Montogue

Quiz EV102

SOLID WASTE ENGINEERING

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PROBLEMS

→ Problem 1.1

A waste sample has the following weight composition. Using the data in the second table below, determine the density of this waste sample.

Component	Percent by mass
Cardboard	8
Food waste	22
Paper	38
Plastics	10
Tin cans	3
Wood	8
Yard wastes	11

Component	Density (kg/m³)	Moisture content (%)	Energy content (kJ/kg)
Cardboard	130	4	16,000
Food waste	360	70	4800
Paper	120	5	16,500
Plastics	100	3	32,500
Tin cans	90	3	700
Wood	100	18	19,000
Yard wastes	125	60	17,000

A) ρ = 96.1 kg/m^3
B) ρ = 109 kg/m^3
C) ρ = 135 kg/m^3
D) ρ = 154 kg/m^3

→ Problem 1.2

Determine the moisture content of the waste sample introduced in Problem 1.1.

A) w = 14.4%
B) w = 26.1%
C) w = 37.5%
D) w = 44.6%

→ Problem 1.3

Determine the as-discarded unit energy content of the waste sample introduced in Problem 1.1.

A) E = 12,250 kJ/kg
B) E = 13,110 kJ/kg
C) E = 15,270 kJ/kg
D) E = 18,600 kJ/kg

→ Problem 1.4

Determine the dry unit energy content of the waste sample introduced in Problem 1.1.

A) E' = 20,660 kJ/kg
B) E' = 22,900 kJ/kg
C) E' = 23,420 kJ/kg
D) E' = 25,630 kJ/kg

▶ Problem 2

A sample of solid waste has the following mass composition. Using the hypothetical per-element compositions listed in the second table below, derive a molecular formula for the organic portion of this waste. Then, estimate the energy content of the waste using the DuLong formula.

Food waste	40%
Leather	10%
Plastics	15%
Rubber	10%
Wood	20%
Yard waste	5%

MSW component	Moisture content (%)	Percentage by weight					
		Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Ash
Food waste	70	50	12	30	2	1	5
Leather	8	50	8	15	15	2	10
Plastics	3	60	10	20	1	1	8
Rubber	2	60	10	0	0	10	20
Wood	18	45	5	45	3	0	2
Yard waste	60	45	5	34	5	1	10

▶ Problem 3

Concerning various aspects of solid waste science, true or false?

1.( ) In a commonsensical classification, municipal solid waste (MSW) is divided into two categories: garbage and rubbish. Garbage is synonymous with food waste, encompassing animal and vegetable residue used in the preparation of food. Rubbish, in turn, includes used goods such as newspaper, tires, bottles, and plastics. Rubbish comprises combustible and noncombustible solid wastes, but does not include food waste.

2.( ) The solid waste composition in developing countries is substantially different from that of developed countries. One appreciable difference in waste composition in developing countries relatively to that of developed countries is a higher fraction of organic putrescibles and a lower fraction of manufactured products such as paper and metals.

3.( ) Since the second half of the twentieth century, paper and paperboard have been the dominant materials in waste generation in the US and most developed countries.

4.( ) Automated collection systems are one means by which a population can dispose of solid waste. Advantages of this system include the inherent convenience of wheeled containers, which are more maneuverable and allow for greater capacity than regular trash cans, and the inherently low cost of the carts supplied to homeowners and the specialized vehicles used in the collection process.

5.( ) In a waste collection operation in an urban district, a population of 4000 residents is to have its solid waste collected once a week. The district wants to collect on Mondays, Wednesdays, and Fridays. A single truck can service 200 customers in a single day and still have time to take the full loads to the landfill. Thus, we may surmise that more than 6 trucks will be required to accommodate the waste production of this district.

6.( ) Landfills can be designed for disposal of municipal solid waste, industrial waste, hazardous waste, and construction/demolition debris. In the US, all four types of landfills are nationally regulated by specific parts of the Code of Federal Regulations (CFR).

7.( ) In general, the five-day biochemical oxygen demand (BOD_5), the total organic carbon (TOC), and the chemical oxygen demand (COD) are all relatively low in the initial months of a landfill, but consistently increase with time.

8.( ) Many modern landfills are lined with geomembranes as a means of improving leachate drainage. The most widely used geomembrane polymer is high-density polyethylene (HDPE). In addition to its excellent hydraulic behavior, HDPE also serves as a mechanical reinforcement, efficiently bearing overlying waste in a ductile manner and withstanding temperature variations without contracting or expanding excessively.

9.( ) Research has consistently shown that shredded municipal solid waste has a more uniform particle size, is fairly homogeneous, and is compacted more readily than unshredded waste, mainly because the larger voids have been eliminated. Nonetheless, experience has demonstrated that landfilling of shredded refuse requires an earth cover, much like unshredded waste. The landfill operator cannot do away with this provision simply because shredded waste is more easily handled.

10.( ) Half-lives for methane production in a landfill depend on the waste's degradability and can vary from 1 to 35 years. They also vary with the moisture content of the waste, as moister waste generally has a greater half-life than dry waste.

11.( ) A biodegrading waste load decomposes in a landfill, producing gas with first-order kinetics and a half-life of 3 years. The time required for 90 percent of the waste mass to be converted to gas is greater than 9 years.

12.( ) The most common types of composting systems are *windrow* composting and *in-vessel* composting. Windrow composting is more expensive to construct, but offers a number of advantages, including faster production of compost and a better control of conditions such as temperature, moisture, and airflow.

13.( ) Dioxins and furans, some of the most toxic substances known to man, are created as products of solid waste incineration. Emissions of these substances can be reduced to nondetectable levels by use of high combustion temperatures – say, over 900°C – and high residence times.

14.( ) A 25-g sample of a refuse-derived fuel (RDF) is combusted in a calorimeter that has a heat capacity of 9000 cal/°C. If the detected temperature rise was 9°C, we may surmise that the heat value of this RDF sample is greater than 15,000 J/g.

15.( ) In the US, over 6 million metric tons of steel were recycled in 2005. Recycled steel saves about 0.5 metric tons of carbon equivalents per ton. For perspective, a car emits about 4.0 million metric tons of CO_2 per year. Accordingly, we surmise that recycling of the foregoing mass of steel is equivalent to taking more than 2.5 million vehicles out of the streets.

16.( ) Plastics can be classified into two types according to how they react to heat: *thermoplastics* and *thermosetting plastics.* Thermoplastics are generally easier to recycle than thermosetting plastics.

17.( ) The degradation of a polymer with successive reprocessing can be associated with changes in the melt flow index (MFI). For many plastics, successive reprocessings are accompanied by a decrease in viscosity and a corresponding rise in MFI.

18.( ) Poly(ethylene terephthalate) is a frequently recycled plastic. One of the main PET-based products is PET photographic film, which is relatively expensive and hence has driven manufacturers such as Fuji and 3M to develop technologies for restitution of this type of product. One important step in PET photographic film recycling is the recovery of the excess mercury that constitutes the film, which can be separated from the polymer and reclaimed.

19.( ) The first step in a glass recycling procedure is to separate the waste by color: clear (flint), green (emerald), or brown (amber). Once the recovered glass has been separated by color, it is crushed into smaller pieces, called *cullet*. When significant quantities of color-separated cullet are accumulated, it may be shipped to container manufacturers to be remade into new glass bottles and jars. Two important drawbacks of current glass recycling technology are the fact that cullet can only be recycled two or three times before becoming irrecoverable and requires higher temperatures – and therefore more energy – than those employed in virgin glassmaking.

20.( ) In the so-called Philadelphia Experiment, one of various field experiments conducted in the 1970s to examine behavioral aspects of littering, researchers took to observe what customers of a hotdog vendor would do with the paper wrap that came with their food. They found that the probability that a customer would litter the paper wrap could be estimated with the equation

$$\Pr\left[\text{littering}\right] = 0.132 + 0.457A + 0.181B + 0.179C$$

where A = 1 if the customer is 18 years old or younger, or A = 0 otherwise; B = 1 if there were no trash cans nearby, or B = 0 otherwise; and C = 1 if the area is dirty, or C = 0 otherwise. With reference to these values, we can surmise that a 32-year-old man who bought a hotdog in a dirty area with no trash cans has a probability of littering greater than 45%.

▶ Problem 4 (Modified from Masters and Ela, 2014, with permission)

How long would it take to fill a 23-m^3 packer truck that compresses waste to 450 kg/m^3 if it travels 60 m between stops at an average of 8 km/h and takes 1 minute to load 90 kg of waste at each stop? If each stop services four homes and two collection runs are made per day, how many customers could be provided with once-per-week service by this single truck (assuming a five-day week)?

A) Time to fill truck = 2.78 h, No. customers = 2300 customers/week
B) Time to fill truck = 2.78 h, No. customers = 4600 customers/week
C) Time to fill truck = 3.94 h, No. customers = 2300 customers/week
D) Time to fill truck = 3.94 h, No. customers = 4600 customers/week

→ Problem 5.1 (Modified from Masters and Ela, 2014, with permission)

Consider the following data for a municipal waste collection system. How many hours per day would the crew have to work if it fills the truck twice per day?

Travel time, garage to route	30 min
Travel time, route to disposal site	20 min
Time to unload at disposal site	10 min
Time from disposal site to garage	15 min
Time spent on worker breaks	45 min/day
Packer truck volume	23 m^3
Compaction ratio	4
Curb volume per service	0.16 m^3/customer
Travel time between stops	30 sec
Customers served per stop	4
Time loading per stop	1 min

A) t = 9.0 h
B) t = 10.0 h
C) t = 11.0 h
D) t = 11.8 h

→ Problem 5.2

Making two runs per day, how many customers would be served per truck if each home has once-per-week service and the truck is used five days per week?

A) n = 2840 customers/week
B) n = 3650 customers/week
C) n = 4420 customers/week
D) n = 5750 customers/week

→ Problem 5.3

Suppose the cost of a crew for one truck is \$35 per hour for the first eight hours per day, plus \$50 per hour for any hours over that amount. Assume the crew works 52 weeks per year. Furthermore, suppose a packer truck has an annualized cost of \$10,000 + \$4500 × L, where L is the truck load in m^3. What is the annual cost of service (crew plus customer) per customer?

A) Customer cost = \$14.10/yr
B) Customer cost = \$26.60/yr
C) Customer cost = \$37.00/yr
D) Customer cost = \$43.20/yr

→ Problem 5.4

To avoid overtime pay, the crew in the previous problem is to work only six hours per day. They still make two runs to the disposal site every day, but their truck is not always full. How many customers would the truck, operated 5 days/week, provide once-per-week service to now?

→ Problem 5.5

To avoid overtime pay, the crew in Problem 5.1 is to work only eight hours per day, which means the truck can be smaller. What minimum-size truck would be needed to serve this route? If the cost of a crew for one truck is $35 per hour for 52 weeks per year, and if packer trucks have an annualized cost of $10,000 + $4500 × *L*, where *L* is the truck load in m^3, what would be the annual cost of service (crew plus truck) per customer? Compare your answer with the result of Problem 5.3.

→ Problem 6.1

Calculate the volumetric flow rate of leachate through a compacted clay liner if the area of the landfill is 20 ha and the liner thickness is 1.2 m. The hydraulic conductivity is 8×10^{-10} m^2/s, and the head of water is 0.5 m.

A) $Q = 8.0\times10^{-5}$ m^3/s
B) $Q = 9.6\times10^{-5}$ m^3/s
C) $Q = 8.0\times10^{-4}$ m^3/s
D) $Q = 9.6\times10^{-4}$ m^3/s

→ Problem 6.2

A landfill that is 14 ha in area has a liner thickness of 0.85 m. Each year 1750 m^3 of leachate is collected, The hydraulic conductivity of the liner is 4.4×10^{-10} m/s. What is the head of water above the liner?

A) $\Delta h = 0.178$ m
B) $\Delta h = 0.366$ m
C) $\Delta h = 0.766$ m
D) $\Delta h = 0.974$ m

▶ Problem 7

A city with a population of 75,000 generates solid wastes at a rate of 2 kg/capita/day. The compacted specific weight of solid wastes in the landfill is 750 kg/m^3 and the average depth of compacted solid wastes in the landfill is 5 m. Determine the required landfill area to accommodate the waste generated by this city over the course of a year.

A) $A = 11.2$ ha
B) $A = 14.6$ ha
C) $A = 19.3$ ha
D) $A = 21.2$ ha

▶ Problem 8

A landfill in Leipzig, Germany serves a population of 560,000 generating MSW at a rate of 1.92 kg/capita/day. The volume of the landfill is 12,100,000 m^3. At the present time, 60% of the landfill capacity is used. The ratio of cover to compacted fill is 1.8. Assuming the density of the compacted waste is 500 kg/m^3, determine the projected life remaining for the landfill.

A) $t = 2.14$ years
B) $t = 3.42$ years
C) $t = 4.67$ years
D) $t = 5.11$ years

▶ Problem 9

The conversion of municipal solid waste of approximate formula $C_aH_bO_cN_d$ into gases can be described by the chemical equation

$$C_aH_bO_cN_d + \left(\frac{4a-b-2c+3d}{4}\right)H_2O \rightarrow \left(\frac{4a+b-2c-3d}{8}\right)CH_4 + \left(\frac{4a-b+2c+3d}{8}\right)CO_2 + dNH_3$$

Determine the volume of methane + carbon dioxide generated in a sanitary landfill by anaerobic digestion of 1000 kg of MSW having $C_{100}H_{160}O_{80}N$ as the approximate chemical formula for its organic portion. The densities of CH_4 and CO_2 at the temperature and pressure of interest are taken as constant and equal to 0.72 kg/m^3 and 2.0 kg/m^3, respectively.

A) $V = 487$ m^3
B) $V = 665$ m^3
C) $V = 711$ m^3
D) $V = 833$ m^3

▶ Problem 10 (Modified from Davis and Masten, 2014)

A developer plans to supply a small district with heat from combustion of methane collected in a nearby landfill. The district consists of 12 households of 4 people each, and MSW generation is 1.2 kg/capita/day. It is anticipated that gas can be produced at an annual rate of 50 L gas/kg of MSW delivered to the landfill and that the gas will contain 75% methane. The heat content of the methane gas is approximately 36,500 kJ/m^3. The homes are estimated to use an average 32×10^5 kJ of heat energy/year. Assuming the gas released in the landfill stems exclusively from waste produced by the district, answer: is the methane produced by the landfill sufficient to accommodate the yearly energy demand of the 12 homes?

α) The landfill gas can sustain the energy demand of all 12 homes.
β) The landfill gas cannot sustain the energy demand of all 12 homes.
γ) There is not enough information.

→ Problem 11.1 (Modified from Mihelcic and Zimmerman, 2014, w/ permission)

Assume all the waste in one section of a landfill was added at the same time. After 6 years, the gas production rate reached its peak. After 24 years (or 18 years after the peak), the production rate had decreased to 10 percent of the peak rate. Assume a first-order decay applies to the gas production rate after the peak is reached. Further, assume no gas is produced prior to the peak of 6 years. What percentage of the total gas production can we predict to have occurred after 24 years?

A) 65% of total gas production will have been attained after 24 years.
B) 75% of total gas production will have been attained after 24 years.
C) 85% of total gas production will have been attained after 24 years.
D) 95% of total gas production will have been attained after 24 years.

→ Problem 11.2

How long do you predict until 99 percent of the gas has been produced?

A) T = 28 years
B) T = 32 years
C) T = 36 years
D) T = 42 years

▶ Problem 12 (Modified from Mihelcic and Zimmerman, 2014, w/ permission)

Equal amounts of two types of waste are disposed into a section of a landfill. They both start producing gas at t = 0, so there is no lag time. Assume first-order decay for gas production. Each type of waste can produce 180 L CH_4/kg of waste. Waste type A produces gas with a half-life of 2.5 years, while waste type B produces gas with a half-life of 5 years. Determine how long until 90 percent of each gas has been produced.

A) T = 7.31 years
B) T = 9.23 years
C) T = 12.7 years
D) T = 14.5 years

→ Problem 13.1 (Data from Mihelcic and Zimmerman, 2014)

Poultry manure waste has a moisture content of 70% and is 6% N (on a dry mass basis). The poultry manure is to be composted with fresh leaves. The fresh leaves have a moisture content of 60% and is 0.8% N (on a dry mass basis). The desired carbon : nitrogen ratio for vegetable wastes is 18. The C:N ratios for poultry manure and fresh leaves are 15 and 41, respectively. Determine the kg of fresh leaves required per kilogram of poultry manure.

A) 0.136 kg of fresh leaves should be added for every kg of poultry manure.
B) 0.405 kg of fresh leaves should be added for every kg of poultry manure.
C) 0.734 kg of fresh leaves should be added for every kg of poultry manure.
D) 0.975 kg of fresh leaves should be added for every kg of poultry manure.

→ Problem 13.2

Nonlegume vegetable wastes have a moisture content of 80% and are 4% N (on a dry mass basis). The vegetable wastes are to be composted with readily available sawdust. The sawdust has a moisture content of 50% and is 0.1% N (on a dry mass basis). The desired carbon : nitrogen ratio for vegetable wastes is 22. The C:N ratios for NLVW and sawdust are 12 and 500, respectively. Determine the kg of sawdust required per kilogram of vegetable waste.

A) 0.335 kg of sawdust should be added for every kg of NLVW.
B) 0.548 kg of sawdust should be added for every kg of NLVW.
C) 0.617 kg of sawdust should be added for every kg of NLVW.
D) 0.975 kg of sawdust should be added for every kg of NLVW.

SOLUTIONS

P.1 ➡ *Solution*

Part 1: As a reference, suppose we have a mass of 1000 kg of solid waste. The contributions of each component to the volume of the sample are calculated below.

Component	Percent by mass	Mass in 1000 kg	Density (kg/m³)	Volume (m³)
Cardboard	8	80	130	0.615
Food waste	22	220	360	0.611
Paper	38	380	120	3.167
Plastics	10	100	100	1.000
Tin cans	3	30	90	0.333
Wood	8	80	100	0.800
Yard wastes	11	110	125	0.880
			Sum	7.406

The total volume is the sum of the values in the blue column, or 7.406 m³. The density of the solid waste sample is then

$$\rho = \frac{1000}{7.406} = \boxed{135\ \text{kg/m}^3}$$

♦ The correct answer is **C**.

Part 2: As a reference, suppose we have a mass of 100 kg of solid waste. The contributions of each component to the dry mass of the sample are computed below.

Component	Percent by mass	Moisture content (%)	Dry mass (kg)
Cardboard	8	4	7.68
Food waste	22	70	6.6
Paper	38	5	36.1
Plastics	10	3	9.7
Tin cans	3	3	2.91
Wood	8	18	6.56
Yard wastes	11	60	4.4
		Sum	73.95

The moisture content of the waste sample is then

$$w = \frac{100 - 73.95}{100} = \boxed{26.1\%}$$

♦ The correct answer is **B**.

Part 3: In order to calculate the energy content of the waste in question, we first determine the contributions of each component to the energy content of a waste mass of 100 kg, as shown in continuation.

Component	Percent by mass	Energy content (kJ/kg)	Total energy (kJ)
Cardboard	8	16000	128000
Food waste	22	4800	105600
Paper	38	16500	627000
Plastics	10	32500	325000
Tin cans	3	700	2100
Wood	8	19000	152000
Yard wastes	11	17000	187000
		Sum	1526700

The as-discarded unit energy content is then

$$E = \frac{1{,}526{,}700}{100} = \boxed{15{,}270\,\text{kJ/kg}}$$

♦ The correct answer is **C**.

Part 4: The dry unit energy content is, accounting for the moisture content calculated on Part 2,

$$\text{Dry energy content} = E' = 15{,}270 \times \left(\frac{100}{100-26.1}\right) = \boxed{20{,}660\,\text{kJ/kg}}$$

♦ The correct answer is **A**.

P.2 ➡ *Solution*

For convenience, suppose we have a waste mass of 100 kg. Using the data we were given, we can determine the dry mass and the per-element mass of the sample, as shown in continuation.

MSW component	Moist mass (kg)	Moisture content (%)	Dry mass (kg)	Chemical composition (kg)					
				Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Ash
Food waste	40	70	12.0	6.000	1.440	3.600	0.240	0.120	0.600
Leather	10	8	9.2	4.600	0.736	1.380	1.380	0.184	0.920
Plastics	15	3	14.6	8.730	1.455	2.910	0.146	0.146	1.164
Rubber	10	2	9.8	5.880	0.980	0.000	0.000	0.980	1.960
Wood	20	18	16.4	7.380	0.820	7.380	0.492	0.000	0.328
Yard waste	5	60	2.0	0.900	0.100	0.680	0.100	0.020	0.200
Totals	100		63.95	33.490	5.531	15.950	2.358	1.450	5.172

The total water mass is 100 – 63.95 = 36.05 kg. This corresponds to 2/18 × 36.05 = 4.01 kg of hydrogen and 16/18 × 36.05 = 32.0 kg of oxygen. Equipped with these data and the results of the previous table, we can determine the percent mass composition of the solid waste sample.

Component	Mass (kg)	Percent by mass
Carbon	33.49	33.49%
Hydrogen	5.531 + 4.01	9.541%
Oxygen	15.95 + 32.0	47.95%
Nitrogen	2.358	2.358%
Sulfur	1.450	1.450%
Ash	5.172	5.172%

The next step is to compute the molar composition of the waste sample. As a reference, we take a mole ratio of one for sulfur. The calculations are summarized below.

Component	Mass (kg)	Molar mass (kg/mol)	No. of moles	Mole ratio
Carbon	33.49	12	2.791	62.02
Hydrogen	4.01	1	4.010	89.11
Oxygen	32	16	2.000	44.44
Nitrogen	2.358	14	0.168	3.743
Sulfur	1.45	32	0.045	1.0

Using the coefficients obtained in the last column, we conclude that the organic portion of the waste sample has an approximate formula $C_{62}H_{89}O_{44}N_4S$.

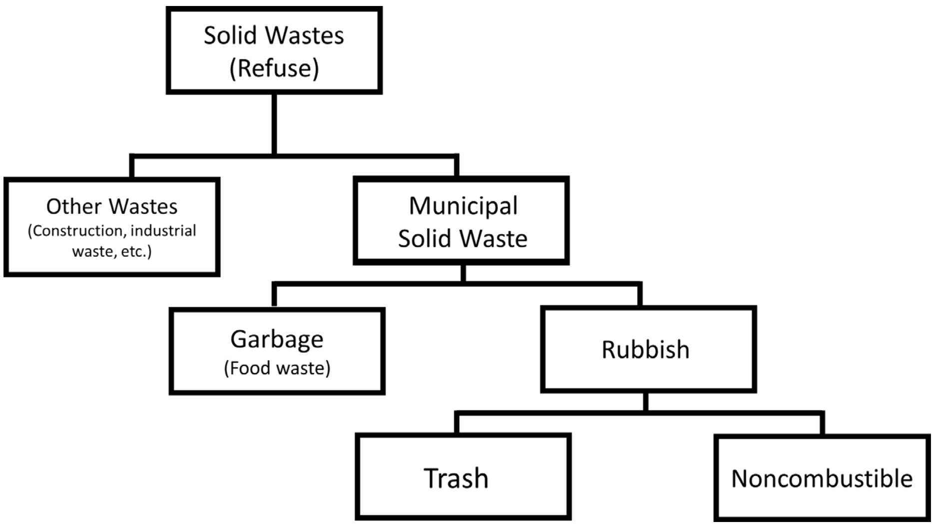
The DuLong formula gives the energy content of the waste as a function of mass compositon; substituting [*C*] = 33.49%, [*H*] = 9.541%, [*O*] = 47.95%, [*N*] = 2.358%, and [*S*] = 1.450% brings to

$$E = 337[C] + 1420\left([H] - \frac{[O]}{8}\right) + 93[S] + 23[N]$$

$$\therefore E = 337\times 33.49 + 1420\left(9.541 - \frac{47.95}{8}\right) + 93\times 1.450 + 23\times 2.358 = \boxed{16{,}500\,\text{kJ/kg}}$$

P.3 ➡ *Solution*

1. True. Garbage is but an alternative term for food waste, and rubbish indeed encompasses any combustible or noncombustible MSW other than food waste. As illustrated below, rubbish can be further subdivided into *trash*, which is the combustible part of rubbish, and noncombustible rubbish.



2. True. Indeed, the waste produced in developing nations tends to have a higher proportion of organic putrescibles and a lower fraction of manufactured goods such as paper, metals, and glass.

3. True. In the US, paper alone accounted for 36.4% and 28% of the materials generated in 1980 and 2009, respectively. The second largest materials component of American MSW is yard trimmings, which constituted 22.7% and 14% of waste generation in 1980 and 2009, respectively.

4. False. While it is true that the wheeled containers used in automated collection systems are an added convenience for customers, the costs associated with the carts and specialized vehicles involved in the implementation of an ACS are by no means low. For example, the capital cost of an automated side-loader is about 20% more than that of a manual rear loader. Additionally, the useful life of an automated vehicle is often less than a rear loader.

5. True. If the number of customers that a single truck can service during the day is known, the number N of collection vehicles needed for a community can be estimated as $N = S\times F/(P\times W)$, where S is the total number of customers serviced, F is the weekly collection frequency, P is the number of customers a single truck can service per day, and W is the number of workdays per week. Substituting the pertaining data into this equation brings to

$$N = \frac{SF}{PW} = \frac{4000\times 1}{200\times 3} = 6.67$$

or

$$\boxed{\lceil N \rceil = 7\ \text{trucks}}$$

6. False. The CFR regulates three of the four landfill types, namely municipal solid waste (40 CFR, Part 258), industrial waste (40 CFR, Part 257), and hazardous waste (40 CFR, Parts 264 and 265). Construction and operation of landfills for construction/demolition debris are regulated at the state level.

7. False. The BOD_5, the TOC and the COD are all relatively high in new landfills, but tend to decrease with time. BOD_5 and COD figures of 20,000 and 18,000 mg/L, respectively, have been quoted for new landfills, while older facilities generally have BOD_5 and COD values no greater than 50 and 300 mg/L.

8. False. While it is true that HDPE offers excellent hydraulic properties, its mechanical performance, like that of many plastics, is rather poor. For one, HDPE is brittle and has a relatively high coefficient of thermal expansion, so that, when contracting under low temperatures, a geomembrane made of this polymer becomes susceptible to stress cracking.

9. False. According to Worrell and Vesilind (see reference below), experience with landfilling of shredded MSW indicates that shredded refuse does not require an earth cover. Reasons for this assertion include:

Odor: The shredded refuse is well mixed and retains its aerobic character when spread in reasonably thin layers, so odor is not a problem.

Rats: There are no large food particles in shredded refuse that could support a rat population.

Insects: The drier refuse, regularly covered with new layers, suppresses insect breeding, and all of the maggots are killed during shredding.

Blowing paper: Small pieces are not caught by the wind and do not blow away, while large pieces of paper and plastics found in a conventional landfill would be readily transported by wind.

Reference: WORRELL, W. and VESILIND, P. (2012). *Solid Waste Engineering*. 2nd edition: Stamford: Cengage Learning.

10. False. On the contrary, dry waste has a greater half-life than moister waste. For that reason, some landfill operators recycle leachate into the waste pile or add other sources of water to the waste as a means to increase the rate of decomposition.

11. True. The rate constant for the reaction is $ln\ 2/t_{1/2} = 0.693/3 = 0.231\ \text{yr}^{-1}$. The time required for 90% decay of the waste mass, in turn, is $-ln\ 0.1/0.231 = 9.97$ years.

12. False. Faster production of compost and better control of operational conditions are generally associated with in-vessel composting, not windrow composting. Common properties of the two composting systems are listed below.

System type	Particle size	Types of waste	Mixing Frequency	Time to obtain compost
Windrows	5 – 20 mm	Mixed yard	Once per week	2 – 4 months
In-vessel	5 – 20 mm	Yard and food	Hourly	1 – 2 months

13. True. Temperatures greater than 900°C and residence times of over one to two seconds are imperative to reduce emissions of dioxins and furans to acceptable levels. Ela and Masters (see reference below) note that, if dioxin-furan precursors such as hydrogen chloride, phenols, and aromatic hydrocarbons are not completely destroyed during combustion, they can react in the presence of fly ash to form new dioxins and furans as the exiting flue gases cool. Complete combustion, combined with downstream emission control systems, are therefore essential to achieve acceptable emission limits.

Reference: MASTERS, G. and ELA, W. (2014). *Introduction to Environmental Engineering and Science*. 3rd edition. Upper Saddle River: Pearson.

14. False. The heat value U of an unknown material is given by

$$U = \frac{C_v \Delta T}{m}$$

where C_v = 9000 cal/°C is the heat capacity of the calorimeter, ΔT = 9°C is the rise in temperature from the thermogram, and m = 25 g is the mass of the unknown material, so that

$$U = \frac{C_v \Delta T}{m} = \frac{9000 \times 9}{25} = 3240\,\text{cal/g}$$

or, equivalently, 13,556 J/g.

15. True. The amount of carbon savings for the recycled steel is determined as

$$\text{Carbon savings} = 6 \times 10^6\,\frac{\text{tons}}{\text{year}} \times 0.5\frac{\text{MTCE}}{\text{ton}} = 3 \times 10^6\,\frac{\text{MTCE}}{\text{year}}$$

This amounts to CO_2 savings such that

$$CO_2\ \text{savings} = 3 \times 10^6\,\frac{\text{MTCE}}{\text{year}} \times \frac{44\,\text{tons CO}_2}{12\,\text{tons C}} = 1.1 \times 10^7\ \text{mt CO}_2/\text{year}$$

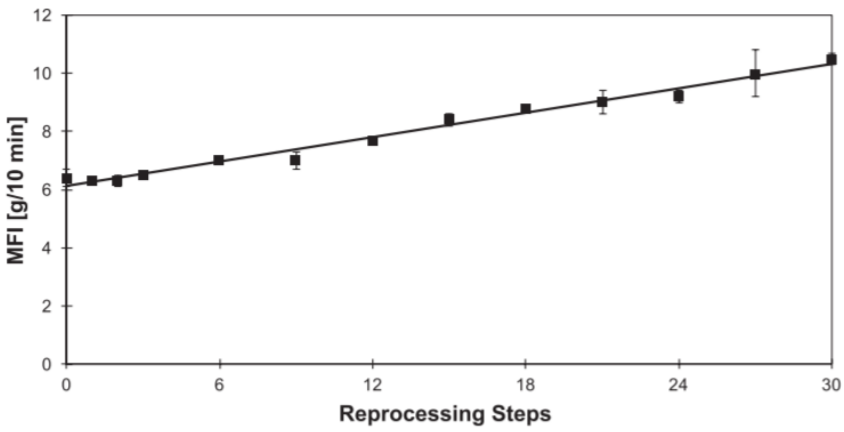
Accordingly, if a car emits 4.0 million metric tons of CO_2 per year, the CO_2 savings calculated above are equivalent to a number of vehicles equal to

$$\text{Car equivalents} = \frac{1.1\times10^7 \text{ mt } CO_2/\text{yr}}{4\,\text{mt } CO_2 \text{ / veh}} = \boxed{2.75\times10^6 \text{ veh/yr}}$$

That is, recycling 6 million mt of steel over the course of a year equates to removing nearly 2.8 million vehicles off the streets.

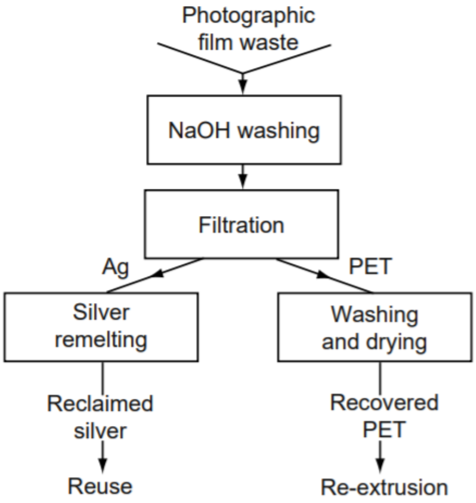
16. True. Thermoplastics can be remelted and remolded into new products, but the same cannot be said of thermosetting plastics, as they decompose when heated.

17. True. Indeed, thermal and mechanical degradation of a polymer with successive reprocessing may be followed by a loss of viscosity and an increase in MFI; this is illustrated below for high-impact polystyrene (HIPS).



It should be noted that not all polymers exhibit this behavior. For some plastics, such as low-density polyethylene (LDPE), degradation with successive uses is followed by uncontrolled cross-linking of polymer chains, leading to a raise in viscosity and a concomitant *decrease* in MFI.

18. False. The metal of interest that constitutes PET photographic film is silver, not mercury; PET film has silver derivatives that may be conveniently recovered. In a typical silver recovery procedure, photographic emulsion layers containing silver are washed with, for example, NaOH, and after separation, silver is recovered on one side and cleaned PET waste on the other side, as schematically illustrated below.



19. False. The two so-called drawbacks mentioned in the statement are both false. First, glass has the unusual property of being 100% recoverable, so that the same glass product (say, a bottle) can be melted down and remade over and over without any product degradation. Moreover, cullet melts at lower temperature than the raw materials from which new glass is made (silica sand, soda ash, and limestone), which helps save energy.

Reference: MASTERS, G. and ELA, W. (2014). *Introduction to Environmental Engineering and Science*. 3rd edition. Upper Saddle River: Pearson.

20. True. For a 32-year-old man, *A* = 0; for an area with no trash cans, *B* = 1; for a dirty area, *C* = 1. Thus,

$$\Pr[\text{littering}] = 0.132 + 0.457\times0 + 0.181\times1 + 0.179\times1 = 0.492 = \boxed{49.2\%}$$

The odds that the man will litter the paper wrap are close to 50%.

P.4 ➡ *Solution*

To begin, we determine the time needed per stop,

$$T = 60\frac{\text{m}}{\text{stop}} \times \frac{1}{8}\frac{\text{hr}}{\text{km}} \times \frac{1}{1000}\frac{\text{km}}{\text{m}} \times 60\frac{\text{min}}{\text{hr}} + 1\,\text{min} = 1.45\,\text{min/stop}$$

The amount of waste loaded per minute, in turn, is

$$\text{Loading} = 90\frac{\text{kg}}{\text{stop}} \times \frac{1}{1.45}\frac{\text{stop}}{\text{min}} = 62.1\,\text{kg/min}$$

The time needed to fill the truck follows as

$$t = 23\,\text{m}^3 \times 450\frac{\text{kg}}{\text{m}^3} \times \frac{1}{62.1}\frac{\text{min}}{\text{kg}} \times \frac{1}{60}\frac{\text{hr}}{\text{min}} = \boxed{2.78\,\text{hr}}$$

The number of homes served per truckload is

$$\frac{\text{Homes}}{\text{Truckload}} = \frac{23\,\text{m}^3 \times 450\,\text{kg/m}^3 \times 4\,\text{homes/stop}}{90\,\text{kg/stop}} = 460\,\text{homes/truckload}$$

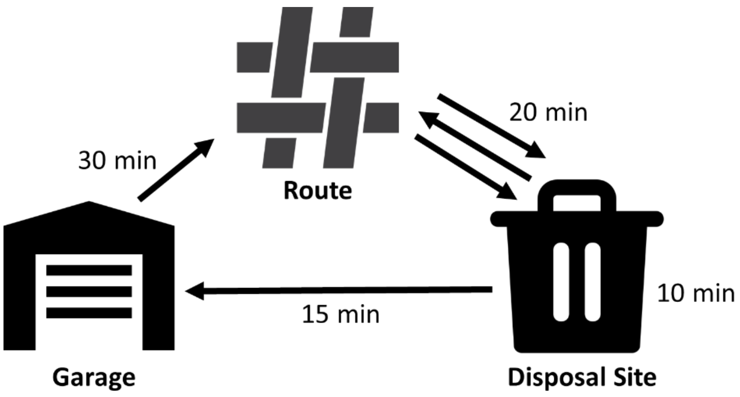
which corresponds to a number of customers

$$C = 460\frac{\text{customers}}{\text{truckload}} \times 2\frac{\text{truckloads}}{\text{day}} \times 5\frac{\text{days}}{\text{week}} = \boxed{4600\,\text{customers/week}}$$

♦ The correct answer is **B**.

P.5 ➡ *Solution*

Part 1: Refer to the following illustration.



The time required for the truck to travel from the garage to the disposal site is 30 min. The time required for the truck to travel from the route to the disposal site is 20 min; since the truck is to be filled twice per day, it must travel from the route to the disposal site, then back to the route, and finally to the disposal site again, totaling 3 × 20 = 60 min. The time to unload at the disposal site is 10 min; since the truck will unload twice, this operation contributes 2 × 10 = 20 min to the time not on route. The time to travel from disposal site to garage is 15 min. We must also account for the time spent on worker breaks, which is 45 min/day. Summing all contributions to time not on route, we obtain

$$\text{Time not on route} = 30 + 60 + 20 + 15 + 45 = 170\,\text{min}$$

Next, we determine the time required to fill a truck,

$$L = 23\,\text{m}^3\text{ in truck} \times 4\frac{\text{m}^3\text{ curb}}{\text{m}^3\text{ in truck}} \times \frac{1}{0.16}\frac{\text{customer}}{\text{m}^3\text{ curb}} \times \frac{1}{4}\frac{\text{stop}}{\text{customers}} \times (1+0.5)\frac{\text{min}}{\text{stop}} = 216\,\text{min/load}$$

The number of hours of work required for two daily loads is then

$$t = \left[2\,\text{loads} \times 216\frac{\text{min}}{\text{load}} + 170\,\text{min}\;(\text{travel, breaks})\right] \times \frac{1}{60}\frac{\text{hr}}{\text{min}} = \boxed{10.0\,\text{hr/day}}$$

♦ The correct answer is **B**.

Part 2: We first compute the number of customers served per load,

$$\text{Customers} = 23\,\text{m}^3\text{ in truck} \times 4\frac{\text{m}^3\text{ curb}}{\text{m}^3\text{ in truck}} \times \frac{1}{0.16}\frac{\text{customer}}{\text{m}^3\text{ curb}} = 575\text{ customers/load}$$

so that

$$n = \text{No. Customers} = 575\frac{\text{customers}}{\text{load}}\times 2\frac{\text{loads}}{\text{day}}\times 5\frac{\text{days}}{\text{week}} = \boxed{5750\,\text{customers/week}}$$

♦ The correct answer is **D**.

Part 3: Noting that, from Problem 5.1, the crew works 10 hr/day, we first determine the annual labor cost,

$$\text{Labor} = \left(\frac{\$35}{\text{hr}}\times 8\frac{\text{hr}}{\text{day}} + \frac{\$50}{\text{hr}}\times 2\frac{\text{hr}}{\text{day}}\right)\times 5\frac{\text{day}}{\text{week}}\times 52\frac{\text{week}}{\text{year}} = \$98{,}800/\text{year}$$

The annualized cost of the packer truck, given a 23-m^3 capacity, is

$$\text{Truck} = 10{,}000 + 4500\times 23 = \$114{,}000$$

Knowing that, from Problem 5.2, 5750 customers are served by this operation, the customer cost is determined to be

$$\text{Customer cost} = \frac{(\$98{,}800 + \$114{,}000)/\text{yr}}{5750\,\text{customers}} = \boxed{\$37.0/\text{yr}}$$

♦ The correct answer is **C**.

Part 4: With the crew working six hours a day and a time not on route of 170 min, the remaining collection time becomes 6 × 60 – 170 = 190 min/day. The number of customers serviced is now

$$\begin{array}{c}\text{Updated}\\ \text{No. customers}\end{array} = 190\frac{\text{min}}{\text{day}}\times\frac{1}{1.5}\frac{\text{stop}}{\text{min}}\times 4\frac{\text{customers}}{\text{stop}}\times 5\frac{\text{days}}{\text{week}} = \boxed{4130\,\text{customers}}$$

Note that the labor cost, in this case, would become

$$\text{Labor} = \left(\frac{\$35}{\text{hr}}\times 6\frac{\text{hr}}{\text{day}}\right)\times 5\frac{\text{day}}{\text{week}}\times 52\frac{\text{week}}{\text{year}} = \$54{,}600/\text{year}$$

which represents a 45% decrease relatively to the labor cost computed in Part 3.

Part 5: For 8 hours of daily work, the collection time is now 8 × 60 – 170 = 310 min/day. With 2 truckloads per day, the number of customers served is

$$\text{No. Customers} = 310\frac{\text{min}}{\text{day}}\times\frac{1}{1.5}\frac{\text{stop}}{\text{min}}\times 4\frac{\text{customers}}{\text{stop}} = 827\,\text{customers}$$

or 414 customers per truckload. At 2 loads per day and 5 days per week, that would give 4140 customers once a week service. The required truck size needed is

$$\text{Truck size} = 414\frac{\text{customers}}{\text{truckload}}\times 0.16\frac{\text{m}^3\text{ at curb}}{\text{customer}}\times\frac{1}{4}\frac{\text{m}^3\text{ in truck}}{\text{m}^3\text{ at curb}} = \boxed{16.6\text{ m}^3}$$

The cost associated with this truck size is calculated as

$$\text{Truck} = 10{,}000 + 4500\times 16.6 = \$84{,}700$$

while the labor cost is

$$\text{Labor} = \left(\frac{\$35}{\text{hr}}\times 8\frac{\text{hr}}{\text{day}}\right)\times 5\frac{\text{day}}{\text{week}}\times 52\frac{\text{week}}{\text{year}} = \$72{,}800/\text{year}$$

It remains to determine the customer cost,

$$\text{Customer cost} = \frac{(\$72{,}800 + \$84{,}700)/\text{yr}}{4140\,\text{customers}} = \boxed{\$38.0/\text{yr}}$$

P.6 ➡ *Solution*

Part 1: We first determine the Darcy velocity for the leachate through the clay layer,

$$v = k\left(\frac{\Delta h}{\Delta L}\right) = \left(8\times 10^{-10}\right)\times 0.5 = 4\times 10^{-10}\text{ m/s}$$

Given A = 20 ha = 20×10⁴ m², the volumetric flow rate is given by

$$Q = vA = \left(4\times10^{-10}\right)\times\left(20\times10^{4}\right) = \boxed{8.0\times10^{-5}\ \text{m}^3/\text{s}}$$

♦ The correct answer is **A**.

Part 2: Since 1750 m³ of leachate is produced every year, we compute an average flow rate

$$Q = \frac{1750}{24\times60\times60\times365} = 5.55\times10^{-5}\ \text{m}^3/\text{s}$$

Noting that A = 14 ha = 14×10⁻⁴ m², we have, using Darcy's law,

$$Q = k\left(\frac{\Delta h}{L}\right)A \to \Delta h = \frac{QL}{kA}$$

$$\therefore \Delta h = \frac{\left(5.55\times10^{-5}\right)\times0.85}{\left(4.4\times10^{-10}\right)\times\left(14\times10^{4}\right)} = \boxed{0.766\ \text{m}}$$

♦ The correct answer is **C**.

P.7 ➡ *Solution*

The population generates 75,000 × 2 = 150,000 kg of waste per day, which corresponds to a volume of 150,000/750 = 200 m³. Dividing this result by the depth of the compacted solid wastes yields 200/5 = 40 m². To withstand the waste load generated by the city for a full year, the landfill area should be 40 × 365 = 14,600 m², or 14.6 ha.

♦ The correct answer is **B**.

P.8 ➡ *Solution*

The variables at hand are related by the landfill volume equation

$$V = \frac{PEC}{D_C}$$

where V is the landfill volume, P is population, E is the ratio of cover to compacted fill, C is the average mass collected per person per year, and D_C is the density of compacted fill. The remaining volume of the landfill is 12,100,00 × (1 – 0.6) = 4.84×10⁶ m³. Substituting this and other data and solving for C, we obtain

$$V = \frac{PEC}{D_C} \to 4.84\times10^{6} = \frac{560{,}000\times1.8\times C}{500}$$

$$\therefore C = 2400\ \text{kg/capita}$$

Dividing this result by the MSW generation rate gives the remaining projected life of the landfill,

$$t = \frac{2400\ \text{kg/capita}}{1.92\ \text{kg/capita/day}} = 1250\ \text{days} = \boxed{3.42\ \text{years}}$$

The landfill can support the waste produced by Leipzig's population for an estimated three years and five months.

♦ The correct answer is **B**.

P.9 ➡ *Solution*

To begin, we substitute a = 100, b = 160, c = 80, and d = 1 in the chemical equation we were given,

$$C_{100}H_{160}O_{80}N + \left(\frac{4\times100-160-2\times80+3\times1}{4}\right)\text{H}_2\text{O} \to \left(\frac{4\times100+160-2\times80-3\times1}{8}\right)\text{CH}_4 + (\ldots)$$

$$(\ldots) + \left(\frac{4\times100-160+2\times80+3\times1}{8}\right)\text{CO}_2 + 1\times\text{NH}_3$$

$$\therefore \text{C}_{100}\text{H}_{160}\text{O}_{80}\text{N} + 20.8\text{H}_2\text{O} \to 49.6\text{CH}_4 + 50.4\text{CO}_2 + \text{NH}_3$$

On a mass-equivalent basis, we have

$$\underbrace{C_{100}H_{160}O_{80}N}_{2654}+\underbrace{20.8H_2O}_{374}\rightarrow\underbrace{49.6CH_4}_{794}+\underbrace{50.4CO_2}_{2220}+\underbrace{NH_3}_{17}$$

From the stoichiometry of the equation above, the mass of methane produced by digestion of 1000 kg of SMW is determined to be

$$m_{CH_4}=\frac{794}{2654}\times 1000=299\,\text{kg}$$

or, expressing this quantity as a volume,

$$V_{CH_4}=\frac{299\,\text{kg}}{0.72\,\text{kg/m}^3}=415\,\text{m}^3$$

The mass of carbon dioxide produced, in turn, is given by

$$m_{CO_2}=\frac{2220}{2654}\times 1000=836\,\text{kg}$$

so that

$$V_{CO_2}=\frac{836\,\text{kg}}{2.0\,\text{kg/m}^3}=418\,\text{m}^3$$

Lastly, adding V_{CH_4} and V_{CO_2} yields

$$V=V_{CH_4}+V_{CO_2}=415+418=\boxed{833\,\text{m}^3}$$

♦ The correct answer is **D**.

P.10 ➡ *Solution*

The amount of methane generated is given by the product (Amount of waste disposed in landfill per person on yearly basis) × (Number of people served by landfill) × (Rate of gas production per mass of solid waste) × (Fraction of methane in gas); in the case at hand,

$$\text{Methane generated}=(365\times 1.2)\times(12\times 4)\times 50\times 0.75=788{,}000\,\text{L methane/year}$$

The heat content of the methane recovered is

$$H=36{,}500\frac{\text{kJ}}{\text{m}^3}\times 788{,}000\frac{\text{L methane}}{\text{year}}\times\frac{1}{1000}\frac{\text{m}^3}{\text{L}}=28.8\times 10^6\ \text{kJ/year}$$

The number of homes that can be heated is then

$$\text{No. of homes}=\frac{\text{Energy generated}}{\text{Energy required per home}}=\frac{28.8\times 10^6\ \text{kJ/year}}{32\times 10^5\ \dfrac{\text{kJ/year}}{\text{home}}}=9\,\text{homes}$$

Thus, the gas produced in the landfill cannot sustain the demand of all 12 homes.

♦ The correct answer is ***B***.

P.11 ➡ *Solution*

Part 1: The rate of gas production when the peak is reached can be estimated with the first-order reaction law

$$\text{Rate}=\dot{V}_{\text{gas}}\times k\times\exp\left[-k\times\left(t-t_{\text{lag}}\right)\right]$$

where $\dot{V}_{gas}$ is the total volume of gas that can be produced per kg of waste, k is a rate constant, t is the time measured from the point the waste is disposed, and t_{lag} is the lag time required before the waste begins to produce gas. Let P denote the peak rate, so that

$$P=\dot{V}_{\text{gas}}\times k\times\exp\left[-k\times\left(6-t_{\text{lag}}\right)\right]\ (\text{I})$$

After 24 years, the rate has reduced to 10 percent of its peak value; in mathematical terms,

$$0.1P = \dot{V}_{\text{gas}} \times k \times \exp\left[-k \times \left(24 - t_{\text{lag}}\right)\right]$$

$$\therefore P = \frac{\dot{V}_{\text{gas}} \times k \times \exp\left[-k \times \left(24 - t_{\text{lag}}\right)\right]}{0.1} \quad \text{(II)}$$

Equating (I) and (II) brings to

$$\dot{V}_{\text{gas}} \times k \times \exp\left[-k\left(6 - t_{\text{lag}}\right)\right] = \frac{\dot{V}_{\text{gas}} \times k \times \exp\left[-k \times \left(24 - t_{\text{lag}}\right)\right]}{0.1}$$

Canceling factors that appear on both sides, applying logarithms and solving for k, we obtain k = 0.128 yr^{-1}. This result can be confirmed with the simple Mathematica code

```
Solve[k * Exp[-k (6 - t)] == (k * Exp[-k (24 - t)])/0.1, k]
```

We are now in position to determine the percentage of gas produced after 24 years. To do so, we appeal to the exponential law

$$C_t = C_0 \exp(-kt) \rightarrow x \times C_0 = C_0 \exp(-kt)$$

$$\therefore x = \exp(-0.128 \times 24) = 0.0463$$

$$\therefore x = 4.63\% \text{ gas remaining}$$

That is, 100 – 4.63 = 95.37% of total gas production will have been attained after 24 years.

♦ The correct answer is **D**.

Part 2: Substituting $C_t = 0.01C_0$ in the exponential law and solving for T, we get

$$C_t = C_0 \exp(-kT) \rightarrow 0.01C_0 = C_0 \exp(-kT)$$

$$\therefore 0.01C_0 = C_0 \exp(-0.128 \times T)$$

$$\boxed{T = 36.0 \text{ years}}$$

♦ The correct answer is **C**.

P.12 ➡ *Solution*

The cumulative production of gas is the sum of the cumulative productions of waste A and waste B; in mathematical terms,

$$\text{Total cum. gas} = \text{Cum. gas A} + \text{Cum. gas B}$$

$$\therefore \text{Total cum. gas}(t) = V_A\left[1 - \exp(-k_A t)\right] + V_B\left[1 - \exp(-k_B t)\right]$$

If m is the mass of each waste type disposed, then 180m is the total volume of gas produced from each type of waste; that is,

$$\therefore \text{Total cum. gas}(t) = 180m\left[1 - \exp(-k_A t)\right] + 180m\left[1 - \exp(-k_B t)\right]$$

Let T denote the time at 90% of each gas has been produced. At this point, the total cumulative gas volume will be 0.9 × (180m + 180m) = 324m. Substituting above, we have

$$324m = 180m\left[1 - \exp(-k_A T)\right] + 180m\left[1 - \exp(-k_B T)\right]$$

$$\therefore 324 = 180\left[1 - \exp(-k_A T)\right] + 180\left[1 - \exp(-k_B T)\right]$$

Using the half-lives we were given, we can replace rate constants k_A = 0.693/2.5 = 0.277 yr^{-1} and k_B = 0.693/2.5 = 0.139 yr^{-1},

$$324 = 180\left[1 - \exp(-0.277T)\right] + 180\left[1 - \exp(-0.139T)\right]$$

Simplifying this relation, we obtain

$$5\left[\exp(-0.277T)+\exp(-0.139T)\right]=1.0$$

or

$$\exp(-0.277T)+\exp(-0.139T)=0.2$$

This equation can be solved with the simple Mathematica code

```
Solve[Exp[-0.277*T] + Exp[-0.139*T] == 0.2, T, Reals]
```

which returns T = 12.7 years.

♦ The correct answer is **C**.

P.13 ➡ *Solution*

Part 1: Assume 1 kg of moist poultry manure waste dry mass. Let m denote the kg of fresh leaves on a dry mass basis. The masses of carbon and nitrogen obtained from each material in the mixture are determined as

$$\text{Dry mass of nitrogen from PM} = 1.0\,\text{kg}\times(1-0.7)\times 0.06 = 0.018\,\text{kg}$$

$$\text{Dry mass of carbon from PM} = 1.0\,\text{kg}\times(1-0.7)\times 0.06\times 15 = 0.27\,\text{kg}$$

$$\text{Dry mass of nitrogen from FL} = m\,\text{kg}\times(1-0.6)\times 0.008 = 0.0032m$$

$$\text{Dry mass of carbon from FL} = m\,\text{kg}\times(1-0.6)\times 0.008\times 41 = 0.131m$$

The overall C:N ratio is then

$$\text{C:N Ratio} = \frac{\text{Mass of carbon from PM} + \text{Mass of carbon from FL}}{\text{Mass of nitrogen from PM} + \text{Mass of nitrogen from FL}}$$

$$\therefore 18 = \frac{0.27+0.131m}{0.018+0.0032m}$$

Solving the first-degree equation above gives m = 0.734 kg. Thus, about 0.73 kg of fresh leaves should be added for each kg of poultry manure to produce an optimal C:N ratio of 18.

♦ The correct answer is **C**.

Part 2: Assume 1 kg of nonlegume vegetable waste dry mass. Let m denote the mass of sawdust on a dry basis. The mass of carbon and nitrogen obtained from each material in the mixture is

$$\text{Dry mass of nitrogen from NLVW} = 1.0\,\text{kg}\times(1-0.8)\times 0.04 = 0.008\,\text{kg}$$

$$\text{Dry mass of carbon from NLVW} = 1.0\,\text{kg}\times(1-0.8)\times 0.04\times 12 = 0.096\,\text{kg}$$

$$\text{Dry mass of nitrogen from sawdust} = m\,\text{kg}\times(1-0.5)\times 0.001 = 0.0005m$$

$$\text{Dry mass of carbon from sawdust} = m\,\text{kg}\times(1-0.5)\times 0.06\times 500 = 0.25m$$

The overall C:N ratio is then

$$\text{C:N Ratio} = \frac{\text{Mass of carbon from NLVW} + \text{Mass of carbon from SD}}{\text{Mass of nitrogen from NLVW} + \text{Mass of nitrogen from SD}}$$

$$\therefore 22 = \frac{0.096+0.25m}{0.008+0.0005m}$$

Solving the first-degree equation above gives m = 0.335 kg. Thus, about 0.34 kg of sawdust should be added for each kg of NLWW to produce an optimal C:N ratio of 22.

♦ The correct answer is **A**.

ANSWER SUMMARY

Problem 1	1.1	C
	1.2	B
	1.3	C
	1.4	A
Problem 2		Open-ended pb.
Problem 3		T/F
Problem 4		B
Problem 5	5.1	B
	5.2	D
	5.3	C
	5.4	Open-ended pb.
	5.5	Open-ended pb.
Problem 6	6.1	A
	6.2	C
Problem 7		B
Problem 8		B
Problem 9		D
Problem 10		β
Problem 11	11.1	D
	11.2	C
Problem 12		C
Problem 13	13.1	C
	13.2	A

REFERENCES

In addition to the textbooks quoted in the solutions section, the following materials were consulted.

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