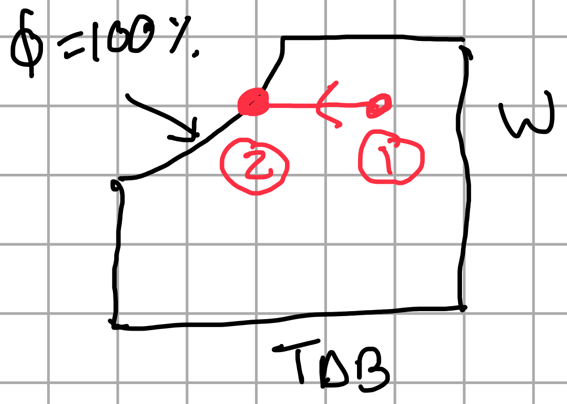
ME 40 - Final Exam Solutions

Short answer:

① A throttling process = constant enthalpy

② Air is cooled from $\phi_1 = 40\%$ to $\phi_2 = 100\%$

↳ w must be const



③ On a psych chart, Constant wet bulb means approximately const enthalpy

④ The adiabatic flame temp, T_{af} gets higher as we approach stoichiometric conditions.

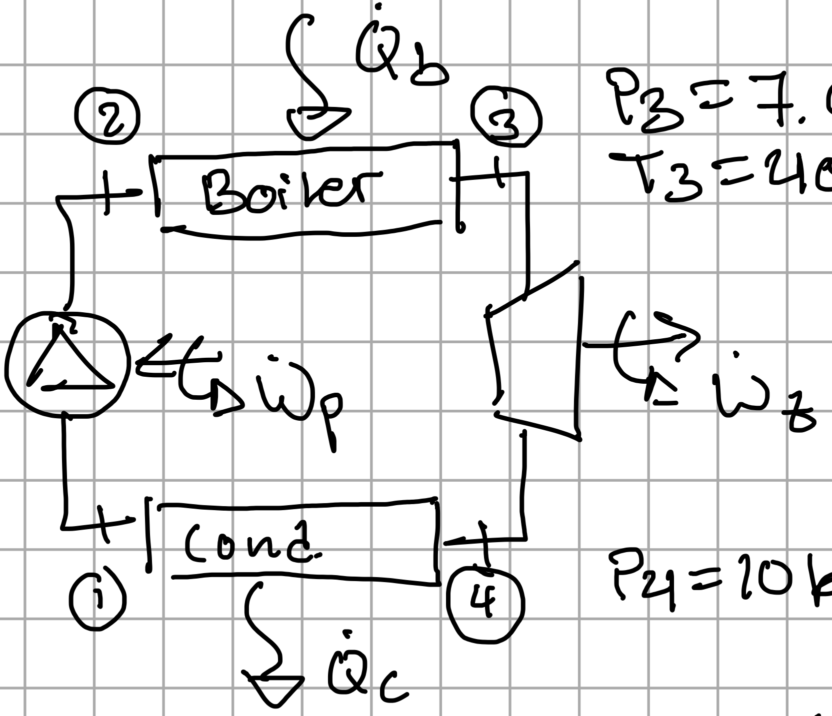
So if α decreases, T_{af} will increase if α is above stoichiometric conditions as we are getting closer to the ideal state

⑤ For a process at Const T, P

$G = U + P\cancel{V} - TS$ → Spontaneous process: $dG < 0$

① Rankine Cycle $\dot{m} = 75.0\ kg/s$

$P_3 = 7.0\ MPa$

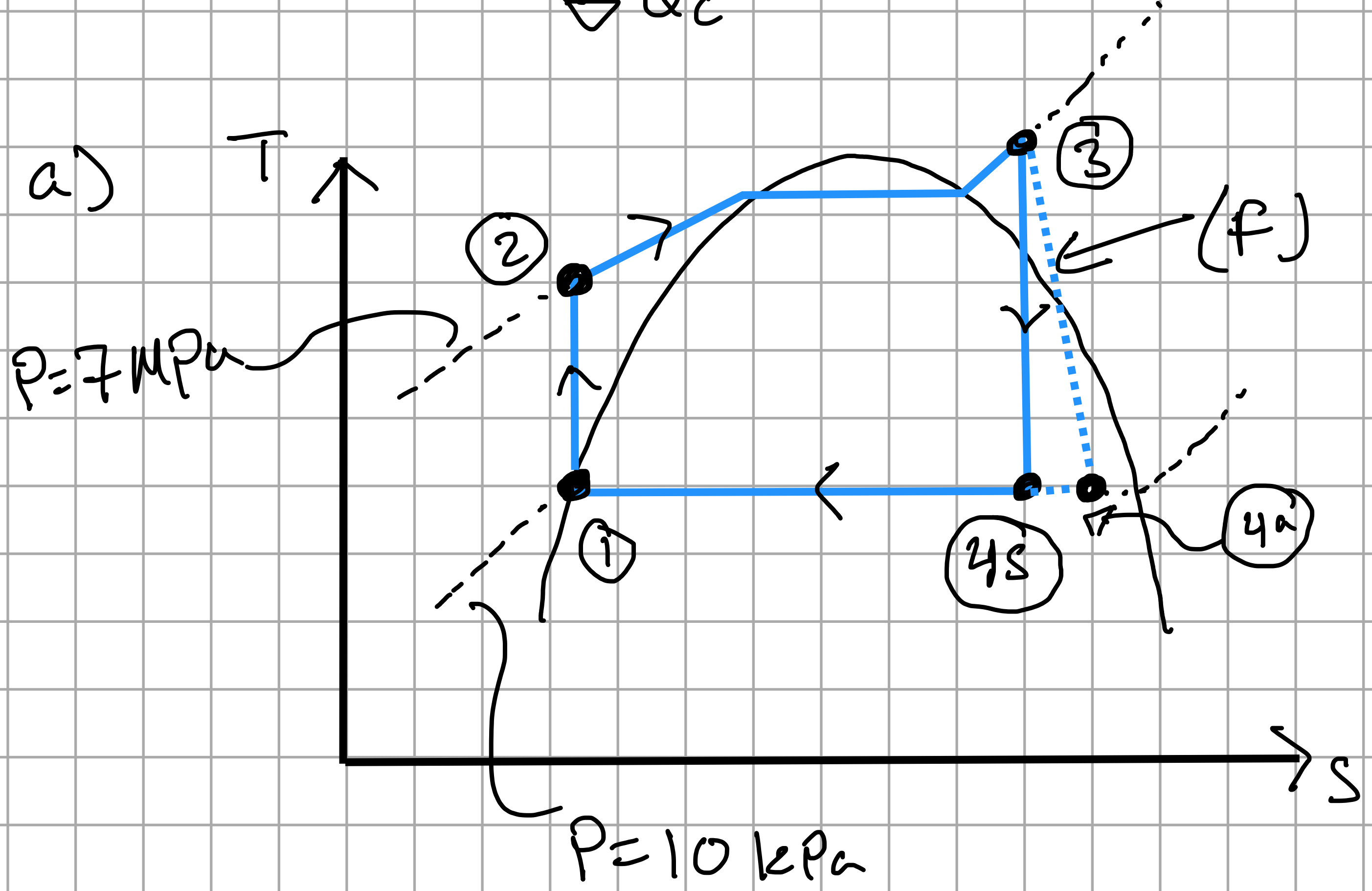


$P_3 = 7.0\ MPa$
$T_3 = 400°C$

$P_1 = 10\ kPa$
- Sat. Liquid

$P_4 = 10\ kPa$

a)



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

$\dot{W}_{net} = \dot{W}_t - \dot{W}_p$

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

$\eta = \frac{\dot{W}_{net}}{\dot{Q}_{in}}$

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

State 1: Sat. Liquid at 10 kPa

↳ Table A-5: $h_1 = 191.81$ kJ/kg
$v_1 = 0.001010$ m³/kg

State 2: Use Reversible work definition for a pump

$\dot{W} = \dot{m}(h_2 - h_1)$ $\dot{W}_{rev} = \dot{m}\int_{P_1}^{P_2} v\,dP$

- for a pump, $\Delta v = 0$ due to incompressibility

↳ $\dot{W} = \cancel{\dot{m}}(h_2 - h_1) = \cancel{\dot{m}} v_1 (P_2 - P_1)$

↳ $h_2 = v_1(P_2 - P_1) + h_1$

$= 0.001010(7000 - 10) + 191.81 = 198.87$ kJ/kg

State 3: SH vapor @ 400°C and 7 MPa

↳ Table A-6: $h_3 = 3159.2$ kJ/kg
$S_3 = 6.4502$ kJ/kg·K

State 4: $P = 10$ kPa, $S_3 = S_4 = 6.4502$
↳ turbine is reversible & adiabatic → $\Delta S = 0$

↳ Table A-5: $S_f = 0.6492$ kJ/kg·K
$S_g = 8.1488$ kJ/kg·K
$S_{fg} = 7.4996$ kJ/kg·K

$S_f < S < S_g$ → 2 phase region

Find Quality: $x = \dfrac{S_4 - S_f}{S_{fg}} = \dfrac{6.4502 - .6492}{7.4996}$

$$x = 0.774$$

Find h_4: $h_4 = h_f + x(h_{fg})$

$h_f = 191.81$ kJ/kg
$h_{fg} = 2392.1$ kJ/kg

$\hookrightarrow h_4 = 191.81 + (0.774)(2392.1) = 2042.12$ kJ/kg

b) $\dot{W}_p = \dot{m}(h_2 - h_1) = 75(198.87 - 191.81)$

$$\boxed{\dot{W}_p = 529.5 \text{ kW}}$$

c) $\dot{Q}_{in} = \dot{m}(h_3 - h_2) = 75(3159.2 - 198.87)$

$$\boxed{\dot{Q}_b = 222024.75 \text{ kW}}$$

d) $\dot{W}_t = \dot{m}(h_3 - h_4) = 75(3159.2 - 2042.12)$

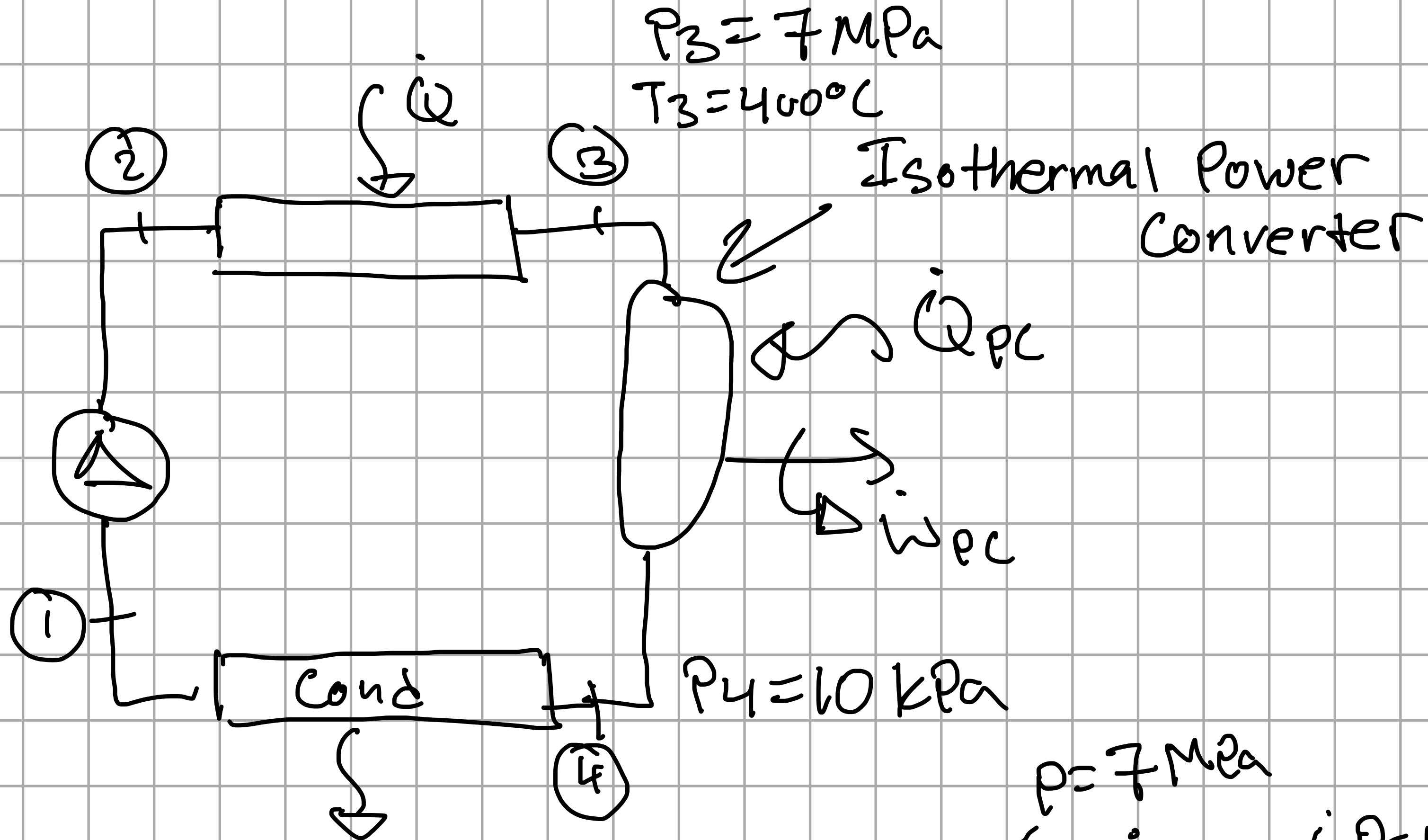
$$\boxed{\dot{W}_t = 83781 \text{ kw}}$$

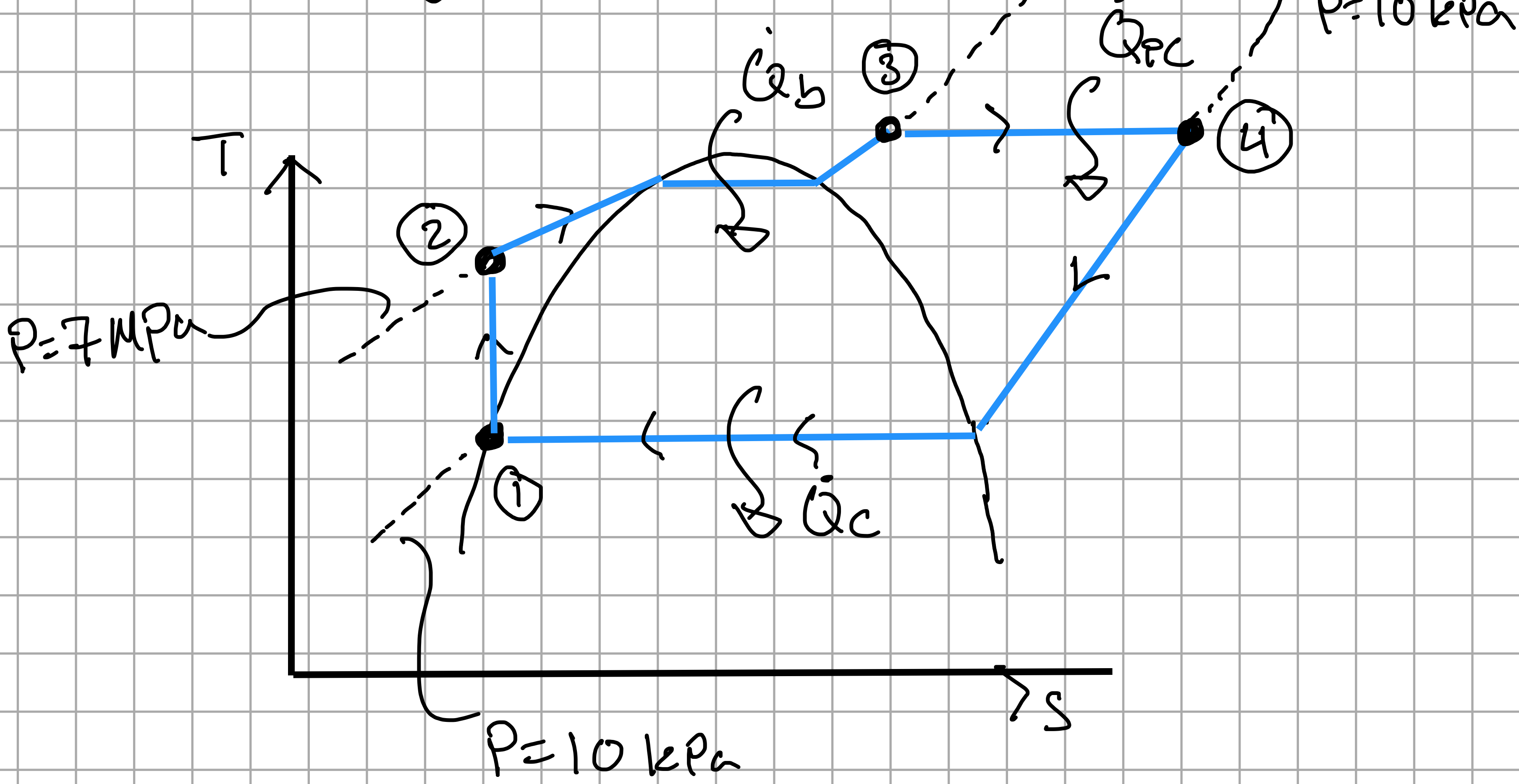
e) $\eta = \dfrac{\dot{W}_{net}}{\dot{Q}_b} = \dfrac{\dot{W}_t - \dot{W}_p}{\dot{Q}_b} = \dfrac{83781 - 529.5}{222024.75}$

$$\boxed{\eta = 0.3749}$$

f) See T-S diagram

g)





h) $\dot{Q}_{PC} + \dot{m}h_3 = \dot{W}_{PC} + \dot{m}h_4$ (1st Law Balance)

$\dot{W}_{PC} = \dot{Q}_{PC} + \dot{m}(h_3 - h_4)$ $\dot{Q}_{PC} = 120000$ kW

From before: $h_3 = 3159.2$ kJ/kg

State 4: SH Vapor $P = 10\ \text{kPa},\ T = 400^\circ C$

↳Table A-6: $h_4 = 3280.0\ \text{kJ/kg}$

↳ $\dot{W}_{pc} = 120\,000 + 75(3154.2 - 3280.0)$

$$\boxed{\dot{W}_{pc} = 110940\ \text{kW}}$$

(i) $\eta = \dfrac{\dot{W}_{net}}{\dot{Q}_{in}} = \dfrac{\dot{W}_{pc} - \dot{W}_{p}}{\dot{Q}_{b} + \dot{Q}_{pc}} = \dfrac{110940 - 529.5}{222624 + 120000}$

$$\boxed{\eta = 0.323}$$

2. combustion

a) $C_3H_8 + a(O_2 + 3.76N_2) \rightarrow bCO_2 + cH_2O$

$+ dN_2$

$b = 3$

$c = 4$

$a(2) \rightarrow b(2) + c(7)$

$a = 5$

$d = 18.8.$

b) molar fuel - air ratio

$\frac{1\text{kmol}}{5\text{kmol}}$

c) $\frac{dE}{dt} = \dot{Q}_{in} - \dot{Q}_{out} + \Sigma H_{react} - \Sigma H_{products}$

Reactants:

$C_3H_8 \rightarrow -103{,}850 \text{ kJ/kmol} + h(\cancel{298}) - h(\cancel{298})$

$O_2 \rightarrow 0 + h(\cancel{298}) - h(29\cancel{8}) -$

$N_2 \rightarrow 0 + h(\cancel{298}) - h(\cancel{298})$

Products:

$CO_2 \rightarrow -393{,}520 + h(700) - h(298)$

$H_2O \rightarrow -285{,}830 + h(700) - h(298)$

$N_2 \rightarrow 0 + h(700) - h(298)$

CO_2

h(700) = 27,125 kJ/kmol

h(298) = 9364 kJ/kmol

H_2O (vapor)

h(700) = 24,088 kJ/kmol

h(298) = 9,904 kJ/kmol

N_2

h(700) = 20,604 kJ/kmol

h(298) = 8,669 kJ/kmol

$$\dot{Q}_{out} = .2\Big[-103{,}850 \text{ kJ/kmol} - 3(-393{,}520 + 27125 - 9364) - 4(-285{,}830 + 24088 - 9904) - 18.8(0 + 20{,}604 - 8669)\Big]$$

$\dot{Q}_{out}$ = 397,875.83 kW