

4D14 – Contaminated Land & Waste Containment Structures
2022-23

Q 1)

a) Within a MSW, reaction types may be broadly classified into Biochemical and Chemical Reactions.

Biochemical reactions consist of converting complex organic compounds into simpler compounds, converting insoluble solids into water-soluble substances.

These reactions consist of hydrolysis, oxidation, and reduction into liquid form. The organic matter is initially degraded by aerobic action and converted into nitrates, sulphates, CO₂ and water (stable compounds). Once the free air and oxygen are exhausted, reactions take place under anaerobic conditions and converts unstable matter into gases such as methane, ammonia, CO₂ and hydrogen sulphide (H₂S). Other compounds such as alcohol's and carboxylic acids may be produced in this process.

Chemical Reactions that take place in the landfill are mainly (I) neutralisation (II) precipitation and (III) reduction. In the landfill the overall dissolved constituents may increase, the strength of the leachate may be decreased. For example, neutralisation may be due to mixing of acids and alkali waste causing precipitation of heavy metals as sulphides, hydroxides and carbonates, and reduction of sulphates to H₂S.

[15%]

b) The important chemicals in clays are Kaolinite, Illite and Montmorillonite. Clay particles have plate like structure and are very active electro-chemically. Clay minerals have commonly, either (I) Silica tetrahedral structure or (II) Magnesium or Aluminium Octahedral structure.

The water adsorbed to the clay minerals contributes to the macroscopic engineering behaviour of the clay. We are primarily concerned that the soil-waste interaction may effect the hydraulic conductivity of the soil. In this regard, we wish to understand the clay-water interaction and the effect of pollutants on hydraulic conductivity.

Clay-Water Interaction: Clay particles are negatively charged and attract (and tightly hold) cations(+). Hence there is a disparity in the electric fields next to clay surface. The charged surface and the adjacent distributed charge together are called diffused double layer.

Dissolution of Soil Minerals: Acids and bases may dissolve certain soil minerals e.g., Al and Fe can be dissolved by acids and Silica can be dissolved by bases. The resulting fines may migrate with seeping fluids and can cause decrease in permeability by plugging the void space. In the long-term, however, migration of fines may increase the permeability due to piping and channel formation within the soil.

Changes in the clay structure: Changes in clay structure occur do cation exchange or by replacement of water by percolating organic fluids. Na, K, Ca and Mg may be attracted to the clay minerals there by changing the clay structure. This will effect the hydraulic conductivity.

Precipitation: As discussed before, precipitation of heavy metals. salts and carbonates may occur. This will cause reduction in hydraulic conductivity due to blocking of the pore space. Site specific tests must be conducted to measure in-situ permeability.

[15%]

c) Waste collected from residential area can contain many hazardous wastes present in everyday products. Examples include paints, varnish, hair sprays, oven cleaners, chlorine bleach, glass cleaners, shoe polish, silver polish, upholstery and carpet cleaners etc. Some estimates give between 0.1 to 1% of MSW from residential areas can contain hazardous waste.

[10%]

d) i) & ii)

No of Houses										
6000	24	28	120		4000			Population increase		
Solid waste (tonnes)		Liquid Waste		Year	Phase 1	Phase 2	Total Population			
Phase I		Phase II			Phase I	Phase II				
Year 1	22643.71			97044480.0	End of	1	15552		15552	
Year 2	24455.21			104808038.4	End of	2	16796		16796	
Year 3	26411.63			113192681.5	End of	3	18140		18140	
Year 4	27732.21	14396.93		118852315.5	End of	4	19047	10080	29127	
Year 5	29118.82	14828.84		124794931.3	End of	5	19999	10584	30583	
Sum	130361.6	29225.8		558692446.7						
Total	159587 tonnes			687635807 litres						

Volume	184182.5593	m3		
Choose 25 m depth				
Area=	7367			
choose 100 m x 80 m				
Volume	200000	m3 >	184183	m3 OK
Landfill Cell can be 100 m x 80 m x 25 m deep				

[20% + 10%]

d) iii)

CaCO ₃ quantity	5157.27	tons
Ca quantity	1512.80	tons
Mg quantity	501.97	tons

[10%]

d) iv)

Revenue generated	
MSW	6064318.72
Hazardous Waste	1196905.01
Total Revenue=	£7,261,224

[10%]

d) v)

Landfill Tax=	£2,393,810
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[10%]

Q2) a) Unsupported height of a vertical trench:

$C_u = 50 \text{ kPa}$

Unit weight = 19.5 kN/m^3

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

$$H_c = \frac{4 \times 50 - 2 \times 40}{17.5}$$

$$H_c = 6.857 \text{ m}$$

This height is > the maximum height allowed by Health & Safety regulations. So precautions must be taken to ensure presence of slurry in the wall at all times.

[10%]

b) Stability of slurry filled trench walls:

when water table is at the bedrock level;

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

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

$$\gamma_f = 17.5 - \frac{4 \times 50 - 2 \times 40}{8} = 2.5 \text{ kN/m}^3$$

When water table is at the surface – it will be the same!

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

$$\gamma'_f = (17.5 - 9.81) - \frac{4 \times 50 - 2 \times 40}{8} = -7.31 \text{ kN/m}^3$$

$$\gamma_f = 9.81 - 7.31 = 2.5 \text{ kN/m}^3$$

[15%]

a iii) Slurry wall permeability:

$$k = \frac{t_s}{\left(\frac{t_s}{k_s}\right) + 2\left(\frac{t_c}{k_c}\right)}$$

$$k = \frac{1.0}{\frac{1}{4.25 \times 10^{-8}} + 2\frac{0.003}{6.5 \times 10^{-9}}}$$

$$k = 4.0896 \times 10^{-8} \text{ m/s}$$

This overall permeability is nearly an order of magnitude smaller than the silty clay's permeability of 3.25×10^{-7} m/s. Therefore the slurry wall is needed to reduce flow of contaminants towards the reservoir.

[15%]

2 b)

Geomembranes – used in landfill liners, along the side slopes, base and top layers of a landfill. Primary function is to stop/reduce the movement of leachate from within the landfill to outside, so that the natural aquifers will not get contaminated with the leachate.

Geotextiles – used as structural supports so that the geomembranes do not get loaded. Geotextiles are normally laid below a geomembrane layer, but multiple layers of geotextiles can be used. Primary function is to carry the mechanical stresses and protect the geomembranes from over loading.

Geonets – used to collect and remove the leachate from the base of the landfills. Geonet layers are laid above the geomembrane so that easy flow of leachate can occur towards the leachate collection pipes.

Geo-grids – these are used for local support of geomembranes, for example if there is a soft peat patch in one area of a landfill site, then geo-grids can be used in that area. Their primary function is also to carry loads.

[other answers such as Geosynthetic clay liners, geo-foams etc. will also be given marks, if their functionality is explained correctly]

[20%]

2 c) Solution mined caverns are spaces left in the ground after ores in liquid form have been extracted.

The following are four major techniques for solution-mining;

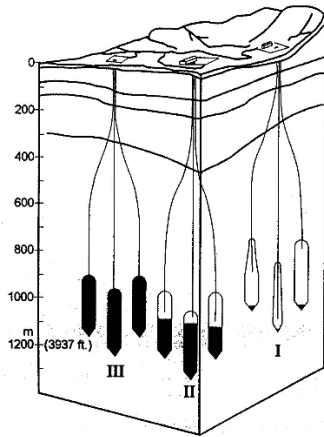
1. Brine-balanced
2. Gas-balanced with zero discharge
3. Atmospheric cavern with controlled gas discharge
4. in-situ solidified waste disposal

Brine-balanced technique involves floating the liquid waste (lighter than brine). The cavern is always full of liquid. When more waste is added the excess brine is displaced via pipes in casing to a brine holding pond. If waste is removed, the reverse happens.

The above technique can also be used if the waste has higher density than brine. The inlet point for waste and outlet point for brine are interchanged.

Gas-balanced technique involves displacing the brine solution with an inert gas and works in a very similar to above, but now the pressure of the gas has to be maintained.

In-situ Solidified Waste method involves mixing waste with a cement or polymer slurry and injection into the cavern. Permanent solidification reduces the risk of presence of potential pathways, seismicity at site.



[20%]

2 d) The ocean topography changes from continental shelves along the beaches/coastline to continental slopes that transition into deep ocean regimes that comprise of abyssal plains and abyssal hills.

When disposing the liquid waste say from a treatment plant of a sewage facility, the outlet pipes can be run into the continental slopes i.e. beyond the continental shelves. This ensures that the liquid waste will not contaminate the near shore regions and the waste will migrate towards the deep ocean regimes.

When disposing low-level radioactive waste, suitable sites will be deep ocean regimes. Every effort should be made to dispose the waste from barges into abyssal plains avoiding any known abyssal hills. This will minimize the spread of the waste after disposal is completed. Due care must also be exercised with regards to the marine environment and ecologically sensitive areas must be avoided.

[20%]

3(a). The solubility of copper in water is very dependent on the pH. Increasing the pH from 6 to 9 will reduce the concentration by 5 orders of magnitude. (see slide 44 in lecture notes). So the water could be treated with a high pH alkaline compound such as limestone, quicklime, caustic soda or soda ash. This will cause copper compounds to be precipitated. (Before release to the environment, it would be necessary to readjust the pH, so the precipitated copper would need to be separated first). Further non-essential information: Not necessary to say which material is used, just necessary to say high alkalinity to raise pH. [20%]

(b) Any one of: Atomic absorption spectrometry (AAS), ICP-OES (inductively coupled plasma optical emission spectrometry, or ICP, ion chromatography, or copper ion electrode analysis. Any one of: X-ray fluorescence spectrometry, copper ion electrode analysis, or a colour change test kit (method is to treat sample with a chemical and measure the intensity of colour with a meter or chart comparison). [10%]

(c) Laboratory or Field Analysis? Summary of Advantages/Disadvantages

- Laboratory analysis –advantages:–Better accuracy
- Identification of contaminants easier
- Wider range of techniques available
- Laboratory analysis –disadvantages:–Possibility of sample loss or decomposition
- Possibility of sample mix-up
- Takes longer
- Can be expensive
- Field analysis –advantages:–Immediate result –can influence where to take the next sample
- Helps to choose the most effective sampling points
- Field analysis –disadvantages:–Not possible with all contaminants
- Generally less sensitive, less accurate
- Generally would recommend both; e.g. 1 in 20 field results should be checked by lab analysis. [20%]

3(d). (i) Tolerable Daily Intake (TDI): Amount of chemical that can be ingested daily over a lifetime without appreciable health risk. Expressed in mass of substance per kg of body weight/day (mg/kg bw/d). These are usually quoted for 'oral' i.e. ingestion or 'inh' if vapour hence inhaled.

Mean Daily Intake (MDI): Average 'background intake' to which people may be exposed to, in mg/d.

Tolerable Daily Soil Intake (TDSI): A proportion of the TDI (mg/kg bw/d) allocated to exposure to contaminants in soil which takes into account MDI i.e. $TDI - MDI$ (MDI converted into right units)

Index Dose (ID): For non-threshold chemicals. Dose 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. Same units as TDI. Tolerable Daily Soil Intake: $TDSI = TDI - MDI$.

Soil Guideline Value (SGV): Concentration of a contaminant in soil where the estimated average daily exposure (ADE) equals the relevant health criteria value (TDSI or ID). Unit mg/kg dry soil. [15%]

(ii) TDI values: These originates from setting of standards of dietary safety for food additives – based on toxicological studies in animals divided by a safety factor, e.g. 100, to cover to humans, some based on WHO drinking water standards. Hence is 5 for Ni. For As and Benzene, no value means these are non-threshold chemicals which are highly toxic and hence there are no TDI for them.

MDI: These are background values that people are usually exposed to through the food chain and other sources. They values are given. As they quoted per body weight, they are different for adults and children with the latter values being much higher. Hence 2.3 and 8 for Ni and 5 and 0.19 for As, which are both for oral intake. For benzene these are inhalation intake pathways of 2.9 and 7.4 for adult and child.

TDSI values: $TDI - MDI$, for when $MDI < TDI$. This applies to Ni for adults hence $TDSI = 5 - 2.3 = 2.7$.

However, for the Ni for child intake $MDI \geq TDI$ and it could be argued that nothing can be allocated to contaminated soil. However this is considered impractical – argument is that there is huge variation around the average MDI for contaminants. Hence: For $MDI < 0.8 TDI$, then $TDSI = TDI - MDI$ and for $MDI \geq 0.8 TDI$, then $TDSI = 0.2 \times TDI$. Hence Ni for a child is $0.2 \times 5 = 1.0$.

For As and Benzene since there is no TDI, the values quoted are of ID and are those from drinking water standard, which is 0.3 and 0.29 respectively.

The SGV are calculation using the CLEA model and linking with the mean contaminant concentration value from the site as measured from sampling.

For the SGV. For Ni and As, those for residential are lower than those for allotment and are in turn lower than for commercial/industrial use. All the values for Ni are higher than those for As since it is less toxic. For Benzene which is the most toxic of the three, the values are much lower. Also as it will mainly be inhaled first, the SGV for allotments is much lower than those for the other two end use categories. [25%]

(iii) Clearly these are three different contaminants, with three different exposure pathways and level of toxicities. Since the latter two are non-threshold contaminants, would be best to consider chemicals individually and not as additives. Similarly the end use should be carefully considered given the presence of benzene on the site and it would be unlikely that this site could be used for allotments after treatment. Furthermore, given that these are a mix of heavy metals and volatile organics, remediation is likely to consider or more than one technique. For example soil vapour extraction could be used to deal with benzene and then followed by stabilisation/solidification for the heavy metals. [10%]

4 (a) Soil Vapour Extraction (SVE): In-situ technique of inducing airflow through soil to enhance volatilisation in the vadose zone into the soil atmosphere, also referred to as in-situ volatilisation, soil vacuum extraction or soil venting. Recovered soil air is usually collected for subsequent treatment. Airflow is induced in the substrate, by applying a pressure gradient (negative) via a blower or a vacuum pump connected to wells placed in contamination zone resulting in movement of soil air and vapour-phase contaminants towards wells. Problem with making all contamination in treatment volume fully accessible to the treatment regime.

Bioventing: Movement of air through the vadose zone to stimulate in-situ biodegradation of organics – using either extraction or injection wells. Movement of the air is controlled to maximise the rate of in-situ biodegradation and should be accompanied by reduction in extracted VOCs in the exhaust air from the process. Nutrients are also added to enhance biological treatment. [10%]

(b) Most favourable site conditions for SVE: contaminant chemistry: vapour pressure >0.5mm Hg, Henry's law constant >100 Atmosphere, soil conditions: high air permeability and high porosity and partial saturation, minimal stratigraphy of clay and silt. Airflow conditions: depth of contamination, soil heterogeneity and position of seasonal groundwater.

Ideal site conditions for bioventing: soil conditions: ideal conditions for microbial activities: microbial presence, soil pH, redox conditions, medium permeability, partial saturation, depth of groundwater. Contaminant properties, absence of inhibitory compounds. [10%]

(c) Both systems have a similar set up and contaminant extraction method. Differences include: bioventing usually involved the introduction of nutrients as well. Bioventing is much slower air flow rate than SVE as its purpose is to biodegrade contaminants in-situ rather than extract them. [10%]

(d) For gasoline, which is highly volatile, SVE would be the most appropriate. For lubricating oil which is non-volatile and high molecular weight hydrocarbon, bioremediation would be the most appropriate. For diesel which is intermediate between the other two, either method could be used and this would depend on the other relevant and controlling parameters including soil conditions. [10%]

(e) Need to ensure that all contamination in treatment volume is fully accessible to treatment regime. This is usually problematic due to the heterogeneous nature of contaminated soils and the ground conditions in general. If the extraction volume or rate in SVE of the biodegradation rate or volume when using bio-venting is less than expected, this would mean that the techniques are not as suitable as initially thought. [10%]

(f) For contamination above the below the groundwater level, SVE could be integrated with air sparging and bioventing could be combined with biosparging. Alternatively a technique which targets groundwater contamination could also be used for example pump and treat, in-situ chemical oxidation. [10%]

(g) Chemical treatment can deal with a range of synthetic organic compounds – not usually suitable for SVE and bioventing. Examples include halogenated compounds e.g. PCBs. This could be implemented using a reducing agent e.g. Fe or use Na or K to strip away chlorine atoms. [10%]

(h) Favourable site conditions for chemical treatment: soil conditions: high chemical oxidant demand, relatively high permeability. Chemicals: those suitable for chemical oxidation or reduction, solubility and K factor. Oxidising or reducing agent can be applied through well, and circulated, or simply pumped into the ground and left there if non-toxic. [10%]

(i) Cut-off walls are low permeability barriers that are constructed to prevent the migration of contaminants from the site outside the barrier boundaries, and can deal with contaminated groundwater as well as the vadose zone. This is a well established strategies that can be easily implemented on any contaminated site and provide immediate remedial approach.

Permeable reactive barrier (PRB) is a more recent and innovative approach that constructs a permeable barriers that facilitates the extraction of contaminants from contaminated groundwater as it passes through the PRB placed in its path. Most applicable to groundwater contamination which can be remediated with specific additives, that can be incorporated within the wall without reducing the permeability. [10%]

(i) A containment approach could be used in parallel or as part of a treatment train system when:

- If the physical or biological technique is not sufficient successful, either because the ground is more heterogeneous than originally expected or the contaminants are not sufficiently available to the treatment approach, or
- if the treatment method is not able to reduce the contamination level to acceptable levels, as is usually the case with some organic contamination,
- or if there are also heavy metal contaminants present, for which both methods are not usually suitable.

A PRB could be implemented together with SVE if there is concern that containment has spread to the groundwater. Also if the physical or chemical approach is taking longer than expected because the site conditions are more difficult, then a cut-off wall could be employed if rapid development of the site is required. Generally a containment approach can provide definite results and guarantee of acceptable remediation. [10%]