

Concordia University
Faculty of Engineering and Computer Science

Date: **March 16, 2018**

Course and No.: **Thermodynamics I ENGR 251 W**

Exam: **Midterm**

Total no. of pages: **9 including the cover sheet and tables in the appendix (Note: Page #9 is blank as a scratch sheet if needed)**

Professor: **Dr. Zhibin Ye**

Time: **11:45 a.m. – 1:15 p.m.**

Location: **MB S2.401, MB S1.430**

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SPECIAL INSTRUCTIONS:

- (1) **Closed book, closed notes**
- (2) **Faculty approved calculators allowed**
- (3) **Write everything on this exam paper**
- (4) **Answer all 3 questions**
- (5) **State your assumptions clearly wherever necessary**
- (6) **Do not tear out any page**

1. (a) Demonstrate that for an ideal gas: $C_p - C_v = R$. [2 marks]
 (b) For an ideal gas undergoing a process, what does the area under a C_v vs. T graph represent? [2 marks]
 (c) For an ideal gas undergoing a process, what does the area under a C_p vs. T graph represent? [2 marks]

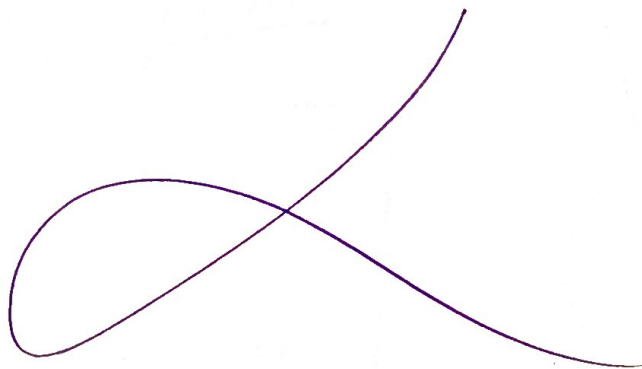
b) The area under the graph represents the ~~enthalpy~~ $= \Delta U$
 c) The area under the graph represents the ~~enthalpy~~ $= \Delta h$
 ~~$P \cdot V = nRT$~~

a) $U = m C_v \Delta T$
 $H = m C_v \Delta T + W = m C_p \Delta T$
 $W = m C_p \Delta T - m C_v \Delta T$

$P \cdot \Delta V = m \Delta T (C_p - C_v)$

$C_p - C_v = \frac{P \Delta V}{m \Delta T} = R_s$

2



$$(T - T_1) = \frac{T_2 - T_1}{x_2 - x_1} (x - x_1)$$

$$v = \frac{V}{m}$$

2. Ammonia, NH_3 , is contained in a sealed rigid Tank at 0°C , $x = 50\%$ and is then heated to 100°C . Find the final state P_2 , u_2 , and the specific work and specific heat transfer involved in the heating process. (Thermodynamic tables of NH_3 are attached, page 5~8.) [18 marks]

$$T_1 = 0^\circ\text{C} = 273.15\text{K}$$

$$x = 0.5$$

$$T_2 = 100^\circ\text{C} = 373.15\text{K}$$

$$V_1 = V_2$$

$$P_1 @ 0^\circ\text{C} = 929.6\text{kPa}$$

$$v_{f1} = 0.001566\text{ m}^3/\text{kg}$$

$$v_{g1} = 0.28920\text{ m}^3/\text{kg}$$

$$v_{fg1} = 0.28763\text{ m}^3/\text{kg}$$

$$\left. \begin{aligned} u_{f1} &= 0.145381\text{ kJ/kg} \\ u_{g1} &= 748.84\text{ kJ/kg} \end{aligned} \right\}$$

$$\left. \begin{aligned} v_1 &= v_2, & v_1 &= v_{f1} \cdot m \\ & & v_2 &= v_{g2} \cdot m \end{aligned} \right\} \Rightarrow v_{f1} = v_{g2}$$

$$v_2 = 0.145381\text{ m}^3/\text{kg}$$

$$\textcircled{B} T_2 @ 100^\circ\text{C}$$

$$v_{f2} = 0.002188$$

$$\left. \begin{aligned} v_{f2} &= 0.002188 \\ v_{g2} &= 0.01784 \end{aligned} \right\} \left. \begin{aligned} v_2 &> v_{f2} \\ v_2 &> v_{g2} \end{aligned} \right\} \Rightarrow \text{Superheated}$$

$$P \cdot v = R_s T$$

$$\frac{P_1 \cdot v_1}{T_1} = R_s$$

$$R_s = 0.2286$$

$$P_2 v_2 = R_s T_2 \Rightarrow P_2 = 586.74\text{ kPa}$$

$$q = \Delta u = u_2 - u_1 = 750.95\text{ kJ/kg}$$

$$w = P_1 \Delta v \quad \left\{ \begin{aligned} &= 0 \\ &\text{real rigid tank} \end{aligned} \right.$$

$$q = w + \Delta u$$

$$2 = \Delta u = 750.95\text{ kJ/kg}$$

(heat into the system)

$$P_1 = 500\text{ kPa}, \quad u_1 = 1501.7$$

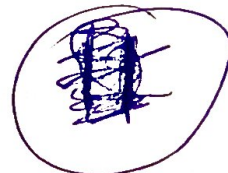
$$P_2 = 600\text{ kPa}, \quad u_2 = 1499.5$$

$$P = 586.74\text{ kPa}, \quad u = ?$$

$$u - u_1 = \frac{u_2 - u_1}{P_2 - P_1} (P - P_1)$$

$$1485.83\text{ kJ/kg}$$

$$u = \frac{u_2 - u_1}{P_2 - P_1} (P - P_1) + u_1 = 1499.79\text{ kJ/kg}$$



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$$W = \frac{P_2 V_2 - P_1 V_1}{1-n} = \frac{m R_s (T_2 - T_1)}{1-n}$$

$$P \cdot V = m R_s T$$

0.18
0.88 0.149
0.076

3. Consider a gas whose molecular weight is 33 g/mol, initially at 3 bar and 300 K, and occupying a volume of 0.1 m³. The gas undergoes a polytropic expansion during which the pressure-volume relation is $PV^{1.3} = \text{constant}$ and the energy transfer by heat to the gas is 3.84 kJ. Assume the ideal gas model with constant $C_v = 0.6 \text{ kJ/(kg K)}$. Neglecting kinetic and potential energy effects, determine

- (a) the final temperature, in K. [12 marks]
- (b) the final pressure, in bar. [5 marks]
- (c) the final volume, in m³. [4 marks]
- (d) the work, in kJ. [5 marks]

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$M = 33 \text{ g/mol}$ $R_s = R_u/M = 0.251$
 $P_1 = 3 \text{ bar} = 300 \text{ kPa}$
 $T_1 = 300 \text{ K}$ $T_2 = 259.58 \text{ K}$
 $V_1 = 0.1 \text{ m}^3$

$$P_1 V_1^n = P_2 V_2^n$$

d) $W = \frac{m R_s \Delta T}{1-n} = 13.5 \text{ kJ}$ (work done by the gas is then to be positive)

$Q = 3.84 \text{ kJ}$
 $n = 1.3$

a) $P_1 \left(\frac{T_1}{P_1}\right)^n = P_2 \left(\frac{T_2}{P_2}\right)^n$
 $P_1 \left(\frac{T_1}{P_1}\right)^n = P_2^{1-n} (T_2)^n$
 $P_1^{1-n} \cdot T_1^n = P_2^{1-n} \cdot T_2^n \rightarrow P_2 = P_1 \cdot \left(\frac{T_1}{T_2}\right)^{\frac{n}{1-n}}$

2

$P_2 = 510 \text{ kPa}$
 $P_2 = 5.1 \text{ bar}$

$C_v = 0.6 \text{ kJ/kgK}$
 $\rho = \frac{P_1 R_s}{P_1} = 0.25 \text{ m}^3/\text{kg}$
 $m = \frac{V_1}{\rho} = 0.4 \text{ kg}$

Q

$$\Delta U = m C_v \Delta T$$

a) $Q = W + \Delta U$
 $= \frac{P_2 V_2}{1-n} - \frac{P_1 V_1}{1-n} + m C_v (T_2 - T_1) = 3.84 \text{ kJ}$
 $= \frac{m R_s (T_2 - T_1)}{1-n} + m C_v (T_2 - T_1) = 3.84 \text{ kJ}$

c) $P_1 V_1^n = P_2 V_2^n$
 $V_2 = \frac{P_1 V_1}{P_2} = 0.06 \text{ m}^3$

$$(T_2 - T_1) \left(\frac{m R_s}{1-n} + m C_v \right) = 3.84 \text{ kJ}$$

$$(T_2 - T_1) \cdot \left(m \left(\frac{R_s}{1-n} + C_v \right) \right) = 3.84 \text{ kJ}$$

$$(T_2 - T_1) (-0.095) = 3.84 \text{ kJ}$$

$T_2 = 259.58 \text{ K}$

