4D14 Contaminated Land and Waste Containment
Cribs April/May 2015

Q1 a) Leachate is the term given to the liquid that collects at the base of any landfill. It is usually a cocktail of chemicals the precise composition of which depends on the nature of the waste deposited into the landfill. Leachate levels are normally restricted by Environmental Agency to about 3ft or 1m above the base liner. [10%]

b) BOD is the Biological Oxygen Demand. This is the oxygen that is taken up during the biological reactions that take place within the waste. COD is the Chemical Oxygen Demand. This is the oxygen taken up during the chemical reactions that take place within the waste. Once covered, the amount of oxygen within the landfill determines whether BOD and COD are met fully. If not, anaerobic reactions start to occur within the landfill leading to the formation of quite different chemical products compared to aerobic reactions. [15%]

c) Reaction types within a waste fill may be broadly classified into organic biochemical and inorganic 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, CO_2 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, CO_2 and hydrogen sulphide (H_2S). Other compounds such as alcohol's and carboxylic acids may be produced in this process. Inorganic 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 H_2S. [15%]

d) i)

Initial population = 8000
Growth rate = 5 %
Later growth rate= 3 %

	Year	Population		Waste arisings (kg)
Jan-16	Dec-16	8400		5241600.0
Jan-17	Dec-17	8820		5503680.0
Jan-18	Dec-18	9085		5668790.4
Jan-19	Dec-19	9357		5838854.1
Jan-20	Dec-20	9638		6014019.7

Total Population = 45300 28266944.3 Total Waste Arisings (kg)
No of households= 18120
Total waste = 28266944.3 kg
28266.9 tons
Unit weight of compacted waste= 6.5 kN/m^3
= 662.6 kg/m^3
Volume of landfill= 42661.3 m^3
Height of landfill = 12.5 m
Area required = 3412.9 m^2
Choose area of 75 ×50 =3750 m^2> 3412.9 m^2, so OK

[30%]

d) ii)

Revenue generated =
Non-Hazardous waste = 27701.6 tons

Hazardous waste=	565.3	tons
Revenue from Non-hazardous waste =	1385080.3	AUD
Revenue from Hazardous waste =	67840.7	AUD
Total Revenue=	1,452,920.9	AUD

[20%]

d) iii)

Landfill tax revenue for Non-hazardous waste=	27701.6	X25=	692,540.0
Landfill tax revenue for Hazardous waste=	565.3	X75=	42,397.5
Total revenue for local Govt.=	734,937.5	AUD	

[10%]

Assessors comments: This question tested the candidates on their knowledge of the chemical and biological conditions that arise in landfills and designing landfills and associated costs of waste disposal. Most popular question, answered by all students, with an average mark of 66%. Generally a straight forward question with part description and part calculations. The second part was done extremely well. Loss of marks in the first half was mainly due to incomplete answers while in the second half due to simple calculation errors.

Q2 a) Geosynthetics are widely used in different parts of a landfill.

i) Geomembrane: A geomembrane is used in the landfill to prevent movement of leachate into the groundwater outside of the landfill. It is normally placed along the side slopes and the base of the landfill. It is also used in the top cover of the landfill, particularly if gas collection systems are to be installed for energy harvesting.

ii) Geotextile: The main function of a geotextile to provide tensile strength to the landfill component. If the self-weight or downdrag stresses are too large for the geomembrane, a geotextile layer is placed below it to provide structural strength.

iii) Geogrid: A geogrid is used to provide structural support in a localised area within a landfill. For example, if a soft region is identified below the base or side slope liners, then geogrid reinforcement can be provided in that region.

iv) GCL: A geosynthetic clay liner (GCL) can be used to combine the functions of a geomembrane and a geotextile. It consists of a layer of geomembrane sandwiched with a layer of clay/bentonite that is glued on. Geotextile layers can also be added to provide additional strength. GCLs can be used to prevent movement of leachate as well as provide structural strength to the landfill components. [20%]

2b) The main source of leakage through a geomembrane is through holes made when it comes into contact with sharp objects in the waste. Although geomembranes can have some leakage through their body, the co-efficient of permeability is very small. Most leakage is therefore through holes. Using Bernouli's orifice equation, the leakage through the geomembrane can be estimated, if the size of the hole is known, using the equation;

$$Q = C_D a_h \sqrt{2gh}$$

where C_D is shape factor, a_h is the area of the hole and h is height of leachate above the hole.

[10%]

2c) Hydrogeological Considerations for siting of an injection well

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.
Areal extent:
The area of influence of the waste front and the pressure front constitute the area of review around an injection well. Waste migrates out primarily due to advection at the time of pressure injection but mainly due to diffusion there after. Volumetric method to determine radial extent r is given as;

$$r = \left(\frac{V}{\pi b n}\right)^{\frac{1}{2}}$$

where V is the Volume of waste injected, b is the average thickness of injection zone and n is the porosity. Simple and based on the assumption that the waste will move out as an expanding cylinder
The above radius may be empirically corrected for dispersion as

$$r' = r + 2.3\sqrt{(D_d r)}$$

where D_d is the coefficient of dispersion (typically 3 ft for Sandstone), and r is radius obtained from volumetric method in feet.

[15%]

2d) Distance to the reservoir= 1000 m (1 km), porosity *n* = 0.45
Hydraulic conductivity of silty sand= 9×10^{-5} m/s and hydraulic gradient = 0.4
Darcy law says v= K i
Therefore, flow velocity v = $9 \times 10^{-5} \times 0.4 = 3.6 \times 10^{-5}$ m/s
Intrinsic velocity $v_f = v/n$ = $3.6 \times 10^{-5}/0.45 = 8 \times 10^{-5}$ m/s
Time taken = 1000 m / $8\times 10^{-5} = 12.5 \times 10^{6}$ seconds or 144.67 days (or ~4.7 months)

[15%]

2e) i) Factor of safety

$$FoS = 2\frac{\sqrt{\gamma\gamma'_f}\tan\phi}{\gamma' - \gamma'_f}$$

Buoyant unit weight of bentonite slurry = 12-10= 2 kN/m^3
Buoyant unit weight of backfill = 14-10= 4 kN/m^3

$$FoS = \frac{2\sqrt{2 \times 4}}{(4-2)} \times tan34 = 1.9077 > 1.5 \ so\ OK$$

[15%]

ii)Overall hydraulic conductivity is given by; $k = \dfrac{t_s}{\left(\frac{t_s}{k_s}\right) + 2\left(\frac{t_c}{k_c}\right)}$

Filter cake thickness = 4 mm = 0.004 m
Minimum thickness of the wall at base = 2m

$$k = \frac{2}{\left(\frac{2}{4.6 \times 10^{-6}}\right) + 2 \times \left(\frac{0.004}{8 \times 10^{-8}}\right)}$$

Overall hydraulic conductivity = k = 3.74×10^{-6} m/s

[15%]

iii) New time for contaminant to reach the water reservoir:
Time taken = ~4.7 months x ($9 \times 10^{-5}/3.74\times 10^{-6}$) = ~ 9.5 years [10%]

Assessors' comments: A question that covered different areas. Answered by 75% of the students with an average mark of 62%. The first half was descriptive and more challenging than the second half, which was mainly calculations. Most students did much better in the second half than the first. The first half requires a lot of details to be provided; many students presented part of the answers required. The second part required the students to remember a number of equations. Some student substituted wrong values in the equations or forgot to use the porosity value provided.

Q3 (a) The major issue with petroleum products contamination is the different nature and properties of its constituents which lead to extensive contamination in both the vadose zone (volatiles) and groundwater zone (LNAPL float and DNAPL sink) etc… [10%]

(b) Ingestion of soil or groundwater, inhalation of indoor or outdoor vapours, dermal exposure of contaminated soils, inhalation of dust. [10%]

(c) A threshold is a dose value of a contaminant (in mg/kg bw/day) below which it has no effect on humans. Hence chemicals without a threshold are those for which a threshold cannot be assumed, e.g. mutagenic and genotoxic carcinogens, for which in theory a single molecule exposure could result in a tumour or mutation, possibly expressed in subsequent generations – assumed they carry a risk at any slight level of exposure, hence their presence in soil needs to be minimised. [10%]

(d) Vapour pressure: Degree to which contaminant partitions into the vapour phase from pure product, in mm Hg. Henry's Law constant is the degree to which contaminant partitions into the vapour phase from aqueous solution in atmospheres. As simplified guidelines, SVE is considered potential remediation if contaminants have following characteristics: vapour pressure ≥ 0.5mmHg & Henry's law constant >100 atmospheres, both at 20^{o}C. [10%]

(e) Most favourable conditions are soil types possessing high air permeability and high porosity, often water permeability >10^{-3}cm/s. Soil moisture content important: high water content reduces air filled voids and hence space available for gas movement, although some water is desirable to achieve contaminant desorption. Stratigraphy consisting of clay and silt will restrict contaminant removal rate so remediation timescales are extended. [10%]

(f) Solubility is very important is SVE/air sparging removal. Contaminants have to be sufficiently volatile and with low enough water solubility to be drawn into air stream. Compounds like MTBE with high solubility but low Henry's Law constant, although could be mobilised through dissolution, cannot be effectively removed with air sparging. [10%]

(g) [10%]

Fraction	Treatment by bioremediation	Treatment by venting or soil vapour extraction	Preferred method
C_6 - C_9	Readily treatable	Readily treatable	Vapour extraction
C_{10} – C_{12}	Readily treatable	Treatable	Vapour extraction
C_{13} – C_{14}	Readily treatable	Slowly treatable	Bioremediation
C_{15} – C_{20}	Treatable	Not treatable	Bioremediation
C_{21} – C_{32}	Slowly treatable	Not treatable	Bioremediation

(h) Both involve the movement of air through the vadose zone using either extraction or injection wells. In bioventing the movement of 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 – so generally uses lower air flow rates than SVE. The latter aims to remove VOCs through volatilisation. [10%]

(g) Pump and treat would be most suitable for a soluble and well defined plume. Air sparging when DNAPLs are present, PRB if a clear plume movement direction and if suitable reactive materials is identified. Also depends on what other treatments being employed at the site. Air sparging would be favourable of soil vapour extraction is being used, PRB when other barrier systems are being employed and pump and treat when dewatering applications are needed. [20%]

Assessors' comments: A question of many parts on various aspects of petroleum products: their properties, contamination issues and remedial measures. Answered by 80% of the students with an average mark of 49%. The question required the students to extract knowledge from across the whole course material hence some students only answered some of the questions. Generally a disappointing performance with many brief and incomplete answers resulting in loss of marks. Some answered parts of the question completely wrong.

Q4 (a) 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%]

(b) see lecture handouts for details. For field analysis use a portable x-ray fluorescence analyser. For lab analysis use GC or ICP etc. [20%]

(c) (i) heterogeneity of contamination within a site,
(ii) variation of concentrations within a contaminated area and
(iii) measurement uncertainties
(iv) Standard of soil sampling and collection technique
(v) Sample preservation prior to arrival in laboratory
(vi) Selection of most appropriate test method
(vii) Stated precision of laboratory test results
(viii) Application of appropriate level of QA to all aspects of process [20%]

(d) (i) No proven or environmentally cost-effective treatment-based technique is available
(ii) Many contaminants are degradable and in time may attenuate to acceptable levels
(iii) Heavy metal contaminants cannot be destroyed hence containment or extraction and recycling are the only options
(iv) Contaminants may be inaccessible
(v) Containment can provide rapid risk management [20%]

(e) Intended to break pathway of pollutant linkages, by restricting movement of water and/or gas and preventing dust blowing off a contaminated site. Cover systems can range from a single layer of top soil no more than 100mm thick (no longer recommended) to a multi-layered construction combining natural materials and geomembranes. Top soil placed above cover system to prevent cracking of any clays used to provide impermeable layer. Cover system must prevent ingress of water into contaminated material and must also prevent built up of water 'ponding'. Cover systems must be designed to take into account local hydrological and climatic conditions. Usually suitable when contaminated soil extent is very large and with no danger of ground water contamination.
[20%]

<u>Assessors' comments:</u> A question on chemical analysis and containment and cover systems. The least popular question, answered by 46% of the students and with an average mark of 63%. A question of two halves: the first on laboratory and field chemical analyses and the second on the merit of containment and cover systems. Generally a well answered questions although the least popular. A number of students were not aware of the in-situ chemical analysis methods. Many answered part (c) incorrectly.