5.5 Power cycles

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

KEY WORDS Rankine cycle • boiler • exhaust quality

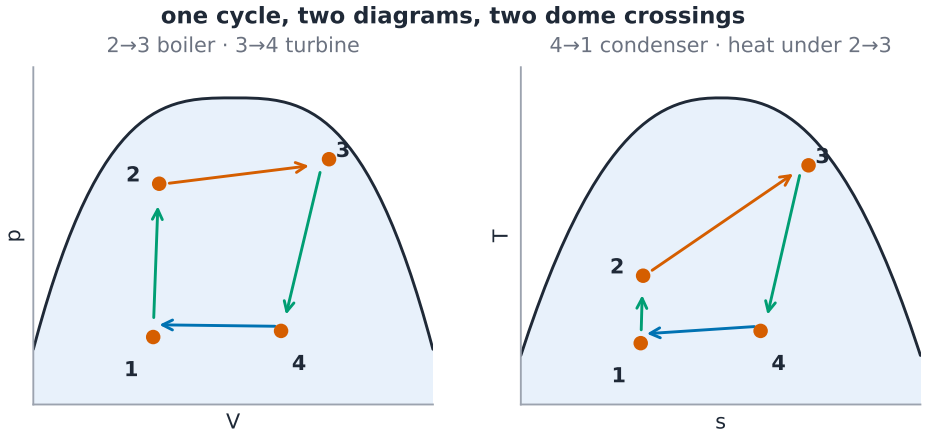
Objective

Walk an ideal Rankine cycle state by state: the isentropic turbine leg through the dome, the liquid pump, heat in, and the thermal efficiency.

1 Key knowledge and worked examples

■ **Four components**

Turbine: $s_4 = s_3$, $h_4 = h_f + x_4\,h_{fg}$. Pump: $h_2 = h_1 + v_f(p_2 - p_1)$. $\eta = (w_t - w_p)/(h_3 - h_2)$.



*Two dome crossings per lap

■ **Worked example. The 4 MPa baseline**

$x_4 = (6.0700 - 0.6492)/7.5009 = 0.7227$, $h_4 = 1921.1$; $w_t = 880.3$, $w_p = 4.0$, $q_{in} = 2605.6$: $\eta = 876.3/2605.6 = 33.6\%$ ✓.

2 Practice

An ideal Rankine cycle: boiler at 8 MPa delivering saturated vapour ($h_3 = 2750.0$ kJ/kg, $s_3 = 5.750$ kJ/(kg K)); condenser at 20 kPa, where $h_f = 250.0$ kJ/kg, $h_{fg} = 2350.0$ kJ/kg, $s_f = 0.830$, $s_{fg} = 7.070$ kJ/(kg K); pump inlet $h_1 = 250.0$ kJ/kg with $v_f = 0.001020$ m^3/kg.

2.1 For this cycle – boiler at 8 MPa giving saturated vapour with $h_3 = 2750.0$ kJ/kg and $s_3 = 5.750$ kJ/(kg K); condenser at 20 kPa with $h_f = 250.0$, $h_{fg} = 2350.0$ kJ/kg, $s_f = 0.830$, $s_{fg} = 7.070$ kJ/(kg K); pump inlet $h_1 = 250.0$ kJ/kg with $v_f = 0.001020$ m^3/kg – the turbine exit quality (four decimals) and exit enthalpy (one decimal, kJ/kg). [4]

2.2 For the cycle of 2.1: the turbine work and the pump work (one decimal each, kJ/kg). [3]

2.3 For the cycle of 2.1: the heat input per kilogram (one decimal, kJ/kg) and the cycle thermal efficiency (one decimal, percent). [3]

2.4 One sentence each: why does raising the boiler pressure raise the efficiency, and why must the exhaust quality be watched even when the arithmetic is clean? [4]

Solutions

2.1

- $x_4 = (s_3 - s_f)/s_{fg} = (5.750 - 0.830)/7.070 = \mathbf{0.6959}$.
- $h_4 = 250.0 + 0.6959 \times 2350.0 = \mathbf{1885.4}$ kJ/kg.

2.2

- $w_t = h_3 - h_4 = 2750.0 - 1885.4 = \mathbf{864.6}$ kJ/kg.
- $w_p = v_f\,\Delta p = 0.001020 \times 7980 = \mathbf{8.1}$ kJ/kg.

2.3

- $h_2 = 250.0 + 8.1 = 258.1$, so $q_{in} = 2750.0 - 258.1 = \mathbf{2491.9}$ kJ/kg.
- $\eta = (864.6 - 8.1)/2491.9 = 856.5/2491.9 = \mathbf{34.4}\%$.

2.4

- Higher boiler pressure raises the average temperature of heat addition, so the second-law ceiling $1 - T_{out}/T_{in,avg}$ rises while the pump cost grows only as $v\,\Delta p$.
- Wet exhaust erodes the last-stage blades: x_4 below roughly 0.88 ruins the machine even when the cycle balances - superheat and reheat exist to keep it dry.

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