ECHE 363. Thermodynamics of Chemical Systems

Spring 2020 Midterm Exam 1

Name: Solution

Date: ____________________

Instructions: You have seventy five minutes to answer all questions. Read the problems carefully and completely before starting to answer. State any assumptions if necessary. Show all steps as partial credit may be given even for a wrong final answer. The final part of the final question is a bonus question. If needed, use both sides of the sheet.

Note: Number of days to Spring Break is 23!

-Instructor Use Only:

Problem 1____

Problem 2____

Problem 3____

Total:_____/100

1. (**40 points**) Consider a closed rigid container with 10 kg of H_2O at 2 bar. H_2O undergoes a process and reaches a final state 10 bar and 400 °C.

   a. What is the volume (m^3) of the container? (10 points)

$\boxed{H_2O}$

$\hat{v}_1 = \hat{v}_2$ (Rigid container, closed) $m_1 = m_2$, V is constant

$= 0.30659 \ m^3/kg$ (10 bar, 400 °C : state 2)

$V = 10 \times 0.30659 = 3.066 \ m^3$

   b. What is the initial temperature (K)? (10 points)

$P_1 = 2$ bar $\hat{v}_1 = 0.30659 \ m^3/kg \Rightarrow$ Saturated H_2O (vapor-liquid)

$T_1 = 120.23°C$ (Appendix B.2)

   c. If applicable, what is the initial quality? (10 points)

$\hat{v}_{1,l} = 0.001061 \ m^3/kg$ $\hat{v}_{1,v} = 0.8857$ (B.2 $P_1 = 2$ bar) $T_1 = 120.23°C$

$\hat{v}_1 = 0.30659 \ m^3/kg$

$x = 0.345 = 34.5\%$

   d. What is the heat transferred (Q, Joules) to the system? (10 points)

$\hat{u}_1 = x \hat{u}_{1v} + (1-x)\hat{u}_{1l}$

$= 1203 \ kJ/kg$

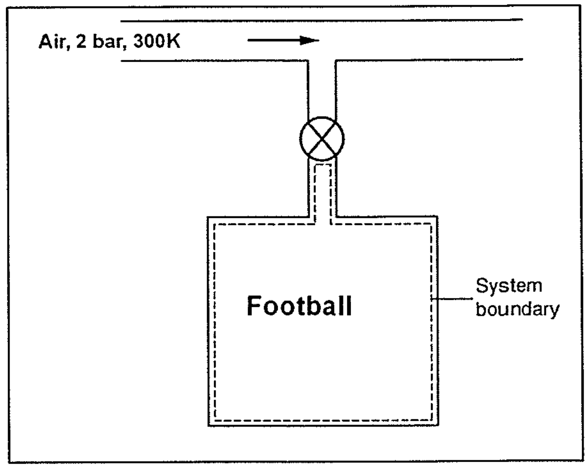
$\hat{u}_2 = 2957.3 \ kJ/kg$

$\Delta\hat{u} = \hat{q} + \cancel{\hat{w}}^{=0}$ (Rigid)

$\hat{q} = \hat{u}_2 - \hat{u}_1 = 1754 \ kJ/kg$

$Q = 17540 \ kJ = 17.5 \ MJ$

2. **(40 points) Deflategate**: Consider the dynamic inflation of a football. For the purpose of this problem, football is modeled as a rigid container that contains vacuum initially. Air (ideal gas) supply is available from a cylinder with a constant pressure of 2 bars and a constant temperature of 300K. You may assume that the c_P (specific heat capacity at constant pressure) for air is approximately constant: c_P=3.5R, where R is the universal gas constant.



a. The football is adiabatically filled until the pressure inside reaches the inlet pressure of 2 bar. Perform mole and energy balance (15 points).

System : Football)

Mole Balance :

$$\frac{dn}{dt} = \dot{n}_{in} - \cancel{\dot{n}_{out}}^{=0} = \dot{n}_{in}$$

$$n_2 - \cancel{n_1}^{=0} = \int \dot{n}_{in}\,dt$$

Energy Balance :

$$\frac{dU_{sys}}{dt} = \dot{n}_{in} h_{in} - \cancel{\dot{n}_{out} h_{out}} + \underbrace{\cancel{\dot{W}_s}}_{\text{Rigid}} + \underbrace{\cancel{\dot{Q}}}_{\text{adiab}}$$

$$\frac{dU_{sys}}{dt} = \dot{n}_{in} h_{in}$$

$$U_2 - \underbrace{\cancel{U_1}^{=0}}_{\text{(vacuum)}} = \int \dot{n}_{in} h_{in}\,dt ; \qquad U_2 = \int \dot{n}_{in} h_{in}\,dt$$

$$U_2 = h_{in} \int \dot{n}_{in}\,dt = h_{in} n_2 \leftarrow \text{from mole balance}$$

$$\frac{U_2}{n_2} = h_{in} ; \qquad \boxed{u_2 = h_{in}}$$

$$h_{in} = u_{in} + (Pv)_{in}$$

b. Determine the temperature of air in the football just after it is filled? (25 points)

$$u_2 = u_{in} + (Pv)_{in} = u_{in} + RT_{in}$$

$$u_2 - u_{in} = RT_{in} ; \quad \Delta u = RT_{in} ; \quad c_v (T_2 - T_{in}) = RT_{in}$$

$$T_2 = \frac{c_p}{c_v} T_{in} ; \qquad \boxed{T_2 = 420K}$$

c. *Bonus part*: Once it is filled, the valve is closed and the football is left in a room (T_R=298 K) until thermal equilibrium is achieved. What is the pressure inside the football? (10 points)

$P_2 = 2\,\text{bar}$
$T_2 = 420\,K$

$P_3 = ?$
$T_3 = 298\,K$

closed system, Rigid container, $\hat{v}_2 = \hat{v}_3$

$$P_2 \hat{v}_2 = RT_2$$

$$P_3 \hat{v}_3 = RT_3$$

$$\frac{P_3}{P_2} = \frac{T_3}{T_2}$$

$$\boxed{P_3 = 2 \, \frac{298}{420} = 1.42\,\text{bar}}$$

3. (**20 points**) In a closed system, an ideal gas initially at a temperature of 350K and a pressure of 200 kPa undergoes a process in which the enthalpy change and the internal energy change are measured to be 2025 J/mol and 1580 J/mol respectively. What is the final temperature of the system?

$\Delta h = 2025 \ J/mol$

$\Delta u = 1580 \ J/mol$

$h = u + Pv$

$\Delta h = \Delta u + \Delta(Pv) = \Delta u + \Delta(RT) = \Delta u + R\Delta T$

$\Delta T = \dfrac{\Delta h - \Delta u}{R}$; $T_2 - T_1 = \dfrac{\Delta h - \Delta u}{R}$

$T_2 = 350 + \dfrac{\Delta h - \Delta u}{R}$

$T_2 = 404 \ K$