

## 4 D14 - Contaminated Land and Waste Containment Systems

Q1 a) Examples of hazardous substances in household MSW include i) bleach ii) Furniture polish iii) silver polish iv) Anti-freeze v) Batteries vi) Paints and thinners etc. If a landfill accepts hazardous waste then the top cover has to be thicker. The minimum top cover thickness can increase from 1m for non-hazardous waste to 1.5m for hazardous waste. [10%]

b) The diffused double layer is the water molecules that can get attached to the clay plate-lets. The thickness of the diffused double layer can be estimated using the Mitchell equation (see data sheets). This thickness of the diffused double layer has a marked influence on the hydraulic conductivity of the liners made from clay. Presence of hydrocarbons in the waste can alter the thickness of the diffused double layer and hence hydraulic conductivity. For example presence of hydrocarbons like Kerosene can increase the hydraulic conductivity of clay by a factor of 400. This can lead to a significant reduction of break through times.

c) Current Population  $P_c = 76000$   
 Time taken for construction = 1 year  
 Waste will be received for = 5 years.  
 Rate of increase of Population = 10%  
 (2)

c i) Population at the beginning of active life of landfill  
 $= P_c \left[1 + \frac{2}{100}\right]^1 = 76000 \times [1.1] = 83600$

Population for Year 1 =  $76000 \left[1 + \frac{10}{100}\right]^2 = 91960$

Similarly for Year 2 = 101156

Year 3 = 111272

Year 4 = 122399

Year 5 = 134639

$\therefore$  Total for 5 years = 561426

Waste produced per person = 15 kg/week

$\therefore$  Total waste =  $561426 \times 15 \times 52$

= 437912280 kg or 4371912 tons

ii)

Average unit weight achieved =  $7.0 \text{ kN/m}^3$  (ie  $700 \text{ kg/m}^3$ )

$\therefore$  Total volume required =  $\frac{437912280}{700} = 625589 \text{ m}^3$ .

$V = L \times B \times H$

choose  $L = 200 \text{ m}$   $B = 125 \text{ m}$   $H = 30 \text{ m}$  (given)

$\therefore V = 750000 \text{ m}^3 > 625589 \text{ m}^3 \quad \checkmark \text{ OK}$

iii) Revenue generated by the landfill =  $4371912 \times \text{£}28.50/\text{ton}$   
 $= 124,599,492$

Construction cost =  $\text{£}48,000,000$

operating cost =  $\text{£}6,000,000 \times 5 = \text{£}30,000,000$

Net profit for 5 years =  $\text{£}46,599,492$

iv) Government Revenue from landfill tax =  $\text{£}8/\text{ton} \times 4371912$   
 $= \text{£}34,975,296$

[40%]

1 d) i) 
$$FoS = \frac{2 \sqrt{\gamma \gamma_b} \tan \phi}{\gamma - \gamma_b}$$

$\gamma$  unit weight of backfill soil =  $19 \text{ kN/m}^3$ .

$\gamma_b$  unit weight of soil-bentonite slurry =  $16.5 \text{ kN/m}^3$ .

$\phi$  = slope angle of the excavation =  $30^\circ$ .

$$\therefore FoS = \frac{2 \sqrt{19 \times 16.5} \tan 30}{(19 - 16.5)} = 8.17 \gg 1$$

$\therefore$  slope is stable.

ii) Average thickness of the wall  $t_w = 2 \text{ m}$ .

Average thickness of the filter cake  $= t_f = 4 \text{ mm}$ .

Hydraulic conductivity of the wall  $K_w = 5 \times 10^{-6} \text{ m/s}$

Hydraulic conductivity of the filter cake  $K_f = 3.5 \times 10^{-8} \text{ m/s}$

$\therefore$  Overall hydraulic conductivity of the wall  $K$

$$K_{\text{overall}} = \frac{t_w}{\frac{t_w}{K_w} + 2 \times \frac{t_f}{K_f}} = \frac{2}{\frac{2}{5 \times 10^{-6}} + \frac{2 \times 0.004}{3.5 \times 10^{-8}}}$$

$$K_{\text{overall}} = 3.18 \times 10^{-6} \text{ m/s}$$

This is  $\ll$  than the  $K = 6.5 \times 10^{-6} \text{ m/s}$  of the sandy stratum.

[40%]

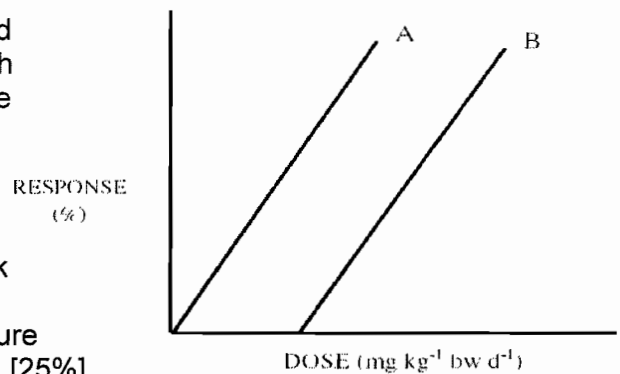
2. (a) (i) Ingestion: outdoor ingestion of soil, indoor ingestion of dust, consumption of homegrown vegetables, ingestion of soil attached to vegetables. Examples: inadvertent ingestion of household dust through hand to mouth contact, ingestion of soil attached to food consumed, inadvertent soil ingestion through hand to mouth contact, ingestion of soil attached to toys by children, soil particles trapped between leaves, soil particles attached to vegetables.

(ii) Dermal absorption: skin contact with outdoor soil, skin contact with indoor dust. Examples: through frequent dermal contact with indoor dust, dermal contact with soil tracked back into the home, direct contact with contaminated soil.

(iii) Inhalation: Outdoor inhalation of fugitive dust, indoor inhalation of dust, outdoor inhalation of soil vapour, indoor inhalation of soil vapour. Examples: inhalation of indoor dust through activities such as cleaning which stir dust into the air, inhalation of dust tracked back into the home from soil, inhalation of wind-blown dust, inhalation of rising vapours from contaminated ground. [25%]

(b) (i) Chemicals with threshold effects (B): Chemicals for which there is a threshold that needs to be present to produce an effect – i.e. below which there is no effect – which may vary between individuals. For these chemicals, Tolerable Daily Soil Intake (DTSI) applies. This is a proportion of the Tolerable Daily Intake ( $\text{mg kg}^{-1} \text{ bw d}^{-1}$ ) allocated to exposure to contaminants in soil which takes into account Mean Daily Intake i.e. TDI - MDI (MDI converted into right units).

(ii) Chemicals with no threshold effects (A): chemicals for which a threshold cannot be assumed e.g. mutagenic and genotoxic carcinogens for which there is no theoretical reason why a single molecule exposure should not result in a tumour or mutation, possibly expressed in subsequent generations – assumed they carry a risk at any slight level of exposure. For these chemicals an Index Dose (ID) applies which presents a minimal human health risk from exposure to soil contaminants (single source). In addition, efforts are still needed to reduce exposure as low as reasonable practicable. [25%]



(c) (i) Residential land-use: Assumes residents have private gardens or access to community open space and takes into account different house designs. CLEA considers options of eating home grown vegetables and not and assumes that the site consists of single property, within a square shaped area, and water for drinking and bathing is obtained from the mains supply. CLEA assumes that exposure pathways will include ingestion and dermal contact of soil and of household dust, inhalation of soil and household dust and inhalation of vapour both inside and outside the dwelling. For eating home grown vegetables, the pathways are extended to include the ingestion of contaminated vegetables and of contaminated soil attached to them. Critical receptor is assumed to be a young female child with duration of exposure covering the first 6 years of life.

(ii) Allotments land-use: The land use will be assumed to be for the purpose of growing fruit and vegetables for own consumption. Some allotment holders also keep animals including rabbits, hens and ducks – potential exposure to contaminated meat has not been considered in this land-use. CLEA assumes that number of visits will vary according to age and season, but with working adults making an average of 2 visits/week with a worst case scenario of 4 hours/visit. The site is assumed to be largely open space. Critical receptor is assumed the same as residential land-use: young female child with the duration of exposure covering first 6 years of life.

(iii) Commercial/industrial land-use: Land use assumes that the workplace is a permanent single- storey where employees spend most time indoors. Site assumes to occupy a total square shaped area with office/factory occupying 0.1 hectare of this space. Assumes that employees are involved in office-based or light physical work. Land use is not intended to include sites involving 100% hardcover, such as car parks, where risk to site user from ingestion or skin contact is minimal while hard cover remains intact. Exposure pathways are assumed to include ingestion of and dermal contact with soil and of building dust, inhalation of soil dust, building dust and vapour both inside and outside building. In terms of exposure it is assumed that employees work a 5-day

week, on average 38.1 hours and have up to 6 weeks leave. Critical receptor being a female worker. [25%]

(d) Average Daily Exposure (ADE): Average daily amount of a contaminant to which a critical human receptor is exposed over duration of exposure

$$ADE = \frac{(IR_{inh} \times EF_{inh} \times ED_{inh})}{BW \times AT} + \frac{(IR_{oral} \times EF_{oral} \times ED_{oral})}{BW \times AT} + \frac{(IR_{dermal} \times EF_{dermal} \times ED_{dermal})}{BW \times AT}$$

inhalation
oral
dermal

Equation includes the following terms:

ADE: Average daily human exposure to a chemical from soil (mg kg<sup>-1</sup> bw d<sup>-1</sup>)

IR: Chemical exposure rate (mg d<sup>-1</sup>) – IR<sub>oral</sub> and IR<sub>inh</sub> usually measured as intakes, IR<sub>dermal</sub> usually measured as uptake, e.g. IR<sub>oral</sub> = C<sub>soil</sub> x SDR where C<sub>soil</sub> is concentration of contaminant in soil (mg g<sup>-1</sup>) and SDR: average daily soil and indoor dust ingestion rate (g d<sup>-1</sup>)

EF: Exposure frequency (d yr<sup>-1</sup>)

ED: Exposure duration (yr)

BW: Human body weight (kg)

AT: averaging time (d)

[25%]

3. (a) (i) Organics: Short chain volatile hydrocarbons, (VOCs)  
 Tars - higher molecular weight hydrocarbons (PAHs)  
 Polycyclic aromatic hydrocarbons, such as naphthalene, anthracene.  
 (ii) Inorganics: Cyanide, sulphide,  
 Heavy metals, such as lead, nickel, chromium, mercury, cadmium.  
 (Phenols also acceptable)

[10%]

- (b) VOCs Gas chromatography  
 PAHs Gas chromatography  
 Cyanide ion chromatography, or alternatively colorimetry: add a specific reagent to give a coloured compound, then use UV/visible spectrometry.  
 Sulphide ion chromatography (or ion selective electrode, or colorimetry, or sulphur can be detected by atomic absorption spectrometry)  
 Heavy metals Atomic absorption spectrometry (AAS) or inductively coupled plasma optical emission spectrometry (ICP-OES)  
 (Note: Tars not soluble in groundwater)  
 Alternatives acceptable for cyanide or sulphide: ion selective electrode, or colorimetry.  
 Alternative method for heavy metals: X-ray fluorescence.

Gas chromatography: The organics are extracted from water into a solvent which is injected and vaporised into a stream of inert helium gas. The gas passes through a heated capillary tube, in which the coating on the walls selectively adsorbs the contaminants and separates them. The temperature of the tube (column) may be gently increased which promotes transfer to the gas phase. The organics are detected as they exit the tube (capillary column), by combustion in a flame which generates ions (flame ionisation detector). The arrival of these ions on an electrode is detected electronically. The exit time of the peak is characteristic of a particular compound, and the peak area is a measure of its concentration.

Ion chromatography: A water sample is pumped through a column of ion exchange particles which selectively attract the anions. They exit the column at different times. Detection is by measuring the conductivity. The exit time of the peak is characteristic of a particular compound, and the peak area is a measure of its concentration.

Optional: The background conductivity of the solution is reduced by a membrane separator, which improves the sensitivity.

Atomic absorption spectrometry: The sample is sprayed into a flame, where metal ions in the solution are converted to the atomic state. Light of a specific wavelength is supplied and the

amount of light absorbed is measured. The concentration of the metal ions is related to the amount of light absorbed, and can be measured against a standard curve. [40%]

(c) (i) Soil Washing: Ex-situ process that employs either mechanical separation (volume reduction) and/or aqueous leaching to remove contaminants from contaminated soils. Fundamental principles are simple and exploit a number of physical properties of the contaminant and soil. These include particle size, particle density, surface chemistry, magnetism, contaminant volatility, contaminant density, contaminant electrochemical properties and solubility. Currently limited to soil types which do not contain significant proportions of organic matter or clay, most effective if fine soil content does not exceed 30%. Stages of process include:

- Preparation and screening: to remove large size material
- Deagglomeration and slurring: of soil using water sprays, some process chemicals such as surfactants may be added to improve suspension of fine particles
- High intensity attrition: of soil using high pressure water sprays to remove surface coatings of contaminants and fine contaminated particles from larger particles such as sand & gravel
- Sizing and classification: of soil to separate soil particles according to size and settling velocity using screens and hydrocyclones
- Further segregation: based on differences in density (using spirals and shaking tables), surface chemistry (froth floatation) etc may be used to concentrate contaminants into a smaller soil volume or to produce fractions more amenable to specific further treatment
- Dewatering: of all soil fractions produced by the separation processes
- Process water treatment: if some contamination has been mobilised into solution
- Management: handling, storage, disposal or treatment

Because essentially a physical separation and volume reduction process, its applicability mainly depends on physical and physico-chemical nature of soil and secondly on nature of contaminants. Two broad categories of applications are: Mixture of non-volatile organics and metals in a relatively coarse-grained soil and materials where alternative options would be too expensive. Contaminant successfully treated with soil washing include: Organics: volatile, semi-volatile, PCBs, pesticides, fuel oils and hydrocarbons. Inorganics: metals, cyanides.

In-situ bioremediation: relies on natural metabolic processes of living organisms, including bacteria and fungi, to destroy contaminants or convert them to less toxic forms hence most useful for the treatment of organic contaminants. Generally not effective for heavy metals but some micro-organisms can sorb inorganic contaminants such as heavy metals. Synthetic chemicals can be calcitrant and can be treated with specific micro-organisms or pre-treated to make them more amenable to biological action. Biological degradation involves oxidation & other processes used by living organisms to metabolise carbon-bearing substrates to generate energy for growth and reproduction. Processes are either aerobic (oxygen requiring) or anaerobic (proceeds in the absence of oxygen). Partial or complete degradation may take place. Bioavailability is considered one of the key limiting factors for bioremediation.

Can be applied in-situ or ex-situ. In-situ applications includes bioventing (pumping or extracting air and nutrients in unsaturated zone), biosparging (pumping air and water in saturated zone) or MNA (combination of naturally occurring processes to reduce risk from contaminants by reduction in contaminant concentration, volume or toxicity and include: dispersion and dilution, sorption, volatilisation, biodegradation, chemical or biological stabilisation, transformation, destruction). Ex-situ applications include treatment beds, biopiles, windrow systems, bioreactors which all have similar processes in mixing, spreading and aerating the soil and adding nutrient as needed. Controlling factors include: (i) contaminant chemistry: ease with which biological processes can degrade hydrocarbons is often controlled by carbon chain length such as the shorter the chain the easier to bioremediation, (ii) soil type: higher granular soil content and lower clay content is preferable, (iii) environmental conditions: Available soil water (65-75% of field capacity), Oxygen (aerobic metabolism: >0.2mg/l dissolved oxygen, minimum air-filled pore space of 5% by volume), Redox Potential (aerobes: > 50 mV, anaerobes: < 50mV), pH (5.5 – 8.5), Nutrients (sufficient nitrogen, phosphorus, carbon etc, suggested C:N:P 120:10:1 – 1000:10:1 Elevated N levels inhibit microbial action), Temperature (15-25°C). [40%]

(ii) Contaminants in gas works sites are complex because they include a wide range of both organics and inorganics with different properties and which cannot be treated by one technique.

Hence most techniques are only applicable to a selected group of contaminants. Soil washing will require full removal of the soil but will result in a small, very concentrated volume of contaminated material going to landfill or other treatment. High costs due to excavation, transport to treatment facility and treatment. No treatment of dissolved contaminants in the groundwater. Hence potentially may contaminate clean replacement soil. Soil washing is more suitable when contamination is principally soil associated or of inorganic origin. In-situ bioremediation treatment will require both bioventing and biosparging to deal with contaminants above and below the water table. Potentially cheaper than soil washing. Additional costs would be associated with vapour extraction unit that would be required in case of volatiles. Effective for the smaller carbon chain length organics and less effective for heavy metals and PAHs. Overall in-situ bioremediation is the more appropriate of the two technologies but will need to be used in combination with other remediation technologies for the more recalcitrant PAHs and heavy metals. [10%]

4 a) Slope Length of the geomembrane  $L = \frac{24}{\sin 60^\circ} = 27.713 \text{ m}$

Mass of the geomembrane =  $20 \text{ kg/m}^2$ .

∴ Total weight of the geomembrane per 1m width

$$= 27.713 \times 20 \times 9.81$$

$$W = 5437.29 \text{ N}$$

$$\text{or } 5.437 \text{ kN}$$

Slope angle  $\beta = 60^\circ$ ; thickness of geomembrane  $t = 4 \text{ mm}$

i) Tensile stress due to self weight  $\sigma_{\text{self}}$ .

$$\sigma_{\text{self}} = \frac{W \sin \beta - F}{1 \times t}$$

where  $F$  is the friction between the geomembrane under side and the clay liner.

$$\therefore F = W \cos \beta \cdot \tan \delta_k$$

$$\delta_k = 8^\circ \text{ (given)}$$

$$\therefore F = 5.437 \times \cos 60^\circ \times \tan 8^\circ$$

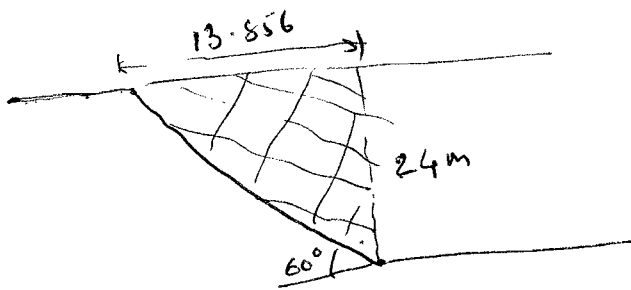
$$= 0.382 \text{ kN/m}$$

$$\therefore \sigma_{\text{self}} = \frac{5.437 \times \sin 60^\circ - 0.382}{1 \times 0.004} = 1081.63 \text{ kN/m}^2$$

$$= \underline{\underline{1.082 \text{ MPa}}}$$

ii) As the waste settles it will create a downward stress in the geomembrane. As a upper bound estimate, we can assume that all the waste in the slope  $\delta_k$  will cause downward. This of course, assumes that the shear strength of waste is small.





Weight of the waste in the  $\Delta$  is

$$= \frac{1}{2} \times 24 \times 13.856 \times 1 \times 8 \text{ kN/m}^3$$

$$W_{\text{waste}} = 1330.176 \text{ kN}$$

$$\sigma_{\text{Downing}} = \frac{W_{\text{waste}} \times \cos 60 \times \tan \phi_u}{1 \times t} ; \phi_u = 5^\circ$$

$$= \frac{1330.176 \times \cos 60 \times \tan 5^\circ}{1 \times 0.004} = 14546.9 \text{ kN/m}^2$$

$$= \underline{\underline{14.55 \text{ MPa}}}$$

iii) The total tensile stress in the geomembrane =  $1.082 + 14.546$   
 $= 15.628 \text{ MPa} \rightarrow 13 \text{ MPa}$   
 Yield stress of HDPE.

$\therefore$  The geomembrane will yield and can suffer rupture.

$\therefore$  Either increase the thickness of the geomembrane to 6mm or provide a geotextile layer to carry the tensile stress.

The later option is normally preferred as geotextile can also give some added protection against puncture of the geomembrane.

[30%]

4 b) Continuity of volume method,

$$\text{Volume of voids } V_v = \pi r^2 \times h \times n$$

where  $n$  is porosity;  $r$  is radius &  $h$  is thickness of the strata.

$$1,600,000 \text{ m}^3 = \pi r^2 \times 8 \text{ m} \times 0.4$$

$$\text{Radius of influence } r = \sqrt{\frac{1.6 \times 10^6}{\pi \times 8 \times 0.4}} = 398.94 \text{ m} \approx 400 \text{ m}$$

This radius of influence will increase with time due to the diffusion processes.

The diffused radius can be obtained as

$$\begin{aligned} r' &= r + 2.3 \sqrt{D_d r} \\ &= 398.94 + 2.3 \times \sqrt{1.2 \times 398.94} \\ &= 449.26 \text{ m} \approx 450 \text{ m} \end{aligned}$$

Thus the radius of influence increases by '50m' due to diffusion. However in reality the radius of influence can be many times more than the estimated radii above. [30%]

4 c) The term pycnocline refers to a zone in the ocean where the temperature changes rapidly with depth. As a result the density of the sea water also changes in this region. This will lead to mixing action of the sea water in this region. Therefore any waste disposed in this zone gets mixed up and is spread

by dispersion.

The zone below the pycnocline is called the oxygen minimum zone. This zone normally marks the depth into which no sunlight penetrates. Waste disposed in this region will suffer anaerobic reactions, due to paucity of oxygen.

The final products formed by the waste disposed into ocean depend on whether the waste is disposed into pycnocline or oxygen minimum zone. [20 r.]

4. d) Hazardous waste such as radioactive waste are disposed into underground repositories. Siting conditions for locating a suitable underground repository are

- The host rock must be of suitable thickness
- high degree of homogeneity of host rock.
- Lateral extent of host rock - must be continuous over several square km.
- high degree of predictable geological stability i.e. not effected by erosion, earthquake or uplift.

Domeal salt formations are considered suitable as they are formed over millions of years by density driven flow. They are homogeneous and Roof Cavens are absent. They are geologically stable in order of millions of years. However, they may give out brine solution that can corrode containers containing the radioactive waste.

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