Exercise walk-through

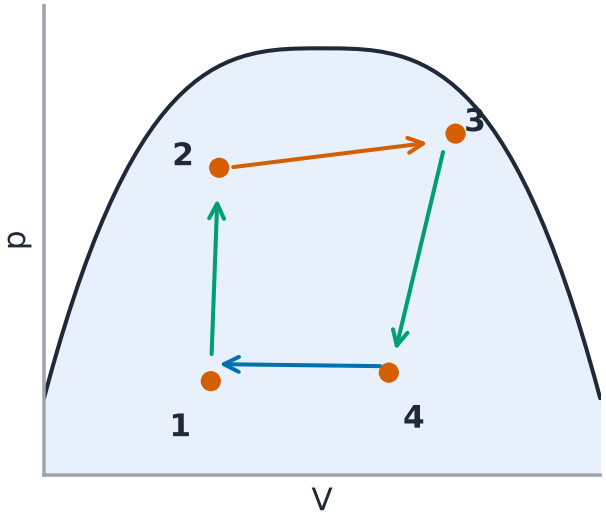
5.5
Power cycles

University Mechanical Engineering

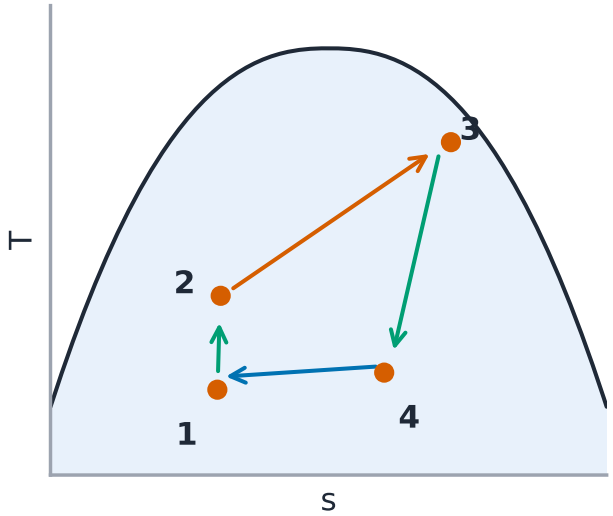
Power cycles: the Rankine baseline

one cycle, two diagrams, two dome crossings

2→3 boiler · 3→4 turbine



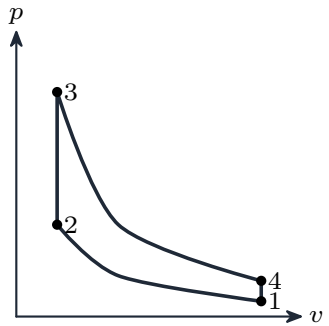
4→1 condenser · heat under 2→3



Rankine at 4 MPa: $\eta = \mathbf{33.6\%}$; superheat lifts it to **36.5%**, drier exhaust.

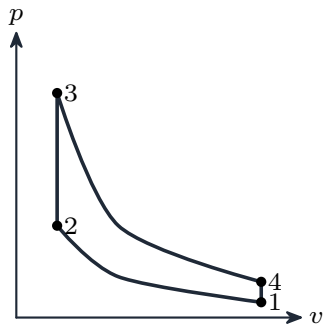
Exercise 2.1

2.1 Find the ideal Otto efficiency for $r = 8$ and for $r = 10$. Give one reason petrol engines do not use much higher ratios. [2]



Exercise 2.1

2.1 Find the ideal Otto efficiency for $r = 8$ and for $r = 10$. Give one reason petrol engines do not use much higher ratios. [2]

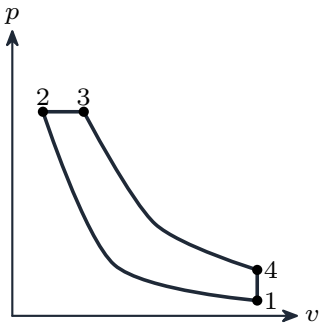


2.1

56.5% and 60.2%; a higher ratio heats the mixture so much that it ignites by itself: **knock**

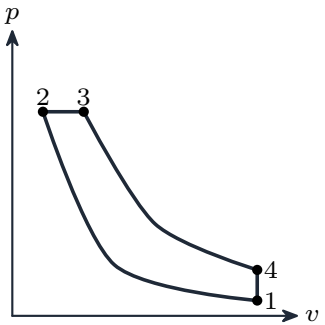
Exercise 2.2

2.2 A Diesel cycle has $r = 18$ and $r_c = 2.0$. Find its ideal efficiency, and compare with an Otto cycle of the same r. [3]



Exercise 2.2

2.2 A Diesel cycle has $r = 18$ and $r_c = 2.0$. Find its ideal efficiency, and compare with an Otto cycle of the same r. [3]

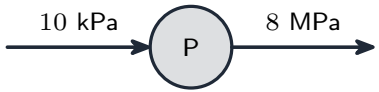


2.2

$\dfrac{r_c^k - 1}{k(r_c - 1)} = \dfrac{1.639}{1.4} = 1.171$; $\eta = 1 - 0.315 \times 1.171 = \mathbf{63.2}\%$; Otto at $r = 18$ would give 68.5%; Diesel engines win because they can use much higher r

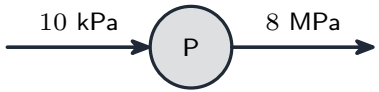
Exercise 2.3

2.3 In a Rankine cycle, water at 10 kPa ($v = 0.00101$ m^3/kg) is pumped to 8 MPa. Find the pump work, and explain why it is so small compared with the compressor work in a gas turbine. [2]



Exercise 2.3

2.3 In a Rankine cycle, water at 10 kPa ($v = 0.00101$ m^3/kg) is pumped to 8 MPa. Find the pump work, and explain why it is so small compared with the compressor work in a gas turbine. [2]

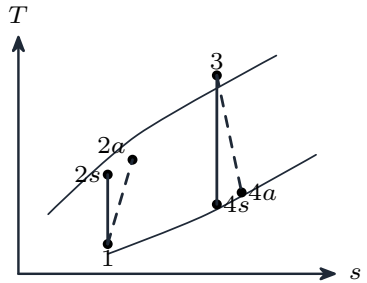


2.3

$w_P = v\Delta p = 0.00101 \times 7990 = \mathbf{8.1\ kJ/kg}$; a liquid has a tiny v, about 1/1000 of a gas, so it takes little work to pressurise

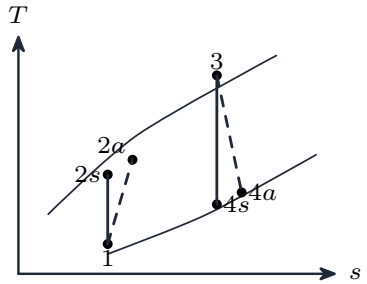
Exercise 2.4

2.4 The Brayton cycle in worked example 2 has a compressor with $\eta_C = 0.85$ and a turbine with $\eta_T = 0.88$. Find the real compressor and turbine work, the net work and the efficiency. [4]



Exercise 2.4

2.4 The Brayton cycle in worked example 2 has a compressor with $\eta_C = 0.85$ and a turbine with $\eta_T = 0.88$. Find the real compressor and turbine work, the net work and the efficiency. [4]



2.4

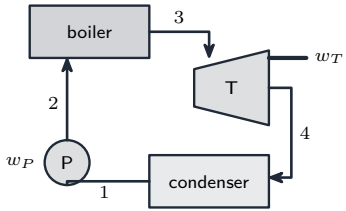
$$w_C = \frac{281}{0.85} = 330 \text{ kJ/kg},\ w_T = 0.88 \times 678 = 597 \text{ kJ/kg};\ w_{net} = \mathbf{267\ kJ/kg}$$

$$T_{2a} = 300 + \frac{330}{1.005} = 629 \text{ K},\ q_{in} = 1.005(1400 - 629) = 775 \text{ kJ/kg};\ \eta = \mathbf{34.4}\%$$

Exercise 3.1

3.1 An ideal Rankine cycle has the boiler at 8 MPa, 500°C ($h_3 = 3399.5$ kJ/kg, $s_3 = 6.7266$ kJ/(kg K)) and the condenser at 10 kPa ($h_f = 191.81$, $h_{fg} = 2392.1$ kJ/kg, $s_f = 0.6492$, $s_{fg} = 7.4996$ kJ/(kg K), $v_f = 0.00101$ m^3/kg).

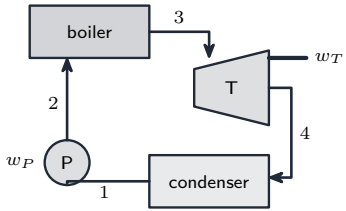
Find the enthalpy at each state, the thermal efficiency, the back-work ratio and the turbine exit quality. [6]



Exercise 3.1

3.1 An ideal Rankine cycle has the boiler at 8 MPa, 500°C ($h_3 = 3399.5$ kJ/kg, $s_3 = 6.7266$ kJ/(kg K)) and the condenser at 10 kPa ($h_f = 191.81$, $h_{fg} = 2392.1$ kJ/kg, $s_f = 0.6492$, $s_{fg} = 7.4996$ kJ/(kg K), $v_f = 0.00101$ m^3/kg).

Find the enthalpy at each state, the thermal efficiency, the back-work ratio and the turbine exit quality. [6]



3.1

$h_1 = 191.81$; $h_2 = 191.81 + 8.07 = 199.88$ kJ/kg

$$x_4 = \frac{6.7266 - 0.6492}{7.4996} = 0.810,\ h_4 = 2130.3 \text{ kJ/kg}$$

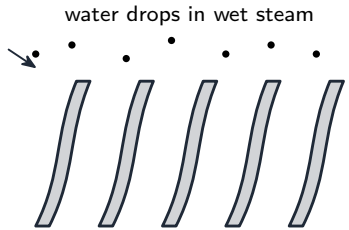
$$w_T = 1269.2,\ q_{in} = 3199.6 \text{ kJ/kg};\ \eta = \frac{1269.2 - 8.1}{3199.6} = \mathbf{39.4}\%$$

back-work ratio = $\mathbf{0.6}\%$; $x_4 = \mathbf{0.81}$

Exercise 3.2

3.2 Turbine blades are damaged by water drops when the exit quality is below about 0.88.

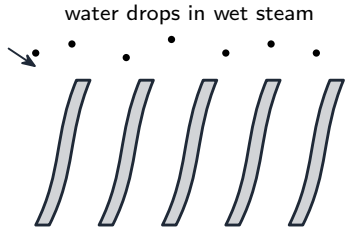
Explain two changes to the cycle in 3.1 that raise the exit quality, and the effect of each on the efficiency. [3]



Exercise 3.2

3.2 Turbine blades are damaged by water drops when the exit quality is below about 0.88.

Explain two changes to the cycle in 3.1 that raise the exit quality, and the effect of each on the efficiency. [3]



3.2

reheat : expand part way, heat the steam again, then expand: drier exit, efficiency about the same or a little higher

a higher boiler **temperature** moves state 3 to higher entropy: drier exit and higher efficiency (limited by the metal)

Exercise 3.3 (a)

3.3 The real gas turbine of practice question 2.4 ($T_{2a} = 629$ K, $w_{net} = 267$ kJ/kg) gets a regenerator with effectiveness 0.80: the compressed air is heated from T_{2a} by 80% of the gap up to the turbine exit temperature T_{4a}.

(a) Find T_{4a}, and show that a regenerator can work here. [2]

Exercise 3.3 (a)

3.3 The real gas turbine of practice question 2.4 ($T_{2a} = 629$ K, $w_{net} = 267$ kJ/kg) gets a regenerator with effectiveness 0.80: the compressed air is heated from T_{2a} by 80% of the gap up to the turbine exit temperature T_{4a}.

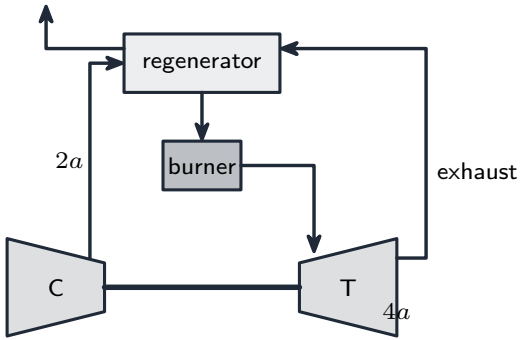
(a) Find T_{4a}, and show that a regenerator can work here. [2]

(a) $T_{4a} = 1400 - \dfrac{597}{1.005} = \mathbf{806\ K}$; $806 > 629$ K, so the exhaust can heat the compressed air

Exercise 3.3 (b)

3.3 The real gas turbine of practice question 2.4 ($T_{2a} = 629$ K, $w_{net} = 267$ kJ/kg) gets a regenerator with effectiveness 0.80: the compressed air is heated from T_{2a} by 80% of the gap up to the turbine exit temperature T_{4a}.

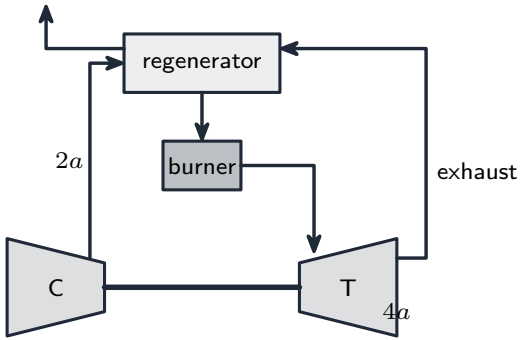
(b) Find the new heat input and efficiency. [3]



Exercise 3.3 (b)

3.3 The real gas turbine of practice question 2.4 ($T_{2a} = 629$ K, $w_{net} = 267$ kJ/kg) gets a regenerator with effectiveness 0.80: the compressed air is heated from T_{2a} by 80% of the gap up to the turbine exit temperature T_{4a}.

(b) Find the new heat input and efficiency. [3]



(b) $T_x = 629 + 0.80(806 - 629) = 771$ K; $q_{in} = 1.005(1400 - 771) = \mathbf{633\ kJ/kg}$; $\eta = \dfrac{267}{633} = \mathbf{42}\%$, up from 34%

Exercise 3.3 (c)

3.3 The real gas turbine of practice question 2.4 ($T_{2a} = 629$ K, $w_{net} = 267$ kJ/kg) gets a regenerator with effectiveness 0.80: the compressed air is heated from T_{2a} by 80% of the gap up to the turbine exit temperature T_{4a}.

(c) The designer wants $r_p = 20$. Then $T_{2a} = 778$ K and $T_{4a} = 691$ K. Decide whether to keep the regenerator, and explain. [3]

Exercise 3.3 (c)

3.3 The real gas turbine of practice question 2.4 ($T_{2a} = 629$ K, $w_{net} = 267$ kJ/kg) gets a regenerator with effectiveness 0.80: the compressed air is heated from T_{2a} by 80% of the gap up to the turbine exit temperature T_{4a}.

(c) The designer wants $r_p = 20$. Then $T_{2a} = 778$ K and $T_{4a} = 691$ K. Decide whether to keep the regenerator, and explain. [3]

(c) now $T_{4a} = 691 < T_{2a} = 778$ K: the regenerator would **cool** the compressed air and waste fuel; drop it at high r_p, or keep r_p low and use the regenerator