ME 40 | Midterm 1 | Ryan Dimick

Multiple Choice Section:

① For a reversible & adiabatic process, $\Delta S = 0$

↳ (b) Se always equals Si

② $m = 1\,kg$
$T_2 = T_1$
$P_2 = 2P_1$

Assumptions:
- Const specific heats

$$S_2 - S_1 = C_p \ln\left|\frac{T_2}{T_1}\right| - R\ln\left|\frac{P_2}{P_1}\right|$$

$$= 0 - R\ln|2| \rightarrow \boxed{S_2 - S_1 = -R\ln(2)}$$

③ $v = 0.001\,m^3/kg$
$P_1 = 100\,kPa$
$P_2 = 300\,kPa$

Assumptions:
- $\Delta KE = 0$
- $\Delta PE = 0$
- v is constant through a pump

Min Work = Reversible work: $W_{rev} = \int_1^2 v\,dP$

$$W_{rev} = v_1 \int_1^2 dP = v_1(P_2 - P_1) = 0.001(300 - 200)$$

$$\boxed{W_{rev} = 0.200\,kJ/kg}$$

④ A carnot cycle may not contain process that are irreversible

⑤ $T_H = 20°C$
$T_L = 0°C$

$$\eta_{carnot} = 1 - \frac{T_L}{T_H} = 1 - \frac{(0+273)}{(20+273)}$$

$$\boxed{\eta_c = 1 - \frac{(273)}{293}}$$

Free Response:

Assumptions
- Ideal gas w/ Const C_p/C_v
-

① Given:

$m = 0.5\,kg$
$P_1 = 100\,kPa$
$T_1 = 10°C$
$R = 2.077\,kJ/kg\cdot K$ (ideal gas)
$C_v = 3.116\,kJ/kg\cdot K$ (constant specific heats)
$P_0 = 500\,kPa$ = atmospheric pressure

a) Piston will begin to move when the pressure in the piston exceeds the atmospheric pressure

↳ $P_2 = 500\,kPa$
↳ $V_2 = V_1$ (No volume change before piston moves)

I Law for a closed system:

$Q_{12} = \Delta U_{12} + \underbrace{\cancel{W_{exp}}}_{0}$ • neglect expansion work since volume doesnt change.

$Q_{12} = \Delta U_{12} = m C_v \Delta T_{12}$ • using equation for const specific heat

$P_1 V_1 = R T_1 \rightarrow \frac{P_1}{T_1} = \text{const} \rightarrow \frac{P_1}{T_1} = \frac{P_2}{T_2}$ • use of ideal gas law

↳ $\frac{100\,kPa}{(10+273)} = \frac{500\,kPa}{T_2} \rightarrow T_2 = 1415\,K = 1142°C$

→ $Q_{12} = \Delta U_{12} = m C_v \Delta T_{12} = (0.5)(3.116)(1142-10)$

$\boxed{Q_{12} = 1763.656\,kJ}$

b) $\Delta S_{12} = m(s_2 - s_1) = m\left[C_v \ln\left|\frac{T_2}{T_1}\right| + \overset{0}{\cancel{R \ln\left|\frac{V_2}{V_1}\right|}}\right]$ (constant volume)

↳ entropy change for ideal gas w/ const specific heats.

$= (0.5)\left[3.116 \ln\left|\frac{1415}{283}\right|\right]$

$\boxed{\Delta S_{12} = 2.507\,\frac{kJ}{K}}$

c) $\Delta S_{res} = \frac{Q_{res}}{T_R} = -\frac{Q_{12}}{T_R}$
$= \frac{-1763.56}{2000} = \boxed{-0.882\,\frac{kJ}{K}}$

- No, they should not be equal. A heat transfer over a finite ΔT is an irreversible process and will lead to some entropy generation.

② Given:

- adiabatic turbine ($\dot{Q}w = 0$) } Assumptions
- Steady state (Neglect ΔKE and ΔPE) }
- $P_1 = 3.0$ MPa
- $T_1 = 300°C$
- $\dot{m}_1 = 14.0$ kg/s
- $P_2 =$ 0.5 MPa at sat. vapor state
- $P_3 = 5.0$ kPa
- Process 1 → 2 is irreversible
- Process 2 → 3 is reversible

a) State 1: At 300°C, $P_{sat} = 8.547$ MPa (Table A-4)
↳ $P_1 < P_{sat}$ so this is a superheated vapor

→ at 3MPa, 300°C: $h_1 = 2994.3$ kJ/kg (Table A-6)
$s_1 = 6.5412$ kJ/kg·k

State 2: At 0.5MPa, Sat. vapor state:

$h_2 = h_g(0.5\text{MPa}) = 2748.1$ kJ/kg (Table A-5)
$s_2 = s_g(0.5\text{ MPa}) = 6.8207$ kJ/kg·k

State 3: Given that process 2-3 is reversible and adiabatic, this is an isentropic process:

$$s_3 = s_2 = 6.8207 \text{ kJ/kg·k}$$

↳ At $P_3 = 5.0$ kPa, $s_3 = 6.8207$ kJ/kg·k :

$s_f = 0.4762$ } $s_f < s < s_g$ → 2-phase mixture
$s_g = 8.3938$ }
(Table A-5)

- Find quality: $x = \frac{s_3 - s_f}{s_g - s_f} = \frac{6.8207 - 0.4762}{8.3938 - 0.4762} = 0.801$

- Use quality to determine h_3:

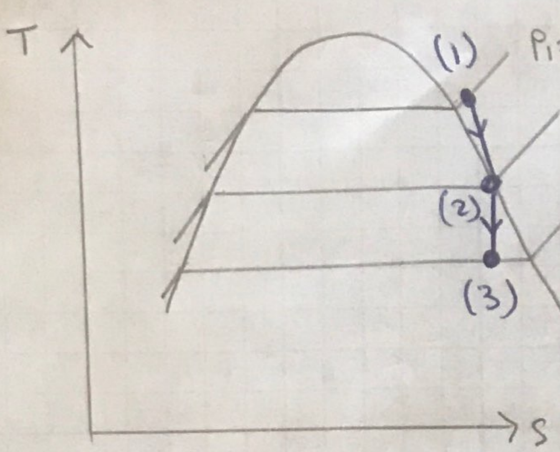
$h_3 = h_f + x(h_{fg})$ → $h_f = 137.75$ kJ/kg
$h_{fg} = 2423.0$ kJ/kg
↳ $h_3 = 137.75 + (0.801)(2423.0)$

$h_3 = 2079.34$ kJ/kg
$s_3 = 6.8207$ kJ/kg-k

$h_1 = 2994.3$ kJ/kg
$s_1 = 6.5412$ kJ/kg·k

$h_2 = 2748.1$ kJ/kg
$s_2 = 6.8207$ kJ/kg

b)



c) Set up open system balance equations: Steady State

I Law balance: $\cancel{\dot{Q}_{in}} + \dot{W}_{in} + \sum \dot{m}_{in}(h_{in} + \cancel{KE_{in}} + \cancel{PE_{in}})$

$= \cancel{\dot{Q}_{out}} + \dot{W}_{out} + \sum \dot{m}_{out}(h_{out} + \cancel{KE_{out}} + \cancel{PE_{out}})$

- neglect $\dot{W}_{in}$, $\dot{Q}_{in}$, $\dot{Q}_{out}$, KE, PE

$\dot{m}_1 h_1 = \dot{W}_{out} + \dot{m}_2 h_2 + \dot{m}_3 h_3$ Given: $\dot{W}_{out} = 11800$ kW

Mass Balance: $\sum \dot{m}_{in} = \sum \dot{m}_{out} \rightarrow \dot{m}_1 = \dot{m}_2 + \dot{m}_3$
- Conservation of mass

$14 = \dot{m}_2 + \dot{m}_3 \rightarrow 14 - \dot{m}_2 = \dot{m}_3$

$\rightarrow (14)(2994.3) = 11800 + \dot{m}_2(2748.1) + (14 - \dot{m}_2)(2079.4)$

$= 11800 + \dot{m}_2(2748.1) + 14(2079.4) - \dot{m}_2(2079.4)$

$1008.64 = \dot{m}_2(668.7) \rightarrow \boxed{\begin{array}{l}\dot{m}_2 = 1.508\text{ kg/s}\\ \dot{m}_3 = 12.49\text{ kg/s}\end{array}}$

d) II Law Open System balance:

$\dot{S}_{gen} = \sum \dot{m}_e s_e - \sum \dot{m}_i s_i - \overset{0\text{ (adiabatic)}}{\cancel{\sum \frac{\dot{Q}}{T}}} = \dot{m}_2 s_2 + \dot{m}_3 s_3 - \dot{m}_1 s_1$

$= 1.508(6.8207) + 12.49(6.8207) - 14(6.5412)$

$\boxed{\dot{S}_{gen} = 3.913\ \frac{kW}{K}}$