# 5.6 Refrigeration and heat pumps

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

**KEY WORDS** vapor-compression cycle • compressor • coefficient of performance

## Objective

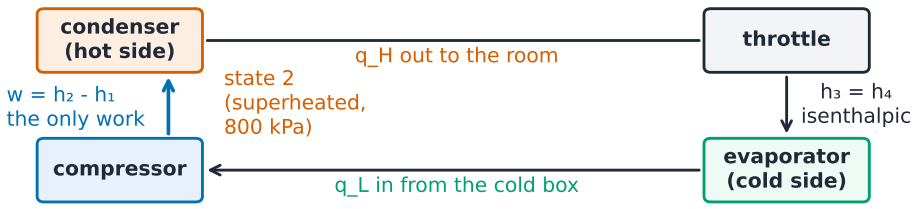
Read the reversed cycle: refrigeration effect and COP from the ports, the heat-pump identity, and the reversed-Carnot ceiling in absolute temperatures.

## 1 Key knowledge and worked examples

### ■ Benefit over cost

$\mathrm{COP}_R = q_L/w_{in}$, $\mathrm{COP}_{HP} = q_H/w_{in} = \mathrm{COP}_R + 1$; throttle keeps $h$; ceiling COP $\le T_{cold}/(T_{hot} - T_{cold})$.

**the reversed machine: one work input**




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

*The compressor is the only work input

### ■ Worked example. The R-134a machine

$q_L = 394.6 - 241.8 = 152.8$, $w_{in} = 432.9 - 394.6 = 38.3$: $\mathrm{COP}_R = \mathbf{3.99}$ ✓ against the ceiling $263.2/41.3 = 6.37$.

## 2 Practice

A vapor-compression machine runs on a refrigerant with $h_1 = 240.0$ kJ/kg (evaporator exit), $h_2 = 290.0$ kJ/kg (compressor exit, superheated), $h_3 = h_4 = 100.0$ kJ/kg (condenser exit, throttle keeps $h$). The cold space sits at $-5\,^\circ$C and the condenser surroundings at $30\,^\circ$C.

**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]

**2.3** The reversed-Carnot ceiling between the cold space at $-5\,^\circ$C (268.2 K) and the condenser surroundings at $30\,^\circ$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]

## Solutions

**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; $\mathrm{COP}_R = 140.0/50.0 = \mathbf{2.80}$.

**2.2**

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

**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**

- 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.

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