BIRLA INSTITUTE OF TECHNOLOGY AND SCIENCE PILANI
K K BIRLA GOA CAMPUS
SECOND SEMESTER 2018-2019
MID-SEMESTER TEST (CLOSED BOOK)

Course title: **THERMODYNAMICS**	Course code: **BITS F111**
Date: 12-03-2019	Duration: 90 min
Time: 2:00 P.M. – 3:30 P.M.	Maximum marks: **90**

- Part A answers should be written in the box provided in the question
- Part A should be submitted within 30 minutes
- For part- A overwritten answer will not be evaluated and no partial marks will be awarded

PART – A **[5 × 6 = 30]**

ID NO:	**NAME:**

1. The barometer contains mercury (ρ = 13.59 g/cm^3). If the local atmospheric pressure is 100 kPa, density of air 1.24 kg/m^3 and g = 9.81 m/s^2, determine the height of the Hg column in mm Hg. **[6]**

Mercury column (mm Hg)	

2. A rigid storage tank holds methane at 135 K, with a quality of 37.2%, and it warms up by 5°C per hour due to a failure in the refrigeration system. How much time will it take for methane to become single phase and what is the pressure then? **[6]**

Time taken (hours)	
Pressure (kPa)	

3. Helium gas expands from initial state of 125 kPa and 0.25 m^3 to 1.5 times its initial volume and to a final pressure of 75 kPa through a polytropic process inside a balloon with polytropic exponent n = 1.67. Calculate the work done during this process. **[6]**

Work done (kJ)	

4. Saturated vapor of R-410a at -20^{o}C is enclosed in a friction-less piston-cylinder arrangement. The refrigerant is cooled to saturated liquid at -20^{o}C under floating pressure. Calculate the specific work done during the process. **[6]**

Specific work done (kJ/kg)	

5. A piston-cylinder device contains 0.8 kg of an ideal gas. Now, the gas is cooled at constant pressure until its temperatures decreases by 10^{o}C. If 16.6 kJ of compression work is done during this process, determine the gas constant and constant-pressure specific heat of the ideal gas if its specific heat ratio is 1.667. **[6]**

Gas constant (kJ/kg.K)	
Specific heat (kJ/kg.K)	

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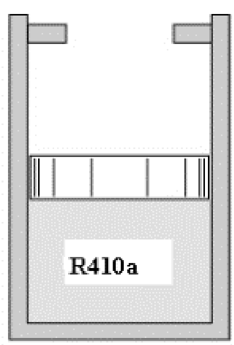
- Each question must start on a new page and answer all parts of a question together.
- Thermodynamics Data book without any defacing is allowed in the examination hall.
- Draw neat sketches with ***pen only*** wherever required.

PART – B **[4 × 15 = 60]**

1. A cylinder containing ammonia is fitted with a piston restrained by an external force that is proportional to cylinder volume squared. Initial conditions are 5°C, 90% quality and a volume of 5 L. A valve on the cylinder is opened and additional ammonia flows into the cylinder until the mass inside has doubled. If at this point the pressure is 1.2 MPa, what is the final temperature? **[15]**

2. The gas space above the water in a closed storage tank contains nitrogen at 25ºC and 100 kPa. Total tank volume is 4 m^3 and there is 500 kg of water at 25ºC. An additional 500 kg of water is now forced into the tank. Take nitrogen as an ideal gas and constant temperature throughout the process, (i) find the final pressure of the nitrogen and (ii) the work done on the nitrogen in this process. **[15]**

3. A vertical cylinder fitted with a piston contains 3 kg of R410a at -5^{o}C as shown in the figure. Heat is transferred to the system, causing the piston to rise until it reaches a set of stops at which point the volume has doubled. Additional heat is transferred until the temperature is 60^{o}C and pressure is 1 MPa. Answer the following questions for this process, (i) determine the initial specific internal energy of R410a, (ii) what will be the pressure and temperature of R410a when the piston just touch the stops, (iii) calculate the work done during the process, (iv) calculate the heat transfer during the process, and (v) Sketch the process in a *P-v* diagram (with saturation dome). [**15]**



4. In an insulated closed rigid container at 1 atm, 50 grams of ice at −20^{o}C is mixed with 100 grams of liquid water at 10^{o}C. At what temperature does the ice-water mixture come to thermal equilibrium at 1 atm? At that thermal equilibrium how much ice will remain? Given: Latent heat of fusion (L_F) = 333 J/g; c_{ice} = 2.22 J/g^{o}C; c_{water} = 4.190 J/g^{o}C. [**15]**

2^{nd} Semester 2018-2019
BITS F111 Thermodynamics
Solution for Mid-Semester Test

Part – A

1. Solution:

$$p_{atm} = \rho_{Hg} g h$$

$$\Rightarrow h = \frac{p_{atm}}{\rho_{Hg} g} = \frac{100\times10^3 \text{ N/m}^2}{\left(13.59\times10^3\right) \text{ kg/m}^3 \times 9.81 \text{m/sec}^2} = 0.750 \text{ m Hg} = \boxed{\textbf{750 mmHg}}$$

2. Solution:

Assume rigid tank v = constant = v_1

v_1 = 0.002592 + 0.372 × 0.12458 = 0.04893 m^3/kg

$v_1 > v_c = 0.00615 \text{ m}^3/\text{kg}$ $\Rightarrow$ liquid level will fall

All single phase when $v_2 = v_1 = v_g = 0.04893 \text{ m}^3/\text{kg} \Rightarrow T_2 = 155 \text{ K}$

$\Delta t = \Delta T / (5^\circ\text{C/h}) = (155-135)/5 =$ **4 hours**

$P = P_{sat}$ = **1295.67 kPa**

3. Solution:

$$W = \frac{p_2V_2 - p_1V_1}{1-n}$$

$$= \frac{75 \text{ kPa}\times0.375 \text{ m}^3 - 125 \text{ kPa}\times0.25 \text{ m}^3}{1-1.67} = \boxed{\textbf{4.66 kJ}}$$

4. Solution:

C.V.: R410a, control mass (Table F.2.1)

State 1 : T = -20°C, $P_{float} = P_{sat}$ = 399.6 kPa. $v_1 = v_g$ = 0.0648 m^3/kg

State 2 : T = -20°C, $P_{float} = P_{sat}$ = 399.6 kPa. $v_2 = v_f$ = 0.000803 m^3/kg

Specific Work done = P×($v_f - v_g$)

= 399.6 kPa × (0.000803-0.0648) m^3/kg = **-25.57 kJ/kg**

5. Solution:

$p_1V_1 = mRT_1$ and $p_2V_2 = mRT_2$

$p_1V_1 - p_2V_2 = mRT_1 - mRT_2$

$p(V_1 - V_2) = {}_1W_2 = mR(T_1 - T_2)$ since $p_1 = p_2 = p$

$$\Rightarrow R = \frac{{}_1W_2}{m(T_1 - T_2)} = \frac{16.6 \text{ kJ}}{0.8 \text{ kg}\times 10 \text{ K}} = \boxed{\textbf{2.075 kJ / kg.K}}$$

$$C_{p0} - C_{v0} = R \Rightarrow C_{p0}\left(1-\frac{1}{\gamma}\right) = R$$

$$C_{p0} = \frac{\gamma R}{\gamma - 1} = \frac{1.667\times2.075 \text{ kJ/kg.K}}{1.667-1} = \boxed{\textbf{5.186 kJ / kg.K}}$$

Part – B

1. Solution:

State 1: $v_1 = 0.001583 + 0.9 \times 0.24140 = 0.21884 \text{ m}^3/\text{kg}$

$P_1 = 515.9 \text{ kPa};\ V_1 = 5 \text{ L} = 0.005 \text{ m}^3$

$m_1 = V_1 / v_1 = 0.005 \text{ m}^3 / 0.21884 \text{ m}^3/\text{kg} = 0.02284 \text{ kg}$

Process: Piston $F_{ext} = KV^2 = PA \Rightarrow P = CV^2 \Rightarrow P_2 = P_1 \ (V_2/V_1)^2$

From the process equation we then get:

$V_2 = V_1 \ (P_2/P_1)^{1/2} = 0.005 \ (1200/515.9)^{1/2} = 0.007625 \text{ m}^3$

State 2: $P_2 = 1.2 \text{ MPa},\ m_2 = 2\, m_1 = 0.04569 \text{ kg}$

$v_2 = V_2 / m_2 = 0.007625 \text{ m}^3 / 0.04569 \text{ kg} = 0.1669 \text{ m}^3/\text{kg}$

$v_2 > v_{g@1200 \text{ kPa}} \Rightarrow$ it is superheated $\Rightarrow 140^\circ\text{C} < T_2 < 160^\circ\text{C}$

$$T_2 = T_a + \left(\frac{v_2 - v_a}{v_b - v_a}\right)(T_b - T_a) = 140 + \left(\frac{0.1669 - 0.16181}{0.17071 - 0.16181}\right)(160 - 140)$$

$= \mathbf{151.43^{O}C} \ \Leftarrow$

2. Solution:

$$\left.\begin{aligned} &\text{State1: Water at } 25^0\text{C} \Rightarrow \text{Compressed liquid} \Rightarrow v \cong v_{f@25^0\text{C}} = 0.001003 \text{ m}^3/\text{kg} \\ &V_{H_2O,1} = 500 \text{ kg} \times 0.001003 \text{ m}^3/\text{kg} = 0.5015 \text{ m}^3 \\ &V_{N_2,1} = 4 \text{ m}^3 - 0.5015 \text{ m}^3 = 3.4985 \text{ m}^3 \end{aligned}\right\}$$

$$\left.\begin{aligned} &\text{State 2: Water at } 25^0\text{C} \Rightarrow \text{Compressed liquid} \Rightarrow v \cong v_{f@25^0\text{C}} = 0.001003 \text{ m}^3/\text{kg} \\ &V_{H_2O,2} = 1000 \text{ kg} \times 0.001003 \text{ m}^3/\text{kg} = 1.003 \text{ m}^3/\text{kg} \\ &V_{N_2,2} = 4 \text{ m}^3 - 1.003 \text{ m}^3 = 2.997 \text{ m}^3 \end{aligned}\right\}$$

Temperature is constant for the process and $\mathbf{N_2}$ **is an ideal gas**.

$$\left.\begin{aligned} &P_{N_2,1} \times V_{N_2,1} = P_{N_2,2} \times V_{N_2,2} \\ &\Rightarrow P_{N_2,2} = \frac{P_{N_2,1} \times V_{N_2,1}}{V_{N_2,2}} = \frac{100 \text{ kPa} \times 3.4985 \text{ m}^3}{2.997 \text{ m}^3} \\ &\qquad = \boxed{116.7 \text{ kPa}} \end{aligned}\right\}$$

The work done on the N_2 is given by:

$$\left. W_{N_2} = \int P_{N_2} dV_{N_2} = P_1 V_1 \ln\left(\frac{V_2}{V_1}\right) = 100 \times 3.4985 \times \ln(2.997/3.4985) = \boxed{-54.13 \text{ kJ}} \right\}$$

3. Solution:

C.V.: R410a, Control mass,

Process: Three steps: $1 \rightarrow 2 \rightarrow 3$, $v_3 = v_2 = 2v_1$

State 3: Table F.2.2 Superheated R410a. (P,T) : (1 MPa, 60^oC)

$v_3 = 0.0347\ m^3/kg$, $u_3 = 301.04$ kJ/kg

State 1 & 2: Table F.2.1

i. $v_1 = v_3/2 = v_2/2 = 0.01735\ m^3/kg$, $T_1 = -5^oC$

Table F.2.1 $v_f < v_1 = 0.01735\ m^3/kg < v_g$ => Saturated mixture

$v_1 = 0.01735 = 0.000841 + x_1 \times 0.03764$ => $\boldsymbol{x_1} = 0.4386$

$u_1 = 49.65 + 0.4386 \times 201.75 =$ **138.14 kJ/kg**

$P_1 = P_{sat@-5^oC} = 678.9$ kPa (Floating Pressure)

ii. When the piston just touches the stops $P_2 = P_1 = 678.9$ kPa

$v_f < v_3 = v_2 = 0.0347 < v_g$ => Saturated mixture and $P_2 < 1000$ kPa and $T_2 < 60^oC$

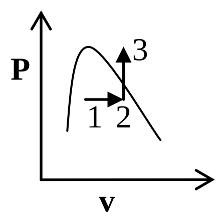
$P_2 = P_1 = P_{sat} =$ **678.9 kPa and** $T_2 = T_{sat} =$ **-5^{o}C**

iii. ${}_1W_2 = P\ m\ (v_2 - v_1) = 678.9 \times 3 \times (0.0347 - 0.01735) =$ **35.34 kJ**

iv. ${}_1Q_3 = m\ (u_3 - u_1) + {}_1W_3 = m\ (u_3 - u_1) + {}_1W_2$ since ${}_2W_3 = 0$

$= 3 \times (301.04 - 138.14) + 35.34 =$ **524.04 kJ**

(v)



4. Solution:

Assumptions: 1) all ice at 0^oC, 2) all liquid water at 10^oC, 3) some ice and some liquid at 0^oC, 4) none of the above. $L_F = 333$ J/g; $c_{ice} = 2.22\ J/g^oC$; $c_{water} = 4.190\ J/g^oC$

First: Find how much energy is available in cooling the water to 0^{o}C.

$Q_{water} = m_{water}\, c_{water}(\Delta T_{water}) = (100g)(4.190\ J/g^oC)(10^oC) = 4{,}190$ J

Second: Find how much energy is needed to warm the ice to 0^{o}C.

$Q_{ice} = m_{ice}\, c_{ice}(\Delta T_{ice}) = (50g)(2.22\ J/g^oC)(20^oC) = 2{,}220$ J

Third: Find how much energy is needed to melt all of the ice.

$Q_{melt} = $ mice $L_F = (50g)(333\ J/g) = 16{,}650$ J

Clearly, enough energy is available to raise the temperature of the ice ($Q_{water} = 4{,}190J$) > ($Q_{ice} = 2{,}220J$) to 0^oC... but not enough to melt all of the ice ($Q_{melt} = 16{,}650J$).

How much ice melted?

($Q_{water} = 4{,}190J$) − ($Q_{ice} = 2{,}220$ J) = 1,970 J available to melt ice

$Q_{melt} = m_{melt}\, L_F \Rightarrow m_{melt} = Q_{melt} / L_F = (1970\ J)/(333\ J/g) = 5.9$ g

Final state: 44.1 grams of ice at 0^oC and 105.9 grams of liquid water at 0^oC.