Thermodynamics

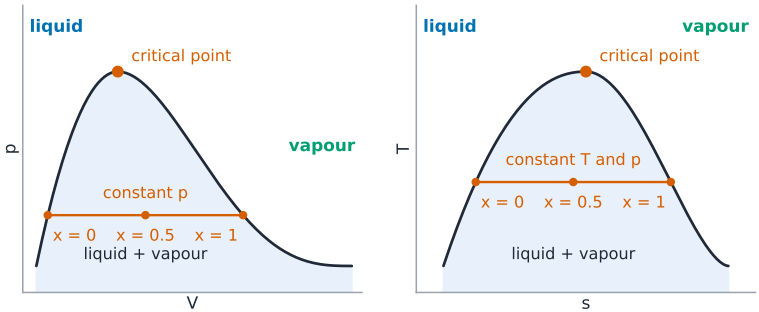
Curated undergraduate study track (not accredited, no external exam). Original explanations and practice only, following the reviewed course handout.

Energy, entropy and the machinery between

- The fifth course in the track: energy, **entropy** and the machinery that turns one into work - how to account for it, how far it can go, and how to know a machine claim is impossible before building it.
- The teaching fluids are water, air and R-134a; every cycle is checked by both laws in the course suite.
- Units 5.1-5.3 build the accounting; 5.4 sets the limits; 5.5-5.6 spend them.

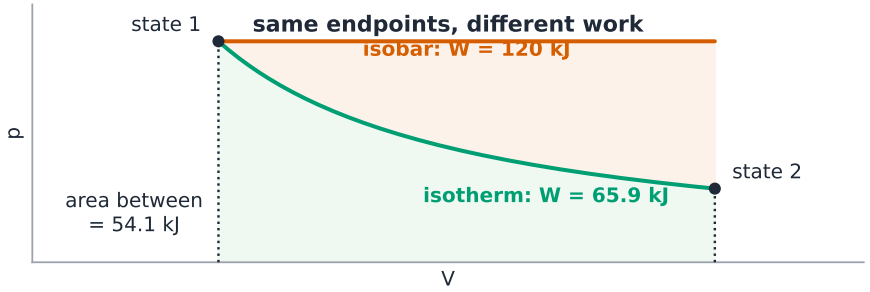
Properties and state: two numbers fix the fluid

the same two-phase region, two axes



At $x = 0.5$, v and h are linear in **quality**: **0.837** m^3/kg, **1547.5** kJ/kg.

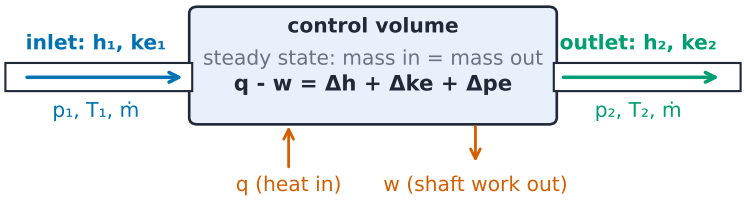
First law, closed systems: work is area



Same endpoints, three paths: isobaric $W = \mathbf{120}$ kJ, isothermal $p_1 V_1 \ln 3 = \mathbf{65.9}$ kJ - the 54.1 kJ gap is the area between the curves. Adiabatic compression to half volume: $p_2 = \mathbf{527.8}$ kPa, $W = \mathbf{-48}$ kJ, $\Delta U = \mathbf{+48}$ kJ.

First law, open systems: enthalpy carries it

steady flow through one control volume



the flow work pv hides inside h = u + pv

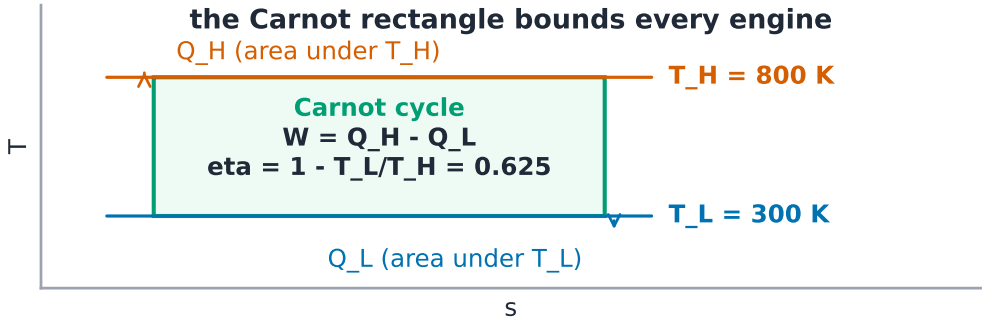
Steady flow: $q - w = \Delta h + \Delta ke + \Delta pe$. Pump $0.5 \to 3$ MPa: $w_p = v\Delta p = \mathbf{2.5}$ kJ/kg. Nozzle $10 \to 300$ m/s: $\Delta h = \mathbf{-44.95}$ kJ/kg. Turbine 3 MPa, 400°C to 50 kPa at $\eta_t = 0.85$: $w = \mathbf{700.0}$ kJ/kg.

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The turbine two-step

1. **Isentropic leg** $s_{2s} = s_1$: $x_{2s} = (6.9212 - 1.0910)/6.5029 = \mathbf{0.89655}$, so $h_{2s} = 340.49 + 0.89655 \times 2305.4 = \mathbf{2407.4}$ kJ/kg.
2. **Price the loss** $w_s = 3230.9 - 2407.4 = \mathbf{823.5}$ kJ/kg; real $w = 0.85 \times 823.5 = \mathbf{700.0}$ kJ/kg.
3. **Back-solve** $h_2 = 3230.9 - 700.0 = \mathbf{2530.9}$ kJ/kg - the exit **state** the cycle sees.

Second law and entropy: the judge



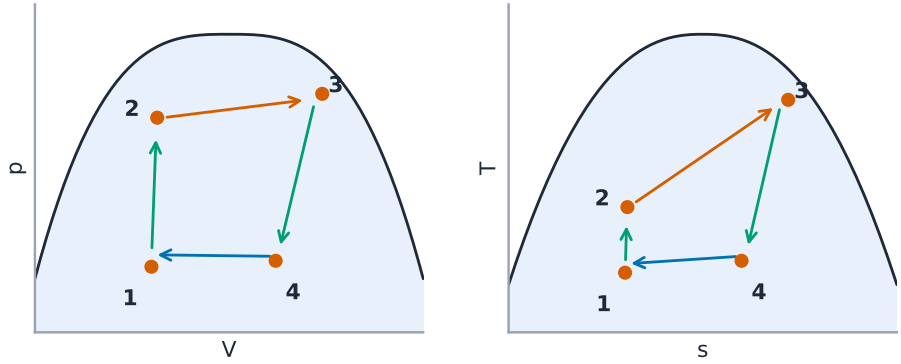
Carnot between 800 K and 300 K: $\eta_C = 1 - T_L/T_H = \mathbf{0.625}$ - a claimed 0.70 engine is impossible on paper. Burn-transfer $\sigma = \mathbf{0.75}$ kJ/K: lost work $T_0\sigma = \mathbf{225}$ kJ.

Power cycles: the Rankine baseline

one cycle, two diagrams, two dome crossings

2→3 boiler · 3→4 turbine

4→1 condenser · heat under 2→3

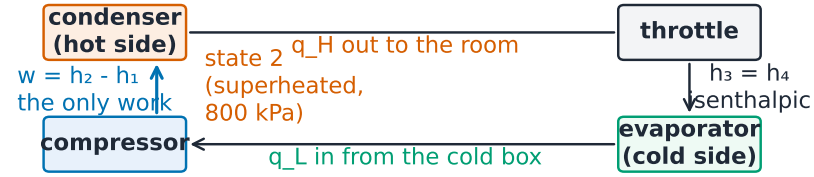


Rankine at 4 MPa gives $\eta = \mathbf{33.6\%}$; superheat lifts it to **39.1%** and dries the

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Refrigeration: the same skeleton, backwards

the reversed machine: one work input



COP_R = q_L / w = 3.99 · COP_HP = q_H / w = 4.99 = COP_R + 1

R-134a, evaporator -10°C, compressor to 800 kPa: $q_L = \mathbf{152.8}$, $w_{in} = \mathbf{38.3}$ kJ/kg, $\mathrm{COP}_R = \mathbf{3.99}$ against the reversed-Carnot ceiling $263.2/41.3 = \mathbf{6.37}$. As a heat pump: $q_H = \mathbf{191.1}$, $\mathrm{COP}_{HP} = \mathbf{4.99} = \mathrm{COP}_R + 1$.

Both laws, one page

1. **Cooling** $q_L = h_1 - h_4 = 394.6 - 241.8 = \mathbf{152.8}$ kJ/kg; $w_{in} = 432.9 - 394.6 = \mathbf{38.3}$; $\mathrm{COP}_R = \mathbf{3.99}$.
2. **Heating** $q_H = h_2 - h_3 = 432.9 - 241.8 = \mathbf{191.1}$ kJ/kg; $\mathrm{COP}_{HP} = \mathbf{4.99}$.
3. **Identity** $\mathrm{COP}_{HP} - \mathrm{COP}_R = (q_L + w)/w - q_L/w = \mathbf{1}$ - same machine, different port.

Check yourself

- The dome walk and the gas? (0.837 m^3/kg, 1547.5 kJ/kg; 0.8497 $\rightarrow$ 0.4248.)
- The three works and the ledger? (120, 65.9, -48 kJ; $\Delta U = +48$.)
- The turbine two-step? (0.89655 $\rightarrow$ 2407.4 $\rightarrow$ 823.5 $\rightarrow$ 700.0 kJ/kg.)
- The bounds and the machines? ($\eta_C = 0.625$, lost work 225 kJ; 33.6% baseline; COP 3.99 vs 6.37.)