4D14 – Contaminated Land & waste Containment Systems. 2013

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Q1

a) The main functions of the top cover of a landfill are

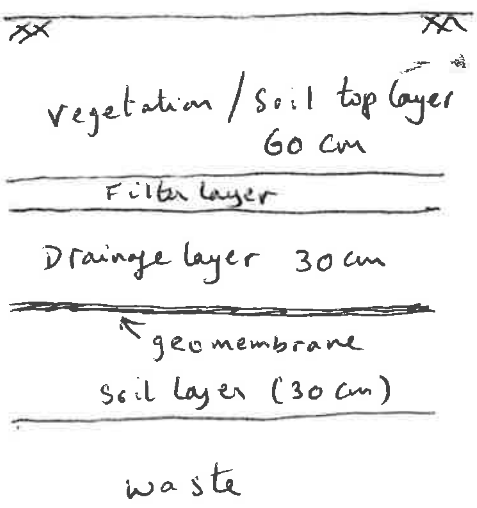
i) to provide a barrier between the waste and the outside environment including animals, humans etc.

ii) to minimise the ingress of precipitation into the landfill thereby reducing the quantity of leachate.

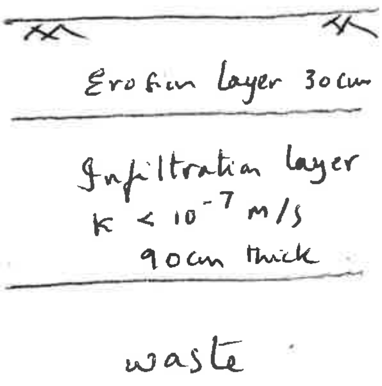
iii) to prevent the landfill gases such as methane, H_2S etc from escaping into the atmosphere and reduce the smells. Also the top cover can be designed to collect the gases and be used to produce energy. [10%]

b) The design of the top cover of a landfill changes depending on whether hazardous wastes or non-hazardous wastes are allowed to be deposited in the landfill.

Hazardous waste



Non-Hazardous waste



[20%]

Q1.

c) The main functions of the base layer of a landfill are

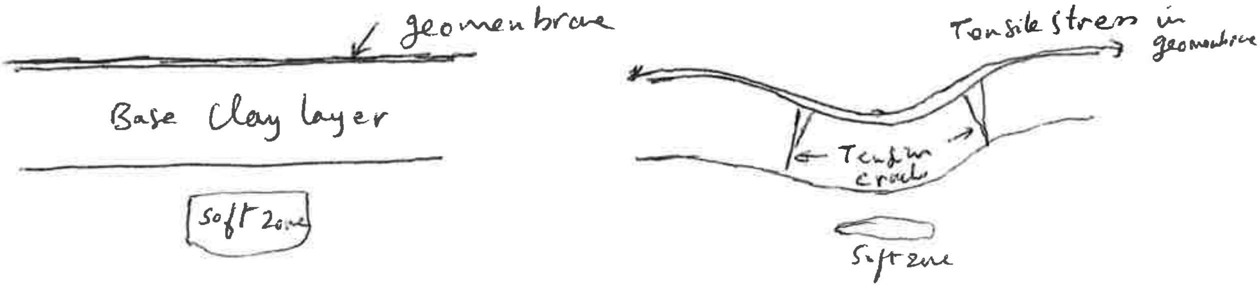
i) to prevent the leachate produced in the landfill from escaping out of the landfill and entering the ground water.

ii) provide structural stability and integrity over the entire base area of the landfill.

iii) to support low permeability layers such as geomembranes and ensure that they do not get into too much tensile stresses.

[10%]

d) Presence of undetected soft soil layers during the site investigation can be a problem for the base layers of a landfill. Once the waste is deposited into the landfill, the soft layers can undergo consolidation settlements. This can induce tensile stresses in the base layers - leading to tension cracks in the compacted base clay layer.

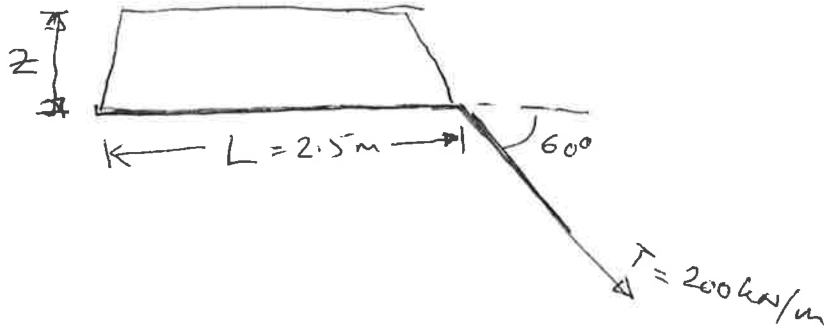


If peat zones are detected before the base layer is placed, use of geo-grids to locally stiffen the soil is recommended. These geo-grids are cost effective solution if the lateral extent of the soft zone is limited.

Alternatively, geotextile layer should be added to the base layer, along with the geomembrane to provide structural stability and overall integrity of the base layer. Remember the height of waste above the base layer can be 30-50 m, creating large vertical stresses on the base layer.

[20%]

Q 1 e)



$\sigma_v = \gamma_d z$. $\gamma_d = 16$ kN/m³ .

Geomembrane friction angles $\delta_U = 6°$
$\delta_L = 10°$

Consider the horizontal equilibrium:

$$L \gamma_d z \tan \delta_U + L(T\sin 60 + \gamma_d z) \times \tan \delta_L = T \cos 60°$$

$$2.5 \times 16\ z \tan 6° + 2.5(200 \sin 60 + 16 z) \tan 10° = 200 \cos 60$$

$$4.2042\ z + 30.54 + 7.0531\ z = 100$$

$$11.2573\ z = 23.6482$$

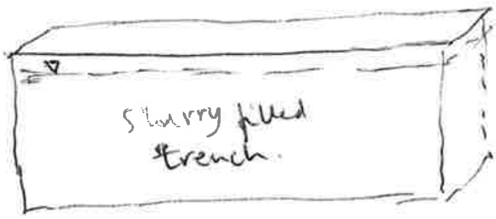
$$z = 6.17\text{m}$$

[40%]

The height of the berm needs to be 6.17m .

You may want to increase this height to 6.2m to allow for reduction in stress at edges of the berm.

2 a) A Slurry wall is constructed by cutting a trench with a back hoe into the ground. After a shallow trench of required width is established



Soil-bentonite slurry is introduced into the trench, and excavation is continued below the slurry. The soil-bentonite slurry provides the lateral stability to the trench. It is very important to maintain the slurry level in the trench and guard against sudden loss of slurry due to permeable layers in the ground. Once the trench reaches the required depth with adequate 'key' into the impermeable layer, the backfill material is placed into the trench. This sinks to the bottom of the trench and the slurry is recovered from the top and can be reused. [15%].

b) Saturated unit weight of silty clay = ~~20~~ 19.2 kN/m^3.

Undrained shear strength $C_u = 25$ kPa.

Unsupported cut height $H_c = \frac{4C_u}{\gamma}$

$$H_c = \frac{4 \times 25}{19.2} = \underline{\underline{5.21\,m}}$$

This is a theoretical limit as we are relying on undrained shear strength (short-term). In any case, Health & Safety requirements do not allow unsupported trench heights > 1.0 m (3ft), to ensure safety of workers. [15%]

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c) $H_c = \frac{4C_u - 2q}{\gamma}$ where q is the surcharge load.

$$= \frac{4 \times 25 - 2 \times 30}{19.2} = \underline{\underline{2.08\,m}}$$

Presence of surcharge reduces the max cut height by more than half. [10

2 d) i) water table well below the depth of the trench.

$H_c = 10$ m. $C_u = 25$ kPa. $\gamma = 19.2$ kN/m³.

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

$$\therefore \gamma - \gamma_f = \frac{4 \times 25 - 2 \times 30}{10} = 4$$

Unit weight of slurry } $\gamma_f = \gamma - 4 = 19.2 - 4 = \underline{\underline{15.2 \text{ kN/m}^3}}$. [10%]

ii) water table at the ground surface.

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

$$\gamma' - \gamma_f' = \frac{4 \times 25 - 2 \times 30}{10}$$

$$= 4$$

$\gamma' = 19.2 - 10 = 9.2$ (taking $\gamma_w = 10$ kN/m³ & $\gamma' = \gamma - \gamma_w$)

$\therefore \gamma_f' = 9.2 - 4 = 5.2$ kN/m³

Buoyant unit weight of the slurry = 5.2 kN/m³. [10%]

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2 e) Injection wells are used to dispose of liquid waste into the ground. The following siting criteria must be satisfied before locating an injection well.

Siting Criteria

- The presence of a water-bearing zone of non beneficial use (saline or economically of little value) that is sufficiently thick and laterally extensive and which has sufficient porosity and permeability to accept liquid wastes at the required rate
- Confinement of the zone of injection both above and below with impermeable zones of sufficient thickness and lateral extent

Absence of faults, fractures, joint systems which would result of migration of waste into other aquifers is important.

Hydrogeological Considerations

Injection zone characteristics

The following are determined for each injection zone on a 'site-specific' basis;

- Hydraulic conductivity
- Porosity
- Stratigraphy (thickness, lateral extent and continuity of layers)
- Formation fracture gradient
- Reservoir pressure and temperature
- Residual oil, gas and water saturations

Confining zone characteristics

- Presence of fracture or fault in confining zone is a worry.
- All the characteristics of injection zone are determined for confining zone but with the aim of making sure no vertical propagation occurs through this zone. [20%]

2 f) i) **Continental slopes**: Continental slopes extend between the Deep Ocean floor and the continental shelf. Their width ranges from 20 km to 100 km. They cover about 10 to 15 % of earth's surface. Waste deposited onto the continental slopes will spread towards the deep ocean floor with time. Hence the zone over which the waste disperses is vastly greater than the zone of deposition of the waste. [10%]

2 f) ii) **Abyssal hills**: Relatively small hills on Abyssal plains with slopes ranging from 1 to 15%. The slopes may adversely affect the range of area through which waste deposited can migrate. The deposited waste may be affected by physical and chemical processes. As the region of spread of the waste is increased vastly, depositing waste on abyssal hills can adversely affect ocean eco-system over a wide area. [10%]

3. (a) (i) Barriers to redevelopment of contaminated sites:

- Government policies strongly in favour of redeveloping brownfield land – much of which is contaminated
- However some developer are reluctant to develop on brownfield land
- Reasons fall into one or more of the following categories: Fear of the unknown, Regulatory control, Delays, Increased costs, Stigma.
- Redevelopment considered 'too risky'

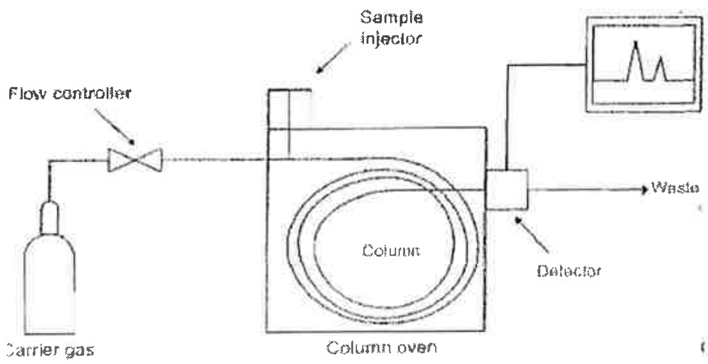
(ii) They can be overcome:

- Thorough understanding of problems that might be encountered, e.g. where contaminants are, contamination level etc
- Careful planning as to how they can be overcome by: detailed assessment of current and previous land activities, detailed site investigation, detailed risk assessment, professional design of remedial works, detailed assessment of costs.
- Specialist environmental insurance can be used to protect against costs [20%]

(b) (i) MTBE, because it is the most soluble in water and has the smallest soil adsorption coefficient or smallest organic carbon/water partition coefficient, or octanol / water partition coefficient.
(ii) xylene, because it is the most insoluble in water and has the largest soil adsorption coefficient or largest organic carbon/water partition coefficient, or largest octanol/water partition coefficient. [20%]

(c) (i) organic compounds such as: any organic compounds which are volatile or semi volatile) E.g. benzene, toluene, ethylbenzene, xylenes, PAH's + others.
(ii) any heavy metals, + sodium, calcium, + practically any element except carbon, hydrogen, nitrogen; (i.e. excluding organic compounds). [20%]

(d) Gas Chromatograph [20%]

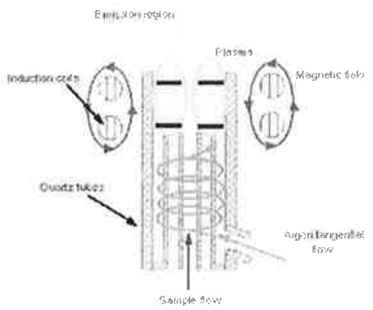


Or description:

- ♦ A gas chromatograph separates compounds according to their volatility, (or boiling point). Samples are typically extracted from water using a solvent, or if quite volatile, just collect the vapour (the headspace) above a sample of water from the site.
- ♦ A sample is injected into a flowing stream of helium gas. It is heated and passed into a thin tube called a capillary column which has the wall coated with a material attractive to organics.

Inductively coupled plasma optical emission spectrometry (ICP-OES)

- Plasma excites atoms which emit light
- Can analyse elements simultaneously, because hardly any interference between atoms
- Expensive



(e) Typical sources of both would be petrol and fuel related chemicals, related chemical plants and processing. Benzene and MTBE have different volatility and solubility, the former more volatile and the latter more soluble. The former is best remediated using soil vapour extraction in the vadose/soil zone and air sparging in the groundwater. Combined system Dual Phase extraction can be used if the contamination is in both the soil and groundwater. For MTBE this can also be used although less effective. Can be performed ex-situ for enhanced effectiveness. In-situ chemical oxidation would be another option. [20%]

4. (a) Four bioremediation processes:

(i) Biodegradation: Decomposition of compound into smaller chemical subunits – does not necessarily result in complete mineralisation. Usually via enzyme activity on compounds absorbed into cells or through activity of enzymes active outside confines of cell. Either aerobic (requires oxygen) or anaerobic (proceeds in absence of oxygen). Aerobic biodegradation could lead to complete mineralisation:

$C_6H_{14} + 9.5O_2 \rightarrow 6CO_2 + 7H_2O$

Anaerobic degradation includes a range of reduction processes:

- Nitrate reduction to nitrogen
- Iron reduction – iron III to iron II
- Sulphate reduction to hydrogen sulphide
- Methanogenesis – carbon dioxide reduction to methane

(ii) Biotransformation: Conversion of contaminant to less toxic and/or less mobile form. Biodegradation to organic 'daughter' compounds. Sometimes only relatively small changes. Activities may affect inorganic compounds: Directly e.g. via the methylation of mercury or Indirectly e.g. through precipitation of heavy metals by biologically produced sulphide. In some cases biotransformation is accompanied by increased toxicity

(iii) Bioaccumulation: Accumulation of contaminants within tissues of biological organisms which can be exploited to concentrate contaminants in harvestable biomass. Bioaccumulation by plants and fungi is well-known phenomenon. See phytoremediation

(iv) Mobilisation (and immobilisation): Mobilisation of contaminants from contaminated soil into solution or gas then separated from soil and recovered or destroyed – produced acids can mobilise heavy metals. Biological immobilisation includes the sorption of metals or organic compounds to plant roots. Bioavailability of sorbed compounds may be reduced by this process, but effect is temporary depending on lifetime of root. [20%]

(b) Ex-situ and in-situ bioremediation techniques:

(i) Ex-situ Bioremediation: Divided into four basic groups:

- Treatment beds: Simplest form of ex-situ bioremediation. Consists of a treatment area (lined with an impermeable liner) for complete collection of leachate. Layer of contaminated soil is spread on top. Conditions for bioremediation enhanced by periodic turning or mixing of soil to introduce oxygen. Nutrients, water or other additives may be also introduced. Soil usually placed to a maximum thickness of 0.3-0.5m, unless effective means of aeration is used e.g. agricultural deep spader.
- Windrow systems: Like composting systems, soil loosely placed in heaped piles (windrows), and aeration occurs usually by periodically turning or mixing windrows with mobile equipment. Bulking agents, such as wood chips, bark or compost, are often added to maintain porosity and encourage airflow – this may affect the suitability of soil for re-use
- Biopiles: Soil is placed as a regularly shaped pile which typically is bunded. Soil in the pile is aerated by using either an injection or vacuum extraction system to push or draw air through the system. These systems are designed to maximise mass transfer of oxygen and provide off-gas collection to control odours and emissions of volatilised contaminants. By using forced aeration the height of soil pile can be increased to 1.5-3m so requiring less space than a treatment unit which makes it less prone to drying and less susceptible to adverse weather
- Bioreactor: Soils mixed with water to form a slurry, which is then treated in a purpose built reactor system with mechanical agitator. Temperature, pH, nutrient and oxygen supply controlled to maximise degradation rate. Bioreactors range from treatment lagoons to contained vessels withdifferent levels of engineering and design.

(ii) In-situ bioremediation systems are based on in-situ movement of air (bioventing and biosparging) and water (using passive amendments or through in situ flushing) to simulate biodegradation of organic contaminants

- Bioventing (similar to SVE): Movement of air through vadose zone stimulates in-situ biodegradation of organics – using either extraction or injection wells. Is an application of SVE, movement of air is controlled to maximise rate of in-situ biodegradation and should be accompanied by reduction in extracted VOCs in the exhaust air from the process – generally uses lower air flow rates than SVE.
- Biosparging (similar to air sparging): Used to optimise biodegradation in saturated zone, air is pumped in small bubbles into the groundwater, encourages bio-degradation of organics both in groundwater and also sorbed onto soil. [15%]

(c) Ideal environmental conditions for bioremediation:

Factor	Optimum levels
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	aerobic: > 50 mV, anaerobic: < 50mV
pH	5.5 – 8.5
Nutrients	sufficient nitrogen, phosphorus, carbon etc, suggested C:N:P 120:10: – 1000:10:1. Elevated N levels inhibit microbial action
Temperature	15-25 ^{o}C

[10%]

(d) Effects of contaminant chemistry and soil type on the effectiveness of bioremediation.
(i) contaminant chemistry: Ease with which biological processes can degrade hydrocarbons is often controlled by carbon chain length, generally C6-C14 compounds are easily biodegradable while C15-C20 are treatable and C21-C32 are slowly treatable. Bioremediation would be recommended for compounds with C15-C32, while soil vapour extraction would be better for more volatile compounds. Presence of inhibitory substances would affect efficiency of treatment e.g. high levels of metals.
(ii) Soil type: Bioremediation of low C chain length compounds insand and gravel soils is much faster than that of high C chain compounds in silts and clays, changing from one month to 1 year. Presence of silt and clay soils substantially influence both air permeability and sorptive properties of the soil. Contaminated soil often exhibits substantial heterogeneity in chemical composition, physical structure & microbial activity. This limits rate and effectiveness of biological treatment as result of:

- variability in contaminant and microbe distribution
- mass transfer limitation as result of physically unavailable material e.g. water
- limitations in rate of desorption of contaminants to bioavailable form. [15%]

(e) Monitored Natural Attenuation (MNA): Under certain conditions, natural processes sufficient for purpose of risk management without need for any engineered intervention. Natural attenuation (NA) is combination of naturally occurring processes that act leading to reduction in contaminant volume, concentration or toxicity. Combined processes include: Dispersion and dilution, Sorption, Volatilisation, Biodegradation, Destruction, Transformation and Chemical or biological stabilisation. NA not 'do-nothing' approach, but based on extensive site characterisation and follow-up monitoring – leading to term monitored natural attenuation (MNA).
Usually applied to chlorinated solvents and hydrocarbons
Applied as follow on treatment for residual contaminants. [15%]

(f) Rhizosphere is the plant root zone within which there are mechanisms which breakdown contaminants through the bioactivity that exists in that zone. Natural substances released by plant e.g. sugars, alcohols, acids contain organic carbon that provides food for soil miroorganisms thereby enhancing their biological activity. [10%]