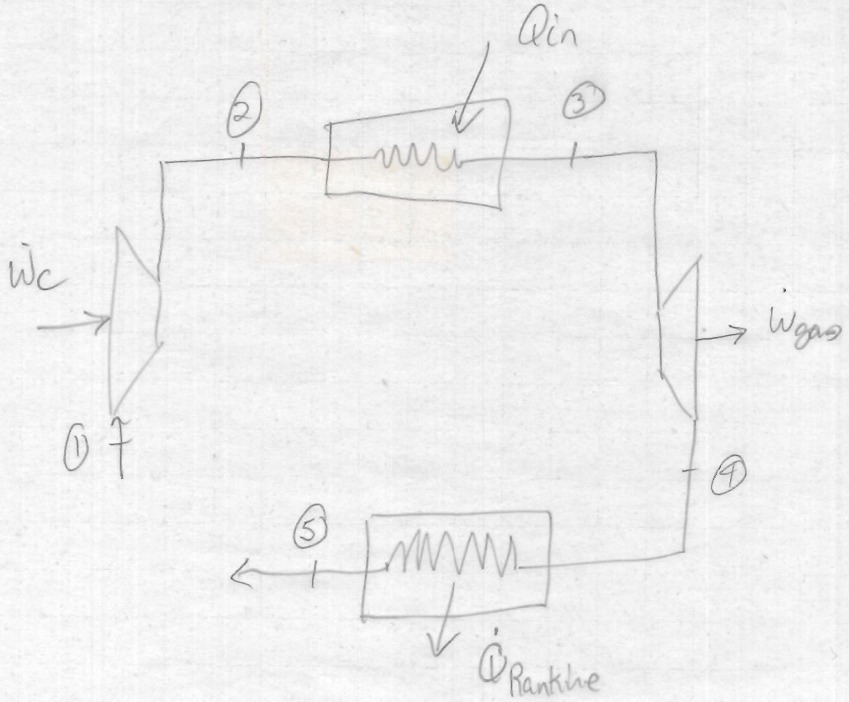
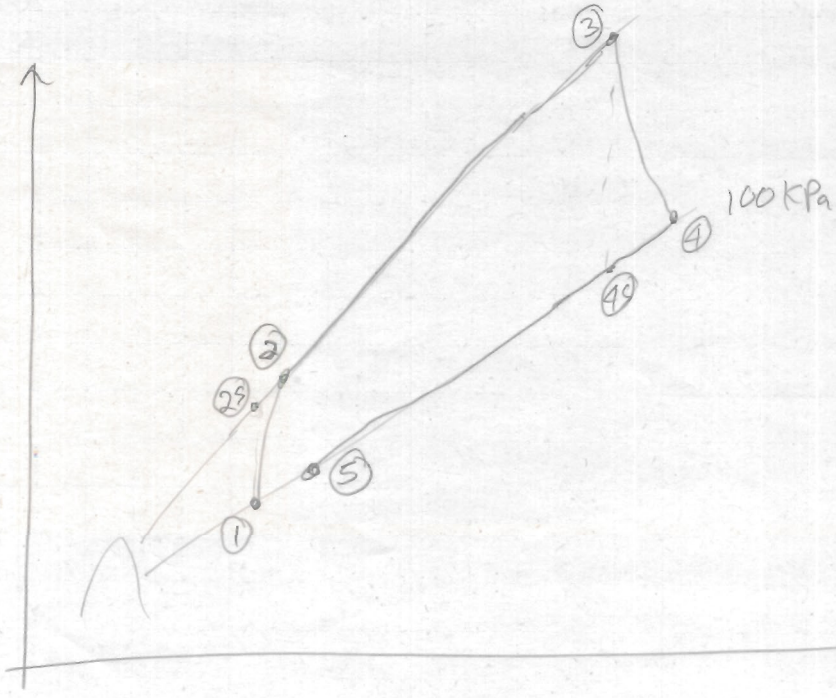
Combined cycle question

Brayton cycle portion:



(7)

a)



- 1 mark for each ~~state~~ point
- 1 mark for each isobar

Given:

$T_1 = 300\,K$

$P_1 = 100\,kPa = P_4$

$P_2 = P_3 = 1.1\,MPa$

$\eta_c = 0.9$

$\dot{m} = 100\,kg/s$

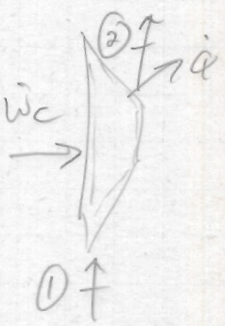
$\dot{Q}_{in} = 75\,MW$

$\eta_t = 0.92$

$T_5 = 420\,K$

compressor

2 marks for 1st law + assumptions



$$\frac{dE_{CV}}{dt} = \dot{W}_c - \dot{Q} + \dot{m}\left(h + \frac{V^2}{2} + gz\right)_1 - \dot{m}\left(h + \frac{V^2}{2} + gz\right)_2$$

(ss; assume adiabatic; ignore ΔKE & ΔPE effects)

$$\dot{W}_c = \dot{m}(h_2 - h_1)$$

$$\dot{W}_{cs} = \dot{m}(h_{2s} - h_1)$$

1 mark isentropic compressor: $\frac{P_{r2}}{P_{r1}} = \frac{P_2}{P_1} = \frac{1.1\ MPa}{100\ kPa} \cdot \frac{1000\ kPa}{MPa}$

$$P_{r2} = (11)(P_{r1})$$

1 mark for lookup

$T_1 = 300K$: $P_{r1} = 1.3860$, $h_1 = 300.19\ \frac{kJ}{kg}$ } Table A-22

$$\therefore P_{r2} = (11)(1.3860) = 15.246$$

$$\frac{T_{2s} - 580}{590 - 580} = \frac{15.246 - 14.38}{15.31 - 14.38}$$

$$\Rightarrow T_{2s} = 589.3K$$ (interpolated from Table A-22)

1 mark ---- kJ

$$\eta_C = \frac{\dot{W}_{cs}/\dot{m}}{\dot{W}_c/\dot{m}} = \frac{h_{2s} - h_1}{h_2 - h_1}$$

1 mark for η_C & $\dot{W}_C$ answer

$$\Rightarrow h_2 = h_1 + \frac{1}{\eta_C}(h_{2s} - h_1)$$

$$= 300.19 + \frac{(595.8 - 300.19)}{0.9}$$

$$= 628.6 \ \frac{KJ}{Kg}$$

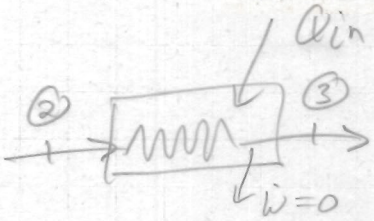
2 marks for h_2 & T_2 interpolation

(2) c) $\boxed{T_2 = 620.5°C}$ (interpolated from Table A-22)

(6) b) $\dot{W}_C = \dot{m}(h_2 - h_1) = (100 \ \frac{Kg}{s})(628.6 - 300.19) \ \frac{KJ}{Kg} \cdot \frac{1 KW}{KJ/s} \cdot \frac{1 MW}{1000 KW}$

$\boxed{\dot{W}_C = 32.8 MW}$

Combustor



1 mark for 1st law + assumptions

$$\frac{dE_{cv}}{dt} = \dot{Q}_{in} - \dot{W} + \dot{m}\left(h + \frac{V^2}{2} + gz\right)_2 - \dot{m}\left(h + \frac{V^2}{2} + gz\right)_3$$

(no work; neglect ΔKE & ΔPE effects)

$$\dot{Q}_{in} = \dot{m}(h_3 - h_2)$$

$$h_3 = \frac{\dot{Q}_{in}}{\dot{m}} + h_2$$

$$= \frac{75 MW}{100 Kg/s} \cdot \frac{1000 KW}{MW} \cdot \frac{KJ/s}{KW} + 628.6 \ \frac{KJ}{Kg}$$

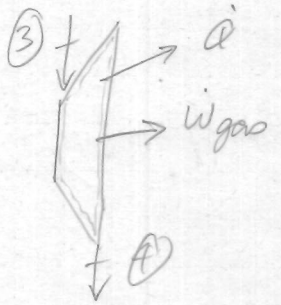
$$h_3 = 1378.6 \ \frac{KJ}{Kg}$$ 1 mark

1 mark

(3) d) $\Rightarrow \boxed{T_3 = 1285.4K}$ (interpolated from Table A-22)

turbine

2 marks for 1st law and assumptions



$$\frac{dE_{CV}}{dt} = -\dot{W}_{gas} - \cancel{\dot{Q}} + \dot{m}\left(h + \frac{V^2}{2} + gz\right)_3 - \dot{m}\left(h + \frac{V^2}{2} + gz\right)_4$$

(steady state; assume adiabatic; ignore ΔKE & ΔPE effects)

$$\dot{W}_{gas} = \dot{m}(h_3 - h_4)$$

$$\dot{W}_{gas,s} = \dot{m}(h_3 - h_{4s})$$

isentropic turbine: $\frac{P_{r4}}{P_{r3}} = \frac{P_4}{P_3}$ 1 mark

$$P_{r4} = \frac{100\ kPa}{1100\ kPa}(315.9)$$ ← interpolated from Table A-22; 1 mark

$$P_{r4} = 28.72$$

$\Rightarrow T_{4s} = 699.5$ (interpolated from Table A-22)

$\Rightarrow h_{4s} = 712.7\ \frac{kJ}{kg}$ 1 mark

$$\eta_t = \frac{\dot{W}_{gas}/\dot{m}}{\dot{W}_{gas,s}/\dot{m}} = \frac{h_3 - h_4}{h_3 - h_{4s}}$$

$$\Rightarrow h_4 = h_3 - \eta_t(h_3 - h_{4s})$$ 1 mark for η_t & $\dot{W}_{gas}$ answer

$$= 1378.6 - (0.92)(1378.6 - 712.7)\ \frac{kJ}{kg}$$

$$= 764.0\ \frac{kJ}{kg}$$

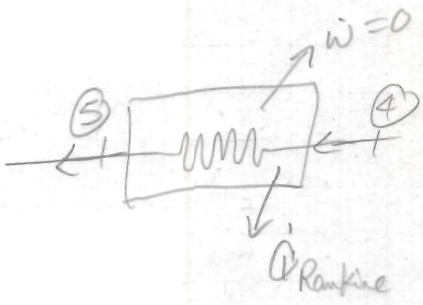
2 marks for h_4 calc and T_4 interpolation

(2) f) $\Rightarrow \boxed{T_4 = 748.8\ K}$

$$\dot{W}_{gas} = \dot{m}(h_3 - h_4) = \left(100 \tfrac{kg}{s}\right)(1378.6 - 766.0)\tfrac{kJ}{kg} \cdot \tfrac{1kW}{1kJ/s}$$

(6) e) $\boxed{\dot{W}_{gas} = 61.3\ MW}$

heat exchanger



2 marks for 1st law + assumptions

SS, no work, ignore ΔKE & ΔPE

$$\frac{dE_{cv}}{dt} = -\dot{Q}_{Rankine} - \dot{W} + \dot{m}\left(h + \frac{V^2}{2} + gz\right)_4 - \dot{m}\left(h + \frac{V^2}{2} + gz\right)_5$$

$$\dot{Q}_{Rankine} = \dot{m}(h_4 - h_5)$$

$T_5 = 420\ K$ (given) $\Rightarrow h_5 = 421.26\ \frac{kJ}{kg}$ 1 mark for h_5 calc

h_4 solved when treating turbine

$$\dot{Q}_{Rankine} = \left(100 \tfrac{kg}{s}\right)(766.0 - 421.26)\tfrac{kJ}{kg}$$ 1 mark for $\dot{Q}_{Rankine}$ calc

(4) g) $\boxed{\dot{Q}_{Rankine} = 34.5\ MW}$