

Quiz 5
Chemical Engineering Thermodynamics
February 26, 2015

1)

P4.8 An adiabatic compressor is used to continuously compress nitrogen ($C_p/R = 7/2$) from 2 bar and 300 K to 15 bar. The compressed nitrogen is found to have an outlet temperature of 625 K. How much work is required (kJ/kg)? What is the efficiency of the compressor?
MW = 28 g/mole; R = 8.314 J/(mole K°)

2)

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°)

3)

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?

Answers Quiz 5
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1)

P4.8 An adiabatic compressor is used to continuously compress nitrogen ($C_p/R = 7/2$) from 2 bar and 300 K to 15 bar. The compressed nitrogen is found to have an outlet temperature of 625 K. How much work is required (kJ/kg)? What is the efficiency of the compressor?
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(P4.8) Adiabatic, steady-state open system $\Rightarrow Q = 0$, & ($C_p/R = 7/2$)..... ig

$$W = \int_{300}^{625} C_p dT = \frac{7R}{2} * (625 - 300) = 9457.175 \text{ kJ / kmole} * \frac{1 \text{ kmole}}{28 \text{ kg}} = 337.76 \text{ kJ / kg}$$

$$\eta = ??$$

$$\Delta S = 0 \Rightarrow \frac{T_2'}{T_1} = \left(\frac{P_2}{P_1} \right)^{\frac{R}{C_p}}$$

$$\Rightarrow T_2' = 533.5 \text{ K}$$

$$\Rightarrow \Delta H' = C_p(T_2' - T_1) = \left(\frac{7 * 8.314}{2} \right) * (533.5 - 300)$$

$$\Rightarrow \Delta H' = 6794.77 \text{ kJ / mol}$$

$$\Rightarrow \eta = \frac{\Delta H'}{\Delta H} = \frac{6794.77 \text{ kJ / kmol}}{337.76 \text{ kJ / kg} * 28 \text{ kg / kmol}} = 0.718$$

$$\Rightarrow \eta = 71.8\%$$

2)

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 $C_p = 44 \text{ J/mol-K}$.

(P4.12)

Ebal: $\Delta H = W$.

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

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

$$W^{\text{act}} = C_p(T_2^{\text{act}} - T_1) = 13400 \Rightarrow T_2^{\text{act}} = (13400/44) + 293 = 597 \text{ K}$$

3)

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 $\Rightarrow T^*/T_1 = (P^*/P_1)^{R/C_p}$

E-bal gives $W_1 = C_p(T^* - T_1) = C_p T_1 [(P^*/P_1)^{R/C_p} - 1]$

Analogous treatment of 2nd compressor and combination gives:

$W = W_1 + W_2 = C_p T_1 \{ [(P^*/P_1)^{R/C_p} - 1] + [(P_2/P^*)^{R/C_p} - 1] \}$

To minimize this function, take the derivative and set to zero

$$\frac{dW}{dP} = C_p T_1 \left[\frac{R/C_p}{P^*} \left(\frac{P^*}{P_1} \right)^{R/C_p} - \frac{R/C_p}{P^*} \left(\frac{P_2}{P^*} \right)^{R/C_p} \right] = 0$$

$$(P^*)^2 = P_1 * P_2 \Rightarrow P^* = (P_1 * P_2)^{1/2}$$

Can you guess what it would be for a three stage compressor?

