Applied Thermodynamics and Boiler Operations

EXAMINATION PRACTICE QUESTIONS

Based on syllabus Units 1–6. 50% of final grade.

Instructions for Use

- Simulate exam conditions: 3 hours, no notes (except steam tables and a non-programmable calculator).
- Attempt all questions. Mark values are shown as [X marks].
- After answering, compare with the suggested solutions.

Section A: Short Answer & Definitions

(40% of final exam – practice 10 questions)

Q1 [4 marks]
Define the following terms:
(a) Dryness fraction
(b) Intensive property
(c) Isentropic process
(d) Priming (boiler operation)

Q2 [4 marks]
State the Kelvin-Planck statement of the second law of thermodynamics. Then state the Clausius statement. Show that they are equivalent.

Q3 [3 marks]
Explain why a boiler must be purged (ventilated) before lighting the burner.

Q4 [3 marks]

List three external water treatment processes and the impurity each removes.

Q5 [4 marks]
Sketch a simple T-s diagram for water. Label: saturated liquid line, saturated vapour line, critical point, wet region, superheat region, constant pressure line.

Q6 [3 marks]
Why is superheated steam used in power plant turbines rather than saturated steam?

Q7 [4 marks]
Describe the daily test procedure for a low water cutoff on a steam boiler. What indicates a failed test?

Q8 [3 marks]
Differentiate between a safety valve and a stop valve. Where is each located on a boiler?

Q9 [3 marks]
Explain what is meant by "excess air" in combustion. State typical excess air percentages for natural gas and for coal.

Q10 [4 marks]
A combined separating and throttling calorimeter is used for very wet steam. Explain why the separating stage is needed.

Section B: Longer Answer & Diagrams

(35% of final exam – practice 4 questions)

Q11 [8 marks]

(a) Draw a labelled cross-section of a three-pass wet-back economic fire-tube boiler. (4 marks)
(b) (b) Give two advantages of the wet-back design over dry-back. (2 marks)
(c) State the typical maximum working pressure for this type. (2 marks)

Q12 [9 marks]
Steam enters a turbine at 3 MPa, 350°C and expands isentropically to 0.1 MPa.

a) Determine the initial specific enthalpy and entropy. (3 marks)
b) Find the final dryness fraction (or temperature if superheated). (3 marks)
c) Calculate the isentropic work output per kg of steam. (3 marks)

Use steam table data provided (or from your tables).

Q13 [8 marks]
Describe the correct procedure for raising steam in a cold water-tube boiler from cold start to normal operating pressure. Include checks on water level, venting, purging, ignition, warming up, and testing safety devices.

Q14 [10 marks]
A boiler burns fuel oil with a calorific value of 42,000 kJ/kg. The boiler generates 5,000 kg/h of steam at 1.5 MPa, saturated, from feedwater at 80°C. The fuel consumption is 350 kg/h.

a) Calculate the boiler efficiency using the direct method. (4 marks)
b) The flue gas temperature is 320°C and ambient air 25°C. Explain how you would estimate the dry flue gas loss. (3 marks)
c) Name three other losses accounted for in the indirect method. (3 marks)

Section C: Problem Solving & Applications

(25% of final exam – practice 2 questions)

Q15 [12 marks]
A Rankine cycle operates with the following conditions:

- Boiler pressure: 4 MPa
- Boiler outlet temperature: 400°C
- Condenser pressure: 10 kPa
- Turbine isentropic efficiency: 85%
- Pump isentropic efficiency: 80%

Neglect KE and PE.

(a) Draw the T-s diagram for the cycle. (2 marks)
(b) Determine the specific enthalpy at each state (1: pump inlet, 2s: pump outlet ideal, 2a: actual pump outlet, 3: turbine inlet, 4s: turbine outlet ideal, 4a: actual turbine outlet). (5 marks)
(c) Calculate the cycle thermal efficiency. (3 marks)
(d) What is the work output per kg of steam? (2 marks)

Q16 [13 marks]

A boiler operator discovers that the gauge glass shows no water during routine inspection.
(a) State the immediate emergency actions. (3 marks)
(b) What are three possible causes of low water level? (3 marks)
(c) After the boiler has cooled, describe the steps to safely investigate and recommission the boiler. (4 marks)
(d) How could this situation have been prevented? (3 marks)

Suggested Answers

Answers – Section A

A1
(a) Dryness fraction (x) = mass of vapour / total mass of wet steam mixture.
(b) Intensive property: independent of system mass (e.g., pressure, temperature).
(c) Isentropic process: reversible and adiabatic → entropy constant (s_1=s_2).
(d) Priming: rapid carryover of water droplets with steam due to sudden load or high TDS.

A2
Kelvin-Planck: No heat engine can convert all heat from a reservoir into work; some must be rejected to a cold reservoir.

Clausius: Heat cannot spontaneously flow from a colder body to a hotter body without external work.
Equivalence: If Kelvin-Planck were false (100% engine), that engine could drive a heat pump to transfer heat from cold to hot without net work → violates Clausius.

A3
To remove any unburned fuel vapours that may have accumulated in the furnace. If ignited, they could cause an explosion.

A4

- Ion exchange (softening): removes Ca^{2+}, Mg^{2+}.
- Dealkalisation: removes bicarbonate alkalinity.
- Demineralisation: removes all dissolved minerals (cations & anions).

A5
Sketch of T-s diagram with: left curve saturated liquid, right curve saturated vapour, dome, critical point at top, wet region under dome, superheat region to right, constant pressure line sloping upward.

A6
Saturated steam contains moisture that can erode turbine blades. Superheated steam is dry and can expand further in the turbine without condensing, improving efficiency and blade life.

A7
Procedure: While boiler is steaming, blow down the low water cutoff float chamber (or test valve). Burner should trip immediately. If burner does not trip, the device is failed – boiler must be taken out of service. Then open blowdown to flush, retest.

A8

- Safety valve: Automatic pressure-relief device, opens at MAWP, no manual operation. Located on steam drum or shell top.
- Stop valve: Manually operated valve to isolate boiler from steam line. Located on main steam outlet.

A9
Excess air = (actual air supplied – stoichiometric air)/stoichiometric air × 100%.
Natural gas: 15–20% excess; Coal: 20–50% excess.

A10
For very wet steam (x low), throttling alone may not produce a superheated final state (remains wet or saturated). The separating calorimeter removes bulk moisture, then the throttling calorimeter gives a superheated state for accurate x calculation.

Answers – Section B

A11

(a) *Sketch*: outer shell, furnace tube at bottom, first pass through furnace, reversal chamber (wet back – submerged), second pass tubes, front reversal, third pass tubes, flue gas exit.

(b) (Advantages: cooler reversal chamber (less thermal stress), lower maintenance, higher efficiency.
(c) (c) ≤ 20 bar (2 MPa) typical.

A12 (using typical steam table values)

At 3 MPa, 350°C (superheated): h_1 ≈ 3116 kJ/kg, s_1 ≈ 6.745 kJ/kgK.
At 0.1 MPa: s_f=1.3026, s_g=7.3589. Since s_1 < s_g, final is wet.
x = (s_1 – s_f)/s_fg = (6.745 – 1.3026)/(7.3589–1.3026) = 5.4424/6.0563 = 0.8986.
h_4 = h_f + x h_fg = 417.5 + 0.8986×2257.5 = 417.5 + 2028.5 = 2446 kJ/kg.
Isentropic work = h_1 – h_4 = 3116 – 2446 = 670 kJ/kg.

A13

Full procedure:

1. Check water level in gauge glass (normal).
2. Open air vent fully.
3. Ensure main stop valve closed.
4. Purge furnace for at least 4 air changes (typically 60 seconds).
5. Light pilot, verify flame, open main fuel (low fire).
6. Warm up slowly – avoid thermal shock (1-2 psi/min).
7. Close air vent when steam appears (≈ 1-2 bar).
8. Blow down gauge glass (steam and water sides).
9. When pressure reaches 75% of MAWP, test safety valves by hand-lift.
10. Continue to normal operating pressure, then open stop valve slowly to warm line.

A14

(a) Steam at 1.5 MPa saturated: from tables h_g ≈ 2789 kJ/kg, h_fw at 80°C ≈ 335 kJ/kg. Heat absorbed = 5000 × (2789 – 335) = 5000 × 2454 = 12.27×10^6 kJ/h.
Fuel input = 350 × 42,000 = 14.7×10^6 kJ/h.
η = 12.27/14.7 = 0.835 = 83.5%.
(b) Dry flue gas loss L1 = m_gas × C_p × (T_exit – T_air) / (m_fuel × CV). Need flue gas mass (from combustion equation).
(c) Other losses: loss due to H_2 in fuel (moisture), radiation loss, blowdown loss, unburned carbon.

Answers – Section C

A15 (values approximate – use actual steam tables)

(a) T-s diagram: 1→2s pump, 2s→3 boiler, 3→4s turbine, 4s→1 condenser.
(a) State 1 (10 kPa sat liq): h1=191.8, v1=0.00101 m^3/kg, s1=0.6493
Pump ideal: Wpump,s = v1(P2-P1)=0.00101×(4000-10)=4.03 kJ/kg → h2s =

h1+Wpump = 195.8
Actual pump: Wpump,a = 4.03/0.80=5.04 → h2a = 191.8+5.04=196.8
State 3 (4 MPa, 400°C): h3=3214, s3=6.769
Isentropic turbine to 10 kPa: s4s = s3 =6.769. At 10 kPa, sf=0.6493, sfg=7.5009 → x4s=(6.769-0.6493)/7.5009=0.8156 → h4s=191.8+0.8156×2392.8=191.8+1951=2142.8
Actual turbine: Wturb,a = 0.85×(3214-2142.8)=0.85×1071.2=910.5 → h4a=3214-910.5=2303.5

(b) Cycle efficiency: Q_in = h3-h2a =3214-196.8=3017.2 kJ/kg; W_net = Wturb,a - Wpump,a =910.5-5.04=905.5 kJ/kg; η=905.5/3017.2=0.300=30.0%

(c) Work output per kg = 905.5 kJ/kg.

A16

(a) Immediate actions: Shut off fuel (emergency stop). Close main steam stop valve. Do NOT add water. Allow boiler to cool naturally.

(d) (b) Causes: Feed pump failure, low water cutoff malfunction (stuck closed), automatic feed regulator stuck shut, leakage from blowdown left open, broken gauge glass giving false reading.

(d) Recommission after cooling: Investigate cause (check pump, valves, controls). Inspect boiler internally for overheating damage (tubes bulging, discolouration). If OK, fill slowly with treated water, perform hydrostatic test if required. Then normal cold startup.

(e) Prevention: Daily low water cutoff test, maintain feed pump, log blowdown operations, routine inspection of gauge glass and try cocks.

Final Advice for the Examination

Ø **Time management:** 3 hours. Allocate about 45 min to Section A, 75 min to Section B, 60 min to Section C.	Ø **Steam tables –** have them handy and practice interpolation.
Ø **Diagrams –** always label axes, points, and lines.	Ø **Safety questions** – always follow the code: low water = immediate fuel shutoff, no water addition.
Ø **Efficiency calculations –** write the formula first, then substitute numbers.	Ø **Final revision**: review the “Key Equations Summary” and practice at least one Rankine cycle problem and one boiler efficiency problem.

Good luck with your final examination!

Additional Support

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