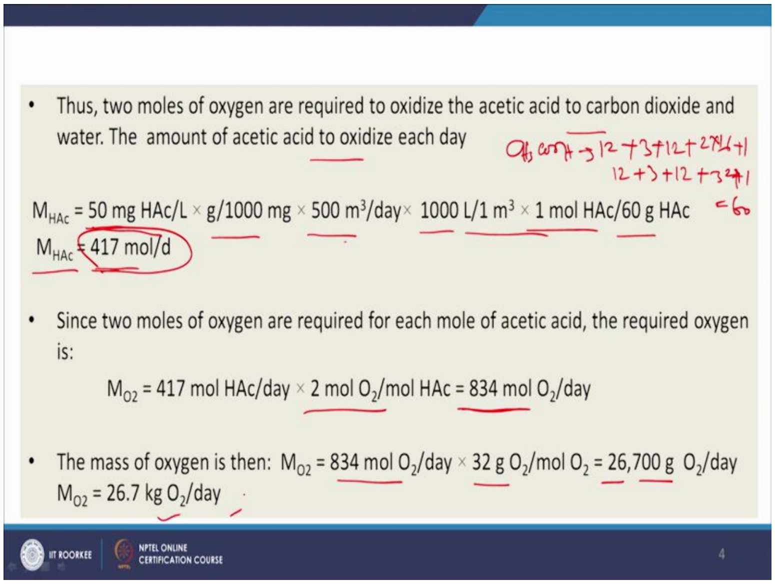
Now, we are coming to problem number 2. So the statement is, acetic acid that is CH_3COOH or vinegar is oxidized to carbon dioxide and water by microbial action. If vinegar manufacturing plant has 50 mg/L of acetic acid in its effluent wastewater, the plant flow is 500 m^3/day, how much oxygen is required each day to oxidize the vinegar? So, that we have to calculate. So we will be writing the stoichiometric equations, and then we will get the mass balance and balance the equation, then we will find out what is the oxygen requirement for the degradation of it.

So, the first the equation must be balanced

$$CH_3COOH + 2O_2 \rightarrow 2CO_2 + 2H_2O$$

So, if they get the balance, so two moles of oxygen is required to react with one mole of acetic acid to give two moles of CO_2 and two moles of H_2O.

(Refer Slide Time: 5:00)



- Thus, two moles of oxygen are required to oxidize the acetic acid to carbon dioxide and water. The amount of acetic acid to oxidize each day

$CH_3COOH \rightarrow 12+3+12+2\times16+1$
$12+3+12+32+1$
$=60$

M_{HAc} = 50 mg HAc/L × g/1000 mg × 500 m^3/day× 1000 L/1 m^3 × 1 mol HAc/60 g HAc
M_{HAc} = 417 mol/d

- Since two moles of oxygen are required for each mole of acetic acid, the required oxygen is:

  M_{O2} = 417 mol HAc/day × 2 mol O_2/mol HAc = 834 mol O_2/day

- The mass of oxygen is then: M_{O2} = 834 mol O_2/day × 32 g O_2/mol O_2 = 26,700 g O_2/day
  M_{O2} = 26.7 kg O_2/day

So, in this case, two moles of oxygen are required to oxidize the acetic acid to carbon dioxide and water that I have discussed. So, the amount thus the amount of acetic acid to oxidize each day, what will be?

M_{HAc} = 50 mg HAc/L × g/1000 mg × 500 m^3/day× 1000 L/1 m^3 × 1 mol HAc/60 g HAc

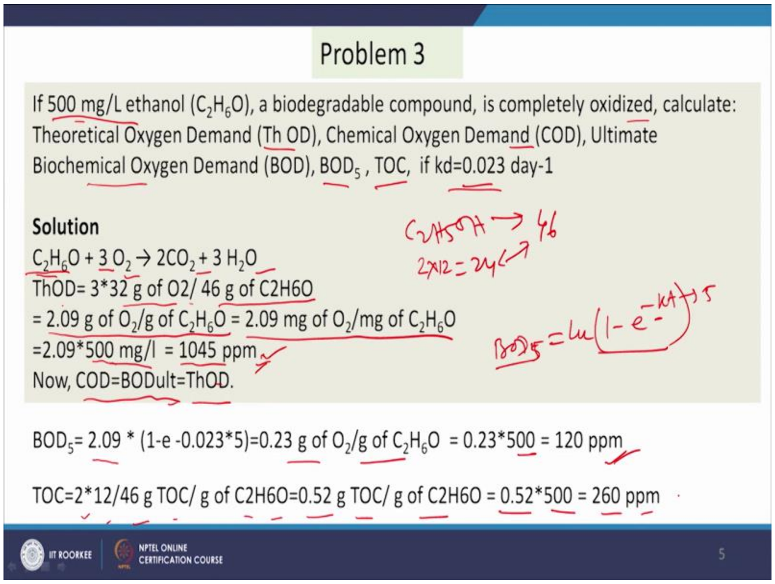
M_{HAc} = 417 mol/d

Since two moles of oxygen are required for each mole of acetic acid, the required oxygen is:

M_{O2} = 417 mol HAc/day × 2 mol O_2/mol HAc = 834 mol O_2/day

The mass of oxygen is then: M_{O2} = 834 mol O_2/day × 32 g O_2/mol O_2 = 26,700 g O_2/day M_{O2} = 26.7 kg O_2/day

(Refer Slide Time: 7:31)



Problem 3

If 500 mg/L ethanol (C_2H_6O), a biodegradable compound, is completely oxidized, calculate: Theoretical Oxygen Demand (Th OD), Chemical Oxygen Demand (COD), Ultimate Biochemical Oxygen Demand (BOD), BOD_5 , TOC, if kd=0.023 day-1

Solution

$C_2H_6O + 3\,O_2 \rightarrow 2CO_2 + 3\,H_2O$

ThOD= 3*32 g of O2/ 46 g of C2H6O

= 2.09 g of O_2/g of C_2H_6O = 2.09 mg of O_2/mg of C_2H_6O

=2.09*500 mg/l = 1045 ppm ✓

Now, COD=BODult=ThOD.

$C_2H_5OH \rightarrow 46$

$2 \times 12 = 24$

$BOD_5 = L_u(1 - e^{-kt})5$

BOD_5= 2.09 * (1-e -0.023*5)=0.23 g of O_2/g of C_2H_6O = 0.23*500 = 120 ppm ✓

TOC=2*12/46 g TOC/ g of C2H6O=0.52 g TOC/ g of C2H6O = 0.52*500 = 260 ppm

Now, problem number two is solved. Now we will see the problem number three, the statement is, if 500 mg/L ethanol a biodegradable compound is completely oxidized, calculate theoretical oxygen demand, chemical oxygen demand, ultimate biochemical oxygen demand, BOD5 and total organic carbon if kd is equal to 0.023 per day. So, we have to calculate all those things that is Th OD, COD and ultimate BOD, BOD5 and TOC.

solution

$C_2H_6O + 3O_2 \rightarrow 2CO_2 + 3\,H_2O$

So, theoretical oxygen demand we can assume that 100 percent conversions of this ethanol is possible by the oxygen. So, then what will be 1 mole ethanol request 3 mole oxygen,

ThOD= 3*32 g of O_2/ 46 g of C_2H_6O

= 2.09 g of O_2/g of C_2H_6O = 2.09 mg of O_2/mg of C_2H_6O

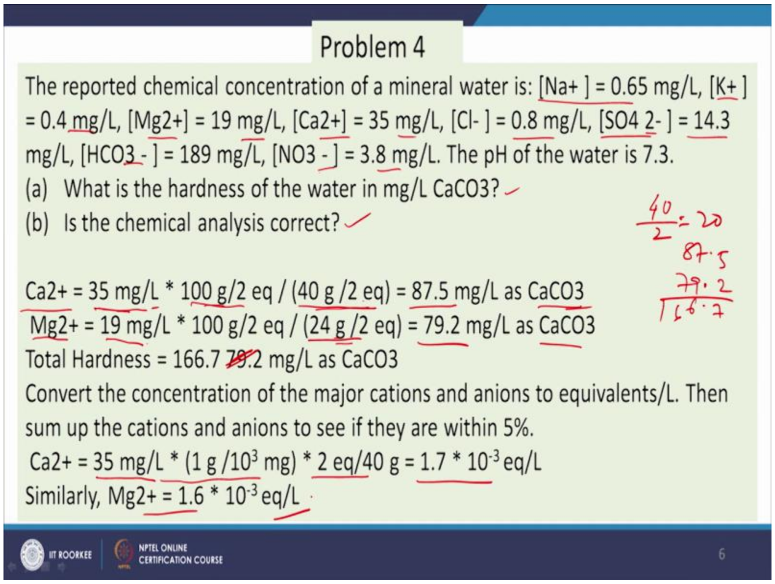
=2.09*500 mg/l = 1045 ppm

Now, COD=BODult=ThOD.

BOD_5= 2.09 * (1-e -0.023*5)=0.23 g of O_2/g of C_2H_6O = 0.23*500 = 120 ppm

TOC=2*12/46 g TOC/ g of C2H6O=0.52 g TOC/ g of C2H6O = 0.52*500 = 260 ppm

(Refer Slide Time: 12:58)



Problem 4

The reported chemical concentration of a mineral water is: [Na+] = 0.65 mg/L, [K+] = 0.4 mg/L, [Mg2+] = 19 mg/L, [Ca2+] = 35 mg/L, [Cl-] = 0.8 mg/L, [SO4 2-] = 14.3 mg/L, [HCO3 -] = 189 mg/L, [NO3 -] = 3.8 mg/L. The pH of the water is 7.3.

(a) What is the hardness of the water in mg/L CaCO3?

(b) Is the chemical analysis correct?

$\frac{40}{2} = 20$

87.5

79.2

166.7

Ca2+ = 35 mg/L * 100 g/2 eq / (40 g /2 eq) = 87.5 mg/L as CaCO3

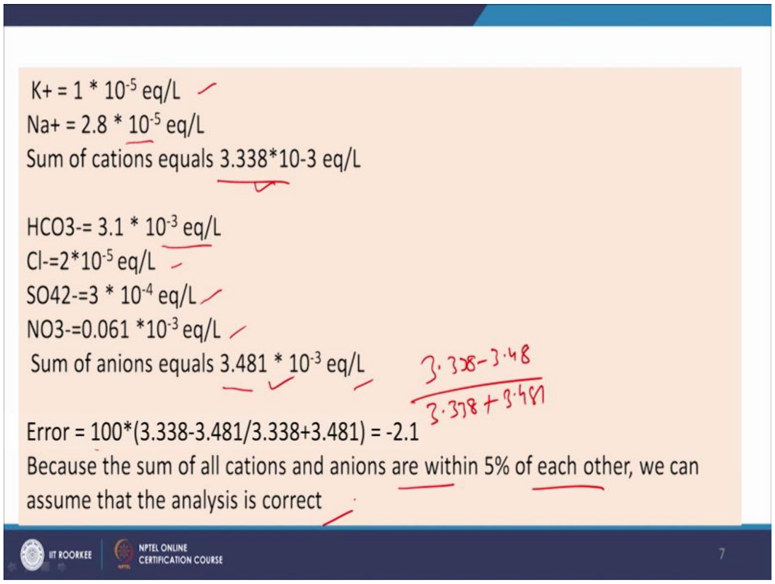
Mg2+ = 19 mg/L * 100 g/2 eq / (24 g /2 eq) = 79.2 mg/L as CaCO3

Total Hardness = 166.7 ~~79.2~~ mg/L as CaCO3

Convert the concentration of the major cations and anions to equivalents/L. Then sum up the cations and anions to see if they are within 5%.

Ca2+ = 35 mg/L * (1 g /10^3 mg) * 2 eq/40 g = 1.7 * 10^{-3} eq/L

Similarly, Mg2+ = 1.6 * 10^{-3} eq/L



K+ = 1 * 10^{-5} eq/L

Na+ = 2.8 * 10^{-5} eq/L

Sum of cations equals 3.338*10-3 eq/L

HCO3-= 3.1 * 10^{-3} eq/L

Cl-=2*10^{-5} eq/L

SO42-=3 * 10^{-4} eq/L

NO3-=0.061 *10^{-3} eq/L

Sum of anions equals 3.481 * 10^{-3} eq/L

$\frac{3.338-3.48}{3.338+3.481}$

Error = 100*(3.338-3.481/3.338+3.481) = -2.1

Because the sum of all cations and anions are within 5% of each other, we can assume that the analysis is correct

Now we will move to problem number four. The statement is the reported chemical concentration of a mineral water is sodium(Na^+) 0.65 mg/L, potassium (K^+) 0.4 mg/L, Mg^{2+} 19 mg/L, Ca^{2+} 35 mg/L Cl^- 0.8 mg/L SO_4^{2-} that is 14.3 mg/L, HCO_3^- 189 mg/L, NO_3^- = 3.8 mg/L, the pH of the water is 7.3, then what is the hardness of the water in mg/L calcium carbonate we have to calculate, we also have to calculate, we also have to see is the chemical analysis correct.

So, what we will do? We will see the error in the iron balance. So iron balance error is necessary to be calculated.

Ca^{2+} = 35 mg/L * 100 g/2 eq / (40 g /2 eq) = 87.5 mg/L as $CaCO_3$

Mg^{2+} = 19 mg/L * 100 g/2 eq / (24 g /2 eq) = 79.2 mg/L as $CaCO_3$

Total Hardness = 166.7 mg/L as $CaCO_3$

Convert the concentration of the major cations and anions to equivalents/L. Then sum up the cations and anions to see if they are within 5%.

Ca^{2+} = 35 mg/L * (1 g /10^3 mg) * 2 eq/40 g = 1.7 * 10^{-3} eq/L

Similarly, Mg^{2+} = 1.6 * 10^{-3} eq/L

K+ = 1 * 10^{-5} eq/L

Na+ = 2.8 * 10^{-5} eq/L

Sum of cations equals 3.338*10-3 eq/L

HCO_3^-= 3.1 * 10^{-3} eq/L

Cl^-=2*10^{-5} eq/L

SO_4^{2-}=3 * 10^{-4} eq/L

NO_3^-=0.061 *10^{-3} eq/L

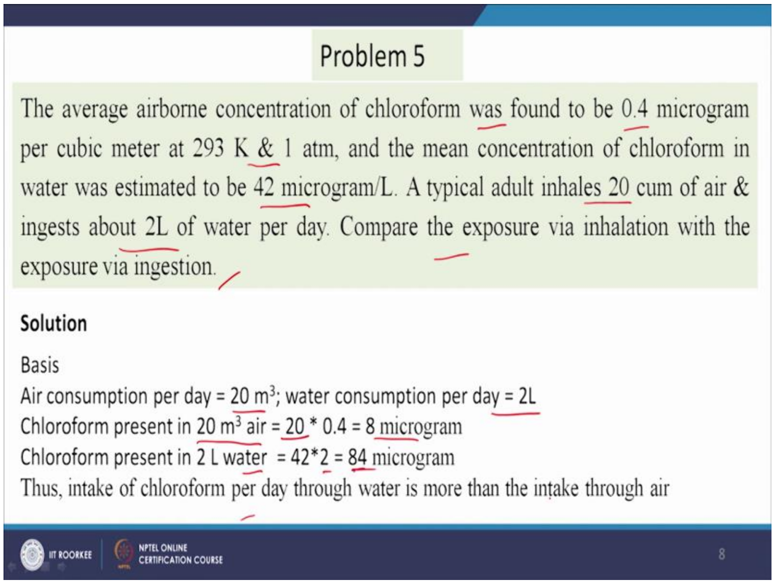
Sum of anions equals 3.481 * 10^{-3} eq/L

Error = 100*(3.338-3.481/3.338+3.481) = -2.1 %

Because the sum of all cations and anions are within 5% of each other, we can assume that the analysis is correct

So, because the sum of all cation and anions are within 5 percent of each other, we can assume that the analysis is correct.

(Refer Slide Time: 19:34)



Problem 5

The average airborne concentration of chloroform was found to be 0.4 microgram per cubic meter at 293 K & 1 atm, and the mean concentration of chloroform in water was estimated to be 42 microgram/L. A typical adult inhales 20 cum of air & ingests about 2L of water per day. Compare the exposure via inhalation with the exposure via ingestion.

Solution

Basis

Air consumption per day = 20 m^3; water consumption per day = 2L

Chloroform present in 20 m^3 air = 20 * 0.4 = 8 microgram

Chloroform present in 2 L water = 42*2 = 84 microgram

Thus, intake of chloroform per day through water is more than the intake through air

Now, we are coming to problem number five, the statement is the average airborne concentration of chloroform was found to be 0.4 microgram/ m^3 at 293K and 1 atmospheric pressure and the mean concentration of chloroform in water was estimated to be 42 microgram/L. A typical adult inhales 20 $m^3$of air and ingests about 2 litres of water per day. Compare the exposure via inhalation with the exposure via ingestion.

So now, we will see let us take a basis, so what is this?

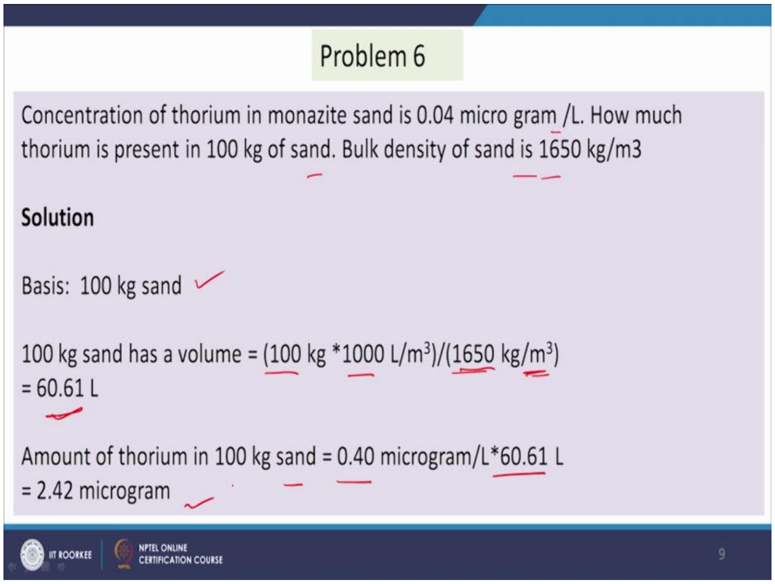
Air consumption per day = 20 m^3; water consumption per day = 2L

Chloroform present in 20 m^3 air = 20 * 0.4 = 8 microgram

Chloroform present in 2 L water = 42*2 = 84 microgram

Thus, intake of chloroform per day through water is more than the intake through air

(Refer Slide Time: 20:44)



Problem 6

Concentration of thorium in monazite sand is 0.04 micro gram /L. How much thorium is present in 100 kg of sand. Bulk density of sand is 1650 kg/m3

Solution

Basis: 100 kg sand

100 kg sand has a volume = (100 kg *1000 L/m^3)/(1650 kg/m^3)
= 60.61 L

Amount of thorium in 100 kg sand = 0.40 microgram/L*60.61 L
= 2.42 microgram

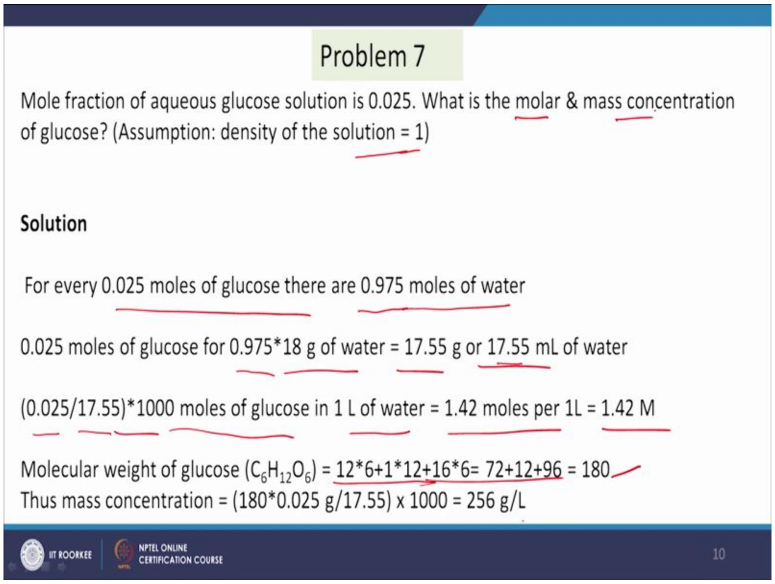
Problem number six, statement is concentration of thorium in monazite sand is 0.04 microgram/L, how much thorium is present in 100 kg of sand? Bulk density of sand is 1650 kg/m^3.

so our basis is 100 kg sand

100 kg sand has a volume = (100 kg *1000 L/m^3)/(1650 kg/m^3) = 60.61 L

Amount of thorium in 100 kg sand = 0.40 microgram/L*60.61 L = 2.42 microgram

(Refer Slide Time: 22:00)



Problem 7

Mole fraction of aqueous glucose solution is 0.025. What is the molar & mass concentration of glucose? (Assumption: density of the solution = 1)

Solution

For every 0.025 moles of glucose there are 0.975 moles of water

0.025 moles of glucose for 0.975*18 g of water = 17.55 g or 17.55 mL of water

(0.025/17.55)*1000 moles of glucose in 1 L of water = 1.42 moles per 1L = 1.42 M

Molecular weight of glucose ($C_6H_{12}O_6$) = 12*6+1*12+16*6= 72+12+96 = 180
Thus mass concentration = (180*0.025 g/17.55) x 1000 = 256 g/L

Now, we are coming to problem number seven. So, the statement is mole fraction of aqueous glucose solution is 0.025, what is the molar and mass concentration of glucose? Assumption density of the solution is 1.

For every 0.025 moles of glucose there are 0.975 moles of water

0.025 moles of glucose for 0.975*18 g of water = 17.55 g or 17.55 mL of water

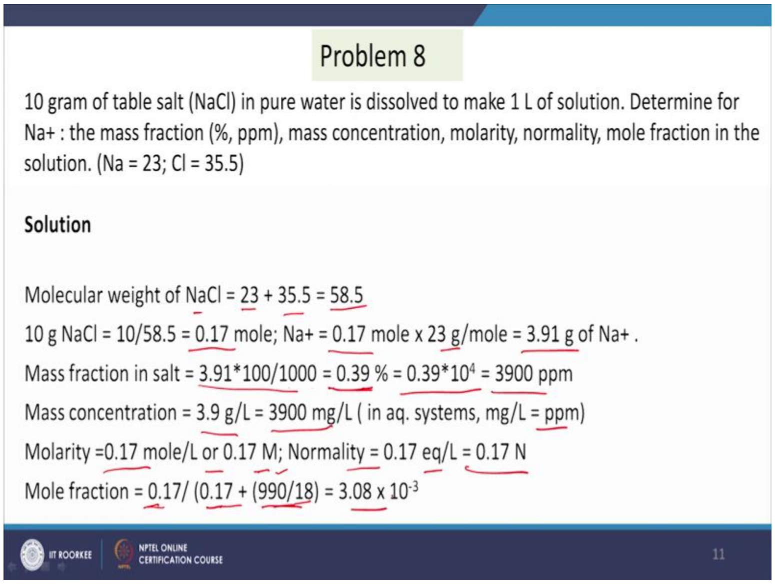
(0.025/17.55)*1000 moles of glucose in 1 L of water = 1.42 moles per 1L = 1.42 M

Molecular weight of glucose ($C_6H_{12}O_6$) = 12*6+1*12+16*6= 72+12+96 = 180

Thus mass concentration = (180*0.025 g/17.55) x 1000 = 256 g/L

So, now we are able to find out the molar concentration and mass concentration of glucose in water.

(Refer Slide Time: 24:04)



Problem 8

10 gram of table salt (NaCl) in pure water is dissolved to make 1 L of solution. Determine for Na+ : the mass fraction (%, ppm), mass concentration, molarity, normality, mole fraction in the solution. (Na = 23; Cl = 35.5)

Solution

Molecular weight of NaCl = 23 + 35.5 = 58.5

10 g NaCl = 10/58.5 = 0.17 mole; Na+ = 0.17 mole x 23 g/mole = 3.91 g of Na+ .

Mass fraction in salt = 3.91*100/1000 = 0.39 % = $0.39*10^4$ = 3900 ppm

Mass concentration = 3.9 g/L = 3900 mg/L (in aq. systems, mg/L = ppm)

Molarity =0.17 mole/L or 0.17 M; Normality = 0.17 eq/L = 0.17 N

Mole fraction = 0.17/ (0.17 + (990/18) = 3.08×10^{-3}

Now, problem number eight, the statement is 10 gram of table salt that is NaCl in pure water is dissolved to make 1 litre of solution. Determine for Na^+: the mass fraction (% ppm) mass concentration, molarity, normality, mole fractions in the solution.

Molecular weight of NaCl = 23 + 35.5 = 58.5

10 g NaCl = 10/58.5 = 0.17 mole; Na^+ = 0.17 mole x 23 g/mole = 3.91 g of Na^+ .

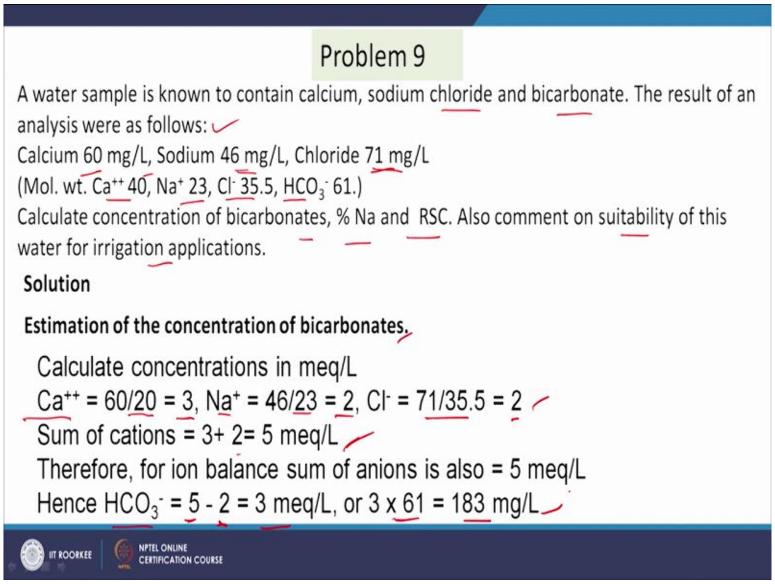
Mass fraction in salt = 3.91*100/1000 = 0.39 % = 0.39×10^4 = 3900 ppm

Mass concentration = 3.9 g/L = 3900 mg/L (in aq. systems, mg/L = ppm)

Molarity =0.17 mole/L or 0.17 M; Normality = 0.17 eq/L = 0.17 N

Mole fraction = 0.17/ (0.17 + (990/18) = 3.08×10^{-3}

(Refer Slide Time: 26:48)



Problem 9

A water sample is known to contain calcium, sodium chloride and bicarbonate. The result of an analysis were as follows:

Calcium 60 mg/L, Sodium 46 mg/L, Chloride 71 mg/L

(Mol. wt. Ca^{++} 40, Na^{+} 23, Cl^{-} 35.5, HCO_3^{-} 61.)

Calculate concentration of bicarbonates, % Na and RSC. Also comment on suitability of this water for irrigation applications.

Solution

Estimation of the concentration of bicarbonates.

Calculate concentrations in meq/L

Ca^{++} = 60/20 = 3, Na^{+} = 46/23 = 2, Cl^{-} = 71/35.5 = 2

Sum of cations = 3+ 2= 5 meq/L

Therefore, for ion balance sum of anions is also = 5 meq/L

Hence HCO_3^{-} = 5 - 2 = 3 meq/L, or 3 x 61 = 183 mg/L

Now, we are going to problem number nine. So, the statement is, a water sample is known to contain calcium, sodium chloride and bicarbonate, the result of an analysis are as follows calcium 60 mg/L, sodium 46 mg/L, chloride 71 mg/L. (molecular weight Ca^{++} 40, Na^{++} 23, Cl^{-} 35.5, HCO_3^{-} 61). Calculate concentration of bicarbonates % sodium and RSC. Also comment on suitability of this water for irrigation applications.

Estimation of the concentration of bicarbonate the first question.

Calculate concentrations in meq/L

Ca^{++} = 60/20 = 3, Na^{+} = 46/23 = 2, Cl^{-} = 71/35.5 = 2

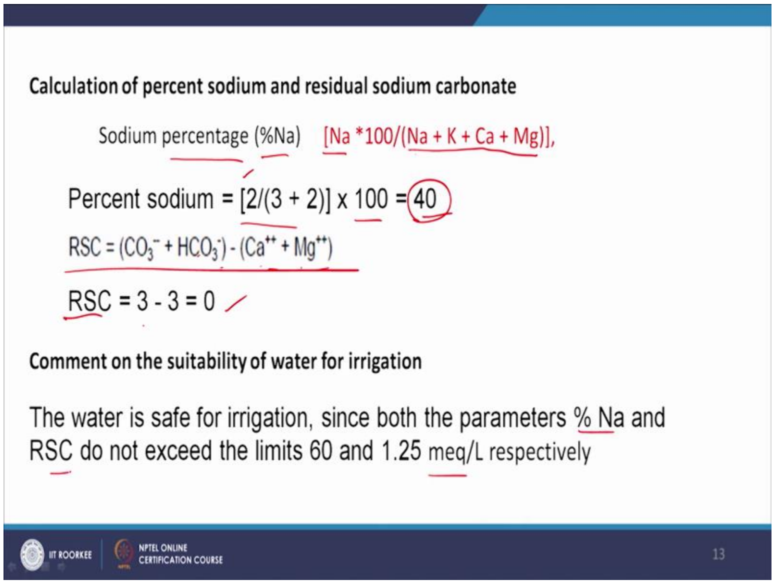
Sum of cations = 3+ 2= 5 meq/L

Therefore, for ion balance sum of anions is also = 5 meq/L

Hence HCO_3^{-} = 5 - 2 = 3 meq/L, or 3 x 61 = 183 mg/L

Then you have to calculate % sodium and RSC.

(Refer Slide Time: 29:38)



Calculation of percent sodium and residual sodium carbonate

Sodium percentage (%Na) [Na *100/(Na + K + Ca + Mg)],

Percent sodium = [2/(3 + 2)] x 100 = 40

RSC = $(CO_3^{-} + HCO_3^{-}) - (Ca^{++} + Mg^{++})$

RSC = 3 - 3 = 0

Comment on the suitability of water for irrigation

The water is safe for irrigation, since both the parameters % Na and RSC do not exceed the limits 60 and 1.25 meq/L respectively

IIT ROORKEE | NPTEL ONLINE CERTIFICATION COURSE

Sodium percentage (%Na) [Na*100/(Na + K + Ca +Mg)

Percent sodium = [2/(3+2)]*100 = 40

RSC = $(CO_3^{-} + HCO_3^{-}) – (Ca^{++} + Mg^{++})$

RSC = 3 -3 = 0

So, we are able to solve the second part and in the last part of this problem it was asked to comment on the suitability of the water for applications in irrigation.

So, we know that there are two criteria, one is your percentage sodium or RSC so if percentage sodium value is less than 60 RSC value less than 1.25 mwq/L then the water is suitable for applications in irrigation. So, in this case these values are 40% and 0 so this is satisfying the conditions for both percentage sodium and RSC values so therefore the water is safe for the irrigation, now the problem is solved. So up to this in this class, thank you very much for your patience.