Quiz 5
Chemical Engineering Thermodynamics
February 17, 2016

1)
P4.12 Ethylene gas is to be continuously compressed from an initial state of 1 bar and 20°C to a final pressure of 18 bar in an adiabatic compressor. If compression is 70% efficient compared with an isentropic process, what will be the work requirement and what will be the final temperature of the ethylene? Assume the ethylene behaves as an ideal gas with C_P = 44 J/mol-K.

MW = 28 g/mole; R = 8.314 J/(mole K°)

2)
4.18 A common problem in the design of chemical processes is the steady-state compression of gases from a low pressure P_1 to a much higher pressure P_2. We can gain some insight about optimal design of this process by considering adiabatic reversible compression of ideal gases with stage-wise intercooling. If the compression is to be done in two stages, first compressing the gas from P_1 to P^*, then cooling the gas at constant pressure down to the compressor inlet temperature T_1, and then compressing the gas to P_2, what should the value of the intermediate pressure be to accomplish the compression with minimum work?

Some useful equations:

R = 8.314 J/mole-K; $N_A = 6.022 \times 10^{23}$; $N_A k_B = R$;

1 Joule = 1 N-m = 1MPa-cm^3 = 1 kg m^2/s^2 = 0.23901 cal

$$d\underline{S} \equiv \frac{d\underline{Q}_{rev}}{T_{sys}}$$

$$\Delta S_{mix}^{is} = -R\sum_i x_i \ln x_i$$

$$(\Delta S)_T = R\ln\left[\frac{V}{V^i}\right]$$

$$(\Delta S)_T = -R\ln\left[\frac{P}{P^i}\right]$$

$$\Delta S = \int_{T_1}^{T_2} \frac{C_P}{T} dT$$

$$\Delta S = \int_{T_1}^{T_2} \frac{C_V}{T} dT$$

$$\Delta S^{vap} = \frac{\Delta H^{vap}}{T^{sat}} \quad \text{and} \quad \Delta S^{fus} = \frac{\Delta H^{fus}}{T_m}$$

$$\Delta S^{ig} = C_V \ln\frac{T}{T^i} + R\ln\frac{V}{V^i} \quad \text{or} \quad \Delta S^{ig} = C_P \ln\frac{T}{T^i} - R\ln\frac{P}{P^i}$$

$$\left(\frac{T_2^{rev}}{T_1}\right) = \left(\frac{P_2}{P_1}\right)^{\left(\frac{R}{C_P}\right)}$$

$$\eta_\theta = \frac{-\dot{\underline{W}}_{S,net}}{\dot{\underline{Q}}_H} = \left(1 + \frac{\dot{\underline{Q}}_C}{\dot{\underline{Q}}_H}\right) = \left(1 - \frac{T_C}{T_H}\right),$$

$$COP \equiv \frac{\dot{\underline{Q}}_C}{\dot{\underline{W}}_{S,net}} = \left(\frac{T_H}{T_C} - 1\right)^{-1} = \frac{T_C}{T_H - T_C},$$

pump or compressor efficiency = $\eta_C = \frac{\underline{W}'}{\underline{W}} \times 100\%$

turbine or expander efficiency = $\eta_E = \frac{\underline{W}}{\underline{W}'} \times 100\%$

Answers Quiz 5
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(P4.12)
Ebal: $\Delta H = W$.

Sbal: $\Delta S^{rev} = 0 \Rightarrow \left(\frac{T_2^{rev}}{T_1}\right) = \left(\frac{P_2}{P_1}\right)^{\left(\frac{R}{Cp}\right)} \Rightarrow T_2^{rev} = (20+273)*18\text{^}(8.314/44) = 506\text{K}.$

$W^{rev} = C_p(T_2^{rev} - T_1) = 44*(506-293) = 9372\text{J/mol} \Rightarrow W_{act} = 9372/0.85 = 13.4\text{kJ/mol}$
$W^{act} = C_p(T_2^{act} - T_1) = 13400 \Rightarrow T_2^{act} = (13400/44)+293 = 597\text{K}$

2)
4.18 A common problem in the design of chemical processes is the steady-state compression of gases from a low pressure P_1 to a much higher pressure P_2. We can gain some insight about optimal design of this process by considering adiabatic reversible compression of ideal gases with stage-wise intercooling. If the compression is to be done in two stages, first compressing the gas from P_1 to P^*, then cooling the gas at constant pressure down to the compressor inlet temperature T_1, and then compressing the gas to P_2, what should the value of the intermediate pressure be to accomplish the compression with minimum work?

(4.18) A common problem in the design of chemical processes is the steady-state compression of gases ...

Solution
E-bal (on 1st compressor): $\Delta H = Q + W = W$
S-bal (on 1st compressor): $\Delta S = 0$
S-bal gives adiabatic reversible ideal gas $\Rightarrow T^*/T_1 = (P^*/P1)^{R/Cp}$
E-bal gives $W_1 = Cp(T^* - T_1) = Cp\, T_1\, [(P^*/P_1)^{R/Cp} - 1]$
Analogous treatment of 2nd compressor and combination gives:
$W = W_1 + W_2 = Cp\, T_1 \{[(P^*/P_1)^{R/Cp} - 1] + [(P_2/P^*)^{R/Cp} - 1]\}$
To minimize this function, take the derivative and set to zero

$$\frac{dW}{dP} = CpT_1\left[\frac{R/Cp}{P^*}\left(\frac{P^*}{P_1}\right)^{R/Cp} - \frac{R/Cp}{P^*}\left(\frac{P_2}{P^*}\right)^{R/Cp}\right] = 0$$

$(P^*)^2 = P_1 * P_2 \Rightarrow P^* = (P_1 * P_2)^{1/2}$
Can you guess what it would be for a three stage compressor?