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4D14 Contaminated Land and Waste Management

QUESTION 1

(a) Petrol (gasoline) is likely to move deeper because it is less viscous than diesel fuel. Petrol is a complex mixture of relatively volatile hydrophobic hydrocarbons that includes aliphatics, aromatics, and additives. Petrol is dominated by compounds with 4 to 12 carbon atoms, whereas diesel fuel is composed primarily of straight-chain unbranched hydrocarbons (C11 to C18-27 range). Diesel fuel has a high percent of longer chain, heavier, less volatile hydrocarbons than petrol.

(b)

(i) From the 4D14 Databook, the properties of toluene are

Henry's constant H = 6.7 atm/M

Molecular weight = 92.1

Gas concentration P = 100 ppmV = 100 x 10^{-6} atm = 1 x 10^{-4} atm.

Using Henry's law, the concentration in soil moisture C = P/H = 1 x 10^{-4}/6.7 = 1.5 x 10^{-5} M.

Convert this to mg/L.

1.5 x 10^{-5} (M)= 1.5 x 10^{-5} (mol/L) x 92.1 (g/mol) x 10^{3} (mg/g) = <u>1.38 mg/L</u>.

(ii) The octanol-water partition coefficient of toluene is logKow=2.73 from the 4D14 Databook.

For aromatic compounds, log K_{oc} = 0.544 (logK_{ow}) + 1.377 = 0.544 x 2.73 + 1.377 = 2.86

Hence, Koc = 728.

The partitioning coefficient Kp is then estimated Kp = focKoc = 0.001 x 728 = 0.728.

Using the linear isotherm model, X = KpC =0.728 x 1.38 = <u>1.0 mg/Kg</u>.

(iii)

Volume of 1kg of soil = 1000g/1.8 (g/cm^3) = 556 cm^3 = 0.556 L = 5.56 x 10^{-4} m^3.

Gas concentration P = 100 (ppmV) x 92.1/24.05 (mg/m^3) = 383 mg/m^3

Mass in 1 kg of soil = V(ϕ_w)C + V(ρ_b)X + V(ϕ_a)P = 0.556 x 0.4 x 0.5 x 1.38 + 1.0 x 1 + 383 x 0.4 x 0.5 x 5.56 x 10^{-4} = 0.153 + 1.0 + 0.043 = <u>1.196 mg/kg of soil</u>.

(c) The Darcy's velocity is v = Ki = 40 x 0.015 = 0.6 m/day.

Retardation factor R = 1 + (ρ_d)Kp/ϕ = 1 + 1.8 x 0.728/0.4 = <u>4.28</u>

The average toluene velocity is 0.6/4.28/0.4 = <u>0.35 m/day</u>.

(d) (i) Air sparging and vapour extraction – Circulate air in the ground and volatilise the toluene. The contaminated gas is extracted by vapour extraction system.

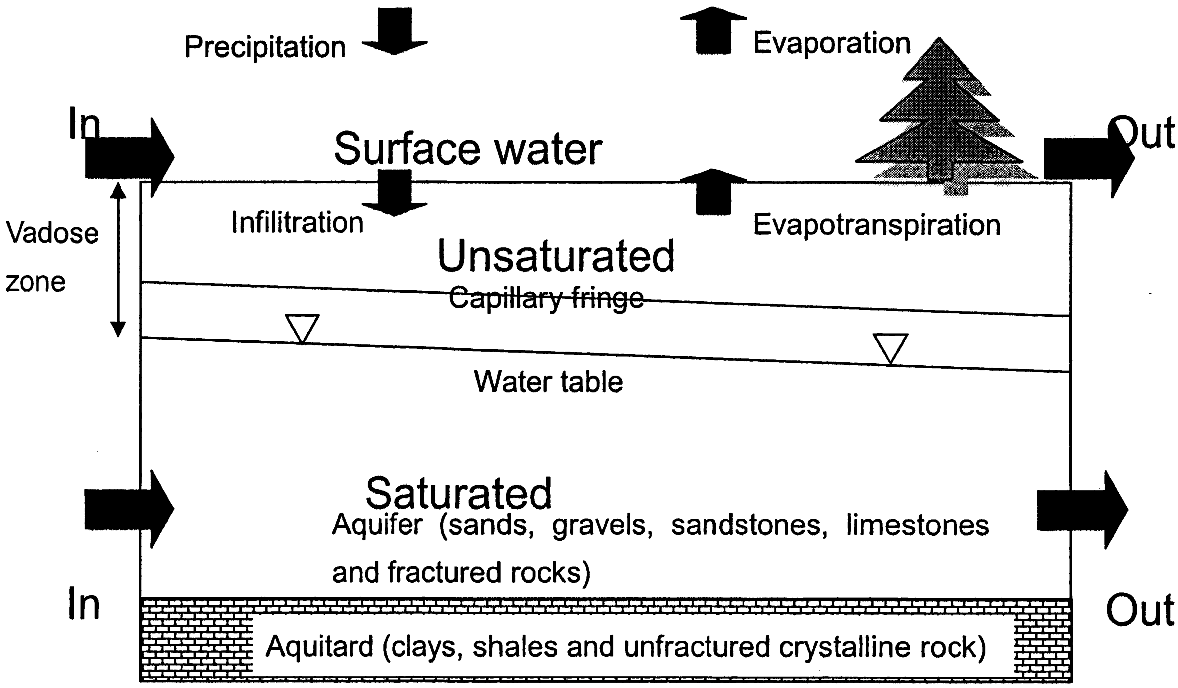
(ii) Excavation – go to landfill or perform on-site chemical treatment.

(iii) Pumping – use of dual pumping system.

(iv) Soil flushing – water or another treatment fluid is introduced to accelerate the movement of contaminants to the water and to facilitate their ultimate recovery through groundwater pumping system.

QUESTION 2

(a)



Hydrological inputs.

- Precipitation and infiltration
- Surface-water inflow into the area
- Groundwater inflow from outside the area
- Artificial import of water into the area through pipes and canals.

Hydrological outputs

- Evapotranspiration from land areas (plants and soils)
- Evaporation of surface water
- Surface water runoff
- Groundwater outflow
- Artificial export of water through pipes and canals.

(a) Chlorinated solvents are chemicals used for metal greasers, drycleaning and paint removers. They are denser than water. Hence, when they are spilled in the subsurface, they penetrated below the water table. They are less viscous than water. Therefore, the penetration front is unstable under gravity dominated flow and move inside the subsurface in a complex manner. Hence, it is very difficult to find them in the subsurface. The solubility values are low and they remain as a continuous contaminant source for very long time. Although small amount of solvents can only dissolve into water, the toxicity is high.

(b) One person in one million people will get a cancer if one million people are exposed to this daily dose value of a chemical throughout their life time, which is usually 70 years. The maximum allowable concentration of this contaminant in water can be estimated by applying this daily dose to an amount of 2L of water, which is consumed daily.

(c) Non-carcinogenic toxic effects have a threshold and below the threshold no adverse effect will occur. For carcinogenic effects, there is no threshold below which no effects will result. Toxicology tests are performed by feeding chemicals in large doses to rodents and then extrapolating the effects to humans exposed to low doses by using extrapolation rates. Tests are performed at doses higher than human exposure in order to elicit response in test animals. Animal to human extrapolation is made by weight using the following formula.
Dose of Human= Dose of Animal x (Body weight of Human/Body Weight of Animal)$^{2/3}$

4D14 Contaminated Land & Waste Containment

3 a) The clay liner of a landfill can come into direct contact with the waste deposited in a landfill if there are no geosynthetic layers used. This may be true for old, single liner landfills. This can lead to interaction of the clay and chemicals present in the waste. The common type of reactions between the waste and clay may lead to a cation exchange and a change in clay structure. Other reactions may lead to replacement of water by percolating organic fluids in the waste. Also acids and bases in the waste may lead to dissolution of soil minerals. [10%]

b) A clay particle has a plate like structure and is of a 2μm size. These clay plate like particles carry a negative charge. Water molecules that get between two clay particles can be held by the negative charge between them and is said to form a diffused double layer. Water held in this way is difficult to remove and reduces the pore space available for fluids to move through clay and therefore results in the low hydraulic conductivity of clays (1×10^{-10} m/s typically). However the hydrocarbons present in waste such as benezene, toulene or Keresone can reduce the thickness of the diffused double layer. This can lead to a 'marked' increase in the hydraulic conductivity of fine grained soils. Presence of hydrocarbons in the waste can lead to a 1500 × increase in the hydraulic conductivity of the clay liner. This can lead to a reduced break through time of the chemicals through the clay liner and its function as a containment barrier can be compromised. [20%]

c) Unit weight of the silty clay $\gamma = 19.6$ kN/m³.
Undrained shear strength $C_u = 30$ kPa.
Permeability is given as 2.4×10^{-5} m/s.
Theoretical limit of a vertical cut height $= H_c = \frac{4 c_u}{\gamma}$

$$\therefore H_c = \frac{4 \times 30}{19.6} = 6.12 \text{ m}$$ [10%]

As we are relying on undrained strength of silty clay, this is only a theoretical limit applicable for short durations of time. Note the permeability value of silty clay.

3d) The surcharge applied by the construction equipment $q = 50$ kPa.
This will reduce the height of unsupported vertical cut.

$$H_c = \frac{4C_u - 2q}{\gamma} = \frac{4 \times 30 - 2 \times 50}{19.6} = 1.02 \text{ m}.$$

The theoretical limit is reduced from 6.12 m to 1.02 m. [10%]

3e) Estimated depth of the slurry wall = 12 m.
This is more than 1.02 m in part d) therefore we need to fill the trench with a slurry.

i) When water table is well below the 12 m depth;

$$H_C = \frac{4C_u - 2q}{\gamma - \gamma_f}$$ where γ_f is the unit weight of slurry

$$\therefore \quad 12 = \frac{4 \times 30 - 2 \times 50}{\gamma - \gamma_f}.$$

$$\therefore \gamma - \gamma_f = \frac{20}{12} = 1.667$$

$$\gamma_f = \gamma - 1.667$$

$$= 19.6 - 1.667 = \underline{17.93} \text{ kN/m}^3.$$ [10%]

ii) When water table is at ground surface

$$H_c = \frac{4C_u - 2q}{\gamma' - \gamma_f'}$$

$$\gamma' - \gamma_f' = \frac{4 \times 30 - 2 \times 50}{12}$$

$$\gamma' = \gamma - \gamma_w = 19.6 - 10 = 9.6 \text{ kN/m}^3.$$

$$\gamma' - \gamma_f' = 1.667$$

$$\gamma_f' = 9.6 - 1.667 = 7.933 \text{ kN/m}^3$$

$\therefore$ Buoyant unit weight of slurry = 7.933 kN/m³.
Unit weight of slurry = 10 + 7.933 = 17.933 kN/m³. (Same as before) [10%]

3f) The formation of the filter cake would reduce the overall permeability

overall permeability of the slurry wall k is calculated as

$$k = \frac{t_b}{\frac{t_b}{k_b} + 2\times\frac{t_f}{k_f}}$$

where t_b is thickness of slurry wall = 1.5 m
t_f is thickness of filter cake = 0.004 m
k_b is the permeability of the soil bentonite slurry = 1.6×10^{-7} m/s
k_f is the permeability of the filter cake = 2.8×10^{-10} m/s

$$\therefore k = \frac{1.5}{\frac{1.5}{1.6\times10^{-7}} + \frac{2\times0.004}{2.8\times10^{-10}}} = 3.95\times10^{-8}\ \text{m/s}.$$

∴ The overall permeability is reduced by formation of the filter cake.
[30%]

4a) Design of a Leachate Collection and Removal System (LCRS).

Plan area of landfill = 400 m x 500 m
Rain fall at site = 1200 mm/year . = 1.2 m/year.

∴ volume of rain water = 240000 m^3.
20% of this enters the landfill = 0.2 x 240000
= 48000 . m^3

Leachate produced is of this order.
∴ Total volume of leachate = 2x48000 = 96000 m^3.

Head of leachate when collected at base = $\frac{96000}{400\times500}$ = 0.48

Assume a porosity of waste $n = 0.5$

$$\therefore \frac{V_v}{V} = 0.5 \Rightarrow \frac{V_v}{0.5} = V$$

∴ Volume need to accommodate 96000 m^3 = $\frac{96000}{0.5}$ = 192000 m^3.

∴ Actual head = $\frac{192000}{400 \times 500}$ = 0.96 m. < 1.2 m thickness of drainage layer OK.

We assume that the maximum head we will allow due to local impermeabilities is 1.2 m. ie just below the surface of the drainage layer.

Spacing of drains:

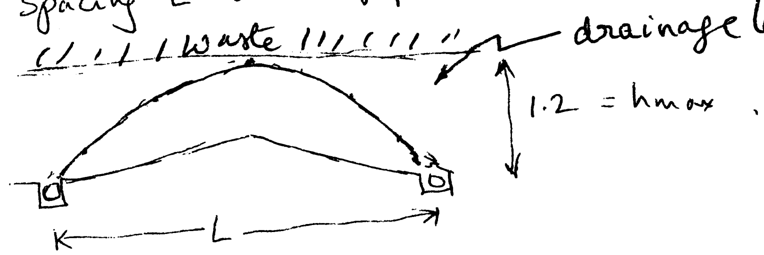
Drainage layer permeability $k = 1.0 \times 10^{-2}$ m/s.

Flow can be calculated as $Q = \frac{96000}{365 \times 24 \times 3600} = 3.0441 \times 10^{-3}$ m^3/s.

Assuming uniform flow rate across the breadth of 500 m, we can get flow rate $q = \frac{3.0441 \times 10^{-3}}{500} = 6.0882 \times 10^{-6}$ m^2/s.

Maximum height of leachate allowed = 1.2 m = h_{max}

∴ Spacing L between pipes is estimated as



$$L = 2 \times h_{max} \times \sqrt{\frac{k}{q}}$$ (from data sheets)

$$L = 2 \times 1.2 \times \sqrt{\frac{1 \times 10^{-2}}{6.0882 \times 10^{-6}}} = 97.3 \text{ m}$$

Choose a spacing of L = 100 m.

∴ we need 4 pipes along the 500m width spaced at 100 m apart (see figure) at the end

Pipe design:

PVC pipes with OD of 120mm and t = 10mm are to be used.

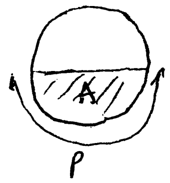
Design these pipes to run half full (gravity flow).

Slope of the ground : 1/1000 .

Use Manning's formula $V = \frac{1.486}{n} R_h^{2/3} s^{1/2}$

R_h = hydraulic radius s = slope .

Manning's Const. n for PVC = 0.01



$R_h = \frac{A}{P} = \frac{\pi r^2/2}{\pi r} = r/2$

limit flow velocity V = 1 m/s .

$\therefore \quad 1 = \frac{1.486}{0.01} \times (r/2)^{2/3} \times (1/1000)^{1/2}$

$r = 0.196$ m .

Inside Diametre of the pipe = 0.392 m .

$\therefore$ PVC pipes with outside dia of 420mm & t = 10mm should be OK ✓

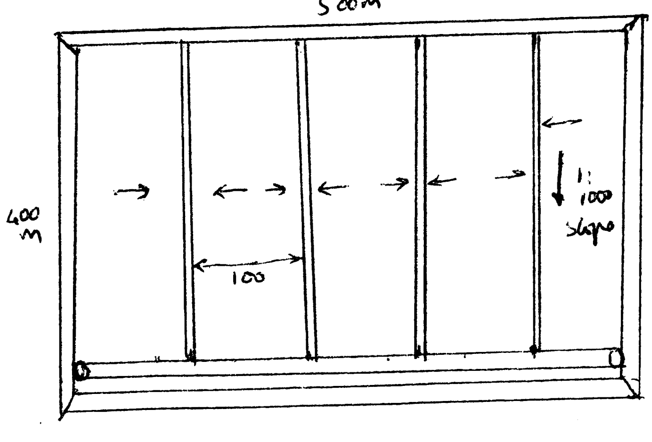
Max. Pipe deflection = $\Delta y = 0.0025 \times \frac{D^2}{t}$ inches .

$= 0.0025 \times \frac{0.42^2}{0.01} \times 25.4 = 1.12$ mm

This max allowable deflection is a bit small but OK ..

(Normally aim for 3 to 4 mm) .

Plan view of LCRS:-



[60%]

4 b) Continental slopes and shelves are sub sea features along the coastlines. Waste deposited on a continental shelf may not spread over a wide region as this region is normally gently sloping. However wave action and mixing may be strong in this region and strong currents may be also present.

Waste deposited in continental slopes may spread over a wide region as the the sea bed in this region can be sloping steeply. On the other hand, the water depth increases in this region and wave effects may be smaller.

[20%]

4 c) Waste can be disposed off into underground caverns from which solution mining has been carried out. Normally this is done in a controlled manner and with volume balance. Only liquid waste is disposed in this way.

i) If the waste is lighter than brine solution, Brine-Balanced technique is used. The cavern is filled with brine solution. As the waste is admitted at the top, brine solution is removed from below. Therefore waste inlet will be at the top elevetation and brine outlet will be at the base of the cavern.

ii) If the waste is heavier than brine, the same procedure as above can be used but by interchanging the inlet & outlet. ie waste is admitted at the base of the cavern and the displaced brine solution is removed from outlet at the top of the cavern.

[20%]
