

PRACTICE PAPER — NATIONAL CERTIFICATION EXAMINATION FOR ENERGY MANAGERS & ENERGY AUDITORS

PAPER – 2: ENERGY EFFICIENCY IN THERMAL UTILITIES

Question code: 5P2CEM001 – 5P2CEM064 | SOLUTIONS & MODEL ANSWERS

Duration: 3 HRS Max. Marks: 150 Pass: 50% marks in the paper

General instructions:

- Please check that this question paper contains 64 questions
- The question paper is divided into three sections
- All questions in all three sections are compulsory
- All parts of a question should be answered at one place
- Use of a non-programmable scientific calculator is permitted; show formula, substitution with units and result for every numerical

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Section – I: OBJECTIVE TYPE

Marks: 50 × 1 = 50

- (i) Answer all 50 questions
- (ii) Each question carries one mark

1. A city gas network plans to blend 20% hydrogen (by volume) into natural gas. Natural gas: HHV 39.8 MJ/Sm³, relative density 0.60. Hydrogen: HHV 12.75 MJ/Sm³, relative density 0.0696. For an unchanged burner and supply pressure, heat input varies with the Wobbe index. By how much does the burner heat input change?

[5P2CEM001 | Chapter 1: Fuels and Combustion | Hydrogen blending in natural gas - Wobbe index and burner heat input]

- a) falls by 9.5%
- b) rises by 5.0%
- c) falls by 4.8%
- d) falls by 13.6%

Correct answer: (c) falls by 4.8%.

Given: blend 80% NG + 20% H₂ by volume; HHV and relative density of each.

Formula: Wobbe index $W = \text{HHV} \div \sqrt{\text{relative density}}$; heat input $\propto W$ at fixed orifice and pressure.

Substitution: $\text{HHV}(\text{blend}) = 0.8 \times 39.8 + 0.2 \times 12.75 = 34.39 \text{ MJ/Sm}^3$; $d(\text{blend}) = 0.8 \times 0.60 + 0.2 \times 0.0696 = 0.4939$; $W = 34.39 \div \sqrt{0.4939} = 48.93$ against 51.38 MJ/Sm³ for NG.

Result: **heat input falls by 4.8%.**

Each Sm³ carries 13.6% less energy, but the lighter gas flows faster, so the Wobbe index changes much less.

Why the other options are wrong: (a) falls by 9.5% – doubles the Wobbe change, treating heat input as proportional to the square of the index. (b) rises by 5.0% – divides by relative density instead of its square root, which overstates the density effect. (d) falls by 13.6% – compares heating values per Sm³ only, ignoring that the lighter blend flows faster through the same orifice.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 1 – Fuels and Combustion.

2. A tanker delivers furnace oil measured as 20,000 litres at 60 °C. The supplier quotes density as 0.950 kg/L at 15 °C, and the oil's volume correction is 0.065% per °C (volume grows with temperature). What mass of oil was actually received?

[5P2CEM002 | Chapter 1: Fuels and Combustion | Furnace oil delivered by volume - temperature correction of the mass received]

- a) 19.56 t
- b) 19.00 t
- c) 18.44 t
- d) 20.44 t

Correct answer: (c) 18.44 t.

Given: 20,000 L at 60 °C; $\rho(15\text{ °C}) = 0.950\text{ kg/L}$; correction 0.00065 per °C; $\Delta T = 45\text{ °C}$.

Formula: $V(15) = V(T) \times (1 - \beta \Delta T)$; $\text{mass} = V(15) \times \rho(15)$.

Substitution: $V(15) = 20,000 \times (1 - 0.00065 \times 45) = 20,000 \times 0.97075 = 19,415\text{ L}$; $\times 0.950$.

Result: **mass received $\approx 18.44\text{ t}$** (18,444 kg).

Hot oil occupies more volume, so billing on hot litres without correction overpays by about 3%. Fuel receipt checks should convert to mass or to 15 °C volume.

Why the other options are wrong: (a) 19.56 t – adds the correction, as if hot oil were denser than cold oil. (b) 19.00 t – applies the 15 °C density to the hot volume without any temperature correction. (d) 20.44 t – divides the volume by density instead of multiplying.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 1 – Fuels and Combustion.

3. Natural gas (NCV 50,000 kJ/kg) burns with 10% excess air, giving 20 kg of flue gas per kg of fuel. Air and fuel enter at 30 °C and the mean specific heat of the flue gas is 1.30 kJ/kg·K. Ignoring dissociation and heat loss, what is the adiabatic flame temperature?

[SP2CEM003 | Chapter 1: Fuels and Combustion | Adiabatic flame temperature of natural gas with excess air]

- a) 1,953 °C
- b) 2,518 °C
- c) 2,054 °C
- d) 2,165 °C

Correct answer: (a) 1,953 °C.

Given: NCV = 50,000 kJ/kg; flue gas = 20 kg/kg fuel; $c_p = 1.30\text{ kJ/kg·K}$; inlet 30 °C.

Formula: $T(\text{ad}) = T(\text{in}) + \text{NCV} \div (m(\text{fg}) \times c_p)$.

Substitution: $30 + 50,000 \div (20 \times 1.30) = 30 + 1,923$.

Result: **$T(\text{ad}) \approx 1,953\text{ °C}$** .

Excess air dilutes the products and lowers the flame temperature, which reduces radiant heat transfer in furnaces.

Preheated air or lower excess air raises it.

Why the other options are wrong: (b) 2,518 °C – uses c_p of air at room temperature (1.005) instead of the hot flue gas value. (c) 2,054 °C – uses the air mass of 19 kg instead of the 20 kg of flue gas (air plus fuel). (d) 2,165 °C – uses the GCV of 55,500 kJ/kg, but water leaves as vapour so only the NCV raises the gas temperature.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 1 – Fuels and Combustion.

4. A boiler is designed for coal with not more than 30% ash. The plant has domestic coal with 42% ash and imported coal with 12% ash (both on the same basis). What mass fraction of imported coal is needed in the blend?

[SP2CEM004 | Chapter 1: Fuels and Combustion | Blending imported and domestic coal to meet an ash limit]

- a) 60.0%
- b) 28.6%
- c) 71.4%
- d) 40.0%

Correct answer: (d) 40.0%.

Given: domestic ash 42%; imported ash 12%; target 30%.

Formula: ash balance: $x \times 12 + (1 - x) \times 42 = 30$, so $x = (42 - 30) \div (42 - 12)$.

Substitution: $x = 12 \div 30$.

Result: **imported coal = 40.0% of the blend.**

Blending must also respect GCV, ash fusion temperature, sulphur and grindability. Mass balances on ash are a simple first check.

Why the other options are wrong: (a) 60.0% – gives the share of domestic coal, reversing the lever rule. (b) 28.6% – divides the ash reduction by the domestic ash content instead of by the difference between the two coals. (c) 71.4% – takes the complement of a wrongly based fraction.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 1 – Fuels and Combustion.

5. A coal-fired boiler burns 10 t/h of coal with 7.2 kg of air per kg of coal. Air density is 1.293 kg/Nm³ at 0 °C and 1 atm. The site is at 45 °C ambient and 0.93 atm (altitude). What actual air flow must the FD fan handle?

[5P2CEM005 | Chapter 1: Fuels and Combustion | Actual volume of combustion air for forced-draught fan selection]

- a) 15.47 m³/s
- b) 18.02 m³/s
- c) 16.76 m³/s
- d) 19.37 m³/s

Correct answer: (d) 19.37 m³/s.

Given: air = 10,000 × 7.2 = 72,000 kg/h; $\rho(N) = 1.293 \text{ kg/Nm}^3$; 45 °C; 0.93 atm.

Formula: $V(\text{actual}) = (\text{mass} \div \rho(N)) \times (T \div 273.15) \times (1 \div p \text{ in atm})$.

Substitution: $72,000 \div 1.293 = 55,684 \text{ Nm}^3/\text{h}$; $\times 318.15 \div 273.15 \div 0.93 = 69,740 \text{ m}^3/\text{h}$.

Result: $\approx 19.37 \text{ m}^3/\text{s}$.

Fans move volume, so hot or high-altitude sites need larger fans for the same combustion air mass.

Why the other options are wrong: (a) 15.47 m³/s – stops at Nm³/s and ignores both temperature and altitude. (b) 18.02 m³/s – corrects for temperature but not for the lower site pressure. (c) 16.76 m³/s – multiplies by the pressure ratio; lower pressure increases volume, so it must divide.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 1 – Fuels and Combustion.

6. An oil burner uses 0.35 kg of atomising steam per kg of furnace oil. The steam (enthalpy 2,768 kJ/kg) comes from a boiler with 82% efficiency, fed at 60 °C (251.2 kJ/kg) and fired with the same oil (GCV 10,200 kcal/kg ($\approx 42,705 \text{ kJ/kg}$)). What fraction of the oil fired is spent raising the atomising steam?

[5P2CEM006 | Chapter 1: Fuels and Combustion | Fuel penalty of steam atomisation of furnace oil]

- a) 2.77%
- b) 2.52%
- c) 1.69%
- d) 2.06%

Correct answer: (b) 2.52%.

Given: 0.35 kg steam/kg oil; $\Delta h = 2,768 - 251.2 \text{ kJ/kg}$; $\eta = 0.82$; $\text{GCV} = 10,200 \times 4.1868 \text{ kJ/kg}$.

Formula: $\text{penalty} = \text{steam ratio} \times \Delta h \div (\eta \times \text{GCV}) \times 100$.

Substitution: $0.35 \times 2,516.8 \div (0.82 \times 42,705) \times 100$.

Result: $\approx 2.52\% \text{ of the oil}$.

Atomising steam is also lost up the stack as water vapour. Keeping steam ratio and oil viscosity right avoids this loss.

Why the other options are wrong: (a) 2.77% – uses the full steam enthalpy without subtracting the feed water heat. (c) 1.69% – multiplies by efficiency instead of dividing. (d) 2.06% – ignores boiler efficiency, so it counts the steam heat rather than the fuel needed to make it.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 1 – Fuels and Combustion.

7. In a bomb calorimeter test, 0.75 g of coal raises the temperature of 2,000 g of water by 2.00 K. The water equivalent of the calorimeter is 450 g, cp of water is 4.187 J/g·K, and fuse wire and acid corrections total 60 J. What is the GCV of the coal?

[5P2CEM007 | Chapter 1: Fuels and Combustion | Gross calorific value from a bomb calorimeter test]

- a) 15.34 MJ/kg
- b) 27.28 MJ/kg
- c) 22.25 MJ/kg
- d) 32.30 MJ/kg

Correct answer: (b) 27.28 MJ/kg.

Given: water 2,000 g; water equivalent 450 g; $\Delta T = 2.00$ K; sample 0.75 g; corrections 60 J.

Formula: $GCV = [(water + water\ equivalent) \times cp \times \Delta T - corrections] \div sample\ mass.$

Substitution: $(2,450 \times 4.187 \times 2.00 - 60) \div 0.75 = 20,456 \div 0.75$ J/g.

Result: **GCV $\approx$ 27.28 MJ/kg** ($\approx$ 6,515 kcal/kg).

The bomb measures GCV because the products cool and water condenses. NCV is found by subtracting latent heat of the water formed.

Why the other options are wrong: (a) 15.34 MJ/kg – multiplies by the sample mass instead of dividing. (c) 22.25 MJ/kg – leaves out the water equivalent of the bomb and vessel. (d) 32.30 MJ/kg – adds the water equivalent twice.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 1 – Fuels and Combustion.

8. A refinery fuel gas contains 70% methane (LFL 5.0%), 20% ethane (LFL 3.0%) and 10% hydrogen (LFL 4.0%) by volume. Using Le Chatelier's rule, what is the lower flammability limit of the mixture in air, used to set gas-detector alarms?

[SP2CEM008 | Chapter 1: Fuels and Combustion | Lower flammability limit of a fuel gas mixture (Le Chatelier rule)]

- a) 5.00%
- b) 3.00%
- c) 4.32%
- d) 4.50%

Correct answer: (c) 4.32%.

Given: $y = 0.70, 0.20, 0.10$; LFL = 5.0, 3.0, 4.0%.

Formula: $LFL(mix) = 1 \div \sum (y(i) \div LFL(i)).$

Substitution: $1 \div (0.70/5.0 + 0.20/3.0 + 0.10/4.0) = 1 \div 0.2317.$

Result: **LFL $\approx$ 4.32% by volume.**

Gas detectors usually alarm at 20–25% of LFL. Hydrogen-rich gases need lower settings and careful purging before light-up.

Why the other options are wrong: (a) 5.00% – takes the main component value, which ignores the more flammable ethane and hydrogen. (b) 3.00% – takes the lowest component value, which is too conservative for the mixture. (d) 4.50% – takes a simple volume-weighted average, whereas the rule uses a harmonic average.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 1 – Fuels and Combustion.

9. A 10 t/h spare boiler is kept hot-banked all year (8,000 h) so it can take load quickly. At full load it needs 2,442 kJ per kg of steam at 85% efficiency. Banking losses are 2.0% of its full-load fuel input; keeping it warm instead by circulating water from the running boiler would cut the loss to 0.5%. Gas costs ₹4.30 per kWh. What is the annual saving?

[SP2CEM009 | Chapter 2: Boilers | Standby losses of a hot-banked spare boiler]

- a) ₹45.1 lakh
- b) ₹41.2 lakh
- c) ₹35.0 lakh
- d) ₹54.9 lakh

Correct answer: (b) ₹41.2 lakh.

Given: steam 10,000 kg/h $\times$ 2,442 kJ/kg; $\eta = 0.85$; loss falls from 2.0% to 0.5% of fuel input; 8,000 h; ₹4.30/kWh.

Formula: fuel input = steam $\times \Delta h \div \eta$; saving = input $\times (2.0\% - 0.5\%) \times$ hours $\times$ price.

Substitution: input = $10,000 \times 2,442 \div 0.85 \div 3,600 = 7,980$ kW; $\times 0.015 \times 8,000 \times ₹4.30.$

Result: **$\approx$ ₹41.2 lakh a year.**

Banked boilers lose heat through radiation and through air drawn through the furnace by natural draught. Closing dampers and warm standby cut the loss.

Why the other options are wrong: (a) ₹45.1 lakh – uses 8,760 h although the boiler is banked for 8,000 h. (c) ₹35.0 lakh – bases the loss on steam output instead of fuel input. (d) ₹54.9 lakh – takes the whole 2.0% banking loss as the saving, ignoring the 0.5% that remains.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 2 – Boilers.

10. A gas-fired boiler cycles on and off 8 times an hour for 6,000 h a year at low load. Each cycle includes 60 s pre-purge and 30 s post-purge at 3,000 m³/h of air (density 1.2 kg/m³, cp 1.005 kJ/kg·K), heated by 120 K as it sweeps the hot furnace. The heat must be replaced at 85% efficiency using gas of 37.68 MJ/Sm³. How much gas is wasted on purging each year?

[SP2CEM010 | Chapter 2: Boilers | Purge losses from frequent on-off cycling of a gas-fired boiler]

- a) 20,333 Sm³
- b) 10,845 Sm³
- c) 13,827 Sm³
- d) 16,267 Sm³

Correct answer: (d) 16,267 Sm³.

Given: purge air = 3,000 × 90 ÷ 3,600 = 75 m³/cycle; 8 cycles/h; 6,000 h; ΔT = 120 K.

Formula: heat per cycle = V × ρ × cp × ΔT; gas = heat × cycles ÷ (η × CV).

Substitution: 75 × 1.2 × 1.005 × 120 = 10,854 kJ; × 48,000 cycles = 521.0 GJ; ÷ (37.68 × 0.85).

Result: ≈ **16,267 Sm³ of gas a year.**

Right-sizing, modulating burners and high turndown cut cycling, which also reduces thermal stress.

Why the other options are wrong: (a) 20,333 Sm³ – uses a 150 K temperature rise instead of the stated 120 K. (b) 10,845 Sm³ – counts only the 60 s pre-purge and ignores post-purge. (c) 13,827 Sm³ – ignores the 85% boiler efficiency when converting heat lost to gas fired.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 2 – Boilers.

11. A coal-fired boiler produces 36,000 kg/h of flue gas (density 1.30 kg/Nm³ at 0 °C, 1 atm). At the entry to the convection bank the gas is at 450 °C and the free flow area is 1.8 m². What is the gas velocity there, which must be kept low to limit fly-ash erosion?

[SP2CEM011 | Chapter 2: Boilers | Flue gas velocity in the convection pass of a coal-fired boiler]

- a) 11.31 m/s
- b) 4.27 m/s
- c) 7.04 m/s
- d) 14.71 m/s

Correct answer: (a) 11.31 m/s.

Given: m = 36,000 kg/h; ρ(N) = 1.30 kg/Nm³; T = 723.15 K; A = 1.8 m².

Formula: V(actual) = m ÷ ρ(N) × (T ÷ 273.15); velocity = V ÷ A.

Substitution: 36,000 ÷ 1.30 ÷ 3,600 = 7.692 Nm³/s; × 2.6474 = 20.36 m³/s; ÷ 1.8.

Result: ≈ **11.31 m/s.**

High-ash Indian coals need low gas velocities in convection passes; erosion rises roughly with the cube of velocity, so excess air and air ingress also matter.

Why the other options are wrong: (b) 4.27 m/s – uses the normal volume and forgets the expansion at 450 °C. (c) 7.04 m/s – uses the Celsius temperature in the gas-law ratio. (d) 14.71 m/s – assumes a density of 1.0 kg/Nm³ instead of 1.30.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 2 – Boilers.

12. A coal-fired boiler burns coal of GCV 4,000 kcal/kg ($\approx 16,747$ kJ/kg) with 16 kg of theoretical air per kg of coal and 25% excess air. On a humid day the air carries 0.025 kg of water vapour per kg of dry air. Flue gas leaves at 200 °C; ambient is 40 °C; cp of water vapour is 1.88 kJ/kg·K. What is the heat loss due to moisture in the air, as % of GCV?

[5P2CEM012 | Chapter 2: Boilers | Boiler loss due to moisture in the combustion air]

- a) 0.90%
- b) 1.12%
- c) 0.48%
- d) 0.72%

Correct answer: (a) 0.90%.

Given: actual air = $16 \times 1.25 = 20$ kg/kg coal; humidity 0.025 kg/kg; $\Delta T = 200 - 40 = 160$ K; GCV = $4,000 \times 4.1868$ kJ/kg.

Formula: loss = air $\times$ humidity $\times$ cp(vapour) $\times$ $\Delta T \div$ GCV $\times$ 100.

Substitution: $20 \times 0.025 \times 1.88 \times 160 \div 16,747 \times 100$.

Result: $\approx 0.90\%$ of GCV.

The vapour enters and leaves as vapour, so only its sensible heat is lost. The loss is small but rises with excess air and stack temperature, which are the levers to control.

Why the other options are wrong: (b) 1.12% – uses the stack temperature instead of the rise above ambient. (c) 0.48% – uses cp of dry air instead of water vapour. (d) 0.72% – uses the theoretical air, forgetting the 25% excess air.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 2 – Boilers.

13. A thermic fluid system holds 12 m³ of oil at 30 °C (density 870 kg/m³). At the 280 °C operating temperature the density is 700 kg/m³. What volume of expansion must the expansion tank accommodate (before any safety margin)?

[5P2CEM013 | Chapter 2: Boilers | Thermic fluid expansion tank sizing]

- a) 2.34 m³
- b) 1.46 m³
- c) 2.91 m³
- d) 4.37 m³

Correct answer: (c) 2.91 m³.

Given: V(cold) = 12 m³; $\rho(30\text{ °C}) = 870$; $\rho(280\text{ °C}) = 700$ kg/m³.

Formula: mass constant: $V(\text{hot}) = V(\text{cold}) \times \rho(\text{cold}) \div \rho(\text{hot})$; expansion = V(hot) – V(cold).

Substitution: $12 \times 870 \div 700 = 14.91$ m³; – 12.

Result: **expansion ≈ 2.91 m³.**

The expansion tank also keeps the pump suction flooded and vents moisture and light ends. It must be above the highest point of the system.

Why the other options are wrong: (a) 2.34 m³ – inverts the density ratio, which gives the shrinkage of a hot volume on cooling. (b) 1.46 m³ – assumes only half the system reaches operating temperature. (d) 4.37 m³ – adds a 50% margin, which the question excludes.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 2 – Boilers.

14. A deaerator heats 15,000 kg/h of feed water (a mix of condensate and make-up) from 70 °C (293.0 kJ/kg) to 105 °C (440.2 kJ/kg) using steam at 3 bar(a): h(f) = 561.4, h(fg) = 2,163.5 and h(g) = 2,724.9 kJ/kg. The steam condenses into the outlet water. What steam flow is needed?

[5P2CEM014 | Chapter 2: Boilers | Steam consumption of a deaerator from an energy balance]

- a) 810 kg/h
- b) 966 kg/h
- c) 1,021 kg/h
- d) 908 kg/h

Correct answer: (b) 966 kg/h.

Given: water 15,000 kg/h; $293.0 \rightarrow 440.2$ kJ/kg; steam h(g) = 2,724.9 kJ/kg.

Formula: $m(s) \times (h(g) - h(out)) = m(w) \times (h(out) - h(in))$.

Substitution: $m(s) = 15,000 \times 147.2 \div (2,284.7)$.

Result: **≈ 966 kg/h of steam.**

Returning more hot condensate cuts deaerator steam. Venting must be kept to the minimum needed to strip oxygen and CO₂.

Why the other options are wrong: (a) 810 kg/h – divides by the steam enthalpy instead of the heat steam gives up down to 105 °C. (c) 1,021 kg/h – uses only the latent heat, ignoring the condensate cooling from 133.5 °C to 105 °C. (d) 908 kg/h – treats 15,000 kg/h as the outlet flow and uses the inlet enthalpy as the reference.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 2 – Boilers.

15. A water-tube boiler tube receives a heat flux of 60 kW/m². Water side: 250 °C, film coefficient 20,000 W/m²·K. The steel wall is 5 mm thick ($k = 45$ W/m·K). A 1 mm scale layer ($k = 1.2$ W/m·K) then forms on the water side. Treating the wall as flat, what is the new outer tube metal temperature?

[SP2CEM015 | Chapter 2: Boilers | Tube metal temperature rise caused by water-side scale]

a) 284.7 °C

b) 300.0 °C

c) 261.0 °C

d) 309.7 °C

Correct answer: (d) 309.7 °C.

Given: $q = 60,000$ W/m²; $h = 20,000$ W/m²·K; steel 0.005/45; scale 0.001/1.2.

Formula: $T(\text{metal}) = T(\text{water}) + q \times (1/h + x(\text{scale})/k(\text{scale}) + x(\text{wall})/k(\text{wall}))$.

Substitution: clean: $250 + 60,000 \times (0.00005 + 0.000111) = 259.7$ °C; scale adds $60,000 \times 0.001 \div 1.2 = 50$ K.

Result: **≈ 309.7 °C.**

Scale is a poor conductor, so the tube runs hotter and can overheat and fail. It also raises stack temperature and fuel use.

Why the other options are wrong: (a) 284.7 °C – uses half the scale thickness, as if it were a radius. (b) 300.0 °C – adds only the scale drop to the water temperature, ignoring the film and steel wall. (c) 261.0 °C – uses the conductivity of steel for the scale layer.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 2 – Boilers.

16. A stack analyser reads 95 ppm NO_x (dry) with 6.5% O₂ (dry) in a gas-fired boiler. The emission limit is stated at 3% O₂ (dry). What is the NO_x concentration corrected to 3% O₂ for comparison with the limit?

[SP2CEM016 | Chapter 2: Boilers | Correcting a measured NO_x concentration to a reference oxygen level]

a) 76.5 ppm

b) 117.9 ppm

c) 205.8 ppm

d) 137.6 ppm

Correct answer: (b) 117.9 ppm.

Given: $C(\text{meas}) = 95$ ppm at 6.5% O₂; reference 3% O₂.

Formula: $C(\text{ref}) = C(\text{meas}) \times (21 - O_2(\text{ref})) \div (21 - O_2(\text{meas}))$.

Substitution: $95 \times 18 \div 14.5$.

Result: **≈ 117.9 ppm at 3% O₂.**

Correction stops plants from meeting limits simply by diluting the flue gas with excess air, which would also waste fuel.

Why the other options are wrong: (a) 76.5 ppm – inverts the correction factor, which lowers instead of raising the diluted reading. (c) 205.8 ppm – scales by the ratio of oxygen percentages instead of the oxygen-free fractions. (d) 137.6 ppm – corrects to 0% O₂ instead of the 3% reference.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 2 – Boilers.

17. A stoker boiler rated 20 t/h on 4,500 kcal/kg coal ($\approx 18,841$ kJ/kg coal) at 80% efficiency has a coal feeder that can deliver at most 4.2 t/h. On a new coal (GCV 3,600 kcal/kg ($\approx 15,072$ kJ/kg)) the boiler efficiency is 77%. Each kg of steam needs 2,500 kJ above feed water. What is the maximum steam output now?

[SP2CEM017 | Chapter 2: Boilers | Boiler derating when firing a lower-GCV coal with a feeder limit]

- a) 15.4 t/h
- b) 16.0 t/h
- c) 20.3 t/h
- d) 19.5 t/h

Correct answer: (d) 19.5 t/h.

Given: feeder 4,200 kg/h; GCV = 3,600 kcal/kg ($\approx 15,072$ kJ/kg); $\eta = 0.77$; $\Delta h = 2,500$ kJ/kg; design rating 20 t/h on 4,500 kcal/kg coal ($\approx 18,841$ kJ/kg coal) at 80%.

Formula: steam = coal $\times$ GCV $\times 4.1868 \times \eta \div \Delta h$.

Substitution: $4,200 \times 3,600 \times 4.1868 \times 0.77 \div 2,500$.

Result: ≈ 19.5 t/h, slightly below the 20 t/h rating.

Low-GCV coal raises the fuel and ash handling load. Feeders, grate area and fans often limit output before the pressure parts do.

Why the other options are wrong: (a) 15.4 t/h – scales the rating by both GCV and efficiency ratios, ignoring the actual feeder capacity. (b) 16.0 t/h – scales the 20 t/h rating by the GCV ratio ($3,600 \div 4,500$) without checking the feeder limit. (c) 20.3 t/h – uses the old 80% efficiency, ignoring the drop on the poorer coal.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 2 – Boilers.

18. A Ruths steam accumulator of 20 m³ is 90% full of water at 10 bar(a) ($h(f) = 762.6$ kJ/kg, density 887 kg/m³). It may discharge down to 4 bar(a) ($h(f) = 604.7$, $h(fg) = 2,133.0$, $h(g) = 2,737.7$ kJ/kg). How much steam can it release to cover a peak?

[SP2CEM018 | Chapter 3: Steam System | Steam accumulator - steam released by a permitted pressure drop]

- a) 1,182 kg
- b) 921 kg
- c) 1,251 kg
- d) 1,313 kg

Correct answer: (a) 1,182 kg.

Given: water = $0.9 \times 20 \times 887 = 15,966$ kg; $h(f)$ falls $762.6 \rightarrow 604.7$ kJ/kg; $h(fg)$ at 4 bar = 2,133.0 kJ/kg.

Formula: steam flashed $\approx m(\text{water}) \times (h(f1) - h(f2)) \div h(fg2)$.

Substitution: $15,966 \times 157.9 \div 2,133.0$.

Result: $\approx 1,182$ kg of steam.

An accumulator lets the boiler fire steadily while it absorbs batch peaks, improving boiler efficiency and steam quality.

Why the other options are wrong: (b) 921 kg – divides by the total enthalpy of steam instead of the latent heat at 4 bar. (c) 1,251 kg – uses the latent heat at 10 bar instead of at the lower discharge pressure. (d) 1,313 kg – takes the whole 20 m³ as water, ignoring the 10% steam space.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 3 – Steam System.

19. A vessel holds 2,000 kg of water at 25 °C, to be heated to 85 °C by a steam coil (area 2.5 m², $U = 800$ W/m²·K) supplied with steam at 3 bar(a), 133.5 °C. Ignoring losses and the vessel's own heat capacity, how long does heat-up take?

[SP2CEM019 | Chapter 3: Steam System | Heat-up time of a batch vessel with a steam coil]

- a) 53.3 min
- b) 56.2 min
- c) 86.3 min
- d) 38.6 min

Correct answer: (b) 56.2 min.

Given: $m = 2,000 \text{ kg}$; $c_p = 4,187 \text{ J/kg}\cdot\text{K}$; $UA = 800 \times 2.5 = 2,000 \text{ W/K}$; $T(s) = 133.5 \text{ }^\circ\text{C}$.

Formula: $t = (m c_p \div UA) \times \ln[(T(s) - T(1)) \div (T(s) - T(2))]$.

Substitution: $(2,000 \times 4,187 \div 2,000) \times \ln(108.5 \div 48.5) = 4,187 \times 0.8052 \text{ s}$.

Result: **$t \approx 3,371 \text{ s} \approx 56.2 \text{ min}$.**

The rate falls as the batch warms. Higher steam pressure or a larger coil shortens heat-up; good air venting keeps U high.

Why the other options are wrong: (a) 53.3 min – uses the arithmetic mean water temperature instead of the logarithmic relation. (c) 86.3 min – uses the final temperature difference throughout, which understates it. (d) 38.6 min – uses the starting temperature difference throughout, which overstates the driving force.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 3 – Steam System.

20. A 200 m furnace-oil line is steam traced and insulated; the measured heat loss is 35 W per metre. The tracer uses steam at 7 bar(g) (8 bar(a): $h(\text{fg}) = 2,047.7 \text{ kJ/kg}$, $h(\text{g}) = 2,768 \text{ kJ/kg}$) and condensate is removed at saturation. What steam does the tracer use?

[SP2CEM020 | Chapter 3: Steam System | Steam consumption of a steam tracer on an oil line]

a) 6.2 kg/h

b) 24.6 kg/h

c) 12.3 kg/h

d) 9.1 kg/h

Correct answer: (c) 12.3 kg/h.

Given: $200 \text{ m} \times 35 \text{ W/m} = 7.0 \text{ kW}$; $h(\text{fg}) = 2,047.7 \text{ kJ/kg}$.

Formula: $\text{steam} = \text{heat loss} \div \text{latent heat}$.

Substitution: $7.0 \text{ kW} \times 3,600 \div 2,047.7$.

Result: **$\approx 12.3 \text{ kg/h}$.**

Tracers run all year, so trap losses and over-pressure add up. Self-regulating electric tracing can be cheaper where steam use is small.

Why the other options are wrong: (a) 6.2 kg/h – halves the loss on the idea that only the lower half of the pipe is heated. (b) 24.6 kg/h – doubles the loss, counting both the pipe and the tracer although the 35 W/m is the measured total. (d) 9.1 kg/h – divides by total enthalpy, but condensate leaves at saturation so only latent heat is given up.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 3 – Steam System.

21. Steam from a 10 bar(a) header ($h(\text{f}) = 762.6$, $h(\text{fg}) = 2,014.6$, $h(\text{g}) = 2,777.1 \text{ kJ/kg}$) is throttled to 1 bar(a), where it is found superheated at $110 \text{ }^\circ\text{C}$ ($h = 2,696.2 \text{ kJ/kg}$; $h(\text{g})$ at 1 bar = $2,675.5 \text{ kJ/kg}$). What is the dryness fraction of the header steam?

[SP2CEM021 | Chapter 3: Steam System | Dryness fraction by a throttling calorimeter]

a) 95.0%

b) 97.1%

c) 85.7%

d) 96.0%

Correct answer: (d) 96.0%.

Given: throttling keeps enthalpy constant; $h = 2,696.2 \text{ kJ/kg}$ after throttling.

Formula: $h(\text{f}1) + x h(\text{fg}1) = h(2)$, so $x = (h(2) - h(\text{f}1)) \div h(\text{fg}1)$.

Substitution: $(2,696.2 - 762.6) \div 2,014.6$.

Result: **$x \approx 96.0\%$.**

Wet steam carries less heat per kg, erodes valves and control seats, and forms a water film that lowers heat transfer. Separators and correct drainage keep dryness up.

Why the other options are wrong: (a) 95.0% – uses saturated enthalpy at 1 bar, ignoring the measured superheat. (b) 97.1% – divides enthalpies directly instead of solving $h = h(f) + x h(fg)$. (c) 85.7% – uses the latent heat at 1 bar instead of at the header pressure.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 3 – Steam System.

22. An autoclave cycle heats 3,000 kg of steel (shell plus load, cp 0.48 kJ/kg·K) from 30 °C to 133.5 °C with steam at 3 bar(a) ($h(fg) = 2,163.5$ kJ/kg), then holds for 1 hour against a 15 kW heat loss. Condensate leaves at saturation. How much steam does one cycle use?

[5P2CEM022 | Chapter 3: Steam System | Steam consumed per autoclave cycle]

- a) 118.8 kg
- b) 68.9 kg
- c) 78.1 kg
- d) 93.8 kg

Correct answer: (d) 93.8 kg.

Given: steel heat = $3,000 \times 0.48 \times 103.5$ kJ; hold loss = $15 \text{ kW} \times 3,600 \text{ s}$; $h(fg) = 2,163.5$ kJ/kg.

Formula: steam = (heat-up + hold loss) ÷ $h(fg)$.

Substitution: $(149,040 + 54,000) \div 2,163.5$.

Result: **≈ 93.8 kg per cycle.**

Batch steam users have a heavy start-up load. Lighter trays and insulation of the shell cut steam per cycle.

Why the other options are wrong: (a) 118.8 kg – counts the hold loss twice. (b) 68.9 kg – counts the heat-up but leaves out the hold-period heat loss. (c) 78.1 kg – assumes the condensate is cooled to 30 °C inside the autoclave.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 3 – Steam System.

23. 8 t/h of condensate leaves the plant at 95 °C but reaches the boiler hotwell at 75 °C through a long bare return line. The boiler is gas-fired (37.68 MJ/Sm^3 , ₹45 per Sm^3 , efficiency 85%) and runs 7,000 h a year. What is the annual fuel cost of this heat loss?

[5P2CEM023 | Chapter 3: Steam System | Fuel cost of condensate cooling in an uninsulated return line]

- a) ₹65.9 lakh
- b) ₹56.0 lakh
- c) ₹47.6 lakh
- d) ₹82.5 lakh

Correct answer: (a) ₹65.9 lakh.

Given: $m = 8,000 \text{ kg/h}$; $\Delta T = 20 \text{ K}$; $\eta = 0.85$; $CV = 37.68 \text{ MJ/Sm}^3$; ₹45/ Sm^3 ; 7,000 h.

Formula: gas = $m \text{ cp } \Delta T \div (\eta \text{ CV})$; cost = gas × hours × price.

Substitution: $8,000 \times 4.187 \times 20 = 669,920 \text{ kJ/h}$; $\div (37,680 \times 0.85) = 20.92 \text{ Sm}^3/\text{h}$.

Result: **≈ ₹65.9 lakh a year.**

Insulating return lines is cheap and also keeps the hotwell hot enough to reduce dissolved oxygen.

Why the other options are wrong: (b) ₹56.0 lakh – ignores boiler efficiency when converting lost heat to fuel. (c) ₹47.6 lakh – multiplies by efficiency instead of dividing. (d) ₹82.5 lakh – uses 8,760 h although the plant runs 7,000 h.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 3 – Steam System.

24. An open hot-water rinse tank (4 m² surface at 80 °C) loses 7.0 kg/m²·h of water by evaporation (latent heat 2,309 kJ/kg). The tank is heated by steam at 3 bar(a) ($h(fg) = 2,163.5$ kJ/kg; $h(g) = 2,724.9$ kJ/kg). Floating plastic balls would cut evaporation by 80%. How much steam is saved in 6,000 h a year?

[5P2CEM024 | Chapter 3: Steam System | Open-tank evaporation loss and floating covers]

- a) 134.4 t
- b) 143.4 t
- c) 113.9 t

d) 179.3 t

Correct answer: (b) 143.4 t.

Given: evaporation = $4 \times 7.0 = 28 \text{ kg/h}$; latent at $80^\circ\text{C} = 2,309 \text{ kJ/kg}$; $h(\text{fg})$ of steam = $2,163.5 \text{ kJ/kg}$; 80% cut; 6,000 h.

Formula: steam saved = $\text{evaporation} \times L(80^\circ\text{C}) \div h(\text{fg}) \times 0.8 \times \text{hours}$.

Substitution: $28 \times 2,309 \div 2,163.5 = 29.9 \text{ kg/h}$; $\times 0.8 \times 6,000$.

Result: **$\approx 143.4 \text{ t}$ of steam a year.**

Surface losses from open tanks are often larger than wall losses. Covers, lids and lower set points are cheap fixes.

Why the other options are wrong: (a) 134.4 t – equates the water evaporated with the steam saved, ignoring the different latent heats. (c) 113.9 t – divides by the total enthalpy of steam instead of its latent heat. (d) 179.3 t – takes the whole evaporation loss as the saving, ignoring that balls cut it by 80%.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 3 – Steam System.

25. An AHU supplies 20,000 kg/h of dry air, half of it fresh air at 0.004 kg/kg humidity ratio and half return air already at the target 0.008 kg/kg. What steam must the humidifier add for the supply to reach 0.008 kg/kg?

[5P2CEM025 | Chapter 3: Steam System | Steam humidification of a fresh-air and return-air mix]

a) 40 kg/h of steam

b) 80 kg/h of steam

c) 48 kg/h of steam

d) 20 kg/h of steam

Correct answer: (a) 40 kg/h of steam.

Given: 20,000 kg/h dry air; 10,000 kg/h fresh at 0.004; 10,000 kg/h return at 0.008; target 0.008 kg/kg.

Formula: steam = $m(\text{dry air}) \times (w(\text{target}) - w(\text{mixed}))$; $w(\text{mixed})$ = mass-weighted mean.

Substitution: $w(\text{mixed}) = (0.004 + 0.008) \div 2 = 0.006$; steam = $20,000 \times (0.008 - 0.006)$.

Result: **40 kg/h of steam**, the same as $10,000 \times 0.004$ for the fresh air alone.

Humidification steam must be clean and dry. Reducing fresh air to the needed minimum cuts both humidification and heating loads.

Why the other options are wrong: (b) 80 kg/h of steam – treats the whole supply as fresh air at 0.004 kg/kg. (c) 48 kg/h of steam – multiplies the given mass flow by an air density of 1.2, as if it were in m^3/h . (d) 20 kg/h of steam – applies the mixed-air deficit of 0.002 kg/kg only to the fresh air.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 3 – Steam System.

26. An EAF shop uses 30 Nm^3 of oxygen per tonne of steel. Each Nm^3 of oxygen injected replaces 3.6 kWh of arc energy, and producing it in the captive oxygen plant takes 0.55 kWh/Nm^3 . What is the net electricity saving per tonne of steel?

[5P2CEM026 | Chapter 4: Furnaces | Electric arc furnace - net electricity saved by oxygen lancing]

a) 108.0 kWh/t

b) 75.0 kWh/t

c) 91.5 kWh/t

d) 124.5 kWh/t

Correct answer: (c) 91.5 kWh/t.

Given: $30 \text{ Nm}^3/\text{t}$; 3.6 kWh saved per Nm^3 ; 0.55 kWh/Nm^3 for oxygen production.

Formula: net saving = $\text{O}_2 \times (\text{arc energy saved} - \text{O}_2 \text{ production energy})$.

Substitution: $30 \times (3.6 - 0.55)$.

Result: **91.5 kWh/t.**

Chemical energy from oxidation of carbon, silicon and iron replaces arc energy and shortens tap-to-tap time, but iron yield loss and refractory wear must be watched and costed.

Why the other options are wrong: (a) 108.0 kWh/t – takes the gross saving and ignores the oxygen plant's power. (b) 75.0 kWh/t – subtracts the oxygen plant power twice. (d) 124.5 kWh/t – adds the oxygen plant power instead of subtracting it.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 4 – Furnaces.

27. A gas-fired heat-treatment furnace must deliver 400 kW net to the load and walls. Each radiant tube burner is rated 45 kW gas input and the tube system efficiency (heat released into the furnace ÷ gas input) is 62%. How many radiant tubes are needed?

[SP2CEM027 | Chapter 4: Furnaces | Number of gas-fired radiant tubes for a heat-treatment furnace]

- a) 15 radiant tubes
- b) 9 radiant tubes
- c) 14 radiant tubes
- d) 24 radiant tubes

Correct answer: (a) 15 radiant tubes.

Given: net duty 400 kW; 45 kW gas input per tube; $\eta = 0.62$.

Formula: tubes = net duty ÷ (input per tube × η), rounded up.

Substitution: $400 \div (45 \times 0.62) = 400 \div 27.9 = 14.34$.

Result: **15 tubes.**

Radiant tubes keep combustion products away from the work, which allows a protective atmosphere. Recuperative burners raise η and cut the tube count.

Why the other options are wrong: (b) 9 radiant tubes – divides by the gas input per tube, ignoring the flue loss inside each tube. (c) 14 radiant tubes – rounds 14.3 down, leaving the furnace short of heat. (d) 24 radiant tubes – applies the efficiency twice.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 4 – Furnaces.

28. An electric resistance furnace is rated 120 kW at 415 V. The plant voltage sags to 390 V for long periods. Assuming constant element resistance, what power does the furnace now draw?

[SP2CEM028 | Chapter 4: Furnaces | Resistance furnace power at reduced supply voltage]

- a) 106.0 kW
- b) 99.6 kW
- c) 112.8 kW
- d) 135.9 kW

Correct answer: (a) 106.0 kW.

Given: $P_1 = 120$ kW at 415 V; $V_2 = 390$ V; R constant.

Formula: $P_2 = P_1 \times (V_2 \div V_1)^2$.

Substitution: $120 \times (390 \div 415)^2 = 120 \times 0.8831$.

Result: **≈ 106.0 kW.**

The furnace takes about 13% longer to heat, raising wall losses per tonne. Thyristor control and voltage correction keep throughput up.

Why the other options are wrong: (b) 99.6 kW – uses a cube law, which applies to fans and pumps, not resistors. (c) 112.8 kW – scales power linearly with voltage, but $P = V^2 \div R$. (d) 135.9 kW – inverts the ratio, as if lower voltage increased the power.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 4 – Furnaces.

29. A reheating furnace fires 2,000 kg/h of oil (GCV 10,000 kcal/kg (≈ 41,868 kJ/kg)) to heat 50 t/h of steel from 40 °C to 1,200 °C (cp 0.16 kcal/kg·°C (≈ 0.670 kJ/kg·K)). Flue gas: 36,000 kg/h at 650 °C (cp 0.25 kcal/kg·°C (≈ 1.05 kJ/kg·K), ambient 40 °C). Wall and opening losses: 3.2 GJ/h. Skid cooling water: 40 m³/h with a 10 K rise. What share of the fuel input is unaccounted?

[SP2CEM029 | Chapter 4: Furnaces | Reheating furnace heat balance - unaccounted loss by difference]

- a) 18.7%
- b) 20.3%

c) 22.3%

d) 24.2%

Correct answer: (b) 20.3%.

Given: fuel = $2,000 \times 10,000$ kcal/h (≈ 11.6 kW); stock $50,000 \times 0.16 \times 1,160$; flue $36,000 \times 0.25 \times 610$; walls 3.2 GJ/h; water $40,000 \times 1 \times 10$ kcal/h (≈ 0.012 kW).

Formula: unaccounted = fuel – (stock + flue + walls + water); share = $\div$ fuel.

Substitution: $83.74 - (38.85 + 22.99 + 3.20 + 1.67)$ GJ/h.

Result: $\approx$ **20.3% unaccounted** (scale, infiltration, radiation from the discharge door).

A large unaccounted figure points to air infiltration or measurement error, so pressure control and flue gas analysis should be checked.

Why the other options are wrong: (a) 18.7% – uses the final steel temperature instead of the temperature rise. (c) 22.3% – leaves out the skid cooling water loss. (d) 24.2% – leaves out the wall and opening losses.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 4 – Furnaces.

30. A walking-beam furnace fires 110 GJ/h at full load. During mill delays (about 600 h a year) operators hold it at 35% of full firing. A delay-mode control would hold at 20%. Gas costs ₹1,000 per GJ. What is the annual saving?

[5P2CEM030 | Chapter 4: Furnaces | Fuel saved by cutting firing during mill delays]

a) ₹132.0 lakh

b) ₹116.5 lakh

c) ₹231.0 lakh

d) ₹99.0 lakh

Correct answer: (d) ₹99.0 lakh.

Given: 110 GJ/h full firing; holding 35% $\rightarrow$ 20%; 600 h; ₹1,000/GJ.

Formula: saving = full firing $\times$ (old – new fraction) $\times$ hours $\times$ price.

Substitution: $110 \times 0.15 \times 600 \times 1,000$.

Result: $\approx$ **₹99.0 lakh a year.**

Delay strategies (lowering zone set points, closing doors, cutting excess air) need to keep the stock hot enough to roll on restart.

Why the other options are wrong: (a) ₹132.0 lakh – gives the cost of holding at the new 20% level. (b) ₹116.5 lakh – divides by a burner efficiency, although 110 GJ/h is already the fuel input. (c) ₹231.0 lakh – gives the whole cost of holding at 35%, not the saving.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 4 – Furnaces.

31. A heat-treatment line needs 0.25 MWh (0.9 GJ) of net heat per tonne. Option 1: electric furnace, efficiency 75%, power ₹8/kWh. Option 2: gas furnace, efficiency 40%, gas 37.68 MJ/Sm³ at ₹45/Sm³, plus 12 kWh/t of fan power. What is the energy cost per tonne of the gas option?

[5P2CEM031 | Chapter 4: Furnaces | Cost per tonne of electric versus gas-fired heat treatment]

a) ₹1,171 per t

b) ₹2,783 per t

c) ₹2,687 per t

d) ₹1,529 per t

Correct answer: (b) ₹2,783 per t.

Given: 0.9 GJ/t net; η (gas) = 0.40; 37.68 MJ/Sm³; ₹45/Sm³; fans 12 kWh/t at ₹8.

Formula: cost = net heat $\div$ ($\eta \times CV$) $\times$ gas price + fan kWh $\times$ tariff.

Substitution: $0.9 \div (0.40 \times 0.03768) = 59.7$ Sm³ $\times 45 = ₹2,687$; + $12 \times 8 = ₹96$.

Result: $\approx$ **₹2,783 per t** against ₹2,667 per t for the electric furnace.

The comparison is close, so tariffs, emission costs and product quality decide. Higher gas efficiency (recuperation) tips it towards gas.

Why the other options are wrong: (a) ₹1,171 per t – ignores the gas furnace efficiency. (c) ₹2,687 per t – leaves out the 12 kWh/t of fan power. (d) ₹1,529 per t – applies the electric furnace's 75% efficiency to the gas furnace.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 4 – Furnaces.

32. A 6 mm OD steam tracer tube is to be lagged with a material of $k = 0.05 \text{ W/m}\cdot\text{K}$. The outside convective coefficient is $8 \text{ W/m}^2\cdot\text{K}$. What is the critical outer radius of insulation, below which adding insulation increases heat loss?

[SP2CEM032 | Chapter 5: Insulation and Refractories | Critical radius of insulation on a small-bore tube]

- a) 12.50 mm
- b) 3.25 mm
- c) 3.12 mm
- d) 6.25 mm

Correct answer: (d) 6.25 mm.

Given: $k = 0.05 \text{ W/m}\cdot\text{K}$; $h = 8 \text{ W/m}^2\cdot\text{K}$; tube radius 3 mm.

Formula: $r(c) = k \div h$ for a cylinder.

Substitution: $0.05 \div 8 = 0.00625 \text{ m}$.

Result: **$r(c) = 6.25 \text{ mm}$** , so a thin layer on the 3 mm tube raises the loss until the outer radius passes 6.25 mm.

This is why small tubes and cables can lose more heat when thinly lagged. Normal steam pipes are well above the critical radius.

Why the other options are wrong: (a) 12.50 mm – uses $2k/h$, the critical radius for a sphere, not a cylinder. (b) 3.25 mm – subtracts the tube radius, giving a thickness instead of a radius. (c) 3.12 mm – uses $k/2h$, halving the cylinder result.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 5 – Insulation and Refractories.

33. A refractory sample weighs 2,500 g dry, 2,700 g after boiling in water (saturated), and 1,500 g when suspended in water while saturated. What is its apparent porosity?

[SP2CEM033 | Chapter 5: Insulation and Refractories | Apparent porosity of a refractory brick by water absorption]

- a) 20.0%
- b) 8.0%
- c) 16.7%
- d) 7.4%

Correct answer: (c) 16.7%.

Given: $D = 2,500 \text{ g}$; $W \text{ (saturated)} = 2,700 \text{ g}$; $S \text{ (suspended)} = 1,500 \text{ g}$.

Formula: $\text{apparent porosity} = (W - D) \div (W - S) \times 100$; $\text{bulk density} = D \div (W - S)$.

Substitution: $(2,700 - 2,500) \div (2,700 - 1,500) = 200 \div 1,200$.

Result: **apparent porosity = 16.7%**; $\text{bulk density} = 2.08 \text{ g/cm}^3$.

Lower porosity improves resistance to slag and gas penetration but raises conductivity and lowers spalling resistance.

Why the other options are wrong: (a) 20.0% – divides by (dry – suspended), which ignores the water in the open pores. (b) 8.0% – divides the absorbed water by the dry weight, which gives water absorption, not porosity. (d) 7.4% – divides by the saturated weight instead of the exterior volume.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 5 – Insulation and Refractories.

34. An insulated duct has an aluminium cladding (emissivity 0.1). Its surface is at 60°C in still air at 30°C , with a convective coefficient of $4.0 \text{ W/m}^2\cdot\text{K}$. Taking $\sigma = 5.67 \times 10^{-8} \text{ W/m}^2\cdot\text{K}^4$, what is the total heat loss per m^2 of surface?

[SP2CEM034 | Chapter 5: Insulation and Refractories | Effect of cladding emissivity on surface heat loss]

- a) 142.0 W/m^2
- b) 189.8 W/m^2
- c) 317.6 W/m^2
- d) 120.0 W/m^2

Correct answer: (a) 142.0 W/m².

Given: $T(s) = 333.15 \text{ K}$; $T(a) = 303.15 \text{ K}$; $\varepsilon = 0.1$; $h(c) = 4.0 \text{ W/m}^2\cdot\text{K}$.

Formula: $q = h(c)(T(s) - T(a)) + \varepsilon\sigma(T(s)^4 - T(a)^4)$.

Substitution: $4.0 \times 30 + 0.1 \times 5.67 \times 10^{-8} \times (1.2319\text{e}+10 - 8.4456\text{e}+09) = 120 + 22.0$.

Result: **$q \approx 142.0 \text{ W/m}^2$.**

Bright cladding radiates little, so at the same surface temperature it loses less heat; but it also runs hotter, which matters for personnel protection limits.

Why the other options are wrong: (b) 189.8 W/m^2 – leaves out the radiation received back from the surroundings ($T(a)^4$).

(c) 317.6 W/m^2 – uses emissivity 0.9, which applies to painted or dull surfaces. (d) 120.0 W/m^2 – counts convection only and ignores radiation.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 5 – Insulation and Refractories.

35. A new castable lining contains 560 kg of free water (7% of its 8 t mass). The dry-out burner heats the water from 30 °C, evaporates it at 100 °C (latent heat 2,257 kJ/kg) and has an effective efficiency of 50%. LPG has an NCV of 46 MJ/kg. How much LPG does dry-out need (water only)?

[5P2CEM035 | Chapter 5: Insulation and Refractories | Fuel needed to dry out a newly cast refractory lining]

a) 124.2 kg

b) 62.1 kg

c) 55.0 kg

d) 31.0 kg

Correct answer: (b) 62.1 kg.

Given: water 560 kg; sensible = $4.187 \times 70 \text{ kJ/kg}$; latent = 2,257 kJ/kg; $\eta = 0.5$; NCV = 46 MJ/kg.

Formula: $\text{LPG} = \text{water} \times (c_p \Delta T + L) \div (\eta \times \text{NCV})$.

Substitution: $560 \times (293.1 + 2,257) = 1,428.1 \text{ MJ}$; $\div (0.5 \times 46)$.

Result: **$\approx 62.1 \text{ kg of LPG}$.**

Dry-out must follow the supplier's heating schedule. Heating too fast turns water to steam inside the lining, which causes spalling.

Why the other options are wrong: (a) 124.2 kg – divides by the efficiency twice. (c) 55.0 kg – counts only the latent heat and not the sensible heating to 100 °C. (d) 31.0 kg – ignores the 50% burner efficiency.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 5 – Insulation and Refractories.

36. An AFBC bed is divided into 3 equal compartments. Each fluidised compartment can run between 60% and 100% of its own rating; any compartment can be slumped (de-fluidised). What is the lowest stable boiler load as a share of full load?

[5P2CEM036 | Chapter 6: FBC Boilers | Turndown of an AFBC boiler by bed compartment slumping]

a) 60% of full load

b) 33% of full load

c) 40% of full load

d) 20% of full load

Correct answer: (d) 20% of full load.

Given: 3 equal compartments; each 60–100% of its rating.

Formula: minimum load = (active compartments $\div$ total) $\times$ minimum fraction.

Substitution: $(1 \div 3) \times 60\%$.

Result: **20% of full load.**

Compartment slumping gives FBC boilers a wide turndown without losing bed temperature, because a slumped bed holds its heat and can be re-fluidised quickly.

Why the other options are wrong: (a) 60% of full load – ignores slumping and assumes all compartments must stay fluidised. (b) 33% of full load – assumes the one active compartment must run at 100%. (c) 40% of full load – keeps two compartments running at 60% each.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 6 – FBC Boilers.

37. An AFBC boiler has a 12 m^2 bed with 0.40 m static height of sand (bulk density $1,500 \text{ kg/m}^3$, $c_p 0.84 \text{ kJ/kg}\cdot\text{K}$). The start-up burner must heat the bed from 30°C to 600°C before coal feeding; its effective efficiency is 40%. LDO has an NCV of 42.7 MJ/kg . How much LDO is needed?

[5P2CEM037 | Chapter 6: FBC Boilers | Start-up oil needed to heat an FBC bed to coal ignition]

- a) 81 kg
- b) 290 kg
- c) 350 kg
- d) 202 kg

Correct answer: (d) 202 kg.

Given: bed mass = $12 \times 0.40 \times 1,500 = 7,200 \text{ kg}$; $c_p = 0.84$; $\Delta T = 570 \text{ K}$; $\eta = 0.4$; NCV = 42.7 MJ/kg .

Formula: $\text{LDO} = m c_p \Delta T \div (\eta \times \text{NCV})$.

Substitution: $7,200 \times 0.84 \times 570 = 3,447 \text{ MJ}$; $\div (0.4 \times 42.7)$.

Result: $\approx 202 \text{ kg of LDO}$.

Keeping the bed hot during short outages (bed banking) avoids repeated start-up oil.

Why the other options are wrong: (a) 81 kg – ignores the 40% start-up burner efficiency. (b) 290 kg – heats the bed to the 850°C operating temperature instead of to coal ignition. (c) 350 kg – uses the particle density of sand ($2,600 \text{ kg/m}^3$) instead of the bulk density.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 6 – FBC Boilers.

38. An FBC boiler fires 6 t/h of coal (GCV $4,000 \text{ kcal/kg}$ ($\approx 16,747 \text{ kJ/kg}$)) at 82% efficiency. Its bed is sized for a heat release rate of 1.6 MW per m^2 of bed plan area, based on total fuel heat input. What bed area is needed?

[5P2CEM038 | Chapter 6: FBC Boilers | Bed plan area of an FBC boiler from heat release rate]

- a) 14.3 m^2
- b) 17.4 m^2
- c) 10.5 m^2
- d) 29.1 m^2

Correct answer: (b) 17.4 m^2 .

Given: coal = $6,000 \text{ kg/h} \times 4,000 \text{ kcal/kg}$ ($\approx 16,747 \text{ kJ/kg}$); 1.6 MW/m^2 .

Formula: $\text{area} = \text{fuel heat input (MW)} \div \text{heat release rate}$.

Substitution: $6,000 \times 4,000 \times 4.1868 \div 3.6 \times 10^6 = 27.91 \text{ MW}$; $\div 1.6$.

Result: $\approx 17.4 \text{ m}^2$.

Too small a bed raises bed temperature and velocity, risking clinker and erosion; too large a bed makes fluidisation uneven at low load.

Why the other options are wrong: (a) 14.3 m^2 – bases the area on the heat absorbed (steam output) instead of the fuel heat input. (c) 10.5 m^2 – counts only the 60% of heat released in the bed, which the design basis excludes. (d) 29.1 m^2 – divides by a 60% bed release fraction, inflating the area.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 6 – FBC Boilers.

39. A gas turbine is rated 30 MW at ISO conditions (sea level, 15°C). It will be installed at a site $1,000 \text{ m}$ above sea level where the ambient pressure is 0.887 atm and the design temperature is also 15°C . Taking output as proportional to the mass of air drawn in, what output can be expected?

[5P2CEM039 | Chapter 7: Cogeneration | Gas turbine output derating at a high-altitude site]

- a) 28.3 MW

- b) 33.8 MW
- c) 26.6 MW
- d) 23.6 MW

Correct answer: (c) 26.6 MW.

Given: rated 30 MW at 1 atm, 15 °C; site 0.887 atm, 15 °C.

Formula: output $\propto$ air density $\propto p \div T$; at equal temperature, output $\propto p$.

Substitution: $30 \times 0.887 \div 1.0$.

Result: $\approx$ **26.6 MW**.

Fuel flow falls in step, so efficiency changes little, but the exhaust flow available for an HRSG also falls about 11%. Hot ambient adds a further temperature derating.

Why the other options are wrong: (a) 28.3 MW – scales with the square root of pressure, as for velocity, not mass flow. (b) 33.8 MW – divides by the pressure ratio, as if thinner air increased output. (d) 23.6 MW – squares the pressure ratio, overstating the loss.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 7 – Cogeneration.

40. A 3 MW back-pressure turbine uses 42 t/h of steam at full load and 4.2 t/h at no load (spinning). Assuming a straight Willans line, what steam flow does it need at 1.8 MW?

[SP2CEM040 | Chapter 7: Cogeneration | Back-pressure turbine steam flow at part load from the Willans line]

- a) 26,880 kg/h
- b) 25,200 kg/h
- c) 22,680 kg/h
- d) 31,080 kg/h

Correct answer: (a) 26,880 kg/h.

Given: full load 3,000 kW at 42,000 kg/h; no load 4,200 kg/h.

Formula: steam = a + b $\times$ P; b = $(42,000 - 4,200) \div 3,000 = 12.6$ kg/kWh.

Substitution: $4,200 + 12.6 \times 1,800$.

Result: $\approx$ **26,880 kg/h** (specific steam rises from 14.0 to 14.93 kg/kWh).

Part loading wastes steam per kWh, so turbines should be sized for the steady process steam demand.

Why the other options are wrong: (b) 25,200 kg/h – scales steam in proportion to load, ignoring the no-load steam. (c) 22,680 kg/h – uses the slope but leaves out the no-load intercept. (d) 31,080 kg/h – adds the no-load steam twice.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 7 – Cogeneration.

41. A 200 kW(e) microturbine without a recuperator uses 1,000 kW of fuel. A recuperator (effectiveness 0.85) is added: compressed air (1.3 kg/s, cp 1.1 kJ/kg·K) leaves the compressor at 200 °C and the turbine exhaust is at 600 °C. Assuming the recovered heat directly replaces fuel and output is unchanged, what is the new electrical efficiency?

[SP2CEM041 | Chapter 7: Cogeneration | Microturbine efficiency gain from an exhaust-to-air recuperator]

- a) 46.7%
- b) 38.9%
- c) 68.6%
- d) 35.8%

Correct answer: (b) 38.9%.

Given: P = 200 kW; fuel = 1,000 kW; $\epsilon = 0.85$; m cp = $1.3 \times 1.1 = 1.43$ kW/K; $\Delta T(\text{max}) = 600 - 200 = 400$ K.

Formula: Q(rec) = ϵ m cp $\Delta T(\text{max})$; $\eta = P \div (\text{fuel} - Q(\text{rec}))$.

Substitution: Q(rec) = $0.85 \times 1.43 \times 400 = 486.2$ kW; $\eta = 200 \div (1,000 - 486.2)$.

Result: $\eta \approx$ **38.9%** (from 20%).

The recuperator lowers the exhaust temperature available for CHP heat recovery, so for high heat demand an unrecuperated unit with a larger heat recovery unit may give a higher total efficiency.

Why the other options are wrong: (a) 46.7% – ignores the effectiveness and recovers the full 400 K temperature difference. (c) 68.6% – adds the recovered heat to the electrical output instead of subtracting it from the fuel. (d) 35.8% – uses $c_p = 1.0 \text{ kJ/kg-K}$ instead of the stated 1.1.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 7 – Cogeneration.

42. A 100 kW(e) solid-oxide fuel cell runs on natural gas at 55% electrical efficiency (NCV basis). Heat recovered for hot water is 25% of the fuel input. How much heat is recovered?

[SP2CEM042 | Chapter 7: Cogeneration | Heat recovered from a solid-oxide fuel cell CHP unit]

- a) 31.2 kW
- b) 81.8 kW
- c) 45.5 kW
- d) 25.0 kW

Correct answer: (c) 45.5 kW.

Given: $P(e) = 100 \text{ kW}$; $\eta(e) = 0.55$; heat = 25% of fuel.

Formula: fuel = $P(e) \div \eta(e)$; heat = $0.25 \times \text{fuel}$.

Substitution: $100 \div 0.55 = 181.8 \text{ kW}$; $\times 0.25$.

Result: **$\approx 45.5 \text{ kW of heat}$** ; total efficiency 80%.

Fuel cells have high electrical efficiency even at small sizes, which gives a low heat-to-power ratio suited to sites with modest heat demand.

Why the other options are wrong: (a) 31.2 kW – takes the fuel input as $100 \div 0.80$ using the total efficiency. (b) 81.8 kW – assumes all non-electric energy is recovered. (d) 25.0 kW – takes 25% of the electrical output instead of the fuel input.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 7 – Cogeneration.

43. A cogeneration plant could run at 10 MW, but the site needs only 7 MW. Surplus power can be exported at ₹4.50/kWh. The marginal cost of generation is ₹5.20/kWh for fuel plus ₹0.30/kWh variable O&M. The plant runs 8,000 h a year. What is the effect of exporting the 3 MW surplus?

[SP2CEM043 | Chapter 7: Cogeneration | Economics of exporting surplus cogeneration power]

- a) a gain of ₹2.40 crore
- b) a loss of ₹1.68 crore
- c) a loss of ₹2.40 crore
- d) a loss of ₹2.63 crore

Correct answer: (c) a loss of ₹2.40 crore.

Given: export 3 MW $\times 8,000 \text{ h} = 24,000 \text{ MWh}$; tariff ₹4.50; marginal cost ₹5.20 + ₹0.30 = ₹5.50/kWh.

Formula: net = export energy $\times$ (tariff – marginal cost).

Substitution: $24,000 \text{ MWh} \times (4.50 - 5.50)$.

Result: **a loss of ₹2.40 crore a year**, so the plant should follow site load.

Export pays only when the tariff exceeds the marginal cost, so the heat-to-power match and tariff must be checked first.

Why the other options are wrong: (a) Gets the sign wrong, treating the export tariff as above marginal cost. (b) Leaves out the variable O&M cost. (d) This option uses 8,760 h although the plant runs 8,000 h.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 7 – Cogeneration.

44. A process releases 500 kW of waste heat at a steady 150 °C (condensing vapour). Ambient is 30 °C. What is the maximum power any heat engine (for example an ORC) could theoretically produce from it?

[SP2CEM044 | Chapter 8: Waste Heat Recovery | Maximum power from a waste heat stream (Carnot limit)]

- a) 358.2 kW
- b) 141.8 kW
- c) 177.2 kW
- d) 400.0 kW

Correct answer: (b) 141.8 kW.

Given: $Q = 500 \text{ kW}$ at $T(H) = 423.15 \text{ K}$; $T(C) = 303.15 \text{ K}$.

Formula: $W(\text{max}) = Q \times (1 - T(C) \div T(H))$.

Substitution: $500 \times (1 - 303.15 \div 423.15) = 500 \times 0.2836$.

Result: **$W(\text{max}) \approx 141.8 \text{ kW}$** ; real ORC units achieve perhaps half of this.

Low-temperature waste heat has low work potential, so direct heat use (preheating, hot water) usually beats power generation.

Why the other options are wrong: (a) 358.2 kW – gives the heat rejected to ambient instead of the work. (c) 177.2 kW – uses 0°C as the sink although ambient is 30°C . (d) 400.0 kW – uses Celsius temperatures in the Carnot ratio; absolute temperatures are needed.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 8 – Waste Heat Recovery.

45. A 300 TR ($\approx 1,055 \text{ kW}$) water-cooled chiller runs at a COP of 5.0 (1 TR = 3.517 kW). A desuperheater on the compressor discharge can recover 15% of the total heat rejected at the condenser. How much heat is available for hot water?

[SP2CEM045 | Chapter 8: Waste Heat Recovery | Heat recovered from a chiller desuperheater for hot water]

a) 189.9 kW

b) 158.3 kW

c) 126.6 kW

d) 211.0 kW

Correct answer: (a) 189.9 kW.

Given: cooling = $300 \times 3.517 = 1,055 \text{ kW}$; COP = 5.0; recovery = 15%.

Formula: heat rejected = cooling $\times (1 + 1/\text{COP})$; recovered = $0.15 \times$ rejected.

Substitution: $1,055 \times 1.2 = 1,266 \text{ kW}$; $\times 0.15$.

Result: **$\approx 189.9 \text{ kW}$** at a temperature high enough for $50\text{--}55^\circ\text{C}$ hot water.

Using rejected heat cuts boiler fuel and slightly lowers condenser load, but the hot-water demand must coincide with chiller running hours.

Why the other options are wrong: (b) 158.3 kW – takes 15% of the cooling load, forgetting the compressor work also rejected. (c) 126.6 kW – subtracts the compressor work from the cooling load instead of adding it. (d) 211.0 kW – takes the whole compressor input as recoverable heat.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 8 – Waste Heat Recovery.

46. A heat recovery unit on an oven exhaust supplies 180 kW of useful heat, replacing gas fired at 85% efficiency (gas ₹45/Sm³, 37.68 MJ/Sm³). It adds 600 Pa of pressure drop on 12 m³/s of air; fan efficiency is 65% and power costs ₹8/kWh. For 6,000 h a year, what is the net annual saving?

[SP2CEM046 | Chapter 8: Waste Heat Recovery | Net saving of a heat recovery unit after the extra fan power]

a) ₹54.6 lakh

b) ₹41.1 lakh

c) ₹49.3 lakh

d) ₹51.2 lakh

Correct answer: (c) ₹49.3 lakh.

Given: heat = 180 kW; $\eta = 0.85$; gas cost = ₹45 $\div 10.47 \text{ kWh} = ₹4.30/\text{kWh}$; fan $\Delta p = 600 \text{ Pa}$, $Q = 12 \text{ m}^3/\text{s}$, $\eta(\text{fan}) = 0.65$.

Formula: saving = (heat $\div \eta$) $\times$ gas cost – ($Q \times \Delta p \div \eta(\text{fan})$) $\times$ tariff.

Substitution: $211.8 \text{ kW} \times ₹4.30 = ₹910/\text{h}$; fan = $7.2 \div 0.65 = 11.08 \text{ kW} \times ₹8 = ₹89/\text{h}$.

Result: **net $\approx ₹49.3 \text{ lakh a year}$.**

Pressure drop is easy to forget. Low-velocity designs and clean surfaces keep the fan penalty small.

Why the other options are wrong: (a) ₹54.6 lakh – ignores the cost of the extra fan power. (b) ₹41.1 lakh – ignores the 85% efficiency of the gas heater being replaced. (d) ₹51.2 lakh – ignores the fan efficiency, taking only the air power.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 8 – Waste Heat Recovery.

47. A sponge-iron kiln's exhaust (60,000 kg/h, c_p 1.1 kJ/kg·K) enters a waste heat boiler at 650 °C. The boiler raises saturated steam at 10 bar(a) (179.9 °C, h_{fg} = 2,014.6 kJ/kg) from feed water already heated to saturation in a separate economiser. With a 30 K pinch point at the evaporator gas outlet, how much steam can the evaporator raise?

[5P2CEM047 | Chapter 8: Waste Heat Recovery | Steam from a waste heat boiler fixed by the pinch-point temperature difference]

- a) 14,418 kg/h
- b) 13,107 kg/h
- c) 15,401 kg/h
- d) 12,318 kg/h

Correct answer: (a) 14,418 kg/h.

Given: $m(g)$ = 60,000 kg/h; c_p = 1.1; $T(in)$ = 650 °C; $T(sat)$ = 179.9 °C; pinch 30 K; h_{fg} = 2,014.6 kJ/kg.

Formula: gas leaving evaporator = $T(sat) + \text{pinch}$; steam = $m(g) c_p (T(in) - T(out)) \div h_{fg}$.

Substitution: $T(out)$ = 209.9 °C; $60,000 \times 1.1 \times 440.1 \div 2,014.6$.

Result: **≈ 14,418 kg/h of steam.**

A smaller pinch raises steam output but needs much more evaporator area. Dust loading in kiln gas also limits how close the approach can be.

Why the other options are wrong: (b) 13,107 kg/h – uses c_p = 1.0 kJ/kg·K instead of the stated 1.1. (c) 15,401 kg/h – ignores the pinch point and cools the gas to the saturation temperature. (d) 12,318 kg/h – uses the heat from 100 °C feed to steam, though the economiser supplies saturated water.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 8 – Waste Heat Recovery.

48. A plate heat exchanger has a 50 kPa pressure drop at design flow. Flow is raised by 30%. In this turbulent range pressure drop varies with flow to the power 1.8. What is the new pressure drop?

[5P2CEM048 | Chapter 9: Heat Exchangers | Plate heat exchanger pressure drop at increased flow]

- a) 84.5 kPa
- b) 104.2 kPa
- c) 80.2 kPa
- d) 65.0 kPa

Correct answer: (c) 80.2 kPa.

Given: Δp_1 = 50 kPa; flow ratio = 1.3; exponent 1.8.

Formula: $\Delta p_2 = \Delta p_1 \times (Q_2 \div Q_1)^{1.8}$.

Substitution: $50 \times 1.3^{1.8} = 50 \times 1.604$.

Result: **≈ 80.2 kPa**; pumping power rises by about 2.08 times.

Higher velocity raises the film coefficient and reduces fouling, but the pressure drop and pump energy rise faster, so there is an optimum.

Why the other options are wrong: (a) 84.5 kPa – uses a square law, overstating the rise in plate channels. (b) 104.2 kPa – uses the exponent for pumping power (1.8 + 1) instead of pressure drop. (d) 65.0 kPa – scales linearly with flow.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 9 – Heat Exchangers.

49. A counterflow exchanger heats feed (20 °C) with effluent (90 °C); both streams have equal capacity rates, so the temperature difference is the same along the exchanger. It runs with a 10 K approach. If the approach is cut to 5 K, by what factor must the area increase?

[5P2CEM049 | Chapter 9: Heat Exchangers | Area needed for a closer approach in a balanced counterflow recovery exchanger]

- a) 2.17 times
- b) 2.00 times
- c) 4.33 times

d) 1.08 times

Correct answer: (a) 2.17 times.

Given: balanced flows, so $\Delta T = \text{approach throughout}$; feed out = 90 – approach.

Formula: $A \propto Q \div \Delta T$, with $Q \propto (T(\text{feed,out}) - 20)$.

Substitution: 10 K: $Q \propto 60$, $A \propto 60 \div 10 = 6.0$; 5 K: $Q \propto 65$, $A \propto 65 \div 5 = 13.0$; $13.0 \div 6.0$.

Result: **area increases about 2.17 times** for 8.3% more heat recovered.

The last few kelvin of recovery are expensive. This trade-off sets $\Delta T(\text{min})$ in pinch analysis.

Why the other options are wrong: (b) 2.00 times – halves the temperature difference but forgets that the duty also increases. (c) 4.33 times – squares the halving of the approach as well as adding the extra duty. (d) 1.08 times – accounts for the extra duty but forgets the smaller temperature difference.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 9 – Heat Exchangers.

50. A test on an oil cooler gives: oil 8 kg/s, cp 2.1 kJ/kg·K, cooled from 140 °C to 90 °C; water 5 kg/s, cp 4.187 kJ/kg·K, heated from 30 °C to 66 °C. What share of the hot-side duty is lost to the surroundings or due to meter error?

[SP2CEM050 | Chapter 9: Heat Exchangers | Heat loss from an exchanger shown by an unequal duty balance]

a) 5.4%

b) 11.5%

c) 28.0%

d) 10.3%

Correct answer: (d) 10.3%.

Given: oil $8 \times 2.1 \times 50$; water $5 \times 4.187 \times 36$.

Formula: imbalance = $(Q(\text{hot}) - Q(\text{cold})) \div Q(\text{hot})$.

Substitution: $Q(\text{hot}) = 840 \text{ kW}$; $Q(\text{cold}) = 753.7 \text{ kW}$; $(840 - 753.7) \div 840$.

Result: $\approx 10.3\%$.

An imbalance above about 5% usually points to flow meter error or poor insulation. It should be resolved before the test is used to judge fouling.

Why the other options are wrong: (a) 5.4% – divides by the sum of both duties. (b) 11.5% – divides by the cold-side duty instead of the hot-side duty. (c) 28.0% – compares temperature changes only, ignoring flows and specific heats.

Ref: BEE Guidebook Book 2 (Paper 2), Ch. 9 – Heat Exchangers.

..... End of Section I

Section – II: SHORT DESCRIPTIVE QUESTIONS

Marks: $8 \times 5 = 40$

(i) Answer all Eight questions

(ii) Each question carries Five marks

S-1 A plant's gas meter recorded 2,50,000 m³ in a month at an average line pressure of 4.0 bar(g) and 35 °C. The contract bills on standard conditions (1.01325 bar(a), 15 °C) and on GCV, at ₹980 per MMBtu (1 MMBtu = 2,52,000 kcal ($\approx 1,055 \text{ MJ}$)). The plant's own lab measured GCV = 9,800 kcal/Sm³ ($\approx 41.0 \text{ MJ/Sm}^3$). The supplier's invoice shows 46,495 MMBtu.

[SP2CEM051 | Chapter 1: Fuels and Combustion | Natural gas invoice check - volume correction to standard conditions and GCV basis]

(a) Convert the metered volume to standard cubic metres (ignore compressibility). [2 Marks]

(b) Calculate the energy in MMBtu and the correct bill using the lab GCV. [2 Marks]

(c) Find the GCV the supplier must have used and the amount in dispute. [1 Mark]

S-1 Ans

(a) [2 marks]

Given: $V = 2,50,000 \text{ m}^3$ at 5.01325 bar(a) and 308.15 K; standard 1.01325 bar(a), 288.15 K.

Formula: $V(\text{std}) = V \times (p \div p(\text{std})) \times (T(\text{std}) \div T)$.

Substitution: $2,50,000 \times (5.01325 \div 1.01325) \times (288.15 \div 308.15) = 2,50,000 \times 4.9477 \times 0.9351$.

Result: **$V(\text{std}) = 11,56,643 \text{ Sm}^3$** . (2 marks)

(b) [2 marks]

Formula: $\text{MMBtu} = \text{Sm}^3 \times \text{GCV} \div 2,52,000$; bill = $\text{MMBtu} \times \text{price}$.

Substitution: $11,56,643 \times 9,800 \div 2,52,000 \times ₹980$.

Result: **energy = 44,981 MMBtu; correct bill = ₹4,40,80,937** ($\approx ₹4.41$ crore). (1 + 1 marks)

(c) [1 mark]

Substitution: $\text{GCV used} = 46,495 \times 2,52,000 \div 11,56,643$; dispute = $(46,495 - 44,981) \times ₹980$.

Result: **GCV used $\approx 10,130 \text{ kcal/Sm}^3$ ($\approx 42.4 \text{ MJ/Sm}^3$); amount in dispute $\approx ₹14,84,163$** a month. The plant should ask for the gas chromatograph report on which the GCV is based, and check that the meter's pressure and temperature transmitters are calibrated. (1 mark)

Marking scheme (5 marks): a) Pressure and temperature correction 2. b) MMBtu 1, bill 1. c) GCV and dispute 1.

Ref: BEE Guidebook Paper 2 (Book 2: Energy Efficiency in Thermal Utilities), Ch. 1 – Fuels and Combustion.

S-2 A stoker boiler burns 6 t/h of coal (GCV 4,200 kcal/kg ($\approx 17,585 \text{ kJ/kg}$), ash 35%) at 80% efficiency. The plant will supply 20% of the heat input from biomass pellets (GCV 4,000 kcal/kg ($\approx 16,747 \text{ kJ/kg}$), ash 3%). Because of higher fuel moisture, efficiency falls to 79%. Steam output is unchanged. Coal emits 1.55 kg CO_2 /kg; biomass CO_2 is treated as neutral. Coal costs ₹6,500/t and pellets ₹7,500/t. The boiler runs 7,500 h a year.

[SP2CEM052 | Chapter 2: Boilers | Biomass pellet co-firing in a coal-fired boiler - fuel, ash, CO_2 and abatement cost]

(a) Calculate the new coal and pellet firing rates. [2 Marks]

(b) Calculate the change in ash generated and the annual CO_2 reduction. [2 Marks]

(c) Calculate the extra annual fuel cost and the cost of CO_2 abatement in ₹ per tonne. [1 Mark]

S-2 Ans

(a) [2 marks]

Given: present heat input = $6000 \times 4200 = 25.20 \text{ Gcal/h}$ at 80%.

Formula: new input = old input $\times \eta(\text{old}) \div \eta(\text{new})$; coal = $0.8 \times \text{input} \div \text{GCV}(\text{coal})$; pellets = $0.2 \times \text{input} \div \text{GCV}(\text{pellet})$.

Substitution: $25.20 \times 80 \div 79 = 25.519 \text{ Gcal/h}$; coal = $0.8 \times 25.519 \times 10^6 \div 4200$; pellets = $0.2 \times 25.519 \times 10^6 \div 4000$.

Result: **coal = 4,861 kg/h; pellets = 1,276 kg/h**. (1 + 1 marks)

(b) [2 marks]

Substitution: ash before = $6000 \times 0.35 = 2,100 \text{ kg/h}$; after = $4,861 \times 0.35 + 1,276 \times 0.03$; $\text{CO}_2 = (6000 - 4,861) \times 1.55 \div 1,000 \times 7,500$.

Result: **ash falls by 360 kg/h (17.2%); CO_2 reduction = 13,244 t a year**. (1 + 1 marks)

(c) [1 mark]

Substitution: hourly cost after = $4.8608 \times 6,500 + 1.2759 \times 7,500 = ₹41,165$; before = $₹39,000 \times 7,500 \text{ h}$.

Result: **extra cost = ₹1,62,34,177 a year; abatement cost $\approx ₹1,226$ per t CO_2** . Pellet storage must be covered and dry, and fouling from alkali-rich biomass ash should be watched. (1 mark)

Marking scheme (5 marks): a) Coal 1, pellets 1. b) Ash 1, CO_2 1. c) Extra cost and abatement cost 1.

Ref: BEE Guidebook Paper 2 (Book 2: Energy Efficiency in Thermal Utilities), Ch. 2 – Boilers.

S-3 A steam heat exchanger heats 10 kg/s of water from 40 °C to 80 °C at full load with steam at 3 bar(a) (133.5 °C) in the shell. A control valve modulates the steam to hold the 80 °C outlet while the water flow varies; the water inlet stays at 40 °C. Condensate drains through a trap and is lifted to an overhead return main at 0.5 bar(g) (1.5 bar(a), saturation 111.4 °C). Take $c_p(\text{water}) = 4.187 \text{ kJ/kg}\cdot\text{K}$ and constant UA.

[SP2CEM053 | Chapter 3: Steam System | Stall point of a modulating steam-heated exchanger lifting condensate]

- (a) Calculate the full-load duty, the LMTD and the UA value. [2 Marks]
- (b) At part load the valve lowers the shell pressure. Find the load (as % of full load) at which the shell temperature falls to 111.4 °C and condensate can no longer leave (stall). [2 Marks]
- (c) State what happens below the stall load and two remedies. [1 Mark]

S-3 Ans**(a) [2 marks]**

Given: $m = 10 \text{ kg/s}$; $40 \rightarrow 80 \text{ °C}$; $T(s) = 133.5 \text{ °C}$.

Formula: $Q = m \cdot c_p \cdot \Delta T$; $LMTD = (\Delta T_1 - \Delta T_2) \div \ln(\Delta T_1 \div \Delta T_2)$; $UA = Q \div LMTD$.

Substitution: $Q = 10 \times 4.187 \times 40$; $LMTD = (93.5 - 53.5) \div \ln(93.5 \div 53.5)$.

Result: **Q = 1,674.8 kW; LMTD = 71.65 K; UA = 23.38 kW/K.** (2 marks)

(b) [2 marks]

Formula: with fixed water temperatures, $LMTD(T(s)) = 40 \div \ln[(T(s) - 40) \div (T(s) - 80)]$; $\text{load} = UA \times LMTD$.

Substitution: $LMTD \text{ at } 111.4 \text{ °C} = 40 \div \ln(71.4 \div 31.4) = 48.69 \text{ K}$; $Q = 23.38 \times 48.69$.

Result: **stall load = 1,138 kW = 68.0% of full load.** (2 marks)

(c) [1 mark]

Result: below the stall load the shell pressure is lower than the back pressure, so condensate backs up and floods the shell. This gives water hammer, corrosion and unstable temperature control. Remedies (any two): a pump-trap or pressure-powered pump; free gravity drainage to a vented receiver and pump; a vacuum breaker with a trap discharging to atmosphere; controlling on the condensate side. ($\frac{1}{2} + \frac{1}{2}$ marks)

Marking scheme (5 marks): a) Duty, LMTD and UA 2. b) LMTD at back pressure 1, stall load 1. c) Effect and remedies 1.

Ref: BEE Guidebook Paper 2 (Book 2: Energy Efficiency in Thermal Utilities), Ch. 3 – Steam System.

S-4 A forging furnace uses 55 kg of furnace oil per tonne of forgings (GCV 10,200 kcal/kg ($\approx 42,705 \text{ kJ/kg}$), ₹48/kg). Conversion to piped natural gas (GCV 9,500 kcal/Sm³ ($\approx 39.8 \text{ MJ/Sm}^3$), ₹45/Sm³) with new burners and automatic air–fuel ratio control is expected to improve furnace efficiency by 12% (relative). Output is 12,000 t a year. Emission factors: oil 3.15 kg CO₂/kg; gas 1.96 kg CO₂/Sm³.

[SP2CEM054 | Chapter 4: Furnaces | Switching a forging furnace from furnace oil to piped natural gas - fuel, cost and CO₂ per tonne]

- (a) Calculate the heat input per tonne now and after conversion, and the gas needed per tonne. [2 Marks]
- (b) Calculate the fuel cost per tonne for both fuels and the annual saving. [2 Marks]
- (c) Calculate the annual CO₂ reduction and give one non-energy benefit. [1 Mark]

S-4 Ans**(a) [2 marks]**

Given: FO 55 kg/t at GCV 10,200 kcal/kg ($\approx 42,705 \text{ kJ/kg}$); PNG raises furnace efficiency by 12% (relative); PNG GCV 9,500 kcal/Sm³ ($\approx 39.8 \text{ MJ/Sm}^3$); ₹48/kg FO, ₹45/Sm³ PNG; 12,000 t/yr; 3.15 kg CO₂/kg FO, 1.96 kg CO₂/Sm³ PNG.

Formula: new heat input = old heat input $\div$ (1 + relative efficiency gain); gas = heat $\div$ GCV.

Substitution: $55 \times 10,200 = 5,61,000 \text{ kcal/t}$; $\div 1.12$; $\div 9,500$.

Result: **heat input = 5,61,000 kcal/t now and 5,00,893 kcal/t after (2.10 GJ/t); gas = 52.73 Sm³/t.** (1 + 1 marks)

(b) [2 marks]

Substitution: oil = $55 \times ₹48$; gas = $52.73 \times ₹45$; saving = $(₹2,640 - ₹2,373) \times 12,000$.

Result: **oil ₹2,640/t; gas ₹2,373/t; saving $\approx$ ₹32.1 lakh a year.** (1 + 1 marks)

(c) [1 mark]

Substitution: $(55 \times 3.15 - 52.73 \times 1.96) \times 12,000 \div 1,000$.

Result: **CO₂ reduction $\approx$ 839 t a year** ($173.2 \rightarrow 103.3 \text{ kg/t}$). Other benefits: no oil storage, heating or atomising steam; no sulphur, so less scale and SO₂; cleaner furnace and better temperature uniformity. (1 mark)

Marking scheme (5 marks): a) Heat input 1, gas per tonne 1. b) Costs 1, saving 1. c) CO₂ and benefit 1.

Ref: BEE Guidebook Paper 2 (Book 2: Energy Efficiency in Thermal Utilities), Ch. 4 – Furnaces.

S-5 A 20 m long rotary calciner has an inside radius of 1.00 m, lined with 230 mm of firebrick ($k = 1.1 \text{ W/m}\cdot\text{K}$) and 115 mm of insulating brick ($k = 0.25 \text{ W/m}\cdot\text{K}$); the thin steel shell can be ignored. The inside face is at 900°C and the shell loses heat to 35°C surroundings with a combined (convection + radiation) coefficient of $15 \text{ W/m}^2\cdot\text{K}$.

[SP2CEM055 | Chapter 5: Insulation and Refractories | Heat loss through the composite cylindrical lining of a rotary kiln shell]

(a) Calculate the heat loss per metre length, the firebrick–insulating brick interface temperature and the shell temperature. [3 Marks]

(b) The insulating brick is replaced by a microporous board of the same thickness ($k = 0.12 \text{ W/m}\cdot\text{K}$). Calculate the new loss, the new shell temperature, and the annual fuel saved (GJ) for the 20 m length if heat is supplied at 70% efficiency for 7,000 h a year. [2 Marks]

S-5 Ans

(a) [3 marks]

Given: $r_1 = 1.0$, $r_2 = 1.23$, $r_3 = 1.345 \text{ m}$; $k = 1.1$ and $0.25 \text{ W/m}\cdot\text{K}$; $h = 15 \text{ W/m}^2\cdot\text{K}$.

Formula: $R(\text{layer}) = \ln(r(\text{out}) \div r(\text{in})) \div (2\pi k)$; $R(\text{surface}) = 1 \div (h \times 2\pi r_3)$; $q = \Delta T \div \Sigma R$ (per metre).

Substitution: $R_1 = \ln(1.23/1.0) \div (2\pi \times 1.1) = 0.02995$; $R_2 = \ln(1.345/1.23) \div (2\pi \times 0.25) = 0.05690$; $R(o) = 1 \div (15 \times 2\pi \times 1.345) = 0.00789$; $\Sigma R = 0.09474 \text{ m}\cdot\text{K/W}$; $q = 865 \div 0.09474$.

Result: **$q = 9,130 \text{ W/m}$; interface temperature = 626.5°C ; shell temperature = 107.0°C .** (1 + 1 + 1 marks)

(b) [2 marks]

Substitution: $R_2 = \ln(1.345/1.23) \div (2\pi \times 0.12) = 0.11854$; $\Sigma R = 0.15638$; $q = 865 \div 0.15638$; saving = $(9,130 - 5,531) \times 20 \div 1,000 \text{ kW} \times 3,600 \times 7,000 \div 10^6 \div 0.7$.

Result: **new loss = $5,531 \text{ W/m}$; shell temperature = 78.6°C ; fuel saved $\approx 2,591 \text{ GJ a year}$** ($\approx \text{₹}25.9$ lakh at $\text{₹}1,000/\text{GJ}$). The firebrick interface temperature rises, so the board's service limit must be checked. (1 + 1 marks)

Marking scheme (5 marks): a) Resistances and q 1, interface temperature 1, shell temperature 1. b) New loss and shell temperature 1, fuel saved 1.

Ref: BEE Guidebook Paper 2 (Book 2: Energy Efficiency in Thermal Utilities), Ch. 5 – Insulation and Refractories.

S-6 An AFBC boiler burns 8 t/h of coal (GCV $3,800 \text{ kcal/kg}$ ($\approx 15,910 \text{ kJ/kg}$), ash 40%) at 78% efficiency. 75% of the ash leaves as fly ash containing 12% carbon; the rest is bed ash with 2% carbon (percentages by mass of the ash sample). Take the CV of carbon as $8,080 \text{ kcal/kg}$ ($\approx 33,829 \text{ kJ/kg}$). Coal costs $\text{₹}5,000/\text{t}$ and the boiler runs 7,000 h a year.

[SP2CEM056 | Chapter 6: FBC Boilers | Unburnt carbon loss in an AFBC boiler and the benefit of fly-ash recirculation]

(a) Calculate the unburnt carbon in fly ash and bed ash (kg/h) and the unburnt loss as % of heat input. [2 Marks]

(b) Recirculating part of the cyclone catch back to the bed cuts carbon in fly ash to 6%. Calculate the new loss and new efficiency. [2 Marks]

(c) Calculate the annual coal saving in tonnes and rupees, and state one precaution. [1 Mark]

S-6 Ans

(a) [2 marks]

Given: ash = $8000 \times 0.4 = 3,200 \text{ kg/h}$; fly ash (mineral) = $2,400 \text{ kg/h}$; bed ash (mineral) = 800 kg/h .

Formula: ash sample = mineral ash $\div (1 - \text{C fraction})$; carbon = sample $\times \text{C fraction}$; loss = carbon $\times 8,080 \div (\text{coal} \times \text{GCV})$.

Substitution: fly: $2,400 \div 0.88 \times 0.12$; bed: $800 \div 0.98 \times 0.02$; loss = $343.6 \times 8,080 \div (8000 \times 3800)$.

Result: **carbon in fly ash = 327.3 kg/h ; in bed ash = 16.3 kg/h ; unburnt loss = 9.13% .** (1 + 1 marks)

(b) [2 marks]

Substitution: fly carbon = $2,400 \div 0.94 \times 0.06 = 153.2 \text{ kg/h}$; loss = $169.5 \times 8,080 \div (8000 \times 3800)$.

Result: **new loss = 4.51% ; efficiency $\approx 82.63\%$** (other losses unchanged). (1 + 1 marks)

(c) [1 mark]

Substitution: coal saving = $8000 \times (1 - 78 \div 82.63) = 448 \text{ kg/h}$; $\times 7,000 \text{ h}$; $\times ₹5,000$.

Result: **coal saving $\approx 3,136 \text{ t a year}$, worth $\approx ₹1.57 \text{ crore}$** . Precaution: recirculated ash raises bed solids loading and erosion of in-bed tubes, so recirculation rate and fan power must be watched. (1 mark)

Marking scheme (5 marks): a) Carbon in each ash 1, loss 1. b) New loss 1, efficiency 1. c) Saving and precaution 1.

Ref: BEE Guidebook Paper 2 (Book 2: Energy Efficiency in Thermal Utilities), Ch. 6 – FBC Boilers.

S-7 An effluent evaporator removes 5,000 kg/h of water. A single-effect steam evaporator would use 1.1 kg of steam per kg of water evaporated, with steam costing ₹2,200/t. An MVR unit recompresses the vapour and uses 22 kWh per tonne of water evaporated plus 100 kg/h of make-up steam; power costs ₹8.00/kWh. Latent heat is 2,300 kJ/kg. The plant runs 6,000 h a year.

[SP2CEM057 | Chapter 7: Cogeneration | Mechanical vapour recompression evaporator compared with steam-heated evaporation]

(a) Calculate the hourly steam cost of the single-effect evaporator. [1 Mark]

(b) Calculate the MVR compressor power, hourly cost and its effective COP (latent heat moved $\div$ compressor power). [2 Marks]

(c) A triple-effect steam evaporator would use $1 \div (0.85 \times 3) \text{ kg steam per kg water}$. Calculate its hourly cost and the annual saving of MVR over it. [2 Marks]

S-7 Ans**(a) [1 mark]**

Given: water 5,000 kg/h; 1.1 kg steam/kg; ₹2,200/t.

Substitution: $5,000 \times 1.1 = 5,500 \text{ kg/h}$; $\times ₹2.2/\text{kg}$.

Result: **steam cost = ₹12,100 per hour**. (1 mark)

(b) [2 marks]

Formula: power = tonnes per hour $\times$ kWh per tonne; $\text{COP} = m \times L \div 3,600 \div \text{power}$.

Substitution: $5 \times 22 = 110 \text{ kW}$; cost = $110 \times 8.00 + 0.1 \times 2,200$; $\text{COP} = 5,000 \times 2,300 \div 3,600 \div 110$.

Result: **compressor power = 110 kW; MVR cost = ₹1,100 per hour; COP ≈ 29** . (1 + 1 marks)

(c) [2 marks]

Substitution: steam = $5,000 \div 2.55 = 1,961 \text{ kg/h}$; cost = $1.961 \times 2,200$; saving = $(4,314 - 1,100) \times 6,000$.

Result: **triple-effect cost = ₹4,314 per hour; MVR saves $\approx ₹1.93 \text{ crore a year}$** over it. MVR suits low boiling-point rise; high-solids liquors need a higher compression ratio and more power. (1 + 1 marks)

Marking scheme (5 marks): a) 1. b) Power and cost 1, COP 1. c) Triple-effect cost 1, saving 1.

Ref: BEE Guidebook Paper 2 (Book 2: Energy Efficiency in Thermal Utilities), Ch. 7 – Cogeneration.

S-8 In an oil-fired boiler's tubular air preheater, flue gas leaves the cold end at 170 °C while ambient air enters at 30 °C. Film coefficients are 40 W/m²·K on the gas side and 60 W/m²·K on the air side; the tube wall resistance is negligible. The acid dew point of the flue gas is 125 °C and the plant wants the metal at least 5 K above it. Air flow is 20 kg/s (cp 1.01 kJ/kg·K). A steam coil air preheater (SCAPH) using 10 bar(a) steam ($h_{fg} = 2014.6 \text{ kJ/kg}$) can warm the air before it enters.

[SP2CEM058 | Chapter 9: Heat Exchangers | Cold-end metal temperature of a tubular air preheater and steam-coil air preheating]

(a) Calculate the tube metal temperature at the cold end and state the consequence. [1 Mark]

(b) Calculate the air inlet temperature needed to keep the metal 5 K above the acid dew point (assume the gas exit temperature stays the same). [2 Marks]

(c) Calculate the SCAPH duty and steam consumption, and suggest one cheaper alternative. [2 Marks]

S-8 Ans

(a) [1 mark]

Given: $h(g) = 40 \text{ W/m}^2\text{K}$, $T(g) = 170^\circ\text{C}$; $h(a) = 60 \text{ W/m}^2\text{K}$, $T(a) = 30^\circ\text{C}$; acid dew point 125°C , so the minimum metal temperature is 130°C ; air 20 kg/s , $cp = 1.01 \text{ kJ/kg K}$; 10 bar(a) steam $h(fg) = 2,014.6 \text{ kJ/kg}$.

Formula: with no wall resistance, the same heat flux crosses both films: $h(g)(T(g) - T(w)) = h(a)(T(w) - T(a))$, so $T(w) = (h(g)T(g) + h(a)T(a)) \div (h(g) + h(a))$.

Substitution: $(40 \times 170 + 60 \times 30) \div 100$.

Result: **$T(w) = 86.0^\circ\text{C}$** , well below the 125°C acid dew point, so sulphuric acid condenses and corrodes and fouls the cold-end tubes. (1 mark)

(b) [2 marks]

Formula: $T(a) = [(h(g) + h(a)) T(w, \text{req}) - h(g) T(g)] \div h(a)$, with $T(w, \text{req}) = 125 + 5 = 130^\circ\text{C}$.

Substitution: $(100 \times 130 - 40 \times 170) \div 60$.

Result: **required air inlet temperature = 103.3°C** . (2 marks)

(c) [2 marks]

Substitution: $Q = 20 \times 1.01 \times (103.3 - 30) = 1,481 \text{ kW}$; steam = $1,481 \div 2014.6 \times 3,600$.

Result: **SCAPH duty = $1,481 \text{ kW}$; steam = $2,647 \text{ kg/h}$** . This is costly, so cheaper options are: recirculating some hot air to the inlet, bypassing part of the cold air, using enamel-coated or glass cold-end tubes that tolerate acid, or switching to low-sulphur fuel to lower the dew point. (1 + 1 marks)

Marking scheme (5 marks): a) Wall temperature and consequence 1. b) Required air temperature 2. c) Duty and steam 1, alternative 1.

Ref: BEE Guidebook Paper 2 (Book 2: Energy Efficiency in Thermal Utilities), Ch. 9 – Heat Exchangers.

..... End of Section II

Section – III: LONG DESCRIPTIVE QUESTIONS

Marks: $6 \times 10 = 60$

(i) Answer all Six questions

(ii) Each question carries Ten marks

L-1 A plant needs 32 MWh of process heat a day (2 MW for 16 h, two shifts) for 300 days a year. It now uses a gas boiler: efficiency 88%, gas ₹45/Sm³ with GCV 37.68 MJ/Sm³, emission factor 0.202 kg CO₂ per kWh of gas. An electrode boiler (efficiency 99%) is proposed. Grid tariff: ₹5.00/kWh off-peak (22:00–06:00) and ₹8.00/kWh at other times; grid emission factor 0.71 kg CO₂/kWh. A pressurised hot-water store can deliver 12 MWh of heat charged off-peak, with 92% storage efficiency.

[SP2CEM059 | Chapter 2: Boilers | Electrifying process heat - electrode boiler with pressurised hot-water storage versus a gas boiler]

(a) Calculate the daily heat cost and CO₂ of the gas boiler. [2 Marks]

(b) Calculate the daily cost and CO₂ if the electrode boiler runs directly on grid power during the shifts. [2 Marks]

(c) Calculate the daily cost and CO₂ with the store charged off-peak and the balance supplied directly. [2 Marks]

(d) Renewable power can be bought through green open access at ₹4.60/kWh round the clock (zero emission factor). Calculate the daily cost, and the annual cost saving and CO₂ reduction against the gas boiler. [2 Marks]

(e) The store holds water between 180°C ($h(f) = 762.6 \text{ kJ/kg}$) and 120°C ($h(f) = 503.8 \text{ kJ/kg}$); mean density 917 kg/m^3 . Calculate the water mass and vessel volume needed. [2 Marks]

L-1 Ans**(a) [2 marks]**

Given: heat $32,000 \text{ kWh/day}$; $\eta = 0.88$; gas = ₹45 $\div (37.68 \div 3.6) = ₹4.299$ per kWh of gas.

Formula: cost = heat $\div \eta \times$ gas price per kWh; CO₂ = heat $\div \eta \times$ emission factor.

Substitution: $32,000 \div 0.88 = 36,364 \text{ kWh of gas; } \times ₹4.299; \times 0.202.$

Result: **gas boiler cost = ₹1,56,340 per day; CO₂ = 7.35 t per day.** (1 + 1 marks)

(b) [2 marks]

Substitution: $32,000 \div 0.99 = 32,323 \text{ kWh} \times ₹8.00; \times 0.71.$

Result: **direct electric cost = ₹2,58,586 per day; CO₂ = 22.95 t per day**, about 3.1 times the gas boiler, because grid power is coal-heavy. (1 + 1 marks)

(c) [2 marks]

Formula: off-peak input = stored heat $\div (\eta(\text{store}) \times \eta(\text{boiler}))$; balance = (heat – stored heat) $\div \eta(\text{boiler})$ at the normal tariff.

Substitution: off-peak = $12,000 \div (0.92 \times 0.99) = 13,175 \text{ kWh} \times ₹5.00$; balance = $20,000 \div 0.99 = 20,202 \text{ kWh} \times ₹8.00.$

Result: **cost with storage = ₹2,27,492 per day; CO₂ = 23.70 t per day.** Storage cuts the electric bill by ₹31,094 a day but still costs more than gas. (1 + 1 marks)

(d) [2 marks]

Substitution: $32,323 \text{ kWh} \times ₹4.60$; annual saving = $(₹1,56,340 - ₹1,48,687) \times 300$; $\text{CO}_2 = 7.35 \times 300.$

Result: **green power cost = ₹1,48,687 per day; saving $\approx$ ₹23.0 lakh a year; CO₂ reduction $\approx$ 2,204 t a year.** Electrification makes economic and climate sense only with low-cost renewable power or deep off-peak tariffs. (1 + 1 marks)

(e) [2 marks]

Formula: water mass = stored heat $\div \Delta h(f)$; volume = mass $\div$ density.

Substitution: $12,000 \text{ kWh} \times 3,600 = 43.2 \text{ GJ}; \div (258.8 \text{ kJ/kg}); \div 917.$

Result: **water mass $\approx$ 1,66,924 kg; vessel volume $\approx$ 182 m³** (plus steam space and margin). (1 + 1 marks)

Marking scheme (10 marks): a) Cost 1, CO₂ 1. b) Cost 1, CO₂ and comment 1. c) Off-peak and balance energy 1, cost and CO₂ 1. d) Cost 1, saving and CO₂ 1. e) Mass 1, volume 1.

Ref: BEE Guidebook Paper 2 (Book 2: Energy Efficiency in Thermal Utilities), Ch. 2 – Boilers.

L-2 A remote unit 1.2 km from the boiler house needs 10,000 kg/h of dry saturated steam at 10 bar(a) (179.9 °C, h_{fg} = 2014.6 kJ/kg). The insulated main loses 110 W per metre at this temperature. Superheated steam has a mean cp of 2.3 kJ/kg·K. Ignore pressure drop. The boiler is gas-fired at 88% efficiency with gas costing ₹4.30 per kWh, and runs 8,000 h a year.

[SP2CEM060 | Chapter 3: Steam System | Superheat needed to deliver dry steam through a long distribution main]

(a) Calculate the total heat loss from the main. [1 Mark]

(b) If saturated steam is sent, calculate the condensate formed in the main and the dryness fraction at the unit. [2 Marks]

(c) Calculate the superheat needed at the boiler so that the steam arrives just dry saturated, and the boiler outlet temperature. [2 Marks]

(d) Better insulation would halve the loss. Calculate the annual fuel cost saving. [2 Marks]

(e) At night the unit draws only 4,000 kg/h but the boiler outlet temperature stays as in (c). Calculate the steam temperature drop the loss would cause, and the dryness at the unit. Comment. [3 Marks]

L-2 Ans

(a) [1 mark]

Given: $L = 1,200 \text{ m}$; loss = $110 \text{ W/m}.$

Substitution: $1,200 \times 110 \div 1,000.$

Result: **heat loss = 132 kW.** (1 mark)

(b) [2 marks]

Formula: condensate = loss $\div h(\text{fg})$; dryness = $1 - \text{condensate} \div \text{steam flow}.$

Substitution: $132 \times 3,600 \div 2014.6 = 235.9 \text{ kg/h}; 1 - 235.9 \div 10,000.$

Result: **condensate = 235.9 kg/h; dryness at the unit = 97.64%** (lower still if traps fail). (1 + 1 marks)

(c) [2 marks]

Formula: superheat $\Delta T = \text{loss} \div (m \times cp)$.

Substitution: $132 \div (10,000 \div 3,600 \times 2.3) = 132 \div 6.389$.

Result: **superheat = 20.7 K; boiler outlet $\approx 200.6^\circ\text{C}$.** (1 + 1 marks)

(d) [2 marks]

Substitution: saved heat = 66 kW; fuel = $66 \div 0.88 = 75.0 \text{ kW} \times ₹4.30 \times 8,000 \text{ h}$.

Result: **saving $\approx ₹25.8$ lakh a year.** (2 marks)

(e) [3 marks]

Substitution: $\Delta T = 132 \div (4,000 \div 3,600 \times 2.3) = 51.7 \text{ K}$, more than the 20.7 K of superheat available; superheat gives 52.8 kW, so 79.2 kW condenses 141.5 kg/h.

Result: **temperature drop needed = 51.7 K; dryness at the unit $\approx 96.46\%$.** The loss is fixed in kW, so at low flow it takes a larger share of the steam. Superheat should be controlled to load, or a separator and good trapping fitted at the unit, and a small local boiler or steam-to-steam reboiler considered for night load. (1 + 1 + 1 marks)

Marking scheme (10 marks): a) 1. b) Condensate 1, dryness 1. c) Superheat 1, outlet temperature 1. d) Fuel and saving 2. e) Temperature drop 1, dryness 1, comment 1.

Ref: BEE Guidebook Paper 2 (Book 2: Energy Efficiency in Thermal Utilities), Ch. 3 – Steam System.

L-3 A container-glass furnace melts 300 t of glass a day for 350 days a year, now with 20% cullet (recycled broken glass) in the charge. The theoretical heat to make 1 t of glass is 2.70 GJ from raw batch (heating, melting, carbonate decomposition and batch gases) and 1.70 GJ from cullet (heating and melting only). The furnace's thermal efficiency (theoretical heat $\div$ fuel heat) is 45% and stays the same. Natural gas: NCV 34.0 MJ/Sm³, ₹45/Sm³, 1.96 kg CO₂/Sm³. Raw batch releases 0.20 t of process CO₂ per tonne of glass made from batch. Raw batch costs ₹6,000/t and 1.2 t of batch is needed per t of glass; sorted cullet costs ₹8,000/t (1 t per t of glass). The plant plans to raise cullet to 50%.

[SP2CEM061 | Chapter 4: Furnaces | Raising the cullet share in a gas-fired glass melting furnace - energy, CO₂ and material cost]

- Calculate the theoretical heat per tonne of glass at both cullet levels. [2 Marks]
- Calculate the fuel heat per tonne and the daily gas consumption at both levels. [2 Marks]
- Calculate the annual gas saving in Sm³ and rupees, and the energy saving per 10% of cullet added. [2 Marks]
- Calculate the annual CO₂ reduction from fuel and from process (carbonate) emissions. [2 Marks]
- Calculate the change in raw-material cost and the net annual benefit, and state one quality condition for cullet. [2 Marks]

L-3 Ans

(a) [2 marks]

Given: 300 t/day glass, 350 days/yr; theoretical heat 2.7 GJ/t (batch) and 1.7 GJ/t (cullet); furnace efficiency 45%; gas NCV 34.0 MJ/Sm³ at ₹45/Sm³.

Formula: theoretical heat = $(1 - \text{cullet}) \times q(\text{batch}) + \text{cullet} \times q(\text{cullet})$.

Substitution: $0.80 \times 2.7 + 0.20 \times 1.7$; $0.50 \times 2.7 + 0.50 \times 1.7$.

Result: **2.50 GJ/t at 20% cullet; 2.20 GJ/t at 50% cullet.** (1 + 1 marks)

(b) [2 marks]

Formula: fuel heat = theoretical heat $\div$ efficiency; gas = output $\times$ fuel heat $\div$ NCV.

Substitution: $2.50 \div 0.45$ and $2.20 \div 0.45$; gas = $300 \times \text{fuel heat} \times 1,000 \div 34.0$.

Result: **fuel = 5.556 and 4.889 GJ/t; gas = 49,020 and 43,137 Sm³/day.** (1 + 1 marks)

(c) [2 marks]

Substitution: $(49,020 - 43,137) \times 350$; $\times ₹45$; per 10% cullet = $(5.556 - 4.889) \div 5.556 \div 3$.

Result: **gas saving = 20,58,824 Sm³ a year, worth $\approx ₹9.26$ crore; about 4.0% energy saving per 10% cullet**, somewhat above the usual 2.5–3% rule of thumb, because the efficiency is taken as constant. (1 + 1 marks)

(d) [2 marks]

Substitution: fuel $\text{CO}_2 = 20,58,824 \times 1.96 \div 1,000$; process $\text{CO}_2 = 300 \times 350 \times 0.2 \times (0.5 - 0.2)$.

Result: **fuel CO_2 cut = 4,035 t; process CO_2 cut = 6,300 t; total $\approx 10,335$ t a year.** (1 + 1 marks)

(e) [2 marks]

Substitution: cost per t glass = $(1 - \text{cullet}) \times 1.2 \times 6,000 + \text{cullet} \times 8,000 = ₹7,360$ and $₹7,600$; $\times 300 \times 350$.

Result: **material cost rises by ₹2.52 crore a year; net benefit $\approx$ ₹6.74 crore a year.** Cullet must be colour-sorted and free of ceramics, stones and metals, which cause defects and can damage the furnace bottom. (1 + 1 marks)

Marking scheme (10 marks): a) 1 + 1. b) Fuel heat 1, gas 1. c) Gas and value 1, % per 10% cullet 1. d) Fuel CO_2 1, process CO_2 1. e) Material cost and net 1, quality condition 1.

Ref: BEE Guidebook Paper 2 (Book 2: Energy Efficiency in Thermal Utilities), Ch. 4 – Furnaces.

L-4 A plant needs 2,400 kW of power and 2,300 kW of hot-water heat around the clock (8,000 h a year). It has two 1,600 kW(e) gas engines with heat recovery. Engine performance (NCV basis): at 100% load, electrical efficiency 42.0% and recoverable heat 43% of fuel; at 75% load, 40.5% and 44%; at 50% load, 37.0% and 46%. Surplus heat is dumped through a radiator; export of power is not allowed. A gas boiler (efficiency 90%) can top up heat. Gas costs ₹4.30 per kWh (NCV) and grid power ₹8.00/kWh.

[SP2CEM062 | Chapter 7: Cogeneration | Dispatching two gas-engine CHP units at part load against grid power and boiler heat]

(a) Option A: both engines at 75% load. Calculate the fuel input, heat recovered and any surplus heat. [2 Marks]

(b) Option B: one engine at 100% and one at 50%. Calculate the fuel input and heat recovered. [2 Marks]

(c) Option C: one engine at 100%, the balance power from the grid and heat top-up from the boiler. Calculate the fuel input, boiler fuel and grid import. [2 Marks]

(d) Calculate the hourly energy cost of A, B and C and of D (no engines: all grid power and boiler heat). Identify the cheapest option. [2 Marks]

(e) Calculate the annual saving of the cheapest option over D and give two operating points to watch. [2 Marks]

L-4 Ans

(a) [2 marks]

Given: two 1,600 kW(e) gas engines; demand 2,400 kW power and 2,300 kW heat, 8,000 h/yr; $\eta(e)$ / heat fraction = 42.0% / 43% (100% load), 40.5% / 44% (75%), 37.0% / 46% (50%); gas ₹4.30/kWh (NCV), grid ₹8.00/kWh; boiler efficiency 90%.

Formula: fuel = power $\div \eta(e)$; heat = fuel $\times$ heat fraction.

Substitution: each engine $1,200 \text{ kW} \div 0.405 = 2,963.0 \text{ kW fuel}$; $\times 2$; heat = $5,925.9 \times 0.44$.

Result: **fuel = 5,925.9 kW; heat recovered = 2,607.4 kW; surplus heat dumped = 307.4 kW.** (1 + 1 marks)

(b) [2 marks]

Substitution: $1600 \div 0.420 = 3,809.5 \text{ kW}$; $800 \div 0.370 = 2,162.2 \text{ kW}$; heat = $3,809.5 \times 0.43 + 2,162.2 \times 0.46$.

Result: **fuel = 5,971.7 kW; heat recovered = 2,632.7 kW** (surplus 332.7 kW). (1 + 1 marks)

(c) [2 marks]

Substitution: engine fuel = 3,809.5 kW; heat = 1,638.1 kW; boiler fuel = $(2,300 - 1,638.1) \div 0.9$; grid = $2,400 - 1,600$.

Result: **engine fuel = 3,809.5 kW; boiler fuel = 735.4 kW; grid import = 800 kW.** (1 + 1 marks)

(d) [2 marks]

Substitution: A = $5,925.9 \times 4.30$; B = $5,971.7 \times 4.30$; C = $(3,809.5 + 735.4) \times 4.30 + 800 \times 8.00$; D = $2,400 \times 8.00 + 2,300 \div 0.9 \times 4.30$.

Result: **A = ₹25,481/h; B = ₹25,678/h; C = ₹25,943/h; D = ₹30,189/h. Option A (both engines at 75%) is cheapest**, because running two engines at part load still beats grid power and the boiler, and part-load efficiency loss at 75% is small. (1 + 1 marks)

(e) [2 marks]

Substitution: $(₹30,189 - ₹25,481) \times 8,000 \text{ h}$.

Result: **annual saving $\approx$ ₹3.77 crore.** Watch: (i) minimum stable engine load and wear from long part-load running; (ii) surplus heat dumped (about 307 kW in A) – a thermal store or absorption chiller could use it; (iii) changes in the gas–grid price ratio, which can change the best dispatch. (1 + 1 marks)

Marking scheme (10 marks): a) Fuel 1, heat and surplus 1. b) Fuel 1, heat 1. c) Engine and boiler fuel 1, grid import 1. d) Costs 1, choice 1. e) Saving 1, operating points 1.

Ref: BEE Guidebook Paper 2 (Book 2: Energy Efficiency in Thermal Utilities), Ch. 7 – Cogeneration.

L-5 An oil-quench furnace line runs 24 h a day. A plate exchanger on the quench oil can recover 120 kW continuously as hot water. Parts washers need 400 kW of heat but run only during one 8 h shift; they are now heated by a gas boiler (efficiency 85%, gas ₹4.30/kWh). A stratified store charged to 85 °C and usable down to 55 °C is proposed; assume 5% of the heat charged is lost while stored. Circulation pumps draw 3 kW for 24 h; power costs ₹8.00/kWh. The plant works 300 days a year and the scheme costs ₹55 lakh.

[SP2CEM063 | Chapter 8: Waste Heat Recovery | Recovering continuous quench-oil heat into a hot-water store for day-shift washers]

- (a) Calculate the heat the washers need from storage or the boiler during the shift, and the heat that can be stored in the other 16 h. [2 Marks]
- (b) Calculate the boiler top-up per day and the water mass (and approximate volume) of the store. [3 Marks]
- (c) Calculate the annual net saving and simple payback. [3 Marks]
- (d) Calculate the recovery COP (useful heat delivered per kWh of pumping energy) and explain how stratification in the store helps. [2 Marks]

L-5 Ans

(a) [2 marks]

Given: recovery 120 kW; demand 400 kW for 8 h; charging 16 h.

Formula: shift deficit = (demand – direct recovery) $\times$ shift hours; stored heat = recovery $\times$ charging hours $\times$ (1 – loss).

Substitution: $(400 - 120) \times 8$; $120 \times 16 \times 0.95$.

Result: **shift deficit = 2,240 kWh; heat stored = 1,824 kWh.** (1 + 1 marks)

(b) [3 marks]

Formula: top-up = deficit – stored heat; $m = \text{stored heat} \times 3,600 \div (cp \Delta T)$.

Substitution: $2,240 - 1,824$; $m = 1,824 \times 3,600 \div (4.187 \times 30)$.

Result: **boiler top-up = 416 kWh a day; store $\approx$ 52,276 kg of water $\approx$ 52 m³** (about 54 m³ at the hot-water density of 970 kg/m³). (1 + 2 marks)

(c) [3 marks]

Substitution: recovered heat used = $120 \times 8 + 1,824 = 2,784$ kWh/day; gas avoided = $2,784 \div 0.85 = 3,275$ kWh $\times$ ₹4.30 $\times$ 300; pumps = $3 \times 24 \times 300 \times ₹8.00$.

Result: **gas saving = ₹42,24,504; pumping = ₹1,72,800; net saving = ₹40,51,704 a year; payback = 1.36 years.** (1 + 1 + 1 marks)

(d) [2 marks]

Substitution: $COP = 2,784 \text{ kWh} \div (3 \times 24) \text{ kWh}$.

Result: **recovery COP $\approx$ 38.7**, so the pumping energy is small beside the heat recovered. Stratification keeps the hottest water at the top for the washers and the coolest at the bottom for the exchanger, so recovery runs at a larger temperature difference and the full 30 K usable range is kept; inlet diffusers and low flow velocity protect it. (1 + 1 marks)

Marking scheme (10 marks): a) Deficit 1, stored heat 1. b) Top-up 1, mass and volume 2. c) Gas saving 1, net saving 1, payback 1. d) COP 1, stratification 1.

Ref: BEE Guidebook Paper 2 (Book 2: Energy Efficiency in Thermal Utilities), Ch. 8 – Waste Heat Recovery.

L-6 A shell-and-tube heater condenses 0.5 kg/s of steam at 4 bar(a) (143.6 °C, $h_{fg} = 2133.0$ kJ/kg) and then subcools the condensate to 100 °C in a separate zone ($cp = 4.23$ kJ/kg·K). It heats 6 kg/s of water (cp 4.187 kJ/kg·K)

entering at 20 °C in counterflow: the water passes the subcooling zone first. Overall coefficients: condensing zone 2,000 W/m²·K; subcooling zone 600 W/m²·K.

[5P2CEM064 | Chapter 9: Heat Exchangers | Zone analysis of a steam heater with a condensate subcooling section]

- (a) Calculate the duty of each zone, the water temperature between the zones and the water outlet temperature. [2 Marks]
- (b) Calculate the LMTD and area of each zone, and the total area. [4 Marks]
- (c) For the same water duty, how much steam would be needed if the condensate left at saturation (no subcooling)? Express the saving from subcooling. [2 Marks]
- (d) A designer sizes the whole unit with one LMTD (water 20 °C to outlet against 143.6 °C) and the condensing U. Calculate that area and comment. [2 Marks]

L-6 Ans

(a) [2 marks]

Given: steam 0.5 kg/s at 143.6 °C, h_{fg} 2,133.0 kJ/kg, condensate subcooled 43.6 K (c_p 4.23 kJ/kg K); water 6 kg/s ($m c_p$ = 25.122 kW/K) entering at 20 °C; U = 2,000 W/m²K (condensing) and 600 W/m²K (subcooling).

Formula: $Q(\text{cond}) = m h_{fg}$; $Q(\text{sub}) = m c_p \Delta T$; water temperatures from $Q = m c_p \Delta T$.

Substitution: $Q(\text{cond}) = 0.5 \times 2133.0$; $Q(\text{sub}) = 0.5 \times 4.23 \times 43.6$; $C(w) = 6 \times 4.187 = 25.122$ kW/K.

Result: **$Q(\text{cond}) = 1,066.5$ kW; $Q(\text{sub}) = 92.2$ kW; water between zones = 23.67 °C; water outlet = 66.12 °C.** (1 + 1 marks)

(b) [4 marks]

Formula: $\text{LMTD} = (\Delta T_1 - \Delta T_2) \div \ln(\Delta T_1 \div \Delta T_2)$; $A = Q \div (U \times \text{LMTD})$.

Substitution: subcooling: $\Delta T = 119.93$ and 80.00 K; condensing: $\Delta T = 119.93$ and 77.48 K.

Result: **$\text{LMTD}(\text{sub}) = 98.62$ K, $A(\text{sub}) = 1.56$ m²; $\text{LMTD}(\text{cond}) = 97.16$ K, $A(\text{cond}) = 5.49$ m²; total area = 7.05 m².** (1 + 1 + 1 + 1 marks)

(c) [2 marks]

Substitution: steam = $(1,066.5 + 92.2) \div 2133.0 = 0.5432$ kg/s against 0.5 kg/s.

Result: **steam without subcooling = 0.5432 kg/s; subcooling saves 8.0% of the steam** and also removes flash steam at the trap. (1 + 1 marks)

(d) [2 marks]

Substitution: $\text{LMTD} = (123.6 - 77.48) \div \ln(123.6 \div 77.48) = 98.75$ K; $A = 1,158.7 \times 1,000 \div (2,000 \times 98.75)$.

Result: **single-zone area = 5.87 m²**, 17% less than the zoned total. The unit would be undersized: the low- U subcooling zone would not achieve the duty, the condensate level would rise and flood condensing area. Zones with different U and temperature profiles must be sized separately. (1 + 1 marks)

Marking scheme (10 marks): a) Zone duties 1, water temperatures 1. b) LMTD and area each zone 1 + 1 + 1, total 1. c)

Steam 1, saving 1. d) Area 1, comment 1.

Ref: BEE Guidebook Paper 2 (Book 2: Energy Efficiency in Thermal Utilities), Ch. 9 – Heat Exchangers.

..... End of Section III

Answer key — Section I

Q	Ans	Q	Ans	Q	Ans	Q	Ans	Q	Ans
1	c	11	a	21	d	31	b	41	b
2	c	12	a	22	d	32	d	42	c
3	a	13	c	23	a	33	c	43	c
4	d	14	b	24	b	34	a	44	b
5	d	15	d	25	a	35	b	45	a
6	b	16	b	26	c	36	d	46	c
7	b	17	d	27	a	37	d	47	a
8	c	18	a	28	a	38	b	48	c
9	b	19	b	29	b	39	c	49	a

10	d	20	c	30	d	40	a	50	d
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