The University of Calgary
Schulich School of Engineering

ENGG 311: Engineering Thermodynamics
Midterm Examination
Fall 17

Open Textbook (or any equivalent textbook), Formula Sheet, Closed Notes, SSE, Calculators Allowed

Time Allowed: 90 minutes **Friday Nov. 3, 2017 – 17:30 h**

Name: Surname Given Names	Lecture Section (Circle one)
	L01 (Dr. Husein); L02 (Dr. Moore)

EXAMINATION INFORMATION

1. Reference to ONLY the Textbook (or any equivalent textbook), Formula Sheet and property tables (8^{th} Edition Cengel & Boles) is permitted during the examination. CLOSED CLASS NOTES. Additional material must not be inserted into the textbook, or the textbook will be confiscated.
2. NO electronic device, other than a calculator, may be brought into the exam. This includes telephones, cameras computers and music players of any kind.
3. SSE approved calculator is allowed.
4. Clearly show all steps involved in each calculation. Marks are awarded for both the method and the final answer
5. Please state any <u>assumptions</u> made wherever necessary.

ADDITIONAL FORMULAS

Surface Area

- Circle $A = \dfrac{\pi D^2}{4}$
- Sphere $A = \pi D^2$
- Cylinder $A = \dfrac{\pi D^2}{2} + \pi D h$

Volume

- Sphere $V = \dfrac{\pi D^3}{6}$
- Cylinder $V = \dfrac{\pi D^2 h}{4}$
- Cone $V = \dfrac{\pi D^2 h}{12}$

Quadratic Polynomial

- $a x^2 + b x + c = 0 \rightarrow x = \dfrac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

Integrals

- $\int_0^x \dfrac{dx}{1-x} = \ln\left(\dfrac{1}{1-x}\right)$
- $\int_0^x \dfrac{dx}{(1-x)^2} = \dfrac{x}{1-x}$
- $\int_0^x \dfrac{dx}{(1+ax)} = \dfrac{1}{a}\ln(1+ax)$

Question	Mark
1	/10
2	/10
3	/10
Total	**/30**

Q1) Air (assume ideal gas) is compressed from an initial state of 87.4 kPa and 3.31×10^{-4} m^3 to a final state of 165.6 kPa and 2.14×0^{-4} m^3. During compression, the pressure varies with volume following PV^n= const. Calculate the heat interaction during this process (J). Assume $C_v^0 = const = 0.718\ \frac{kJ}{kg\cdot K}$.

Air (ideal gas) : $R = 0.2870\ \left(\frac{kJ}{kg\cdot K}\right)$ "Table A-1" ; Polytropic compression

State 1 : $P_1 = 87.4$ kPa ; $V_1 = 3.31\times10^{-4}\ (m^3)$

State 2 : $P_2 = 165.6$ kPa ; $V_2 = 2.14\times10^{-4}\ (m^3)$

$Q_{net} = ?$

Soln :

① Sys : Closed ; ② W.-F. : air (assume pure subs + ideal gas)

③ Process : Polytropic compression ; ④ Q_{net} can be obtained from energy balance : $Q_{net} - W_{net} = m\Delta U$ "Stationary simple compressible sys"

$\therefore W_{net} = W_b = \int_{V_1}^{V_2} P\,dV = \frac{P_2V_2 - P_1V_1}{1-n}$ "Polytropic process"

$\therefore P_1V_1^n = Const = P_2V_2^n \Rightarrow \left(\frac{P_1}{P_2}\right) = \left(\frac{V_2}{V_1}\right)^n$ OR $n = \frac{\ln(P_1/P_2)}{\ln(V_2/V_1)}$

$\therefore n = \frac{\ln(87.4/165.6)}{\ln(2.14\times10^{-4}/3.31\times10^{-4})} = 1.46$ ∞

$\therefore W_{net} = \frac{(165.6)(2.14\times10^{-4}) - (87.4)(3.31\times10^{-4})}{1-1.46} = -14.15\ (J)$ ($\because W_{net} < 0 \Rightarrow$ Work done on the system)

$\therefore m\Delta U = \int_{T_1}^{T_2} C_v\,dT$ assume $C_v = Const = C_v @ 300K = 0.718\ \left(\frac{kJ}{kg\cdot K}\right)$ "Table A-2"

$\therefore \Delta U = C_v(T_2 - T_1)$

$\therefore m_1 = m_2 \Rightarrow \frac{P_1V_1}{RT_1} = \frac{P_2V_2}{RT_2}$

$\Rightarrow \frac{T_2}{T_1} = \frac{P_2V_2}{P_1V_1}$

$\therefore m\Delta U = C_v \frac{P_1V_1}{RT_1}(T_2 - T_1) \Rightarrow m\Delta U = C_v \frac{P_1V_1}{RT_1}\left(\frac{P_2V_2T_1}{P_1V_1} - T_1\right)$

$\Rightarrow m\Delta U = C_v\left(\frac{P_2V_2}{R} - \frac{P_1V_1}{R}\right) \Rightarrow m\Delta U = \frac{C_v}{R}(P_2V_2 - P_1V_1)$

$\therefore m\Delta U = \frac{0.718\ (kJ/kg\cdot K)}{0.2870\ (kJ/kg\cdot K)}\left[(165.6)(2.14\times10^{-4}) - (87.4)(3.31\times10^{-4})\right] kJ \doteq 16.28\ (J)$

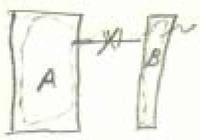
$\therefore Q_{net} - (-14.15) = 16.28 \Rightarrow \boxed{Q_{net} = +2.13\ J}$

added to the system

Note $Q_{net} \sim 0 \Rightarrow$ Process is adiabatic

Q2) Two tanks (A and B) are connected through a valve. The volume of tank A is 75 liters while that of tank B is 50 liters. Initially tank A contains carbon monoxide (CO) gas at a pressure of 1,000 kPa and a temperature of 30°C. Tank B is initially evacuated. The valve connecting the tanks is opened and the contents of the tanks are allowed to come to an equilibrium state at a temperature of 22°C. Assuming CO behaves as an ideal gas and that $C_v^0 = 0.744 \frac{kJ}{kg\cdot K}$:

a) Calculate the mass of CO which is initially contained in tank A (kg).
b) Calculate the masses of CO in tanks A and B after the valve is opened and the two tanks come to equilibrium (kg).
c) Calculate the work done on the CO (kJ).
d) Calculate the heat transfer to the CO as the two tanks come to equilibrium (kJ).



Boundary CO $\quad M = 28.011 \quad R = 0.2968 \frac{kJ}{kg\,K}$

$C_v^0 = 0.744 \frac{kJ}{kg\,K}$

Tank A: a. $m_A = \dfrac{P_{A_1} V_{A_1}}{R T_{A_1}} = \dfrac{(1000\,kPa)\left(\frac{75}{1000}\,m^3\right)}{0.2968 \frac{kPa\,m^3}{kg\,K}\,(30+273)K}$

$= \underline{\underline{0.834\,kg}}$ ← (a)

Tank B: $\quad m_{B_1} = 0$

After tanks connected, CO contained in both tanks

Mass balance $\quad m_{A_1} + \underbrace{m_{B_1}}_{0} = m_{A_2} + m_{B_2}$

$V_{A_1} + V_{B_1} = V_{A_2} + V_{B_2} = (75+50)\,l = 0.125\,m^3$

∴ At state 2.

$V_2 = 0.125\,m^3 \quad T_2 = 22°C = 295K. \quad m_2 = m_{A_2} + m_{B_2} = m_{A_1} = 0.834\,kg.$

∴ $P_2 = \dfrac{m_2 R T_2}{V_2} = \dfrac{(0.834\,kg)\left(0.2968 \frac{kPa\,m^3}{kg\,K}\right) \times 295K}{0.125\,m^3}$

$P_2 = 584.2\,kPa$

b. ∴ $m_{A_2} = \dfrac{P_{A_2} V_{A_2}}{R T_{A_2}} = \dfrac{(584.2\,kPa)(0.075\,m^3)}{\left(0.2968 \frac{kPa\,m^3}{kg\,K}\right)(295K)} = 0.500\,kg.$

$m_{B_2} = \dfrac{P_{B_2} V_{B_2}}{R T_{B_2}} = \dfrac{(584.2\,kPa)(0.050\,m^3)}{0.2968 \frac{kPa\,m^3}{kg\,K} \times 295K} = 0.334\,kg.$ b.

$\overline{0.834\,kg.}$

c. $W = \int P\,dV = 0$ as $dV = 0$

(d) $Q - \cancel{W} = m_{A_2} u_{A_2} + m_{B_2} u_{B_2} - m_{A_1} u_{A_1} - \underbrace{m_{B_1}}_{0} u_{B_1}$

$= m_2 u_2 - m_{A_1} u_{A_1}$

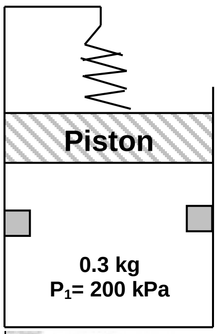
$= m_{A_1} [u_2 - u_1] = m_{A_1} C_v^0 [T_2 - T_1]$

$Q = (0.834\,kg)\left(0.744 \frac{kJ}{kg\,K}\right)[22-30]°C \times \frac{1K}{1°C}$

$= \underline{\underline{-4.96\,kJ}}$ (Heat transferred from tanks).

Q3) A spring-loaded frictionless piston-cylinder device contains 0.30 kg of superheated steam at 200 kPa is cooled to a final temperature of 20ºC. At the final state, 0.29 kg existed in the liquid phase. If the final volume is 80% of its initial volume and the stops set at 0.20 m^3, calculate:

a) The temperature of the system at the initial state (ºC)
b) The boundary work involved in the process (kJ)
c) The heat interaction with the surrounding (kJ)
d) Sketch the process on a P-υ diagram.



$m = 0.3$ kg ; Spring attached throughout ; State 1: $P_1 = 200$ kPa

State final: $T_f = 20°C$, $m_\ell = 0.29$ kg $\Rightarrow x_f = \frac{0.3-0.29}{0.3} = 0.033$; $V_f = 0.8\ V_1$

V corresponding to the stops $= 0.2\ m^3$

a) $T_1 = ?$; b) $W_b = ?$; c) $Q = ?$, d) Sketch P-υ diagram

Soln:

① Sys: closed ; ② W.F.: Water (use prop. tables) ; ③ Process: Linear-spring + could be isochoric

1st need to establish if piston hits the stops @ the final stage or not.

∴ @ the final state ⇒ l-υ mix @ $T_f = 20°C$ & $x_f = 0.033$: Table A-4:

∴ $\upsilon_f @ 20°C = 0.001002\ (m^3/kg)$ & $\upsilon_g = 57.762\ (m^3/kg)$ ⇒ $\upsilon_{Final} = 0.001002 + 0.033\,(57.762-0.00100)$ $= 1.926\ (m^3/kg)$

∴ $V_{Final} = m\,\upsilon_{Final} = (0.3\ kg)(1.926\ \frac{m^3}{kg}) = 0.578\ (m^3)$

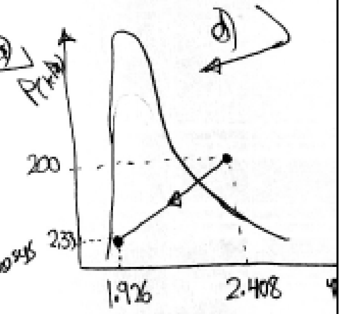
∴ $V_{Final} > V$ corresponding to stops ⇒ Piston does not hit the stops.

⇒ P varies linearly with υ

∴ $V_1 = \frac{V_{Final}}{0.8} \Rightarrow V_1 = 0.722 (m^3)$ & $\upsilon_1 = \frac{0.722 (m^3)}{0.3 (kg)} = 2.408\ (\frac{m^3}{kg})$

∴ @ $P_1 = 200$ kPa , $\upsilon_1 > \underbrace{\upsilon_g\ (0.88578\ m^3/kg)}_{\text{Table A-5}}$ ⇒ State 1 superheated vapor

∴ $T_1 = \underbrace{700 + \frac{700-800}{2.24434-2.47550}(2.408-2.24434)}_{\text{Table A-6}} = 770.8°C$ ← a)



b) ∴ Spring engage & piston did not reach the stops ⇒

$W_b = \int_{P_1}^{P_2} P\,dV = \frac{P_1+P_2}{2}(V_2 - V_1)$ ∴ $P_2 = P^{sat}_{20°C} = 2.339$ (kPa)

∴ $W_b = \frac{(200+2.339)\ kPa}{2}(0.578 - 0.722)\,m^3 = \boxed{-14.57\ kJ}$ ← b) work done on the sys

c) 1st Law: $Q_{net} - W_{net} = m(u_2 - u_1)$ Stationary closed system

∴ $u_1 = 3479.9 + \frac{(3479.9-3664.7)}{700-800}(770.8-700) = 3{,}610.7\ (kJ/kg)$ (Table A-6)

$u_2 = 83.913 + 0.033\,(2318.4) = 160.4\ (kJ/kg)$

∴ $Q_{net} - (-14.57)\,kJ = 0.3\,(kg)\,(160.4 - 3{,}610.7)(\frac{kJ}{kg})$ ⇒ $\boxed{Q_{net} = -1050\ kJ}$ ← c)

lost to the surrounding