FE Environmental

Free practice problems and worked solutions

This sample contains 15 original problems, one from each knowledge area, already available free on EngineerProof. The original Form A problem numbers are retained. This is a sample, not a complete 110-question exam or a predictor of your NCEES result.

Work the questions before consulting the solutions. Each solution includes the calculation and an explanation of the other choices. The full forms, contents, and purchase conditions are at:

https://engineerproof.inshihub.com/fe-environmental

Included knowledge areas

Practice questions

Mathematics

3. A completely mixed lagoon of volume $500\ \mathrm{m}^3$ initially holds a contaminant at $40\ \mathrm{mg/L}$. Contaminant-free water enters at $25\ \mathrm{m}^3/\mathrm{h}$ and the lagoon discharges at the same rate. Within the lagoon the contaminant also decays by a first-order reaction with $k = 0.030\ \mathrm{h}^{-1}$. The contaminant concentration after 30 h is most nearly:

   (A) 3.6 mg/L

   (B) 8.9 mg/L

   (C) 16.3 mg/L

   (D) 22.0 mg/L

Probability and Statistics

7. A rapid field immunoassay screens groundwater samples for total coliform. Historically, 6% of samples drawn from the well field are contaminated. The assay returns a positive result for 95% of contaminated samples and for 4% of uncontaminated samples. The probability that a sample returning a positive result is actually contaminated is most nearly:

   (A) 0.057

   (B) 0.095

   (C) 0.603

   (D) 0.950

Ethics and Professional Practice

12. A licensed engineer prepares the noncompliance report required by an industrial facility's NPDES permit. The permit limits total suspended solids to a monthly average mass loading of 250 lb/day. For the reporting month the average discharge is 1.8 MGD at a total suspended solids concentration of 22 mg/L. The percentage by which the monthly average loading exceeds the permitted mass limit is most nearly:

(A) 24%

(B) 32%

(C) 76%

(D) 132%

Engineering Economics

17. A 30,000 m^3/d water treatment plant must select a disinfection process for a 20-year study period. Ultraviolet disinfection has a capital cost of USD 850,000, annual operation and maintenance of USD 62,000, and a salvage value of USD 90,000 at the end of year 20. Sodium hypochlorite disinfection has a capital cost of USD 520,000, annual operation and maintenance of USD 105,000, and no salvage value. At an interest rate of 6% per year, the present worth advantage of the ultraviolet alternative is most nearly:

(A) USD 163,000

(B) USD 191,000

(C) USD 253,000

(D) USD 452,000

Fundamental Principles

22. An aerated lagoon is modeled as a completely mixed flow reactor at steady state. The lagoon receives 2,400 m^3/d with a soluble BOD of 180 mg/L, its liquid volume is 9,600 m^3, and soluble BOD is removed by a first-order reaction with $k = 0.35$ d^{-1}. The effluent soluble BOD is most nearly:

(A) 75 mg/L

(B) 105 mg/L

(C) 129 mg/L

(D) 166 mg/L

Environmental Chemistry

30. A laboratory acetate buffer contains 0.050 mol/L acetic acid and 0.030 mol/L sodium acetate, with $pK_a = 4.76$. Strong acid is then added to a concentration of 0.010 mol/L with negligible volume change. The pH after the addition is most nearly:

(A) 4.28

(B) 4.36

(C) 4.54

(D) 5.24

Health Hazards and Risk Assessment

37. A private well serving a residence contains tetrachloroethylene at 35 μg/L. An adult weighing 180 lb ingests 0.60 gal/day of this water 350 days per year for 26 years. The endpoint of interest is non-carcinogenic, so the averaging time equals the exposure duration. The chronic daily intake is most nearly:

(A) 1.1×10^{-4} mg/(kg-day)

(B) 2.5×10^{-4} mg/(kg-day)

(C) 3.5×10^{-4} mg/(kg-day)

(D) 9.3×10^{-4} mg/(kg-day)

Fluid Mechanics and Hydraulics

45. A centrifugal pump handles 0.075 m^3/s of water. The 250 mm suction line carries a gauge reading of -25 kPa; the 150 mm discharge line carries a gauge reading of $+310$ kPa at a point 0.60 m above the suction gauge. Head loss between the two gauges is negligible. The total dynamic head developed by the pump is most nearly:

(A) 30.5 m

(B) 33.9 m

(C) 34.7 m

(D) 35.5 m

Thermodynamics

57. A morning sounding at a proposed incinerator site records air temperatures of 21.3°C at 10 m and 19.0°C at 160 m above grade. The dry adiabatic lapse rate is 9.8°C/km. Which of the following best describes the stability of the layer and the expected stack plume behavior?

(A) Superadiabatic and unstable; looping plume

(B) Neutral; coning plume

(C) Subadiabatic and stable; fanning plume

(D) Temperature inversion; ground-level fumigation

Surface Water Resources and Hydrology

59. Three recording rain gauges serve a 45.0 km^2 basin. Storm depths and the corresponding Thiessen polygon areas are: gauge 1, 62 mm over 14.0 km^2; gauge 2, 88 mm over 22.5 km^2; gauge 3, 45 mm over 8.5 km^2. The average storm depth over the basin is most nearly:

(A) 58.4 mm

(B) 62.0 mm

(C) 65.0 mm

(D) 71.8 mm

Groundwater, Soils, and Sediments

68. Two monitoring wells screened in the same unconfined sand aquifer are 240 m apart along the direction of flow. The measured hydraulic heads are 96.4 m and 94.0 m. The aquifer has a hydraulic conductivity of 25 m/day, a total porosity of 0.38, and an effective porosity of 0.30. The average linear (seepage) velocity of the groundwater is most nearly:

(A) 0.075 m/day

(B) 0.25 m/day

(C) 0.66 m/day

(D) 0.83 m/day

Water and Wastewater

80. A granular media filter with a 20 ft by 24 ft plan area operates at a filtration rate of 4.0 gpm/ft^2 for a 60 h run, then is backwashed at 18 gpm/ft^2 for 10 min. The backwash water expressed as a percentage of the water filtered during the run is most nearly:

(A) 0.062 %

(B) 1.25 %

(C) 3.1 %

(D) 12.5 %

Air Quality and Control

94. A cyclone receives gas at an inlet velocity of 18 m/s through a rectangular inlet 0.20 m wide, with 5 effective turns in the body. Gas viscosity is 1.81×10^{-5} Pa·s and gas density is 1.2 kg/m^3; particle density is 1,800 kg/m^3. The cut diameter for 50% collection efficiency is most nearly:

(A) 5.66 μm

(B) 8.00 μm

(C) 12.7 μm

(D) 17.9 μm

Solid and Hazardous Waste

101. A transfer station ships municipal solid waste to a regional landfill in transfer trailers with a 20 ton payload. The round-trip haul distance is 120 mi and the hauling contract pays USD 2.85 per mile of travel. Transfer station processing costs USD 7.40 per ton. The combined processing and haul cost is most nearly:

(A) USD 15.95 per ton

(B) USD 17.47 per ton

(C) USD 24.50 per ton

(D) USD 41.60 per ton

Energy and Environment

108. A regional grid generates 3,200 GWh from coal at 0.95 t CO_2/MWh, 4,800 GWh from natural gas at 0.42 t CO_2/MWh, and 2,000 GWh from zero-emitting renewables in one year. The carbon intensity of the delivered electricity is most nearly:

(A) 457 kg CO_2/MWh

(B) 506 kg CO_2/MWh

(C) 590 kg CO_2/MWh

(D) 632 kg CO_2/MWh

Worked solutions

Mathematics

Problem 3

Answer: (A)

A completely mixed lagoon of volume 500 m^3 initially holds a contaminant at 40 mg/L. Contaminant-free water enters at $25 \text{ m}^3/\text{h}$ and the lagoon discharges at the same rate. Within the lagoon the contaminant also decays by a first-order reaction with $k = 0.030 \text{ h}^{-1}$. The contaminant concentration after 30 h is most nearly:

Washout and reaction combine into a single first-order coefficient of 0.080 h^{-1}*, leaving about 3.6 mg/L after 30 h.*

Washout and reaction both remove mass in proportion to the instantaneous concentration, so the unsteady mass balance collapses to one lumped rate constant.

$$V\frac{dC}{dt} = -QC - kVC$$

$$\frac{dC}{dt} = -\left(\frac{Q}{V} + k\right)C$$

Hydraulic washout at Q/V and reaction at k are additive because both are first order in C.

$$\frac{Q}{V} + k = \frac{25}{500} + 0.030 = 0.080 \text{ h}^{-1}$$

Exponential decay from the initial 40 mg/L over 30 h leaves

$$C = 40e^{-(0.080)(30)} = 40(0.0907) = 3.6 \text{ mg/L}$$

FE REFERENCE HANDBOOK — MATHEMATICS: DIFFERENTIAL EQUATIONS, FIRST-ORDER LINEAR HOMOGENEOUS WITH CONSTANT COEFFICIENTS

WHY THE OTHER CHOICES APPEAR

(B) Neglects the reaction and uses washout alone: $40e^{-(0.050)(30)} = 8.9$ mg/L.

(C) Neglects washout and uses the decay constant alone: $40e^{-(0.030)(30)} = 16.3$ mg/L.

(D) Subtracts the decay rate from the washout rate instead of adding: $40e^{-(0.020)(30)} = 22.0$ mg/L.

Probability and Statistics

Problem 7

Answer: (C)

A rapid field immunoassay screens groundwater samples for total coliform. Historically, 6% of samples drawn from the well field are contaminated. The assay returns a positive result for 95% of contaminated samples and for 4% of uncontaminated samples. The probability that a sample returning a positive result is actually contaminated is most nearly:

About 60 percent of positive results are true detections, because at 6 percent prevalence the uncontaminated 94 percent of samples yields nearly as many false positives as there are true ones.

Positive results arise from two disjoint populations, so the conditioning denominator is the total positive rate, not the false-positive rate alone.

$$P(+) = P(+\,|\,C)\,P(C) + P(+\,|\,\overline{C})\,P(\overline{C})$$

$$P(+) = (0.95)(0.06) + (0.04)(0.94) = 0.0570 + 0.0376 = 0.0946$$

Bayes' theorem reweights the contaminated branch against that total to reverse the direction of conditioning.

$$P(C\,|\,+) = \frac{P(+\,|\,C)\,P(C)}{P(+)} = \frac{0.0570}{0.0946} = 0.603$$

Prevalence dominates the result: the clean fraction contributes 0.0376 of false-positive mass against only 0.0570 of true-positive mass, so nearly two of every five positives are spurious.

$$\frac{0.0376}{0.0946} = 0.397$$

FE REFERENCE HANDBOOK — ENGINEERING PROBABILITY AND STATISTICS: BAYES' THEOREM

WHY THE OTHER CHOICES APPEAR

(A) This is the joint probability P(C and +) = (0.95)(0.06) = 0.0570, reported without dividing by the total positive rate.

(B) This is the marginal probability of a positive result, P(+) = 0.0946, which is only the denominator of the Bayes expression.

(D) This is the sensitivity P(+|C) = 0.95, obtained by reversing the direction of conditioning.

Ethics and Professional Practice

Problem 12

Answer: (B)

A licensed engineer prepares the noncompliance report required by an industrial facility's NPDES permit. The permit limits total suspended solids to a monthly average mass loading of 250 lb/day. For the reporting month the average discharge is 1.8 MGD at a total suspended solids concentration of 22 mg/L. The percentage by which the monthly average loading exceeds the permitted mass limit is most nearly:

Loading of 330 lb/day against a 250 lb/day limit places the month 32 percent above the permitted mass discharge.

Mass loading, not concentration, is the permitted quantity, so flow and concentration combine through the standard 8.34 lb per million gallons per mg/L factor.

$$M = Q \cdot C \cdot 8.34 = (1.8)(22)(8.34) = 330.3 \text{ lb/day}$$

Exceedance in a noncompliance report is measured against the permit limit, which is the fixed regulatory reference, rather than against the observed loading.

$$\frac{330.3 - 250}{250} \times 100\% = 32.1\%$$

Restating the limit as an equivalent permitted concentration of 16.7 mg/L against the measured 22 mg/L reproduces the same margin.

$$C_{permit} = \frac{250}{(1.8)(8.34)} = 16.65 \text{ mg/L}$$

$$\frac{22}{16.65} - 1 = 0.321$$

FE REFERENCE HANDBOOK — ENVIRONMENTAL ENGINEERING: MASS LOADING RATE (FLOW-CONCENTRATION PRODUCT) AND WATER/WASTEWATER UNIT CONVERSIONS

WHY THE OTHER CHOICES APPEAR

(A) Divides the 80.3 lb/day excess by the measured loading instead of the permit limit: 80.3/330.3 = 24.3%.

(C) Reports the limit as a fraction of the measured loading, 250/330.3 = 75.7%, mistaking that ratio for the exceedance.

(D) Reports the full ratio of loading to limit, 330.3/250 = 132%, without subtracting the 100% baseline.

Engineering Economics

Problem 17

Answer: (B)

A 30,000 m^3/d water treatment plant must select a disinfection process for a 20-year study period. Ultraviolet disinfection has a capital cost of USD 850,000, annual operation and maintenance of USD 62,000, and a salvage value of USD 90,000 at the end of year 20. Sodium hypochlorite disinfection has a capital cost of USD 520,000, annual operation and maintenance of USD 105,000, and no salvage value. At an interest rate of 6% per year, the present worth advantage of the ultraviolet alternative is most nearly:

Ultraviolet disinfection is cheaper in present worth by roughly USD 191,000, because USD 43,000 per year of avoided operating cost outweighs its USD 330,000 capital premium.

Equal 20-year lives permit a direct present-worth comparison of the two cost streams at 6% per year.

$$(P/A, 6\%, 20) = \frac{1-(1.06)^{-20}}{0.06} = 11.470$$

$$(P/F, 6\%, 20) = (1.06)^{-20} = 0.3118$$

Salvage enters the ultraviolet stream as a single credit at year 20, discounted like any other future amount.

$$PW_{UV} = 850,000 + 62,000(11.470) - 90,000(0.3118) = 1,533,000 \text{ USD}$$

Hypochlorite buys a lower first cost at the price of a much heavier chemical and labor burden every year.

$$PW_{Cl} = 520,000 + 105,000(11.470) = 1,724,000 \text{ USD}$$

Discounted savings of 43,000 USD per year, plus the residual credit, more than repay the 330,000 USD capital premium.

$$\Delta PW = 1,724,000 - 1,533,000 = 191,000 \text{ USD}$$

FE REFERENCE HANDBOOK — ENGINEERING ECONOMICS: PRESENT WORTH ANALYSIS, UNIFORM SERIES PRESENT WORTH FACTOR

WHY THE OTHER CHOICES APPEAR

(A) Omits the year-20 salvage credit entirely, giving 1,724,342 - 1,561,135 = 163,000 USD.

(C) Credits the full 90,000 USD salvage without discounting it, giving 1,724,342 - 1,471,135 = 253,000 USD.

(D) Compounds the salvage forward with (F/P, 6%, 20) = 3.207 instead of discounting it, crediting 288,600 USD and giving 1,724,342 - 1,272,493 = 452,000 USD.

Fundamental Principles

Problem 22

Answer: (A)

An aerated lagoon is modeled as a completely mixed flow reactor at steady state. The lagoon receives 2,400 m^3/d with a soluble BOD of 180 mg/L, its liquid volume is 9,600 m^3, and soluble BOD is removed by a first-order reaction with $k = 0.35\ d^{-1}$. The effluent soluble BOD is most nearly:

Complete mixing forces the entire reactor to sit at its effluent concentration, and the steady-state balance then fixes that concentration at 75 mg/L.

Hydraulic residence time follows from the liquid volume and the throughput flow.

$$\tau = \frac{V}{Q} = \frac{9,600}{2,400} = 4.0\ \text{d}$$

A steady-state balance sets the influent load equal to the effluent load plus the reaction loss, and because the tank contents are at the effluent concentration the reaction term uses C rather than C_0.

$$QC_0 = QC + kCV$$

$$C = \frac{C_0}{1 + k\tau} = \frac{180}{1 + (0.35)(4.0)} = 75\ \text{mg/L}$$

FE REFERENCE HANDBOOK — ENVIRONMENTAL ENGINEERING: COMPLETELY MIXED FLOW REACTOR, FIRST-ORDER REACTION

WHY THE OTHER CHOICES APPEAR

(B) Reports the BOD removed, 180 - 75 = 105 mg/L, instead of the concentration leaving the lagoon.

(C) Omits the unity term in the denominator, 180/[(0.35)(4.0)] = 129 mg/L.

(D) Inverts the residence time to Q/V = 0.25 d, giving 180/[1 + (0.35)(0.25)] = 166 mg/L.

Environmental Chemistry

Problem 30

Answer: (A)

A laboratory acetate buffer contains 0.050 mol/L acetic acid and 0.030 mol/L sodium acetate, with $pK_a = 4.76$. Strong acid is then added to a concentration of 0.010 mol/L with negligible volume change. The pH after the addition is most nearly:

Converting a third of the acetate to acetic acid triples the acid-to-base ratio and pulls the pH down to about 4.28.

Added protons convert acetate to acetic acid mole for mole, so both members of the pair change before any equilibrium relation is written.

$$[\text{HA}] = 0.050 + 0.010 = 0.060 \text{ mol/L}$$

$$[\text{A}^-] = 0.030 - 0.010 = 0.020 \text{ mol/L}$$

Henderson-Hasselbalch governs because both conjugate members survive the addition in large excess, which is precisely the buffer capacity being tested.

$$\text{pH} = pK_a + \log\frac{[\text{A}^-]}{[\text{HA}]} = 4.76 + \log\frac{0.020}{0.060} = 4.28$$

FE REFERENCE HANDBOOK — CHEMISTRY: ACID-BASE EQUILIBRIA (HENDERSON-HASSELBALCH EQUATION)

WHY THE OTHER CHOICES APPEAR

- **(B)** Reduces the acetate to 0.020 mol/L but leaves the acid at 0.050 mol/L, giving 4.76 + log(0.4) = 4.36.
- **(C)** Reports the buffer pH before the acid addition, 4.76 + log(0.030/0.050) = 4.54.
- **(D)** Inverts the ratio in the logarithm, giving 4.76 + log(0.060/0.020) = 5.24.

Health Hazards and Risk Assessment

Problem 37

Answer: (D)

A private well serving a residence contains tetrachloroethylene at 35 μg/L. An adult weighing 180 lb ingests 0.60 gal/day of this water 350 days per year for 26 years. The endpoint of interest is non-carcinogenic, so the averaging time equals the exposure duration. The chronic daily intake is most nearly:

Because the averaging time equals the exposure duration, the two cancel and the intake reduces to a daily dose scaled by exposure frequency, about 9.3×10^{-4} *mg/(kg-day).*

Intake equations are written on a body-mass basis, so the pound and gallon values must become kilograms and litres before anything else.

$$180 \text{ lb} \times 0.4536 \text{ kg/lb} = 81.65 \text{ kg}$$

$$0.60 \text{ gal/day} \times 3.785 \text{ L/gal} = 2.271 \text{ L/day}$$

Averaging time for a threshold endpoint is the exposure duration itself, which fixes the denominator at 26 years expressed in days.

$$AT = 26 \text{ yr} \times 365 \text{ d/yr} = 9,490 \text{ d}$$

$$CDI = \frac{C \cdot IR \cdot EF \cdot ED}{BW \cdot AT}$$

The exposure frequency of 350 d/yr leaves roughly 96 percent of the averaging period as exposed time, so the intake stays close to the daily dose during exposure.

$$CDI = \frac{(0.035)(2.271)(350)(26)}{(81.65)(9,490)} = 9.3 \times 10^{-4}\ \mathrm{mg/(kg \cdot d)}$$

FE REFERENCE HANDBOOK — ENVIRONMENTAL ENGINEERING: RISK ASSESSMENT, CHRONIC DAILY INTAKE EQUATION

WHY THE OTHER CHOICES APPEAR

(A) Treats the given 180 and 0.60 as kilograms and litres with no conversion: $(0.035)(0.60)(350)(26)/[(180)(9,490)] = 1.1 \times 10^{-4}$ mg/(kg-day).

(B) Converts body weight to 81.65 kg but leaves the ingestion rate at 0.60 L/day: $191.1/774,840 = 2.5 \times 10^{-4}$ mg/(kg-day).

(C) Averages over a 70-year lifetime (25,550 d) although the endpoint is non-carcinogenic: $723.3/[(81.65)(25,550)] = 3.5 \times 10^{-4}$ mg/(kg-day).

Fluid Mechanics and Hydraulics

Problem 45

Answer: (D)

A centrifugal pump handles 0.075 $\mathrm{m^3/s}$ of water. The 250 mm suction line carries a gauge reading of −25 kPa; the 150 mm discharge line carries a gauge reading of +310 kPa at a point 0.60 m above the suction gauge. Head loss between the two gauges is negligible. The total dynamic head developed by the pump is most nearly:

Total dynamic head reaches 35.5 m, with the suction vacuum and the contraction to 150 mm both adding to the head rise.

Continuity fixes both velocities from the single discharge, and the reduced discharge bore nearly triples the velocity.

$$V_s = \frac{0.075}{\frac{\pi}{4}(0.250)^2} = 1.53\ \mathrm{m/s}$$

$$V_d = \frac{0.075}{\frac{\pi}{4}(0.150)^2} = 4.24\ \mathrm{m/s}$$

Pump head is the total head rise across the flanges, so the pressure, velocity, and elevation terms all enter.

$$h_p = \frac{p_d - p_s}{\gamma} + \frac{V_d^2 - V_s^2}{2g} + \Delta z$$

A 25 kPa vacuum on the suction side enlarges the pressure difference to 335 kPa rather than shrinking it.

$$h_p = \frac{335}{9.81} + \frac{18.01 - 2.33}{19.62} + 0.60$$

$$h_p = 34.15 + 0.80 + 0.60 = 35.5 \text{ m}$$

FE REFERENCE HANDBOOK — FLUID MECHANICS: ENERGY EQUATION WITH PUMP HEAD; CONTINUITY EQUATION

WHY THE OTHER CHOICES APPEAR

(A) Reading the suction gauge as +25 kPa instead of a vacuum gives (310 − 25)/9.81 + 0.80 + 0.60 = 30.5 m.

(B) Reversing the sign of the velocity-head difference gives 34.15 − 0.80 + 0.60 = 33.9 m.

(C) Dropping the velocity-head difference leaves 34.15 + 0.60 = 34.7 m.

Thermodynamics

Problem 57

Answer: (A)

A morning sounding at a proposed incinerator site records air temperatures of $21.3^{\circ}\mathrm{C}$ at 10 m and $19.0^{\circ}\mathrm{C}$ at 160 m above grade. The dry adiabatic lapse rate is $9.8^{\circ}\mathrm{C/km}$. Which of the following best describes the stability of the layer and the expected stack plume behavior?

The layer cools at $15.3^{\circ}\mathrm{C/km}$, much steeper than the dry adiabatic $9.8^{\circ}\mathrm{C/km}$, so displaced parcels stay buoyant and the plume loops.

Stability is judged by the environmental lapse rate measured across the sounding layer.

$$\Gamma = \frac{21.3 - 19.0}{160 - 10} \times 1000 = 15.3^{\circ}\mathrm{C/km}$$

A parcel cooling at the dry adiabatic rate rises into air that has cooled faster, so it stays warmer and lighter than its surroundings and the strong vertical motion drives the plume into a looping pattern.

$$\Gamma = 15.3 > \Gamma_d = 9.8^{\circ}\mathrm{C/km}$$

FE REFERENCE HANDBOOK — ENVIRONMENTAL ENGINEERING: ATMOSPHERIC STABILITY, DRY ADIABATIC LAPSE RATE

WHY THE OTHER CHOICES APPEAR

(B) Follows from treating any temperature decrease with height as adiabatic by default, without evaluating 2.3 °C over 0.150 km = 15.3 °C/km against 9.8 °C/km.

(C) Comes from comparing the raw 2.3 °C temperature drop with the 9.8 °C/km rate without converting the 150 m layer thickness to kilometers.

(D) Comes from reversing the two readings so temperature appears to rise with height.

Surface Water Resources and Hydrology

Problem 59

Answer: (D)

Three recording rain gauges serve a 45.0 km² basin. Storm depths and the corresponding Thiessen polygon areas are: gauge 1, 62 mm over 14.0 km²; gauge 2, 88 mm over 22.5 km²; gauge 3, 45 mm over 8.5 km². The average storm depth over the basin is most nearly:

Weighting each gauge by its polygon area gives 71.8 mm, well above the unweighted mean because the wettest station governs half the basin.

Area weighting governs here because the polygons differ by nearly a factor of three, and an unweighted mean would give the driest station equal standing.

$$\bar{P} = \frac{\sum P_i A_i}{\sum A_i}$$

Gauge 2 holds half the basin area and therefore controls the accumulated product.

$$\sum P_i A_i = 868 + 1980 + 382.5 = 3230.5\ \text{km}^2 \cdot \text{mm}$$

The equivalent uniform depth sits above the 65 mm arithmetic mean precisely because the wettest gauge carries the largest polygon.

$$\bar{P} = \frac{3230.5}{45.0} = 71.8\ \text{mm}$$

FE REFERENCE HANDBOOK — WATER RESOURCES AND ENVIRONMENTAL ENGINEERING: PRECIPITATION, AREAL AVERAGE BY THIESSEN POLYGON WEIGHTING

WHY THE OTHER CHOICES APPEAR

(A) 58.4 mm comes from inverting the weights, using 1/A_i instead of A_i: 13.634 / 0.23352 = 58.4 mm.

(B) 62.0 mm is the single nearest-station depth adopted for the whole basin instead of weighting all three gauges.

(C) 65.0 mm is the arithmetic mean of the three depths, (62 + 88 + 45)/3, with the polygon areas ignored.

Groundwater, Soils, and Sediments

Problem 68

Answer: (D)

Two monitoring wells screened in the same unconfined sand aquifer are 240 m apart along the direction of flow. The measured hydraulic heads are 96.4 m and 94.0 m. The aquifer has a hydraulic conductivity of 25 m/day, a total porosity of 0.38, and an effective porosity of 0.30. The average linear (seepage) velocity of the groundwater is most nearly:

Water particles advance at about 0.83 m/day, because the Darcy flux of 0.25 m/day is carried only through the 30 percent of the cross section that is interconnected pore space.

Darcy's law supplies the specific discharge, a flux referred to the gross cross-sectional area rather than a particle speed.

$$i = \frac{96.4 - 94.0}{240} = 0.0100$$

$$q = Ki = (25)(0.0100) = 0.25 \text{ m/day}$$

Seepage velocity corrects that flux for the fraction of the section actually open to transport, which is the effective porosity and not the total porosity.

$$v = \frac{q}{n_e} = \frac{0.25}{0.30} = 0.83 \text{ m/day}$$

FE REFERENCE HANDBOOK — WATER RESOURCES AND ENVIRONMENTAL ENGINEERING: DARCY'S LAW

WHY THE OTHER CHOICES APPEAR

(A) 0.075 m/day results from multiplying the Darcy flux by the effective porosity instead of dividing, $(0.25)(0.30)$.

(B) 0.25 m/day is the Darcy flux Ki reported directly, with the porosity correction omitted.

(C) 0.66 m/day divides the flux by the total porosity 0.38 rather than by the effective porosity 0.30.

Water and Wastewater

Problem 80

Answer: (B)

A granular media filter with a 20 ft by 24 ft plan area operates at a filtration rate of 4.0 gpm/ft^2 for a 60 h run, then is backwashed at 18 gpm/ft^2 for 10 min. The backwash water expressed as a percentage of the water filtered during the run is most nearly:

Backwash consumes about 1.25 *percent of production: the wash rate is 4.5 times the filtration rate, but the run lasts 360 times as long as the wash.*

Plan area cancels from both volumes, leaving a ratio of rate times duration in gallons per square foot.

$$\frac{V_{bw}}{V_f} = \frac{(18)(10)}{(4.0)(60 \times 60)}$$

Run length in minutes is $3,600$, so 180 gal/ft^2 of wash water stands against $14,400$ gal/ft^2 filtered.

$$\frac{180}{14,400} = 0.0125 = 1.25\%$$

FE REFERENCE HANDBOOK — WATER AND WASTEWATER: GRANULAR MEDIA FILTRATION, FILTRATION AND BACKWASH RATES

WHY THE OTHER CHOICES APPEAR

(A) Inverts the rate ratio, computing (4.0/18)(10/3,600) = 6.2 x 10^-4 = 0.062%.

(C) Takes the run as 24 h, comparing 86,400 gal of backwash with 2,764,800 gal filtered.

(D) Reads the run length as 6 h, a decimal slip that inflates the ratio tenfold to 12.5%.

Air Quality and Control

Problem 94

Answer: (A)

A cyclone receives gas at an inlet velocity of 18 m/s through a rectangular inlet 0.20 m wide, with 5 effective turns in the body. Gas viscosity is 1.81×10^{-5} Pa·s and gas density is 1.2 kg/m³; particle density is 1,800 kg/m³. The cut diameter for 50% collection efficiency is most nearly:

Centrifugal drift working against Stokes drag across the 0.20 m inlet width yields a cut diameter of about 5.7 μm.

Cut diameter follows from the particle that just traverses the inlet width under centrifugal drift opposed by Stokes drag during the effective number of turns.

$$d_{pc} = \sqrt{\frac{9\mu W}{2\pi N_e V_i(\rho_p - \rho_g)}}$$

Air viscosity in SI is 1.81×10^{-5} Pa·s rather than the numerically similar poise value, and the gas density is only a 0.07 percent correction to the particle density.

$$2\pi N_e V_i(\rho_p - \rho_g) = 2\pi(5)(18)(1,798.8) = 1.017 \times 10^6$$

Numerator and denominator combine to a cut size in the 5 to 10 μm band that defines high-efficiency cyclone duty and explains their use as precleaners.

$$9\mu W = 9(1.81 \times 10^{-5})(0.20) = 3.258 \times 10^{-5}$$

$$d_{pc} = \sqrt{\frac{3.258 \times 10^{-5}}{1.017 \times 10^6}} = 5.66 \times 10^{-6} \text{ m}$$

FE REFERENCE HANDBOOK — ENVIRONMENTAL ENGINEERING: AIR POLLUTION CONTROL, CYCLONE 50% COLLECTION EFFICIENCY FOR PARTICLE DIAMETER

WHY THE OTHER CHOICES APPEAR

(B) Omits the factor 2 in the denominator, doubling the radicand to 6.405e-11 m^2 and giving 8.00 μm.

(C) Leaves the number of effective turns out of the denominator, raising the radicand fivefold to 1.601e-10 m^2 and giving 12.65 μm.

(D) Uses 1.81e-4 Pa·s for viscosity, the poise value read as a Pa·s value, raising the radicand tenfold and giving 17.9 μm.

Solid and Hazardous Waste

Problem 101

Answer: (C)

A transfer station ships municipal solid waste to a regional landfill in transfer trailers with a 20 ton payload. The round-trip haul distance is 120 mi and the hauling contract pays USD 2.85 per mile of travel. Transfer station processing costs USD 7.40 per ton. The combined processing and haul cost is most nearly:

Haul charges of 17.10 USD/ton over the round trip plus the 7.40 USD/ton processing fee total 24.50 USD/ton.

Haul payment is earned on every mile travelled, so the stated round-trip distance already covers the loaded and the empty leg.

$$C_{haul} = 120 \text{ mi} \times 2.85 \text{ USD/mi} = 342 \text{ USD/load}$$

Payload sets the accounting basis, because one trailer carries the whole load charge.

$$c_{haul} = \frac{342}{20} = 17.10 \text{ USD/ton}$$

Transfer station processing is already quoted on a mass basis and adds without conversion.

$$c_{total} = 17.10 + 7.40 = 24.50 \text{ USD/ton}$$

FE REFERENCE HANDBOOK — ENGINEERING ECONOMICS: COST ESTIMATION, UNIT COST BASIS

WHY THE OTHER CHOICES APPEAR

(A) Halves the given distance to a one-way 60 mi haul: 60 x 2.85/20 + 7.40 = 15.95 USD/ton.

(B) Treats the 7.40 USD/ton processing fee as a per-load charge: (342 + 7.40)/20 = 17.47 USD/ton.

(D) Doubles an already round-trip mileage to account for the return leg twice: 2(342)/20 + 7.40 = 41.60 USD/ton.

Energy and Environment

Problem 108

Answer: (B)

A regional grid generates 3,200 GWh from coal at 0.95 t CO_2/MWh, 4,800 GWh from natural gas at 0.42 t CO_2/MWh, and 2,000 GWh from zero-emitting renewables in one year. The carbon intensity of the delivered electricity is most nearly:

Fossil generation emits 5.06 million tonnes across the year, and spreading that over all 10,000 GWh delivered gives about 506 kg CO_2 per MWh.

Only the two fossil sources emit, each contributing its generation times its own emission factor.

$$m_{\text{coal}} = (3.2 \times 10^6 \text{ MWh})(0.95) = 3.04 \times 10^6 \text{ t}$$

$$m_{\text{gas}} = (4.8 \times 10^6 \text{ MWh})(0.42) = 2.016 \times 10^6 \text{ t}$$

Renewable output carries no emissions but still reaches customers, so it belongs in the denominator, where it dilutes the fossil contribution.

$$I = \frac{5.056 \times 10^6 \text{ t}}{10 \times 10^6 \text{ MWh}} = 0.5056 \text{ t/MWh}$$

$$I = 506 \text{ kg CO}_2\text{/MWh}$$

FE REFERENCE HANDBOOK — ENERGY AND ENVIRONMENT: EMISSION FACTORS AND CARBON INTENSITY OF ELECTRICITY GENERATION

WHY THE OTHER CHOICES APPEAR

(A) Averaging the three emission factors without weighting them by generation, $(0.95 + 0.42 + 0)/3 = 0.457$ t/MWh, gives 457 kg CO_2/MWh.

(C) Interchanging the coal and gas generation shares, $0.48(0.95) + 0.32(0.42) = 0.590$ t/MWh, gives 590 kg CO_2/MWh.

(D) Dividing the same emissions by fossil generation alone, $5.056 \times 10^6/8 \times 10^6 = 0.632$ t/MWh, gives 632 kg CO_2/MWh and describes the fossil fleet rather than the delivered mix.