

Exercise walk-through

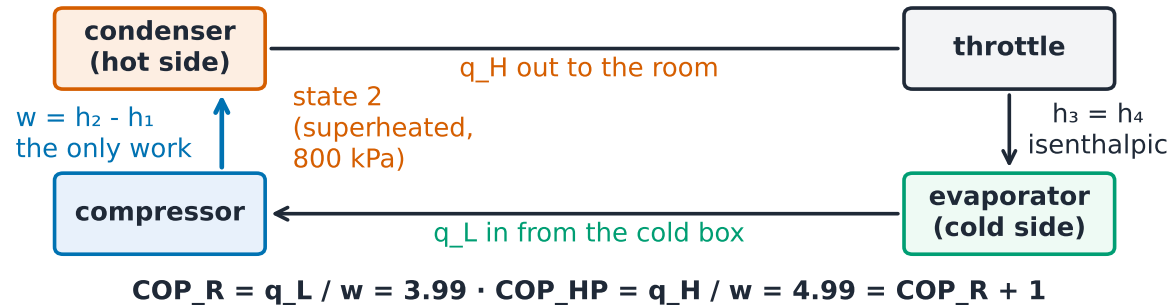
5.6

Refrigeration and heat pumps

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Refrigeration: the same skeleton, backwards

the reversed machine: one work input



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

Both laws, one page

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

Check yourself

- The dome walk and the gas? ($0.837 \text{ m}^3/\text{kg}$, 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? ($0.89655 \rightarrow 2407.4 \rightarrow 823.5 \rightarrow 700.0 \text{ kJ/kg}$.)
- The bounds and the machines? ($\eta_C = 0.625$, lost work 225 kJ ; 33.6% baseline; COP 3.99 vs 6.37 .)

Exercises 2.1-2.2

2.1 With $h_1 = 240.0$ (evaporator exit), $h_2 = 290.0$ (compressor exit) and $h_3 = h_4 = 100.0$ kJ/kg: the refrigeration effect, the compressor work (one decimal each, kJ/kg) and the COP of refrigeration (two decimals). [4]

2.2 For the machine of 2.1: the heating effect (one decimal, kJ/kg) and the COP as a heat pump (two decimals), showing the identity between the two COPs. [4]

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2.1

- $q_L = h_1 - h_4 = 240.0 - 100.0 = \mathbf{140.0}$ kJ/kg.
- $w_{in} = h_2 - h_1 = 290.0 - 240.0 = \mathbf{50.0}$ kJ/kg; $\text{COP}_R = 140.0/50.0 = \mathbf{2.80}$.

2.2 For the machine of 2.1: the heating effect (one decimal, kJ/kg) and the COP as a heat pump (two decimals), showing the identity between the two COPs. [4]

2.2

- $q_H = h_2 - h_3 = 290.0 - 100.0 = \mathbf{190.0}$ kJ/kg.
- $\text{COP}_{HP} = 190.0/50.0 = \mathbf{3.80}$; identity: $q_H/w - q_L/w = (q_L + w_{in})/w - q_L/w = 1$, and $2.80 + 1 = 3.80$ ✓.

Exercises 2.3·2.4

2.3 The reversed-Carnot ceiling between the cold space at -5°C (268.2 K) and the condenser surroundings at 30°C (303.2 K) (two decimals), and one sentence on whether the machine of 2.1 is viable. [3]

2.4 One sentence each: why does the cycle use a throttle instead of a turbine, and why must the ceiling use absolute temperatures? [3]

Exercises 2.3-2.4

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2.3

- Ceiling = $268.2 / (303.2 - 268.2) = 268.2 / 35.0 = \mathbf{7.66}$.
- The machine's 2.80 sits well below 7.66, so it is viable - the ceiling forbids only COPs above it.

2.4 One sentence each: why does the cycle use a throttle instead of a turbine, and why must the ceiling use absolute temperatures? [3]

2.4

- The expansion spans a wet two-phase flow where a tiny turbine is not worth building; a throttle is cheap, isenthalpic and destroys only a few kJ/kg, which the compressor simply re-pays.
- The bound comes from Carnot ratios of absolute temperatures: $T_{cold} / (T_{hot} - T_{cold})$ with kelvin; using differences of Celsius readings changes the ratio and misprices the ceiling.