

## Exam II Solution

### 1) Theorem of Clausius

Any work cycle can be broken into an equivalent number of adiabatic and isothermal steps

b) 2 types of perpetual motion machines are:

1) A machine that transfer heat from a cold source to a hot source

2) A machine that transfer a single state entirely to work

c) fundamental relationship in terms of enthalpy

$$dH = TdS + Vdp$$

d)  $\Delta S = 0$

e)  $\left(\frac{\partial U}{\partial V}\right)_T = T\left(\frac{\partial P}{\partial T}\right)_V - P$

f)  $\eta = 1 - \frac{T_c}{T_H}$  find  $\Delta\eta$

$$T_{H1} = 450^\circ\text{C} = 450 + 273 = 723\text{K}$$

$$T_c = 25 + 273 = 298\text{K}$$

$$T_{H2} = 1000^\circ\text{C} = 1000 + 273 = 1273\text{K}$$

$$\eta_1 = 1 - \frac{298\text{K}}{723} = 0.5878$$

$$\eta_2 = 1 - \frac{298}{1273} = 0.7659$$

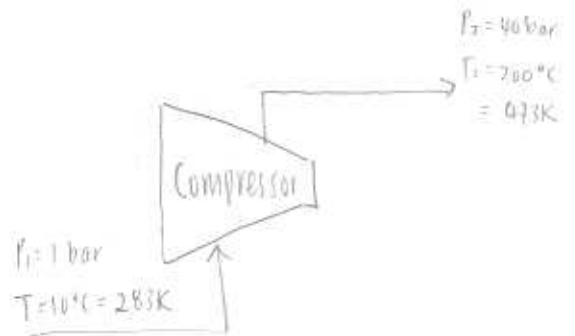
$$\Delta\eta = \eta_2 - \eta_1 = 0.77 - 0.58 = 0.1781$$

2) Find  $\Delta S$  and  $\Delta H$

a)  $C_2H_2$  is ideal gas

b)  $C_2H_2$  is real gas

c)  $V_2$  (specific volume for ideal/real gas)



a) Ideal gas

$$\frac{\Delta S}{R} = \int_{T_0}^T \frac{C_p^ig}{R} \frac{dT}{T} - \ln \frac{P}{P_0} \quad (\text{Eq. 5.14}) \text{ or } (5)$$

$$\Delta S = \int_{T_0}^T C_p^ig \frac{dT}{T} - R \ln \frac{P}{P_0} \quad (6-87)$$

$$\frac{C_p}{R} = 1.424 + 0.0144T$$

$$C_p = R (1.424 + 0.0144T)$$

$$C_p = 11.839 + 0.1197T$$

$$\Delta S = \int_{283}^{973} (11.839 + 0.1197T) dT = 8.314 \ln \frac{40}{1}$$

$$\Delta S = 10815.6 \frac{J}{\text{mol} \cdot K}$$

$$\Delta H = \int_{T_0}^{T_1} C_p dT \quad (5)$$

$$\Delta H = \int_{283}^{973} (11.839 + 0.1197T) dT$$

$$\Delta H = 10846.3 \frac{J}{\text{mol}}$$

Given that

$$P_c = 50.4 \text{ bar}$$

$$T_c = 282.3 \text{ K}$$

$$W = 0.087$$

$$Z_c = 0.281$$

$$MW = 28.054$$

$$C_p/R = 1.424 + 0.0144T(K)$$

b) Real gas

ideal gas  $\therefore P_1 = 1 \text{ bar}$

$$\Delta S = \int_{T_1}^{T_2} C_p \frac{dT}{T} - R \ln \frac{P_2}{P_1} + S_2^R - S_1^R \quad (\text{Eq. 6.83})$$

$$T_{r,2} = \frac{T_2}{T_c} = \frac{473}{482.3 \text{ K}} = 1.68$$

$$S_2^R = R \left[ \frac{S_0^R}{R} + w \frac{S_1^R}{R} \right] \quad (\text{Eq. 6.77})$$

$$P_{r,2} = \frac{40}{50.4} = 0.79$$

From Lee-Kesler Tables: (Appendix Table E.9 & E.10, p.676-p.677)

$$S_2^R = 8.314 \frac{\text{J}}{\text{mol} \cdot \text{K}} [-0.141 + (0.087)(-0.059)]$$

$$S_2^R = -1.22 \frac{\text{J}}{\text{mol} \cdot \text{K}}$$

$$\Delta S = \underbrace{\int_{T_1}^{T_2} C_p \frac{dT}{T} - R \ln \frac{P_2}{P_1}}_{\text{value from ig.}} + S_2^R$$

$$= 10815.6 - 1.22 \frac{\text{J}}{\text{mol} \cdot \text{K}}$$

$$\boxed{\Delta S = 10814.4 \frac{\text{J}}{\text{mol} \cdot \text{K}}}$$

$$\Delta H = \int_{T_1}^{T_2} C_p dT + H_2^R - H_1^R \quad \text{ideal gas}$$

$$H_2^R = +R T_c \left[ \frac{H_0^R}{R T_c} + w \frac{H_1^R}{R T_c} \right] \quad (\text{Eq. 6.76})$$

From Lee-Kesler Table (Appendix Table E.7-E.8, p.674-p.675)

$$H_2^R = 8.314 \frac{\text{J}}{\text{mol} \cdot \text{K}} (282.3 \text{ K}) [-0.317 + (0.087)(0.011)]$$

$$H_2^R = -741.8 \frac{\text{J}}{\text{mol}}$$

$$\boxed{\Delta H = 10846.3 + (-741.8 \frac{\text{J}}{\text{mol}}) = 10104.5 \frac{\text{J}}{\text{mol}}}$$

c) Specific volume as ideal gas (final condition)

$$P_2 V_2 = R T_2$$

$$V_2 = \frac{R T_2}{P_2} = \frac{83.14 \frac{\text{cm}^3 \text{bar}}{\text{mol K}} (473 \text{K})}{(40 \text{bar})} = 983.1 \frac{\text{cm}^3}{\text{mol}} = 0.983 \frac{\text{L}}{\text{mol}}$$

Real:  $V_2 = \frac{Z R T_2}{P_2}$

Lee-Kessler Tables

$$Z = Z^0 + W Z^1$$

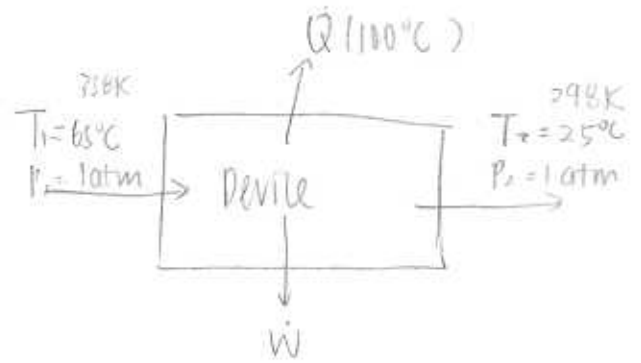
$$Z^0 = 0.9539 \quad Z^1 = 0.0669$$

$$Z = 0.9539 + 0.087(0.0669) = 0.95972$$

$$V_2 = 0.95972 \left( 83.14 \frac{\text{cm}^3 \text{bar}}{\text{mol K}} \right) \left( \frac{473 \text{K}}{40 \text{bar}} \right) = 943.53 \frac{\text{cm}^3}{\text{mol}} = 0.943 \frac{\text{L}}{\text{mol}}$$

3)

$$\Delta S_{\text{Tot}} \geq 0 ?$$



$$\Delta S_{\text{system}} = \left( C_p \ln \frac{T_2}{T_1} + R \ln \frac{P_2}{P_1} \right) \dot{n}$$

$$\dot{n} = 1500 \frac{\text{L}}{\text{min}} \left( \frac{1 \text{ cm}^3}{1 \text{ mL}} \right) \left( \frac{1000 \text{ mL}}{\text{L}} \right) \left( \frac{1 \text{ mol}}{24.775 \text{ cm}^3} \right) = 60.54 \frac{\text{mol}}{\text{min}} \quad C_p = \frac{7}{2} R$$

$$V_{\text{standard}} = \frac{8.314 \frac{\text{cm}^3 \text{ bar}}{\text{mol K}} (298 \text{ K})}{1 \text{ bar}} = \frac{24775.7 \text{ cm}^3}{\text{mol}}$$

$$\Delta S_{\text{system}} = \left( -3.665 \frac{\text{J}}{\text{mol K}} \right) (60.54 \frac{\text{mol}}{\text{min}}) = -221.88 \frac{\text{J}}{\text{min K}}$$

$$\Delta S_{\text{sink}} = \frac{\dot{Q}}{T_c} = \frac{8000 \frac{\text{J}}{\text{min}}}{293 \text{ K}} = 27.3 \frac{\text{J}}{\text{min K}}$$

$$\Delta S_{\text{Tot}} = -221.88 \frac{\text{J}}{\text{min K}} + 27.3 \frac{\text{J}}{\text{min K}} = -194.58 \frac{\text{J}}{\text{min K}}$$

$$\Delta S_{\text{Total}} < 0 \quad \boxed{\text{Not Possible}}$$

$$\Delta H = Q + W$$

$$\dot{n} C_p \Delta T = Q + W$$

$$\dot{n} \left( \frac{7}{2} (8.314 \frac{\text{J}}{\text{mol K}}) \right) (298 - 338) = -8,000 \frac{\text{J}}{\text{min}} - 100 \frac{\text{J}}{\text{s}} \left( \frac{60 \text{ s}}{\text{min}} \right)$$

$$\dot{n} = 12.03 \frac{\text{mol}}{\text{min}}$$

$$PV = RT \quad v = \frac{RT}{P}$$

$$\dot{V} = 12.03 \frac{\text{mol}}{\text{min}} \left( \frac{24775.7 \text{ cm}^3}{\text{mol}} \right) \left( \frac{1 \text{ L}}{1000 \text{ mL}} \right) \left( \frac{1 \text{ mL}}{1 \text{ cm}^3} \right) = 298 \frac{\text{L}}{\text{min}}$$