UNIVERSITY MECHANICAL ENGINEERING • EXERCISE SHEET

5.4 Second law and entropy

Name: _____ Class: _____ Date: _____ **Total: 14 marks**

KEY WORDS entropy • Carnot cycle • lost work

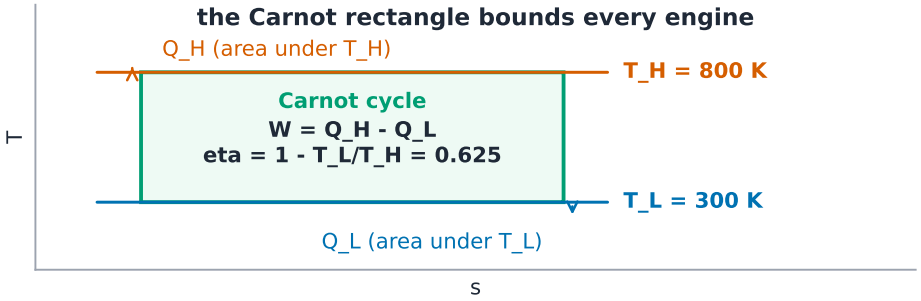
Objective

Use the second law: the Carnot bound from reservoir temperatures, the entropy balance with production, and lost work as $T_0\sigma$.

1 Key knowledge and worked examples

■ **The judge**

$\eta_C = 1 - T_L/T_H$ (absolute temperatures); $\sigma \geq 0$ for every process; lost work $= T_0\sigma$; reversible heat is T-s area.



*The Carnot rectangle bounds every engine

■ **Worked example. The burn-transfer**

$\sigma = Q(1/800 - 1/2000) = 0.75$ kJ/K; lost work $= 300 \times 0.75 = 225$ kJ ✓ - exactly the exergy destroyed.

2 Practice

All temperatures absolute; $T_0 = 300$ K unless stated.

2.1 The Carnot efficiency between reservoirs at 900 K and 320 K (three decimals), and whether a claimed 0.67 engine between them is possible (one sentence). [3]

2.2 A Carnot engine takes 2000 kJ from the 900 K reservoir and rejects to 320 K: the work, the heat rejected (one decimal, kJ) and the entropy change of each reservoir (three decimals, kJ/K). [5]

2.3 Heat 1500 kJ is transferred directly from a 600 K reservoir to a 300 K one: the entropy produced (two decimals, kJ/K) and the lost work at $T_0 = 300$ K (kJ). [4]

2.4 One sentence each: why must $ds = \delta q_{rev}/T$ use a reversible path, and why does a throttling valve produce entropy even though it is adiabatic? [2]

Solutions

2.1

- $\eta_C = 1 - 320/900 = \mathbf{0.644}$.
- $0.67 > 0.644$ exceeds the Carnot bound, so the claim is impossible - no prototype needed.

2.2

- $Q_L = Q_H\, T_L/T_H = 2000 \times 320/900 = \mathbf{711.1}$ kJ.
- $W = 2000 - 711.1 = \mathbf{1288.9}$ kJ.
- $\Delta S_{hot} = -2000/900 = \mathbf{-2.222}$, $\Delta S_{cold} = +711.1/320 = \mathbf{+2.222}$ kJ/K ✓ - the universe is unchanged: reversible.

2.3

- $\sigma = Q(1/300 - 1/600) = 1500 \times 0.003333 - 1500 \times 0.001667 = \mathbf{2.50}$ kJ/K.
- Lost work $= T_0\sigma = 300 \times 2.50 = \mathbf{750}$ kJ.

2.4

- The definition evaluates $\int \delta q/T$ along a path where the system is in internal equilibrium; on an irreversible path the same integral underestimates the change - use the entropy balance with σ instead.
- Throttling keeps h while dropping p irreversibly, so $s_2 > s_1$ with $q = 0$: $\sigma = s_2 - s_1 > 0$.

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