

IMPORTANT QUESTION & ANSWERS

Department of Mechanical Engineering

SUBJECT CODE: ME 8391

SUBJECT NAME: ENGINEERING THERMODYNAMICS

STUCOR APP

ME8391 ENGINEERING THERMODYNAMICS L T P C
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OBJECTIVES:

- To familiarize the students to understand the fundamentals of thermodynamics and to perform thermal analysis on their behavior and performance.
(Use of Standard and approved Steam Table, Mollier Chart, Compressibility Chart and Psychrometric Chart permitted)

UNIT I BASIC CONCEPTS AND FIRST LAW 9

Basic concepts - concept of continuum, comparison of microscopic and macroscopic approach. Path and point functions. Intensive and extensive, total and specific quantities. System and their types. Thermodynamic Equilibrium State, path and process. Quasi-static, reversible and irreversible processes. Heat and work transfer, definition and comparison, sign convention. Displacement work and other modes of work .P-V diagram. Zeroth law of thermodynamics – concept of temperature and thermal equilibrium– relationship between temperature scales –new temperature scales. First law of thermodynamics –application to closed and open systems – steady and unsteady flow processes.

UNIT II SECOND LAW AND AVAILABILITY ANALYSIS 9

Heat Reservoir, source and sink. Heat Engine, Refrigerator, Heat pump. Statements of second law and its corollaries. Carnot cycle Reversed Carnot cycle, Performance. Clausius inequality. Concept of entropy, T-s diagram, Tds Equations, entropy change for - pure substance, ideal gases - different processes, principle of increase in entropy. Applications of II Law. High and low grade energy. Available and non-available energy of a source and finite body. Energy and irreversibility. Expressions for the energy of a closed system and open systems. Energy balance and entropy generation. Irreversibility. I and II law Efficiency.

UNIT III PROPERTIES OF PURE SUBSTANCE AND STEAM POWER CYCLE 9

Formation of steam and its thermodynamic properties, p-v, p-T, T-v, T-s, h-s diagrams. p-v-T surface. Use of Steam Table and Mollier Chart. Determination of dryness fraction. Application of I and II law for pure substances. Ideal and actual Rankine cycles, Cycle Improvement Methods - Reheat and Regenerative cycles, Economiser, preheater, Binary and Combined cycles.

UNIT IV IDEAL AND REAL GASES, THERMODYNAMIC RELATIONS 9

Properties of Ideal gas- Ideal and real gas comparison- Equations of state for ideal and real gases- Reduced properties-.Compressibility factor-.Principle of Corresponding states. -Generalised Compressibility Chart and its use-. Maxwell relations, Tds Equations, Difference and ratio of heat capacities, Energy equation, Joule-Thomson Coefficient, Clausius Clapeyron equation, Phase Change Processes. Simple Calculations.

UNIT V GAS MIXTURES AND PSYCHROMETRY 9

Mole and Mass fraction, Dalton's and Amagat's Law. Properties of gas mixture - Molar mass, gas constant, density, change in internal energy, enthalpy, entropy and Gibbs function. Psychrometric properties, Psychrometric charts. Property calculations of air vapour mixtures by using chart and expressions. Psychrometric process - adiabatic saturation, sensible heating and cooling, humidification, dehumidification, evaporative cooling and adiabatic mixing. Simple Applications

TOTAL : 45 PERIODS

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ME8391 ENGINEERING THERMODYNAMICS

Objectives of the Subject

- To familiarize the students to understand the fundamentals of thermodynamics and to perform thermal analysis on their behavior and performance.
- To understand the basic terminologies and basic concepts of thermodynamics such as system, processes and cycles and about the thermodynamics properties emerging out of laws of thermodynamics.
- To integrate zeroth and first law to coin second law of thermodynamics and to understand the concepts of Carnot cycle, Clausius inequality, application of second law and availability analysis.
- To study about the properties of pure substances and application of first and second law to for pure substances and also extension to steam power cycles such as Rankine cycle.
- To learn about the properties of ideal and real gases to compare and contrast against them and about thermodynamic relations and to apply the concepts of thermodynamic principles to Psychrometric processes.
- To apply the principles of thermodynamics to Mechanical Engineering applications.

Need and Importance for Study of the subject

Thermodynamics is one of the most fundamental courses in mechanical engineering. Anything and everything in the day to day life carry the aspects of the application of thermodynamics right from energy conversion during metabolism to energy harnessing from sources. Knowledge of thermodynamics helps to understand how power plant works whether it is gas or thermal power plant. For analysing and designing Heat exchangers, pumps, compressors, boilers, combustion chambers, turbines, condensers, refrigeration and air conditioning, IC engine, flow through pipes and so on you need strong thermodynamics knowledge and I think all this is done by mechanical engineers in particular this subject deals with the

application in IC engines, Aircraft engines, compressors, nozzles, refrigerators and air conditioning system.

Industry Connectivity and Latest Developments

Since this is a fundamental subject, the students will be taken to Thermal labs and Fluid Machinery labs where the application of thermodynamic concepts can be very well explained.

Industrial Visit (Planned if any)

Course Outcomes

The students will be able to

1. Differentiate between open and closed system and various thermodynamics flow and non flow processes. Understand the direction of heat flow and the possibility of any real processes and also about maximum available energy
2. To understand the formation of steam and properties of pure substances and steam.
3. To use the properties of ideal and real gases to apply the concepts in compressible flow and know the implementation of laws of thermodynamics on thermodynamic relations.
4. To apply the concepts of thermodynamic principles to Psychometrics processes.
5. To apply the principles of thermodynamics to Mechanical Engineering applications.

Pre-requisites

The pre-requisite knowledge required by the Students to study this Course are Engineering Physics, Engineering chemistry and Basic Mathematics.

**ME8391- ENGINEERING THERMODYNAMICS
DETAILED LESSON PLAN**

Sl. No.	Unit No.	Topic	Hou rs	Refer ence s
BASIC CONCEPTS AND FIRST LAW				
1.	Unit- 1	Basic concepts - concept of continuum, comparison of microscopic and macroscopic approach	2	T1, T2
2.		Path and point functions. Intensive and extensive, total and specific quantities. System and their types.	2	T1, T2
3.		Thermodynamic Equilibrium State, path and process. Quasi-static, reversible and irreversible processes.	2	T1, T2
4.		Heat and work transfer, definition and comparison, sign convention. Displacement work and other modes of work .P-V diagram	2	T1, T2
5.		Zeroth law of thermodynamics – concept of temperature and thermal equilibrium– relationship between temperature scales –new temperature scales.	2	T1, T2
6.		First law of thermodynamics –application to closed and open systems – steady and unsteady flow processes.	2	T1, T2
		Unit I	12	
		Cumulative Hrs.	12	
SECOND LAW AND AVAILABILITY ANALYSIS				
7.	Unit- 2	Heat Reservoir, source and sink. Heat Engine, Refrigerator, Heat pump. Statements of second law and its corollaries.	2	T1, T2

8.		Carnot cycle Reversed Carnot cycle, Performance. Clausius inequality. Concept of entropy, T-s diagram, Tds Equations	3	T1, T2
9.		Entropy change for - pure substance, ideal gases - different processes, principle of increase in entropy.	2	T1, T2
10.		Applications of II Law. High and low grade energy. Available and non-available energy of a source and finite body. Energy and irreversibility.	3	T1, T2
11.		Expressions for the energy of a closed system and open systems. Energy balance and entropy generation. Irreversibility. I and II law Efficiency.	2	T1, T2
		Unit II	12	
Cumulative Hrs.			24	
PROPERTIES OF PURE SUBSTANCE AND STEAM POWER CYCLE				
12.		Formation of steam and its thermodynamic properties, p-v, p-T, T-v, T-s, h-s diagrams. p-v-T surface. Use of Steam Table and Mollier Chart. Determination of dryness fraction.	4	T1, T2
13.	Unit-3	Application of I and II law for pure substances.	2	T1, T2
14.		Ideal and actual Rankine cycles, Cycle Improvement Methods - Reheat and Regenerative cycles, Economiser, preheater	4	T1, T2
15.		Binary and Combined cycles.	2	T1, T2
		Unit III	12	
Cumulative Hrs			36	

IDEAL AND REAL GASES, THERMODYNAMIC RELATIONS				
16.	Unit-4	Properties of Ideal gas- Ideal and real gas comparison- Equations of state for ideal and real gases- Reduced properties	3	T1, T2
17.		Compressibility factor-.Principle of Corresponding states. -Generalised Compressibility Chart and its use	2	T1, T2
18.		Maxwell relations, Tds Equations, Difference and ratio of heat capacities, Energy equation, Joule-Thomson Coefficient	4	T1, T2
19.		Clausius Clapeyron equation, Phase Change Processes. Simple Calculations.	3	T1, T2
		Unit IV	12	
Cumulative Hrs			48	
GAS MIXTURES AND PSYCHROMETRY				
20.	Unit-5	Mole and Mass fraction, Dalton's and Amagat's Law. Properties of gas mixture	2	T1, T2
21.		Molar mass, gas constant, density, change in internal energy, enthalpy, entropy and Gibbs function	3	T1, T2
22.		Psychrometric properties, Psychrometric charts. Property calculations of air vapour mixtures by using chart and expressions.	3	T1, T2
23.		Psychrometric process – adiabatic saturation, sensible heating and cooling, humidification, dehumidification, evaporative cooling and adiabatic mixing. Simple Applications	4	T1, T2
		Unit V	12	
Cumulative Hrs.			60	

TEXT BOOKS :

1. Nag.P.K., "Engineering Thermodynamics", 4th Edition, Tata McGraw-Hill, New Delhi, 2008.
2. Natarajan E., "Engineering Thermodynamics: Fundamentals and Applications", Anuragam Publications, 2012.

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1. Cengel. Y and M.Boles, "Thermodynamics - An Engineering Approach", 7th Edition, TataMcGraw Hill, 2010.
2. Holman.J.P., "Thermodynamics", 3rd Edition, McGraw-Hill, 1995.
3. Rathakrishnan. E., "Fundamentals of Engineering Thermodynamics", 2nd Edition, Prentice-Hall of India Pvt. Ltd, 2006
4. Chattopadhyay, P, "Engineering Thermodynamics", Oxford University Press, 2010.
5. Arora C.P, "Thermodynamics", Tata McGraw-Hill, New Delhi, 2003.
6. Van Wylen and Sonntag, "Classical Thermodynamics", Wiley Eastern, 1987
7. Venkatesh. A, "Basic Engineering Thermodynamics", Universities Press (India) Limited, 2007.
8. Kau-Fui Vincent Wong, "Thermodynamics for Engineers", CRC Press, 2010 Indian Reprint.
9. Prasanna Kumar: Thermodynamics "Engineering Thermodynamics" Pearson Education, 2013

UNIT-1

BASIC CONCEPTS AND FIRST LAW

PART-A

1. What is microscopic approach in thermodynamics? Nov/Dec-2013

In microscopic approach, thermodynamic properties are considered at the molecular level. This approach is also called as statistical thermodynamics.

2. Define extensive property. Nov/Dec-2013

The properties which are dependent on the mass of the system are called extensive properties. Example: Total energy, Total volume, weight etc.

3. Define: Thermodynamic Equilibrium. May/June-2014

A system will be in a state of thermodynamic equilibrium, if the conditions for the following three types of equilibrium are satisfied.

- (a) Mechanical equilibrium
- (b) Thermal equilibrium
- (c) Chemical equilibrium

4. Differentiate between point function and Path function. May/June-2014

The quantities which are independent on the process or path followed by the system is known as point functions.

Example: Pressure, volume, temperature, etc.,

The quantities which are dependent on the process or path followed by the system is known as path functions.

Example: Heat transfer, work transfer.

5. Enlist the similarities between work and heat. Nov/Dec-2014

- i) Both work and heat are directional quantities because both have magnitude and direction in relation to whether the energy is entering or leaving the system.
- ii) Both are boundary phenomenon because they are only recognised when energy crosses the system boundary.
- iii) According to the second law of thermodynamics statements, a system processes energy.
- iv) Both work and heat are associated with a process as the system follows a path from state to another state.
- v) Both work and heat are path functions

6. Compare heat transfer with work transfer

Nov/Dec-2014

Heat is a form of energy in transit. It is a boundary phenomenon, since it occurs only at the boundary of a system. Energy transfer by virtue of temperature difference only is called heat transfer. All other energy interactions may be termed as work transfer.

7. State the first law for a closed system undergoing a process and a cycle.

April/May-2015

First law of thermodynamics states that when system undergoes a cyclic process The net heat transfer is equal to work transfer. $\oint Q = \oint W$

8. Why does free expansion have zero work transfer? April/May-2015

The expansion of a gas against vacuum is called as free expansion.

The reasons for free expansion have zero work transfer are:

- 1. There is no work crosses boundary of the system.
- 2. It is not a quasi-static process
- 3. There is no resistance to the fluid.

9. Define the Zeroth law of thermodynamics.

April/May-2015,2016

Zeroth law of thermodynamics states that when two systems are separately in thermal equilibrium with a third systems, then they themselves are in thermal equilibrium with each other. It is a base for temperature measurement.

10. List any five physical properties of matter which can be used for measurement of temperature.

April/May-2015

Pressure, Volume, Resistance, Thermal e.m.f, Length

11. State the thermodynamic definition of work.

Nov/Dec-2015

In thermodynamics, Work is said to be done by a system if the sole effect on things external to the system can be reduced to the raising of a weight.

12. Classify the following properties as intensive or extensive or neither

**a) Pressure b) Temperature c) Volume d) Internal energy e) Volume per mole
f) Enthalpy per unit mass.**

Nov/Dec-2015

- a. Pressure – Intensive property
- b. Temperature – Intensive property
- c. Volume – Extensive property
- d. Internal energy – Extensive property
- e. Volume per mole – Intensive property
- f. Enthalpy per unit mass - Intensive property

PART - B

1. A mass of air is initially at 260°C and 700kPa, and occupies 0.028m³. The air is expanded at constant pressure to 0.084m³. A polytropic process with n=1.5 is then carried out followed by a constant temperature process which completes a cycle. All the processes are reversible.

- i) Sketch the cycle in T-S and P-V planes**
- ii) Find the heat received and heat rejected in the cycle.**

iii) Find the efficiency of the cycle.

May/June - 2016

Given Data:

$$T_1 = 260^\circ\text{C}$$

$$P_1 = 700\text{kPa} = P_2$$

$$V_1 = 0.028\text{ m}^3$$

Process 2-3 is polytropic

$$V_2 = 0.084\text{ m}^3$$

Process 1-2 is constant pressure

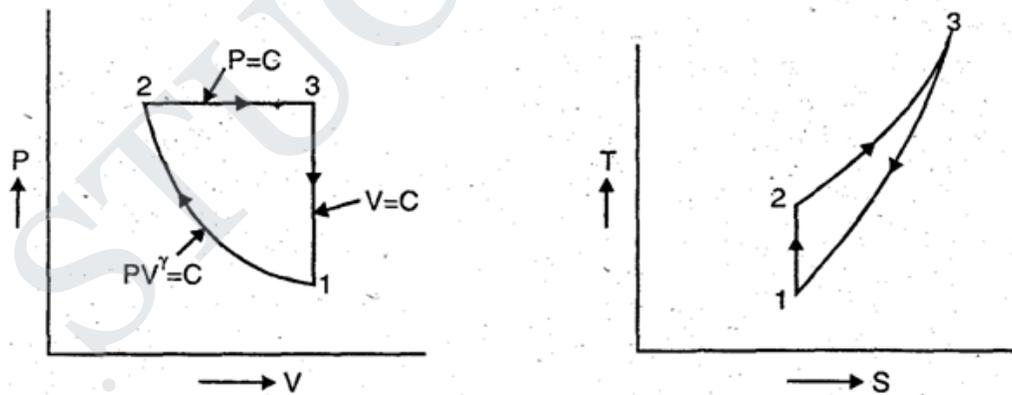
Process 3-1 is constant temperature

To find:

Sketch P-V and T-S diagram,

Q and η

Solution:



Process 1-2:

1. Constant pressure process, $\frac{V_2}{V_1} = \frac{T_2}{T_1}$

$$T_2 = 1599\text{K}$$

$$\text{Mass of air, } m = \frac{pV}{RT} = 0.128 \text{ kg}$$

$$\text{Workdone, } W_{1-2} = p (V_2 - V_1) = 39.2 \text{ kJ}$$

$$\text{Heat transfer, } Q_{1-2} = mC_p(T_2 - T_1) = 137.13 \text{ kJ}$$

Process 2-3:

For polytropic process,

$$\frac{T_1}{T_2} = \left(\frac{p_3}{p_2}\right)^{\frac{n-1}{n}}$$

$$P_3 = 25.93 \text{ kPa}$$

From $pV = mRT$

$$V_3 = \frac{mRT_3}{p_3} = 0.755 \text{ m}^3$$

$$\text{Polytropic work, } W_{2-3} = \frac{p_1V_1 - p_2V_2}{n-1} = 78.446 \text{ kJ}$$

$$\text{Heat transfer, } Q_{2-3} = \frac{\gamma - n}{\gamma - 1} \times W_{2-3} = -19.612 \text{ kJ}$$

Process 3-1

$$T_1 = T_3 = 260^\circ\text{C} = 533 \text{ K for constant temperature process}$$

$$\text{Work transfer, } W_{3-1} = -p_3V_3 \ln\left(\frac{p_1}{p_3}\right)$$

$$Q = -64.52 \text{ kJ (work input)}$$

Heat received in this cycle, $Q_s = 137.13 \text{ kJ}$ (consider only +ve heat)

Heat rejected in this cycle, $Q_R = 84.132 \text{ kJ}$ (consider only -ve heat)

$$\text{Efficiency of the cycle, } \eta = \frac{\text{Workdone}}{\text{Heat supplied}}$$

Efficiency of the cycle, $\eta = 1 - \frac{Q_R}{Q_S} = 38.74\%$

2. A room for four person has 2 fans each consuming 0.18 kW power and three 100 W lamps. Ventilation air at the rate of 80kg/hr enters with an enthalpy of 84 kJ/kg and leaves with an enthalpy of 59 kJ/kg. If each person puts out heat at the rate of 630 kJ/hr. determine the rate at which heat is removed by a room cooler, so that a steady state is maintained in the room.

May/June-2016 (8marks)

Given Data:

$n_p = 4$ (person), $n_f = 2$

$W_f = 0.18\text{kW}$ (each)

$W_l = 100\text{W}$ (each)

Mass of air, $m = 80\text{kg/hr}$

Enthalpy of air entering, $h_1 = 84 \text{ kJ/kg}$

Enthalpy of air leaving, $h_2 = 59 \text{ kJ/kg}$

$Q_p = 630 \text{ kJ/hr}$ (each person)

To find:

The rate of heat is to be removed

Solution:

Rate of energy increase = Rate of energy inflow - Rate of energy outflow

$$E = m \left(h_1 + \frac{c_1^2}{2} + z_1 g + Q \right) - m \left(h_2 + \frac{c_2^2}{2} + z_2 g + W \right) \dots (1)$$

Assuming that, $\frac{c_1^2 - c_2^2}{2} = 0$

Now, the equation (1) reduces to

$$\begin{aligned} Q &= E - m(h_1 - h_2) - W \\ &= -0.7\text{kW} \end{aligned}$$

$$m (h_1 - h_2) = 0.55 \text{ kW}$$

W = electrical energy input

$$= n_f W_f + n_l W_l$$

$$= 0.66 \text{ kW}$$

$$Q = -0.7 - 0.556 - 0.66 = -1.916 \text{ Kw}$$

b) An insulated rigid tank of 1.5 m³ of air with a pressure of 6 bar and 100°C discharges air in to the atmosphere which is at 1 bar through a discharge pipe till its pressure becomes 1 bar.

i) Calculate the velocity of air in the discharge pipe.

ii) Evaluate the work that can be obtained from the frictionless turbine using the kinetic energy of that air. May/June - 2016(8 marks)

Given Data:

$$V_i = V_f = V = 1.5 \text{ m}^3$$

$$p_i = 6 \text{ bar} = 600 \text{ kPa}$$

$$p_f = 1 \text{ bar} = 100 \text{ kPa}$$

$$T_d = T_f$$

$$\gamma = 1.4$$

$$R = 0.287 \text{ kJ/kg.K}$$

$$C_v = 0.718 \text{ kJ/kg.K}$$

For air $C_p = 1.005 \text{ kJ/kg.K}$

To Find:

i) velocity of air in the discharge pipe

ii) work that can be obtained from the frictionless turbine using the kinetic energy of that air

Solution:

It is the case of Tank discharged air. As it is insulated ($Q=0$), it can be considered as adiabatic process.

$$\frac{T_f}{T_i} = \left(\frac{p_f}{p_i}\right)^{\frac{\gamma-1}{\gamma}}$$

$$T_f = 223.6\text{K}$$

$$m_i = \frac{p_i V_i}{RT_i} = 8.407 \text{ kg}$$

$$m_f = \frac{p_f V_f}{RT_f} = 6.069 \text{ kg}$$

$$Q = (m_f u_f - m_i u_i) + (m) \left(h_d + \frac{C_d^2}{2000} \right) = 0 \text{ in kJ/kg } (h_d)$$

$$C_d = \sqrt{2000 \left(\frac{(m_f u_f - m_i u_i)}{m} - h_d \right)}$$

$$C_2 = 410.9 \text{ m/s}$$

$$\text{Turbine work} = \text{Kinetic energy} = \frac{1}{2} m C_2^2 = 51290 \text{ J}$$

$$\text{Turbine work} = \text{kinetic energy} = 512.59 \text{ KJ}$$

3. Determine the heat transfer and its direction for a system in which a perfect gas having molecular weight of 16 is compressed from 101.3kPa, 20°C to a pressure of 600 kPa following the law $pV^{1.3}=\text{constant}$. Take specific heat at constant pressure of gas as 1.7kJ/kg K. May/June - 2014

Given Data:

$$\text{Molecular weight } M = 16$$

$$P_1 = 101.3\text{kPa}$$

$$p_2 = 600\text{kPa}$$

$$T_1 = 20 + 273 = 293\text{K}$$

$$pV^{1.3} = \text{constant}$$

$$\gamma = 1.4$$

$$R = 0.287 \text{ kJ/kg.K}$$

$$C_p = 1.7 \text{ kJ/kg.K}$$

To Find:

Q and its Direction

Solution:

Gas constant of perfect gas ,

$$R = R_u/M = 8.314/16 = 0.508$$

$$R = C_p - C_v = 1.7 - 0.508 \\ = 1.192 \text{ kJ/kg.K}$$

$$\gamma = C_p / C_v = 1.7 / 1.192 = 1.42$$

During polytropic process

$$T = T_1 (P_2/P_1)^{n-1/n} \\ = 293(600/101.3)^{1.3-1/1.3} \\ = 441.11\text{K}$$

$$\text{Work transfer } W = \frac{mR(T_1 - T_2)}{n-1} = \frac{1 \times 0.508(293 - 441.11)}{1.3-1} \\ = -250.79 \text{ kJ/kg}$$

$$\text{Heat transfer } Q = \frac{\gamma - n}{\gamma - 1} \times W = \frac{1.42 - 1.3}{1.42 - 1} \times -250.79 \\ = -71.65 \text{ kJ/kg}$$

The negative sign indicates the heat rejection from the system

4. Three grams of nitrogen gas at 6 atm and 100°C in a frictionless piston cylinder device is expanded adiabatically to double its initial volume, then compressed at constant pressure to its initial volume and then compressed

again at constant volume to its initial state. Calculate the net work done on the gas. Draw the P-V diagram for the processes. Nov/Dec - 2014

Given Data:

$$m = 3\text{kg}$$

$$P_1 = 6\text{atm} = 6 \times 1.0132 = 6.0792\text{bar}$$
$$= 6.0792 \times 100 = 607.92\text{kPa}$$

$$T_1 = 160^\circ\text{C} = 160 + 273 = 433\text{K}$$

Process 1-2 is adiabatic expansion ($V_2 = 2V_1$)

Process 2-3 is Constant pressure process ($P_2 = P_3$)

Process 3-1 is Constant volume process ($V_3 = V_1$)

To Find:

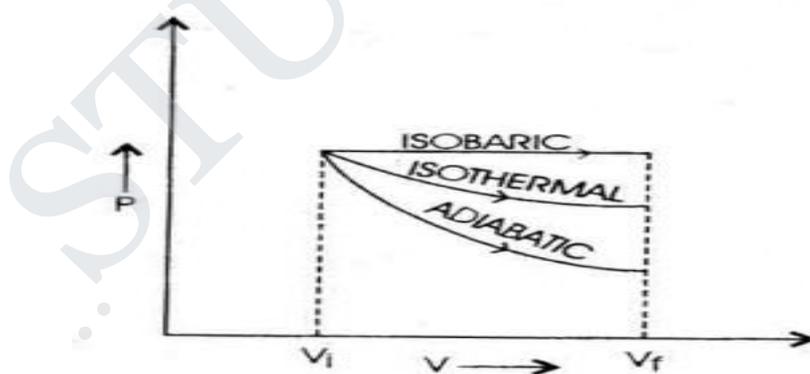
$$W_{\text{net}}$$

Solution:

Molecular weight of nitrogen $M = 2 \times 14 = 28$

Gas constant of nitrogen gas ,

$$R = R_u/M = 8.314/28 = 0.297 \text{ kJ/kg.K}$$



Process 1-2

Adiabatic expansion process

$$P_1 V_1^\gamma = P_2 V_2^\gamma$$

$$P_2 = P_1 \left(\frac{V_1}{2V_1} \right)^\gamma = P_1 \left(\frac{1}{2} \right)^\gamma$$

$$P_2 = 6.0792 \times \left(\frac{1}{2} \right)^{1.4}$$

$$= 2.304 \text{ bar} = 230.4 \text{ kPa}$$

From ideal gas equation,

$$P_1 V_1 = mRT_1$$

$$V_1 = \frac{mRT_1}{P_1} = \frac{0.003 \times 0.297 \times 433}{607.92} = 0.000635 \text{ m}^3$$

$$V_2 = 2V_1 = 2 \times 0.000635 \text{ m}^3$$

$$\text{Work done } W_{1-2} = \frac{p_1 V_1 - p_2 V_2}{n-1}$$

$$= \frac{607.92 \times 0.000635 - 230.4 \times 0.00127}{1.4-1} = 0.319 \text{ KJ}$$

Process 2-3

For Constant Pressure process

$$\text{Work done, } W_{2-3} = P_2 (V_3 - V_2)$$

$$= 230.4 \times (0.000635 - 0.00127) \quad (\because V_3 = V_1)$$

$$= -0.146 \text{ KJ}$$

Process 3-1

For Constant Volume process

$$\text{Work done, } W_{3-1} = 0$$

$$\text{Net Work done } W_{\text{net}} = W_{1-2} + W_{2-3} + W_{3-1}$$

$$= 0.319 - 0.146 + 0$$

$$= 0.173 \text{ KJ}$$

5. 90kJ of heat is supplied to a system at a constant volume. The system rejects 95kJ of heat at constant pressure and 18 kJ of work is done on it. The system is brought to original state by adiabatic process. Determine

Nov/Dec- 2014

- i) The adiabatic work
- ii) The values of internal energy at all states if initial value is 105kJ.

Given Data:

$$Q_{1-2} = 90\text{KJ}$$

$$Q_{2-3} = -95\text{KJ} \text{ (negative sign indicates the heat rejection)}$$

$$W_{2-3} = -18\text{KJ} \text{ (negative sign indicates the work done on the system)}$$

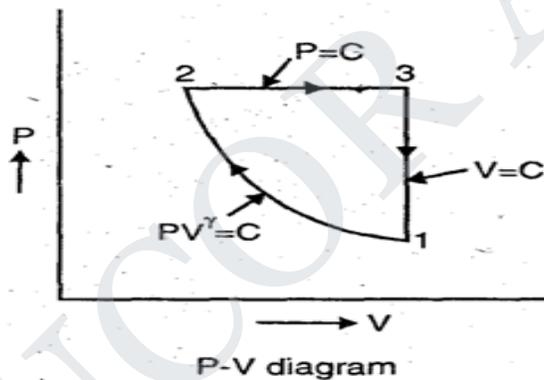
Process 3-1 is adiabatic. So $Q_{2-3} = 0$

$$U = 105\text{KJ}$$

To find:

$$W, \Delta U$$

Solution:



Process 1-2

For Constant Volume process

$$\text{Work done, } W_{1-2} = 0$$

Based on first law of thermodynamics,

$$\text{Heat done } Q_{1-2} = W_{1-2} + \Delta U$$

$$\Delta U = 90\text{KJ}$$

$$\text{But } \Delta U = U_2 - U_1$$

$$90 = U_2 - 105$$

$$U_2 = 195\text{KJ}$$

Process 2-3

For Constant Pressure process

$$Q_{2-3} = -95\text{KJ}$$

$$W_{2-3} = -18\text{KJ}$$

Based on first law of thermodynamics,

$$\text{Heat done } Q_{1-2} = W_{1-2} + \Delta U$$

$$95 = -18 + \Delta U$$

$$\Delta U = -95 + 18 = -77\text{KJ}$$

But

$$\Delta U = U_3 - U_2$$

$$-77 = U_3 - 195$$

$$U_3 = 195 - 77$$

$$= 118\text{KJ}$$

Process 1-2

For adiabatic process

$$Q_{2-3} = 0$$

Based on first law of thermodynamics,

$$\Phi dQ = \Phi dW$$

$$Q_{1-2} + Q_{2-3} + Q_{3-1} = W_{1-2} + W_{2-3} + W_{3-1}$$

$$90 - 95 + 0 = 0 - 18 + W_{3-1}$$

$$W_{3-1} = 13\text{KJ}$$

6. Air flows steadily at the rate of 0.04 kg/s through an air compressor, entering at 6 m/s with a pressure of bar and a specific volume of 0.85 m³/kg

and leaving at 4.5 m/s with a pressure of 6.9 bar and a specific volume of 0.16 m³/kg. The internal energy of the air leaves at 88 kJ/kg greater than that of entering air. Cooling water surrounding the cylinder absorbs heat from the air at the rate of 59W. Calculate the power required to drive the compressor and the inlet and outlet cross-sectional areas. Nov/Dec – 2015(16marks)

Given Data:

$$m = 0.5 \text{ Kg}$$

$$C_1 = 6 \text{ m/S}$$

$$P_1 = 100 \text{ kpa}$$

$$v_1 = 0.85 \text{ m}^3/\text{kg}$$

$$C_2 = 5 \text{ m/S}$$

$$P_2 = 690 \text{ kpa}$$

$$v_2 = 0.16 \text{ m}^3/\text{kg}$$

$$u_2 - u_1 = 88 \text{ KJ/Kg}$$

$$Q = -59 \text{ Kw}$$

To find:

$$P, D_1/D_2$$

Solution:

Steady Flow Energy Equation (SFEE) given by

$$m(u_1 + p_1 v_1 + C_1^2/2 + Z_1 g) + Q = m(u_2 + p_2 v_2 + C_2^2/2 + Z_2 g) + W$$

$$0.04 (100 \times 0.85) + 6^2/20000 - 59 = 0.04 (690 \times 0.16) + 5^2/20000 + W$$

$$\text{Work input } W = - 63.52 \text{ Kw}$$

The negative sign indicates that the work is done on the system

From Continuity equation

$$A_1 C_1 / v_1 = A_2 C_2 / v_2$$

$$A_1 / A_2 = C_2 v_1 / C_1 v_2 = 3.98$$

$$D_1 / D_2 = 1.99$$

7. A gas undergoes a thermodynamic cycle consisting of the following process:

(i) Process 1-2 : constant pressure $p_1 = 1.4$ bar, $V_1 = 0.028\text{m}^3$, $W_{12} = 10.5$ kJ.

(ii) Process 2-3 : Compression with $pV = \text{constant}$, $U_3 = U_2$

(iii) Process 3-1: Constant volume $U_1 - U_3 = -26.4\text{kJ}$.

There are no significant changes in KE and PE

1) Sketch the cycle on a pV diagram.

2) Calculate the network for the cycle in kJ.

3) Calculate the heat transfer for process 1-2

4) Show that $\sum Q_{\text{cycle}} = \sum W_{\text{cycle}}$

May-June 2015

Given Data:

$$P_1 = p_2 = 1.4 \text{ Bar}$$

$$V_1 = 0.028\text{m}^3$$

$$\text{Work interaction } W_{1-2} = 10.5\text{KJ}$$

2-3 Compression process with $pV = \text{Constant}$

3-1 Constant volume process

$$U_1 - U_2 = -26.4\text{KJ}$$

To find

$$W_{\text{net}}$$

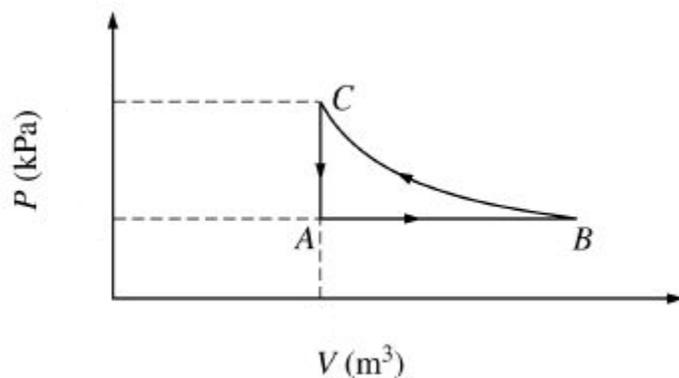
$$Q$$

Solution:

1-2 constant pressure process:

$$W_{1-2} = p_1(V_2 - V_1)$$

$$V_2 = 0.103 \text{ m}^3$$



2-3 constant temperature process:

$$W_{2-3} = p_2 V_2 \ln \frac{v_1}{v_3}$$

$$W = -18.78 \text{ kJ}$$

Change in internal energy,

$$\Delta U = U_3 - U_2 = 0 \text{ for isothermal process}$$

Heat transfer, $Q_{2-3} = \text{work transfer, } W = -18.78 \text{ kJ}$

3-1 constant volume process:

$$V_1 = V_3 = 0.103 \text{ m}^3$$

Work transfer, $W_{3-1} = 0$

Heat transfer, $Q_{3-1} = U_1 - U_3 = -26.4 \text{ kJ}$

$$\begin{aligned} \text{Network of the cycle, } W_{\text{net}} &= W_{1-2} + W_{2-3} + W_{3-1} \\ &= -8.28 \text{ kJ} \end{aligned}$$

Internal energy for process 1-2, U_{1-2}

$$\begin{aligned} \therefore U_{1-2} &= U_2 - U_1 \\ &= 26.4 \text{ kJ} \end{aligned}$$

$$\begin{aligned} \text{Heat transfer, } Q_{1-2} &= W_{1-2} + U_{1-2} \\ &= 36.9 \text{ kJ} \end{aligned}$$

Net heat transfer of the cycle,

$$Q_{\text{net}} = Q_{1-2} + Q_{2-3} + Q_{3-1}$$

$$= - 8.28 \text{ kJ}$$

Hence, $\sum Q_{\text{cycle}} = \sum W_{\text{cycle}}$ proved.

8. A gas occupies 0.3 m^3 at 2 bar. It executes a cycle consisting of processes:

- (i) 1 - 2, constant pressure with work interaction of 15kJ
- (ii) 2 - 3, compression process which follows the law $pV = C$ and $U_3 = U_2$ and
- (iii) 3 - 1, constant volume process, and reduction in internal energy is 40kJ

Neglecting the changes in Kinetic energy and Potential energy. Draw pV diagram for the process and determine network transfer for the cycle. Also show that first law is obeyed by the cycle. April-May 2017 (13 MARK)

Given:

$$p_1 = p_2 = 2 \text{ bar} = 200 \text{ kN/m}^2$$

$$V_1 = 0.3 \text{ m}^3$$

$$W_{1-2} = 15 \text{ kJ}$$

$$U_1 - U_3 = 40 \text{ kJ}$$

To Find:

Network transfer for the cycle?

Solution:

Process 1-2 Constant pressure process:

$$W_{1-2} = p_1(V_2 - V_1)$$

$$15 = 200 \times (V_2 - 0.3)$$

$$V_2 = 0.375 \text{ m}^3$$

Process 2-3 Constant Temperature process:

$$W_{2-3} = p_2 V_2 \ln\left(\frac{V_3}{V_2}\right)$$

$$= 200 \times 0.3 \times \ln\left(\frac{0.3}{0.375}\right)$$

$$(V_3 = V_1)$$

$$W_{2-3} = -13.388 \text{ kJ}$$

$$\text{Also, } p_2 V_2 = p_3 V_3$$

$$p_3 = \frac{200 \times 0.375}{0.3}$$

$$p_3 = 250 \text{ kN/m}^2$$

Change in internal energy $\Delta U = 0$ for isothermal process

Process 3-1 Constant volume process

$$V_2 = V_3 = 0.375 \text{ m}^3$$

Work transfer, $W = 0$

Heat transfer, $Q = 40 \text{ kJ}$

9. In a gas turbine, the gases enter the turbine at the rate of 5 kg/s with a velocity of 50 m/s and the enthalpy of 900 kJ/kg and leaves the turbine with 150 m/s and the enthalpy of 400 kJ/kg. The loss of heat from the gas to the surroundings is 25 kJ/kg. Assume $R = 0.285 \text{ kJ/kg K}$, $C_p = 1.004 \text{ kJ/kg K}$ and the inlet conditions to be at 100 kPa and 27°C. Determine the work done and diameter of the inlet pipe.
April-May 2017 (13 MARK)

Given:

$$m = 5 \text{ kg/s}$$

$$C_1 = 50 \text{ m/s}$$

$$h_1 = 900 \text{ kJ/kg}$$

$$C_2 = 150 \text{ m/s}$$

$$h_2 = 400 \text{ kJ/kg}$$

$$R = 0.285 \text{ kJ/kgK}$$

$$C_p = 1.004 \text{ kJ/kgK}$$

$$Q = -25 \text{ kJ/kg}$$

$$p_1 = 100 \text{ kPa } T_1 = 27 \text{ }^\circ\text{C}$$

To find:

1. work done
2. diameter of the inlet pipe.

Solution:

The steady flow energy equation is given by

$$\left(h_1 + \frac{C_1^2}{2} + Z_1 g \right) + Q = \left(h_2 + \frac{C_2^2}{2} + Z_2 g \right) + W$$

$$Z_1 = Z_2$$

$$\left(900 + \frac{(50)^2}{2000} \right) - 25 = \left(400 + \frac{(150)^2}{2000} \right) + W$$

$$876.25 = 411.25 + W$$

$$W = 465 \text{ kJ/kg}$$

$$\text{Power} = mW$$

$$= 5 \times 465$$

$$= 2325 \text{ kW}$$

$$m = \frac{A_1 C_1}{V_1}$$

we know

$$p_1 V_1 = mRT_1$$

$$V_1 = \frac{0.285 \times 300}{100}$$

$$V_1 = 0.855 \text{ m}^3$$

$$A_1 = \frac{mV_1}{C_1}$$

$$= \frac{5 \times 0.855}{50}$$

$$A_1 = 0.0855 \text{ m}^2$$

$$\frac{\pi}{4} d_1^2 = 0.0855$$

$$d_1 = 0.3299 \text{ m}$$

10. A Piston -cylinder device contains 0.15kg of air initially at 2 MPa and 350°C. The air is first expanded isothermally to 500KPa, then compressed polytropically with a polytropic exponent of 1.2 to the initial pressure and finally compressed at the constant pressure to the initial state .Determine the boundary work for each process and the network of the cycle.

NOV/DEC 2016 (13 MARK)

Given data:

$$m = 0.15 \text{ kg}$$

$$p_1 = 2 \text{ MPa} = 2000 \text{ KPa} = p_3$$

$$T_1 = 350^\circ\text{C} = 270 + 350 = 621 \text{ K} = T_2$$

$$P_2 = 500 \text{ KPa}$$

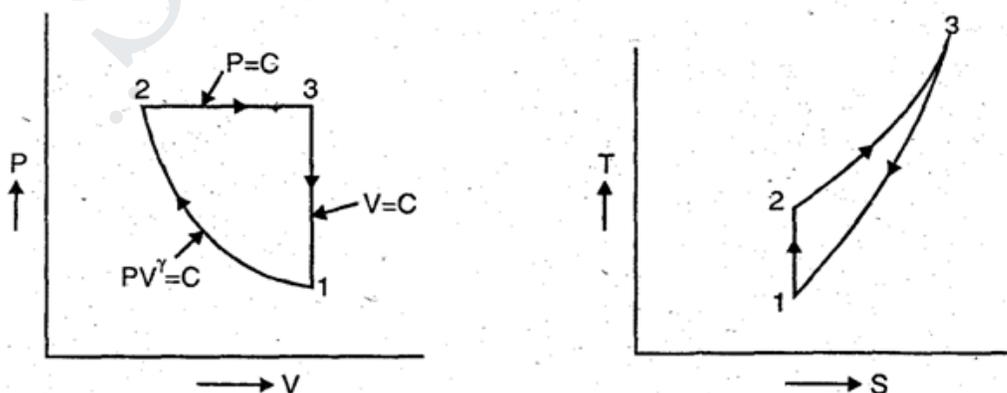
$$n = 1.2$$

Process 1-2 is isothermal (Expansion)

Process 2-3 is polytropic (Compression)

Process 3-1 is constant pressure (Compression)

Solution:



Process 1-2: Isothermal Expansion process

$$\begin{aligned} \text{Volume at rate,1, } V_1 &= m R T_1 / P_1 \\ &= 0.15 * 0.287 * 623 / 2000 \\ &= 0.0134 \text{m}^3 \end{aligned}$$

$$\begin{aligned} \text{Volume at rate,2, } V_2 &= m R T_2 / P_2 \\ &= 0.15 * 0.287 * 623 / 500 \\ &= 0.054 \text{m}^3 \end{aligned}$$

Constant temperature process,

$$\begin{aligned} \text{Work transfer, } W_{1-2} &= m R T_1 \ln(p_1/p_2) \\ W_{1-2} &= 0.15 * 0.287 * 623 \ln(2000/500) \\ &= 37.18 \text{KJ} \end{aligned}$$

Process 2-3: Polytropic compression process

For Polytropic process,

$$\begin{aligned} P_2 V_2^n &= P_3 V_3^n \\ V_3 &= \left(\frac{P_2}{P_3} \right)^{1/n} V_2 = \left(\frac{500}{2000} \right)^{1/1.2} * 0.054 = 0.017 \text{m}^3 \end{aligned}$$

$$\begin{aligned} \text{Polytropic work } W_{2-3} &= \frac{P_2 V_2 - P_3 V_3}{n-1} \\ &= \frac{500 * 0.054 - 2000 * 0.017}{1.2-1} \\ &= -35 \text{KJ} \end{aligned}$$

Process 3-1:

$$\text{Workdone, } W_{3-1} = p_3 (V_1 - V_3) \text{ for constant pressure processes}$$

$$=2000(0.0134-0.017)$$

$$= -7.2\text{kJ}$$

$$\text{Net work, } W_{\text{net}} = W_{1-2} + W_{2-3} + W_{3-1}$$

$$= 37.18 - 35 - 7.2$$

$$=5.2\text{kJ}$$

11. Air enters the compressor of a gas- turbine plant at ambient conditions of 100kPa and 25°C with a low velocity and exits at 1MPa and 347° C with a velocity of 90 m/s .The compressor is cooled at a rate of 1500KJ/min and the power input to the compressor is 250KW. Determine the mass flow rate of air through the compressor. Assume $C_p = 1.005\text{KJ/KgK}$

NOV/DEC 2016 (7 MARK)

Given data:

$$P_1 = 100\text{kPa}$$

$$T_1 = 25^\circ\text{C} = 25 + 273 = 298\text{K}$$

$$C_1 = 0$$

$$P_2 = 1\text{MPa}$$

$$T_2 = 347^\circ\text{C} = 347 + 273 = 620\text{K}$$

$$C_2 = 90\text{ m/s}$$

$$Q = 1500\text{KJ/min}$$

$$P = 250\text{KW}$$

$$C_p = 1.005\text{KJ/KgK-}$$

Solution:

SFEE is given by

$$m(h_1 + C_1^2/2 + Z_1g) + Q = m(h_2 + C_2^2/2 + Z_2g) + W$$

$$m(h_1 - h_2) + C_1^2/2 - C_2^2/2 = W - Q$$

Assume $Z_1 = Z_2$

$$m (1.005 (298 - 620) + 0 - 90^2/2000 = - 250 - (-25)$$

$$m = 0.687 \text{ kg/s}$$

PART - C

12. Air at 80 kPa, 27 °C and 220 m/s enters a diffuser at a rate of 2.5 kg/s and leaves at 42 °C. The exit area of the diffuser is 400cm². The air is estimated to lose heat at a rate of 18 kJ/s during this process.

(i) the exit velocity and

(ii) the exit pressure of the air. APRIL/ MAY 2017 (15 MARK)

Given:

$$P_1 = 80 \text{ kPa} = 80 \text{ kN/m}^2$$

$$C_1 = 220 \text{ m/s}$$

$$m = 2.5 \text{ kg/s}$$

$$T_1 = 27 \text{ °C} = 27 + 273 = 300 \text{ K}$$

$$T_2 = 42 \text{ °C} = 42 + 273 = 315 \text{ K}$$

$$A_2 = 400 \text{ cm}^2 = 0.04 \text{ m}^2$$

$$Q = -18 \text{ kJ/s}$$

To find:

1. $C_2 = ?$
2. $P_2 = ?$

Solution:

For Isentropic flow

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$
$$= 80 \times \left(\frac{315}{300}\right)^{0.4}$$

$$P_2 = 94.89 \text{ kN/m}^2$$

SFEE FOR Nozzle

$$m \times \frac{C_1^2}{2} + h_1 + Q = h_2 + \frac{C_2^2}{2} \times m$$

$$C_2 = \sqrt{2m[(h_1 - h_2) + Q + C_1^2]}$$

$$C_2 = \sqrt{2 \times 2.5 [C_p(T_1 - T_2) + Q + C_1^2]}$$

$$C_2 = \sqrt{5 [1005(300 - 315) - 18 + 220^2]}$$

$$C_2 = 408.08 \text{ m/s}$$

Unit - II

SECOND LAW AND AVAILABILITY ANALYSIS

Part - A

- 1. What is a thermal energy reservoir? Explain the term 'Source' and 'Sink'. [Apr/May 15/ R-2013]**

Thermal energy reservoir: Infinite body which supplies or receives the heat continuously without change in its temperature.

Source: Reservoir which supplies the heat to work absorbing or work developing device.

Sink: Reservoir which receives the heat from work absorbing or work developing device.

- 2. What is a reversed heat engine? [Apr/May-15/ R-2013]**

A reversed heat engine is a device works on reversed Carnot cycle which absorbs work energy. Reversed heat engines operate as heat pump or refrigerator.

- 3. Express Clausius inequality for various process. [Nov/Dec-15/R-2013] or State Entropy principle**

a. $\oint \frac{dQ}{T} = 0$, the cycle is reversible

b. $\oint \frac{dQ}{T} < 0$, the cycle is irreversible and possible

c. $\oint \frac{dQ}{T} > 0$, the cycle is impossible.

- 4. Define second law efficiency. [Nov/Dec-15/R-2013]**

Second law efficiency is defined as the ratio of change in the available energy of the system and change in the available energy of the source.

5. State Clausius Statement of Second law of thermodynamics[Nov/Dec-13/R-2008]

It states that it is impossible to construct a device which, operating in a cycle, will produce no effect other than the transfer of heat from a cooler to a hotter body.

6. State : Kelvin –Planck Statement.[May/June -14/ R-2008]

Kelvin-Planck states that it is impossible for a heat engine to produce net work in a complete cycle if it exchanges heat only with bodies at a single fixed temperature.

7. Write Carnot theorem and its corollaries. [May/June -14/ R-2008]

Carnot theorem: It states that of all heat engines operating between a given constant temperature source and a given constant temperature sink, none has a higher efficiency than a reversible engine.

Corollaries:

1. The efficiency of all reversible heat engines operating between the same temperature levels is the same.
2. The efficiency of a reversible engine is independent of the nature or amount of the working substance undergoing the cycle.

8. An inventor claims to have developed an engine which absorbs 100 KW of heat from a reservoir at 1000 K produces 60 KW of work and rejects heat to a reservoir at 500K. will you advise investment in its development. [Nov/Dec-14/R-2013]

Given Data: $Q = 100 \text{ kW}$; $T_1 = 1000 \text{ K}$; $W = 60 \text{ kW}$; $T_2 = 500 \text{ K}$

Solution: Carnot efficiency $\eta_{carnot} = 1 - \frac{T_2}{T_1} = 1 - \frac{500}{1000} = 50\%$

Engine efficiency $\eta_{engine} = 1 - \frac{W}{Q} = 1 - \frac{60}{100} = 60\%$

$\eta_{engine} > \eta_{carnot}$, so it is not advisable to invest in developing this engine

9. A turbine gets a supply of 5 kg of steam at 7 bar, 250° C and discharged it at 1 bar. Calculate the availability. [Nov/Dec-14/R-2013]

Given Data: $m = 5 \text{ kg}$; $P_1 = 7 \text{ bar}$; $T_1 = 250^\circ \text{ C}$; $P_2 = 1 \text{ bar}$

Solution: For turbine Availability $B = m [h_1 - h_2]$

From Mollier diagram at @ 7 bar and 250°C $h_1 = 2954 \text{ kJ/kg}$;

Draw vertical line up to 1 bar and read enthalpy $h_2 = 2581 \text{ kJ/kg}$.

$$B = 5 [2954 - 2581] = 1865 \text{ kW}$$

10. A reversible heat engine operates between a source at 800°C and a sink at 30°C. What is the least rate of heat rejection per kW network output of the engine?[May/ June 2016/ R2013]

Given data : $T_1 = 800 + 273 = 1073 \text{ K}$, $T_2 = 30 + 273 = 303 \text{ K}$, $W = 1 \text{ kW}$

To find : Q_r

$$\text{Solution : } \eta = \frac{T_1 - T_2}{T_1} = \frac{1073 - 303}{1073} = 71.76\%$$

$$\eta = \frac{W}{Q_S} ; 0.71765 = \frac{1}{Q_S} ; Q_S = 1.3934 \text{ kW} ;$$

$$Q_r = Q_S - W = 1.393 - 1 = 0.393 \text{ kW}$$

11. Define irreversibility? What are the causes of irreversibility?[Nov/Dec-15/R-2008], [May/ June 2016/ R2013]

It is defined as the actual work done by a system is always less than the idealized reversible work, and the difference between the two is called irreversibility. $I = W_{rev} - W = W_{max} - W$

Causes of irreversibility:

- i. Lack of equilibrium
- ii. Heat transfer through a finite temperature difference
- iii. Lack of pressure equilibrium within the interior of the system
- iv. Free expansion
- v. Dissipative effects

12. List the limitation of first law of thermodynamics?[May/June 2016/R8]

- (i) First law of thermodynamics does not specify the direction of flow of heat and work.
- (ii) First law does not give any information on whether that changes of state or process is at all feasible or not.

13. In an isothermal process 1000 kJ of work done by the system at a temperature 200°C. What is the entropy change of this process?[May/ June 2016/ R2008]

Given Data: $W = 1000$ kJ, $T = 200 + 273 = 473$ K ; To find : $\Delta S = ?$

In isothermal process $Q = W = 1000$ KJ

$$\Delta S = \frac{Q}{T} = \frac{1000}{473} = 2.114 \text{ kJ/kg K}$$

14. A closed insulated vessel contains 200 kg of water. A paddle wheel immersed in the water is driven at 400 rev/min with an average torque of 500 Nm. If the test run is made for 30 minutes. Determine rise in the temperature of water . Take specific heat of water 4.186 KJ/Kg K.[Apr/may-2015/ R2008]

Given Data: $m_w = 200$ kg; $N = 400$ rpm; Torque = 500 Nm; time $t = 30$ min;

$C_{pw} = 4.186$ KJ/Kg k

To find : ΔT

Solution : Work done by Paddle wheel (Brake power) = Heat gain by water

$$2 \pi N \text{ Torque} \cdot t = m_w C_{pw} \Delta T$$

$$2 \pi 400 \times 500 \times 30 = 200 \times 4.186 \times 10^3 \times \Delta T ; \Delta T = 45^\circ \text{C}$$

15. A heat engine supplies with 2512 kJ/min of heat at 650°C. Heat rejection take place at 100°C. specify which of the following heat rejection represents reversible, irreversible or impossible result (i) 867 kJ/min (ii) 1015 kJ/min [Apr/May-2015/ R2008]

Given data : $T_1 = 650 + 273 = 923\text{K}$; $T_2 = 100 + 273 = 373\text{K}$; $Q_1 = 2512\text{ kJ/min} = 41.87\text{ kJ/sec}$; $Q_{2(i)} = 867\text{ kJ/min} = 14.45\text{ kJ/sec}$; $Q_{2(ii)} = 1015\text{ kJ/min} = 16.92\text{ kJ/sec}$

Solution:

$$\eta_{Carnot} = \frac{T_1 - T_2}{T_1} = \frac{923 - 373}{923} = 59.59\%$$

Case (i) $Q_2 = 867\text{ kJ/min}$

$$\eta_{act} = \frac{Q_1 - Q_2}{Q_1} = \frac{41.87 - 14.45}{41.87} = 65.47\%$$

it is impossible because $\eta_{Carnot} < \eta_{act}$

Case (ii) $Q_2 = 1015\text{ kJ/min}$

$$\eta_{act} = \frac{Q_1 - Q_2}{Q_1} = \frac{41.87 - 16.92}{41.87} = 59.59\% ; \text{ it is reversible because}$$

$$\eta_{Carnot} = \eta_{act}$$

PART - B

1. a. In a Carnot cycle the maximum pressure and temperature are limited to 18 bar and 410°C. The volume ratio of isentropic compression is 6 and isothermal expansion is 1.5. Assume the volume of the air at the beginning of isothermal expansion as 0.18m³. Show the cycle P-V and T-S diagram and determine (i) the pressure and temperature at main points (ii) Thermal efficiency of the cycle. [May/June -2016 / R-2008] (8 marks)

Given Data :

The highest pressure $P_2 = 18 \text{ bar}$

The highest temperature $T_2 = 410 + 273 = 683 \text{ K} = T_3$

Volume $V_2 = 0.18 \text{ m}^3$

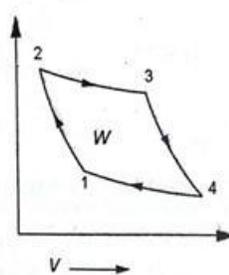
$$\frac{V_1}{V_2} = 6 ; V_1 = 1.08 \text{ m}^3$$

$$\frac{V_3}{V_2} = 1.5 ; V_3 = 0.27 \text{ m}^3$$

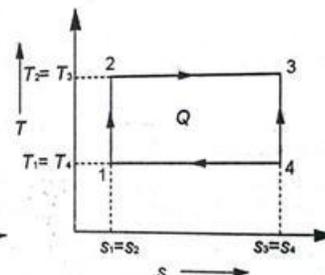
Solution:

Process 1-2:

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$$



(a) p-V diagram



(b) T-s diagram

$$\frac{683}{T_1} = (6)^{1.4-1}$$

$$T_1 = 333.5 \text{ K} = T_4$$

$$\frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^{\gamma}$$

$$\frac{18}{P_1} = (6)^{1.4}$$

$$P_2 = 1.46 \text{ bar}$$

Process 2-3:

$$P_2 V_2 = P_3 V_3$$

$$18 \times 0.18 = P_3 \times 0.27$$

$$P_3 = 12 \text{ bar}$$

Process 3-4 :

$$\frac{P_4}{P_3} = \left(\frac{V_3}{V_4}\right)^{\gamma}$$

$$\frac{P_4}{12} = \left(\frac{1}{6}\right)^{1.4}$$

$$P_4 = 0.977 \text{ bar.}$$

Thermal efficiency of cycle

$$\eta = \frac{T_2 - T_1}{T_3}$$

$$\eta = \frac{683 - 333.55}{683}$$

Thermal efficiency of the cycle = 51.16%

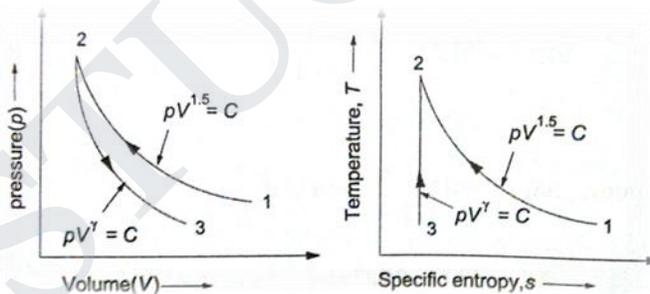
1.b. 5 m³ of air at 2 bar 27°C is compressed up to 6 bar pressure following $PV^{1.2} = \text{constant}$. It is subsequently expanded adiabatically to 2 bar. Considering the two process to be reversible, determine the network, net heat transfer, change in entropy. Also plot the process on T-S and P-V diagram [MAY/JUN 2014 /R-2008] [8 marks]

Given Data :

- $V_1 = 5 \text{ m}^3$
- $P_1 = 2 \text{ bar}$
- $T_1 = 27 + 273 = 300 \text{ K}$
- $P_2 = 6 \text{ bar}$
- $PV^{1.3} = C$
- $n = 1.3$
- $P_3 = 2 \text{ bar}$

Process : 1-2 Polytropic ; Process : 2-3
Reversible adiabatic

To find : W, Q, ΔS and T-S and P-V Diagram



Solution:

Process 1-2 :

From general equation

$$P_1 V_1 = m R T_1$$

$$m_1 = \frac{P_1 V_1}{R T_1} = \frac{2 \times 100 \times 5}{0.287 \times 300} = 11.61 \text{ kg}$$

From polytropic Process relation

$$T_2 = T_1 \left(\frac{P_2}{P_1} \right)^{n-1/n} = 300 \left(\frac{6}{2} \right)^{1.3-1/1.3} = 386.57 \text{ K}$$

Work done

$$W_{1-2} = \frac{mR(T_1 - T_2)}{n-1} = \frac{11.61 \times 0.287 \times (300 - 386.57)}{1.3-1} = -961.52 \text{ kJ}$$

Heat transfer

$$Q_{1-2} = W_{1-2} \left(\frac{\gamma - n}{\gamma - 1} \right) = -961.52 \left(\frac{1.4 - 1.3}{1.4 - 1} \right) = -240.38 \text{ kJ}$$

Change in entropy

$$\Delta S_{1-2} = mR \ln \left(\frac{P_1}{P_2} \right) + mC_p \ln \left(\frac{T_2}{T_1} \right)$$

$$\Delta S_{1-2} = 11.61 \times 0.287 \ln \left(\frac{2}{6} \right) + 11.61 \times 1.005 \times \ln \left(\frac{386.57}{300} \right) = -0.702 \text{ kJ / K}$$

Process 2-3:

From adiabatic process relation

$$T_3 = T_2 \left(\frac{P_3}{P_2} \right)^{\gamma-1/\gamma} = 386.57 \left(\frac{2}{6} \right)^{1.4-1/1.4} = 282.43 \text{ K}$$

Work done

$$W_{2-3} = \frac{mR(T_2 - T_3)}{\gamma - 1} = \frac{11.61 \times 0.287 \times (386.57 - 282.43)}{1.4 - 1} = 867.5 \text{ kJ}$$

Heat transfer for adiabatic process

$$Q_{2-3} = 0$$

Change in entropy

$$\Delta S_{2-3} = mR \ln\left(\frac{P_2}{P_1}\right) + mC_p \ln\left(\frac{T_3}{T_2}\right)$$

$$\Delta S_{2-3} = 11.61 \times 0.287 \ln\left(\frac{6}{2}\right) + 11.61 \times 1.005 \times \ln\left(\frac{282.43}{386.57}\right) = -0.00174 \text{ kJ/K}$$

$$\text{Net work transfer } W = W_{1-2} + W_{2-3} = -961.52 + 867.5 = -94.02 \text{ kJ}$$

$$\text{Net Heat transfer } Q = Q_{1-2} + Q_{2-3} = -240.38 + 0 = -240.38 \text{ kJ}$$

$$\text{Change in entropy } \Delta S = \Delta S_{1-2} + \Delta S_{2-3} = -0.702 - 0.00174 = -0.7034 \text{ kJ/K}$$

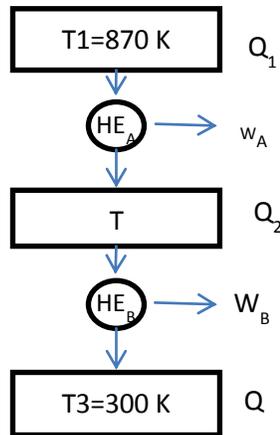
2. Two Carnot engines A and B are operated in series. The first one receives heat at 870 K and reject to a reservoir at T. B receives heat rejected by the first engine and in turn rejects to a sink at 300 K. Find the temperature T for (a) Equal work outputs of both engine (b) Same efficiencies [Nov/Dec-2013 / R-2008] [12 -marks]

Given Data :

$$T_1 = 870 \text{ K}; T_3 = 300 \text{ K}$$

To find : Intermediate Temperature T_2

Solution : Case (a) Equal work output of Engine



$$\frac{Q_1 - Q_2}{T_1 - T_2} = \frac{Q_2 - Q_3}{T_2 - T_3} \quad \text{here } W_A = Q_1 - Q_2 \text{ and } W_B = Q_2 - Q_3$$

$$\frac{W_A}{870 - T} = \frac{W_B}{T - 300} \quad \text{here } W_A = W_B \text{ so both are cancelled}$$

$$870 - T = T - 300$$

$$2T = 1170$$

$$T = 585 \text{ K}$$

Case (b) Same efficiency

$$\eta_A = \frac{T_1 - T}{T_1}; \eta_B = \frac{T - T_3}{T} \quad \text{here } \eta_A = \eta_B$$

$$\frac{870 - T}{870} = \frac{T - 300}{300} \quad 870T - T^2 = 870T - 261000$$

$$T^2 = 261000 \rightarrow T = 510.88 \text{ K}$$

3. A heat pump working on a reversed Carnot cycle takes in energy from a reservoir maintained at 3°C and delivers it to another reservoir where temperature is 77°C. The heat pump drives power for its operation from a reversible heat engine operating within the higher and lower temperature limits of 1077°C and 77°C. For 100kJ/S of energy supplied to the reservoir at 77°C, estimate the energy from the reservoir at 1077°C. [Nov/Dec-15 / R-2008][11 marks]

Given Data:

$$T_1 = 1077 + 273 = 1350 \text{ K};$$

$$T_2 = 77 + 273 = 350 \text{ K} = T_4$$

$$T_3 = 3 + 273 = 300 \text{ K}$$

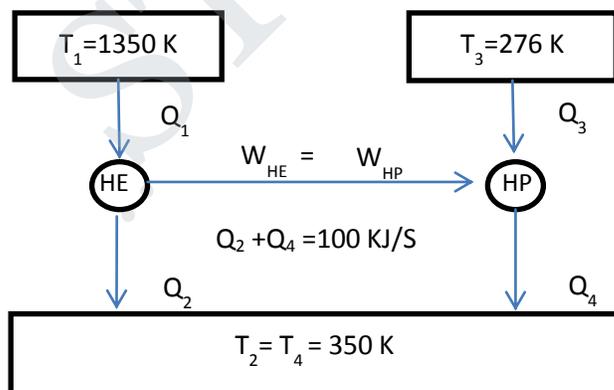
$$Q_2 + Q_4 = 100 \text{ kW [kJ/s=kW]}$$

To find : Q_1

Solution :

$$\text{Efficiency of HE} = \frac{T_1 - T_2}{T_1} = \frac{1350 - 350}{1350} = 0.7407$$

$$\text{COP of HP} = \frac{T_4}{T_4 - T_3} = \frac{350}{350 - 276} = 4.7297$$



$$\eta_{HE} = \frac{W_{HE}}{Q_1} = \frac{W_{HE}}{Q_2 + W_{HE}}; 0.7407 Q_2 + 0.7407 W_{HE} = W_{HE}; W_{HE} = 2.8565 Q_2;$$

$$\eta_{HE} = \frac{W_{HE}}{Q_1} = \frac{W_{HE}}{Q_2 + W_{HE}}; 0.7407 Q_2 + 0.7407 W_{HE} = W_{HE}; W_{HE} = 2.8565 Q_2$$

$$Q_2 + Q_4 = 100 \text{ kJ/s [Given in the problem]}$$

$$Q_4 = 100 - Q_2$$

$$COP \text{ OF HP} = \frac{Q_4}{W_{HP}}; 4.7297 = \frac{Q_4}{2.8565 Q_2}; [W_{HP} = W_{HE} = 2.8565 Q_2]$$

$$4.7297 = \frac{100 - Q_2}{2.8565 Q_2}; Q_2 = 6.8916 \text{ kW}; W_{HE} = 2.8565 Q_2 = 19.6589 \text{ kW};$$

$$Q_1 = W_{HE} + Q_2 = 26.577 \text{ kW}$$

4. A Reversible heat engine operates between two reservoirs at temperature of 600°C and 40°C. The engine drives a reversible refrigerator which operates between reservoirs at temperature of 40°C and -20°C. The heat transfer to the heat engine is 2000 kJ and the network output for the combined engine & refrigerator is 360 kJ. Calculate (1) the heat transfer to the refrigerant and the net heat transfer to the reservoir at 40°C. [Apr/May-15/ R-2013] [16 MARKS] (2) Reconsider (1) given that the efficiency of the heat engine and cop of the refrigerator are each 40% of their maximum possible value. [Nov/Dec-14 /R-2008]

Given Data:

$$T_1 = 600 + 273 = 873 \text{ K,}$$

$$T_2 = 40 + 273 = 313 \text{ K} = T_4;$$

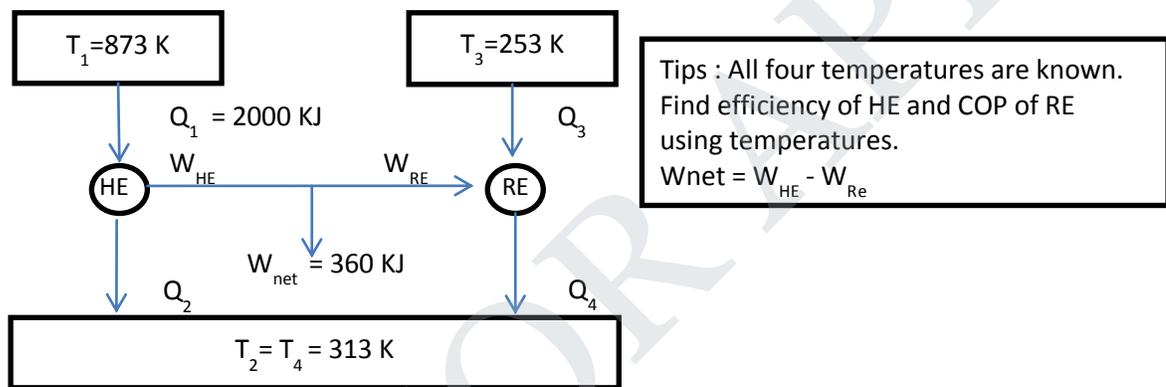
$$T_3 = -20 + 273 = 253 \text{ K;}$$

$$Q_1 = 2000 \text{ KJ;}$$

$$W_{\text{NET}} = 360 \text{ KJ}$$

To find :

$$Q_3, Q_{\text{Rnet}} = Q_2 + Q_4$$



Case (i)

Efficiency of Heat engine

$$\eta_{\text{max}} = \frac{T_1 - T_2}{T_1} = \frac{873 - 313}{873} = 0.642$$

Heat rejection by Heat engine

$$\eta_{\text{max}} = \frac{Q_1 - Q_2}{Q_1}; 0.642 = \frac{2000 - Q_2}{2000}; Q_2 = 716 \text{ kJ}$$

Work output of Heat engine

$$W_{\text{HE}} = Q_1 - Q_2 = 2000 - 716 = 1284 \text{ kJ}$$

Work input of Refrigerator

$$W_{\text{NET}} = W_{\text{HE}} - W_{\text{RE}}; W_{\text{RE}} = 924 \text{ kJ}$$

COP of refrigerator

$$COP_{max} = \frac{T_3}{T_4 - T_3} = \frac{253}{313 - 253} = 4.22$$

$$COP_{max} = \frac{Q_3}{W_{RE}} ; 4.22 = \frac{Q_3}{922.93} ; Q_3 = 3899 \text{ kJ} ;$$

$$Q_4 = Q_3 + W_{RE} = 4823 \text{ KJ}$$

Net heat rejected to 40°C reservoir $Q_{Rnet} = Q_2 + Q_4 = 5539 \text{ kJ}$

Case (ii)

Efficiency of the actual heat engine cycle

$$\eta = 0.4 \times \eta_{max} = 0.4 \times 0.642$$

$$W_{HE} = 0.4 \times 0.642 \times 2000 = 513.6 \text{ kJ}$$

$$W_{RE} = 513.6 - 360 = 153.6 \text{ kJ}$$

COP of the actual refrigeration cycle

$$COP = 0.4 \times COP_{max} = 0.4 \times 4.22 = 1.69$$

Therefore, $Q_3 = 153.6 \times 1.69 = \mathbf{259.6 \text{ kJ}}$

$$Q_4 = 259.6 + 153.6 = \mathbf{413.2 \text{ kJ}}$$

$$Q_2 = Q_1 - W_{HE} = 2000 - 513.6 = \mathbf{1486.4 \text{ kJ}}$$

Net heat rejected to 40°C reservoir $Q_{Rnet} = Q_2 + Q_4 = \mathbf{1899.6 \text{ kJ}}$

5. a. A metal block with $m=5\text{kg}$, $C=0.4 \text{ kJ/kg K}$ at 40°C is kept in a room at 20°C . it is cooled in the following two ways:

- (i) Using a Carnot engine (Executing integral number cycle) with the room itself as the cool reservoir
- (ii) Naturally

In each case, calculate the change in entropy of the block, of the air of the room and of the universe. Assume that the metal block has constant specific heat. [May/June -2016 / R-2008] [8 marks]

Given Data:

$$m = 5 \text{ kg}$$

$$C = 0.4 \text{ kJ/Kg K}$$

$$T_1 = 40 + 273 = 313 \text{ K}$$

$$T_2 = 20 + 273 = 293 \text{ K}$$

Solution :

(i) Cooling Naturally

Heat absorbed by air dQ = Heat released by the metal block

$$dQ = m C (T_1 - T_2) = 5 \times 0.4 \times (40-20) = 40 \text{ kJ}$$

Entropy Change of the block

$$\begin{aligned} \Delta S_{\text{block}} &= \int_{313}^{293} m c \frac{dT}{T} \\ &= 5 \times 0.4 \ln(293/313) = -0.132 \text{ kJ/K} \end{aligned}$$

Entropy Change of atm.

$$\Delta S_{\text{air}} = \frac{dQ}{T} = \frac{40}{293} = 0.1365 \text{ kJ/K}$$

Entropy of universe: $S_{\text{uni}} = \Delta S_{\text{block}} + \Delta S_{\text{air}} = -0.132 + 0.1365 = 0.0045 \text{ kJ/K}$

(ii) Cooling using Carnot engine

If the metal block cools naturally, heat removed from metal block

$$dQ = 40 \text{ kJ}$$

$$\text{Entropy of block } \Delta S_{\text{block}} = -0.132 \text{ kJ/K}$$

Entropy of Carnot engine $\Delta S_{\text{Carnot}} = 0$

For Carnot engine efficiency

$$\eta_{\text{Carnot}} = \frac{T_1 - T_2}{T_2}$$

$$\eta_{\text{Carnot}} = \frac{313 - 293}{313} = 6.39 \%$$

$$\eta_{\text{Actual}} = \frac{\text{Work output}}{\text{Heat supplied}} = \frac{W}{dQ}$$

$$0.0639 = \frac{W}{40}$$

$$W = 2.556 \text{ kJ}$$

$$\text{Entropy of air } \Delta S_{\text{air}} = \frac{dQ + W}{T_{\text{air}}}$$

$$\Delta S_{\text{air}} = \frac{40 + 2.556}{293} = 0.1452 \text{ kJ/K}$$

Entropy of universe

$$\Delta S_{\text{uni}} = \Delta S_{\text{block}} + \Delta S_{\text{Carnot}} + \Delta S_{\text{air}} = -0.132 + 0 + 0.1452 = 0.2772 \text{ kJ/K}$$

$$\Delta S_{\text{uni}} = 0.2772 \text{ kJ/K}$$

5.b. 50 kg of water is at 313 K and enough ice at -5°C is mixed with water in an adiabatic vessel such that at the end of the process all the melts and water at 0°C is obtained. Find the mass of ice required and entropy change of water and ice. Given $C_p = 4.2 \text{ kJ/kg K}$, C_p of ice = 2.1 kJ/kg K and latent heat of ice = 335 kJ/kg . [Apr/May-2016/R-2013] [8 marks]

Given data:

$$m_w = 50 \text{ kg};$$

$$T_w = 313 \text{ K},$$

$$T_{ice} = -5 + 273 = 268 \text{ K};$$

$$\text{Final temperature } T_f = 0 + 273 = 273 \text{ K};$$

$$C_{p_w} = 4.2 \text{ kJ/kg K};$$

$$C_{p_{ice}} = 2.1 \text{ kJ/kg K};$$

$$LH_{ice} = 335 \text{ kJ/kg}$$

To find :

- (i) mass of ice
- (ii) entropy change of water and ice.

Solution:

Heat lost by water = Heat gain by ice.

Water lost sensible heat from 313 K to 273 K = Ice gain heat (sensible heat from 268 to 273 K + Latent heat)

$$m_w \times C_{p_w} \times (T_w - T_f) = m_{ice} [(C_{p_{ice}} (T_f - T_{ice}) + \text{Latent heat})]$$

$$50 \times 4.2 \times (313 - 273) = m_{ice} [(2.1 \times (273 - 268) + 335)]$$

$$m_{ice} = 24.31 \text{ kg}$$

Entropy change of water

$$\Delta S_{water} = \int_{313}^{273} \frac{dQ}{T} = m_w \times C_{p_w} \ln(T_f/T_w) = 50 \times 4.2 \times \ln(273/313)$$

$$\Delta S_{water} = 28.713 \frac{\text{kJ}}{\text{K}}$$

Entropy change of Ice = Sensible heat + Latent Heat

$$\Delta S_{ice} = \int_{268}^{273} \frac{dQ}{T} + \int \frac{dQ}{T} = m_{ice} \times C_{p_{ice}} \ln\left(\frac{T_f}{T_{ice}}\right) + \frac{m_{ice} \times LH}{T_f}$$

$$\Delta S_{ice} = 24.31 \times 2.1 \ln\left(\frac{273}{268}\right) + \frac{24.31 \times 335}{273} = 30.7746 \frac{\text{kJ}}{\text{K}}$$

6. a. 2 kg of air at 500 kpa 80°C expands adiabatically in a closed system until its volume is doubled and its temperature become equal to that the surrounding at 100 kpa and 5°C. Find maximum work, change in availability and the irreversibility. [APR/MAY 2015 /R-2013][16 marks]

Given data :

$$m = 2 \text{ kg ;}$$

$$P_1 = 500 \text{ kpa;}$$

$$T_1 = 80 + 273 = 353 \text{ K;}$$

$$V_2 = 2V_1;$$

$$T_2 = T_0 = 5 + 273 = 278 \text{ K,}$$

$$P_2 = P_0 = 100 \text{ kPa}$$

To Find : maximum work, change in availability and the irreversibility

Solution :

$$\begin{aligned} \text{Entropy change of air } \Delta S &= m C_v \ln \left(\frac{T_1}{T_2} \right) + m R \ln \left(\frac{V_1}{V_2} \right) \\ &= 2 \left[0.718 \ln \left(\frac{353}{278} \right) + 0.287 \ln \left(\frac{V_1}{2V_1} \right) \right] \\ &= -0.05486 \text{ kJ/K} \end{aligned}$$

$$W_{\max} = (U_1 - U_2) - T_0 (S_1 - S_2) = m C_v (T_1 - T_2) - T_0 (S_1 - S_2)$$

$$W_{\max} = 2 \times 0.718 \times (353 - 278) - (278 \times -0.05486) = 122.951 \text{ kJ}$$

$$\text{Volume } V_1 = \frac{mRT_1}{P_1} = \frac{2 \times 0.287 \times 353}{500} = 0.405 \text{ m}^3 ; V_2 = 2 V_1 = 2 \times 0.405$$

$$\text{Volume } V_1 = 0.8104 \text{ m}^3$$

Change in availability

$$\phi_1 - \phi_2 = (U_1 - U_2) - T_0 (S_1 - S_2) + P_0 (V_1 - V_2)$$

$$\phi_1 - \phi_2 = 122.951 + 100 (0.405 - 0.8104) = 82.4 \text{ kJ}$$

$$\text{Irreversibility} = T_0 (S_1 - S_2) = 278 (0.05486) = 15.25 \text{ kJ}$$

7.a. 5kg of air at 550 K and 4 bar is enclosed in a closed vessel (i) determine the availability of the system if the surrounding pressure and temperature are 1 bar 290 K (ii) If the air is atmospheric pressure cooled at constant pressure to the atmospheric temperature, determine the availability and effectiveness. [NOV/DEC 2014 /R-2013] [10 marks]

Give Data :

$$m = 5 \text{ kg};$$

$$T_1 = 550 \text{ K};$$

$$P_1 = 4 \text{ bar} = 4 \times 10^5 \text{ N/m}^2;$$

$$T_2 = T_0 = 290 \text{ K};$$

$$P_2 = P_0 = 1 \text{ bar} = 1 \times 10^5 \text{ N/m}^2.$$

To find : Availability and effectiveness

Solution

Case (i)

$$\text{Availability of the system} = m[(u_1 - u_0) - T_0 (s_1 - s_0)]$$

$$s_1 - s_0 = Cp \ln \left(\frac{T_1}{T_0} \right) - R \ln \left(\frac{P_1}{P_0} \right) = 1.005 \ln \left(\frac{550}{290} \right) - 0.287 \ln \left(\frac{4}{1} \right)$$

$$= 0.246 \frac{\text{kJ}}{\text{kg K}}$$

$$\text{Availability of the system} = m[Cp (T_1 - T_0) - T_0 (s_1 - s_0)]$$

$$\text{Availability of the system} = 5 [1.008 (550 - 290) - 0.246] = 576.7 \text{ kJ}$$

Case (ii)

Heat transferred during cooling

$$Q = m \times C_p \times (T_1 - T_0) = 5 \times 1.005 \times (550 - 290)$$

$$= \mathbf{1306.5 \text{ kJ}} \rightarrow \text{Heat lost by system}$$

Change in entropy during cooling

$$\Delta S = m \times C_p \times \ln\left(\frac{T_1}{T_0}\right) = 5 \times 1.005 \times \ln\left(\frac{550}{290}\right) = \mathbf{3.216 \frac{kJ}{K}}$$

$$\text{Unavailable portion of this entropy} = T_0 \times \Delta S = 290 \times 3.216 = \mathbf{932.64 \text{ kJ}}$$

$$\text{Available energy} = 1306.5 - 932.64 = \mathbf{373.86 \text{ kJ}}$$

$$\text{Effectiveness } \epsilon = \frac{\text{Available energy}}{\text{Availability of the system}} = \frac{373.86}{576.7}$$

$$= \mathbf{0.648 \text{ or } 64.8 \%}$$

7.b. A heat engine receives 800 kJ of heat from the reservoir at 1000 K and rejects 400 kJ at 400 K. If the surrounding is at 300 K. calculate the first and the second law efficiency, and the relative efficiency of the heat engine. [Apr/May-2016/R-2013] [6 marks]

Give Data : $Q_1 = 800 \text{ kJ}$; $T_1 = 1000 \text{ K}$; $Q_2 = 400 \text{ kJ}$; $T_2 = 400 \text{ K}$; $T_0 = 300 \text{ K}$

To find : Ist and IInd law efficiency , Relative efficiency

Solution :

$$\text{Heat engine efficiency} \quad \eta_{HE} = \frac{W}{T_1} = \frac{400}{800} = \mathbf{50\%}$$

Efficiency of reversible heat engine operating with atmosphere as sink

$$\eta_{RHEo} = \frac{T_1 - T_0}{T_1} = \frac{1000 - 300}{1000} = \mathbf{70\%}$$

The second law efficiency of heat engine

$$\eta_{II HE} = \frac{\eta_{HE}}{\eta_{RHEo}} = \frac{50}{70} = 71.43\%$$

The efficiency of reversible heat engine

$$\eta_{RHE} = \frac{T_1 - T_2}{T_1} = \frac{1000 - 40}{1000} = 60\%$$

The relative efficiency

$$\eta_{HE R} = \frac{\eta_{HE}}{\eta_{RHE}} = \frac{50}{60} = 83.33\%$$

8. A heat pump operates on a carnot heat pump cycle with a COP of 8.7. it keeps a space at 24°C by consuming 2.15 kw of power. Determine the temperature of the reservoir from which the heat is absorbed and the heating load provided by the heat pump. NOV/DEC 2016 (7 MARK)

Given data:

Carnot COP of heat pump = 8.7

$T_H = 24^\circ\text{C} = 297 \text{ K}$

Power consumption or work done = 2.15 kw

Solution:

$$\text{COP of carnot pump} = \frac{T_H}{T_H - T_L}$$

$$8.7 = \frac{297}{297 - T_L}$$

$$T_L = 262.86 \text{ K} = -10.14^\circ\text{C}$$

For reversible heat pump,

Actual COP of heat pump = carnot COP of heat pump

$$\frac{Q_H}{Q_H - Q_L} = \frac{T_H}{T_H - T_L}$$

$$\frac{1}{1 - \frac{Q_L}{Q_H}} = \frac{1}{1 - \frac{T_L}{T_H}}$$

$$1 - \frac{Q_L}{Q_H} = 1 - \frac{T_L}{T_H}$$

$$\frac{Q_L}{Q_H} = \frac{T_L}{T_H}$$

$$Q_L = \frac{T_L}{T_H} \times Q_H$$

$$Q_L = \frac{262.86}{297} \times Q_H = 0.89Q_H$$

But, work done = $Q_H - Q_L$

Substituting Q_L in work done,

$$\begin{aligned} 2.15 &= Q_H - 0.89Q_H \\ &= 0.11Q_H \end{aligned}$$

Heating load, $Q_H = 19.55 \text{ kW}$.

9. A 30 kg iron block and a 40 kg copper block, both initially at 80° C. Thermal equilibrium is established after an while as a result of heat transfer between the blocks and the lake water. Determine the total entropy change for this process.

NOV/DEC 2016 (8 MARK)

Given data:

$$M_{\text{iron}} = 30 \text{ kg}$$

$$M_{\text{copper}} = 40 \text{ kg}$$

$$T_{\text{iron}} = T_{\text{copper}} = 80^\circ \text{ C} = 273 + 80 = 353 \text{ K}$$

$$T_{\text{lake}} = 15^\circ \text{C} = 273 + 15 = 288 \text{ K}$$

Solution:

$$C_{P \text{ iron}} = 0.45 \text{ kJ/kg}^\circ\text{C} = 0.45 \text{ kJ/kgK}$$

$$C_{P \text{ copper}} = 0.386 \text{ kJ/kg}^\circ\text{C} = 0.386 \text{ kJ/kgK}$$

$$\begin{aligned} \text{Entropy change of iron, } \Delta S_{\text{iron}} &= \int_{353}^{288} m_{\text{iron}} C_{P \text{ iron}} \frac{dT}{T} \\ &= m_{\text{iron}} C_{P \text{ iron}} \ln \left[\frac{T}{353} \right]_{353}^{288} \\ &= 30 \times 0.45 \ln \left[\frac{288}{353} \right] = -3.14 \text{ kJ/K} \end{aligned}$$

Heat absorbed by lake from both blocks,

δQ = heat released by iron block + heat released by copper block

$$\delta Q = m_{\text{iron}} C_{P \text{ iron}} (T_{\text{iron}} - T_{\text{lake}}) + m_{\text{copper}} C_{P \text{ copper}} (T_{\text{copper}} - T_{\text{lake}})$$

$$\delta Q = 30 \times 0.45(353 - 288) + 40 \times 0.386(353 - 288) = 1881.1 \text{ kJ}$$

$$\text{Entropy change of lake, } \Delta S_{\text{lake}} = - \frac{\delta Q}{T} = \frac{1881.1}{288} = 6.53 \text{ kJ/K}$$

$$\begin{aligned} \text{Total entropy change, } \Delta s &= \Delta s_{\text{iron}} + \Delta S_{\text{copper}} + \Delta S_{\text{lake}} = -2.75 - 3.14 + 6.53 \\ &= 0.64 \text{ kJ/K.} \end{aligned}$$

10. A heat pump working on the carnot cycle takes in heat from a reservoir at 5 °C and delivers heat to a reservoir at 60 °C. The heat pump is driven by a reversible heat engine which takes in heat from reservoir at 840 °C and rejects to a reservoir at 60 °C. The reversible heat engine also drives a machine that absorbs 30 kW. If the heat pump extracts 17 kJ/s from 5 °C reservoir, determine

- (i) the rate of heat supply from the 840 °C source, and
- (ii) the rate of heat rejection to the 60 °C sink

APRIL/MAY 2017 (13 MARK)

Given:

$$T_1 = 840 + 273 = 1113 \text{ K}$$

$$T_2 = 60 + 273 = 333 \text{ K}$$

$$T_3 = 5 + 273 = 278 \text{ K}$$

$$T_4 = 60 + 273 = 333 \text{ K}$$

$$Q_3 = 17 \text{ kJ/s}$$

$$W_3 = 30 \text{ kW}$$

To find:

- (i) the rate of heat supply from the 840 °C source, and
- (ii) the rate of heat rejection to the 60 °C sink

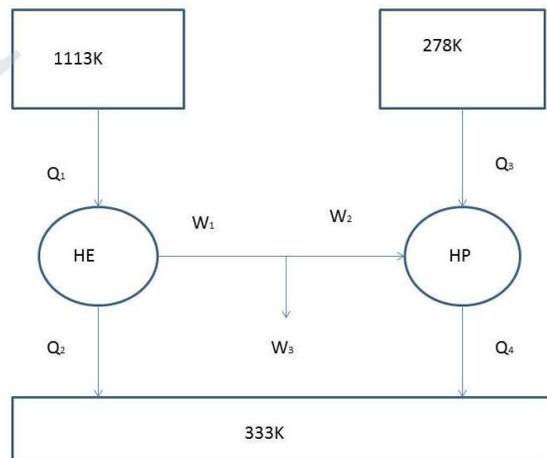
Solution:

$$COP_{HP} = \frac{T_H}{T_H - T_L} = \frac{T_4}{T_4 - T_3} = \frac{333}{333 - 278} = 6.055$$

$$COP_{HP} = \frac{Q_{S2}}{Q_{S2} - Q_{R2}} = \frac{Q_4}{Q_4 - Q_3}$$

$$6.055 = \frac{Q_4}{Q_4 - 17}$$

$$Q_4 = 20.36 \text{ kJ/s}$$



$$W_2 = Q_4 - Q_3 = 20.36 - 17 = 3.36 \text{ kJ/s}$$

$$W_1 = W_2 + W_3 = 3.36 + 30 = 33.36 \text{ kW}$$

Maximum Efficiency of heat engine

$$\eta_{\max} = \frac{T_H - T_L}{T_H} = \frac{T_1 - T_2}{T_1}$$

$$= \frac{1113 - 333}{1113} = 0.7 = 70\%$$

$$\eta_{\max} = \frac{W_1}{Q_1}$$

$$Q_1 = \frac{W_1}{\eta_{\max}} = \frac{33.36}{0.7} = 47.66 \text{ kW}$$

$$W_1 = Q_1 - Q_2$$

$$Q_2 = 47.66 - 33.36 = 14.3 \text{ kW}$$

Net heat transferred to the reservoir at 60 °C

$$= Q_2 + Q_4 = 14.3 + 20.36 = 34.9 \text{ kW}$$

11. An inventor claims to have developed a refrigeration system that removes heat from the closed region at - 12°C and transfers it to the surrounding air at 25°C while maintaining a COP of 6.5 . is this claim reasonable?

NOV/DEC 2016 (6 MARK)

Given data:

$$T_L = -12^\circ \text{C} = -12 + 273 = 261 \text{ K}$$

$$T_H = 25^\circ \text{C} = 25 + 273 = 298 \text{ K}$$

$$\text{COP of refrigerator} = 6.5$$

Solution:

$$\text{COP of carnot refrigerator} = \frac{T_L}{T_H - T_L} = \frac{261}{298 - 261} = 7.05$$

It is observed that the actual COP of refrigerator is less than carnot COP. Therefore, the claim is possible.

12. How much of the 100 kJ of thermal energy at 650 K can be converted to useful work? Assume the environment to be at 25°C. NOV/DEC 2016 (5 MARK)

Given data:

$$Q = 100 \text{ kJ}$$

$$T = 650 \text{ K}$$

$$T_o = 25^\circ \text{ C} = 273 + 25 = 298 \text{ K}$$

Solution:

Available energy or useful energy,

$$\begin{aligned} A.E &= Q - Q \frac{T_o}{T} = Q \left(1 - \frac{T_o}{T} \right) \\ &= 100 \left(1 - \frac{298}{650} \right) = 54.15 \text{ kJ}. \end{aligned}$$

PART - C

13. A quantity of air undergoes a thermodynamic cycle consisting of three processes. Process 1 - 2 : Constant volume heating from $P_1 = 0.1 \text{ MPa}$, $T_1 = 15^\circ \text{C}$, $V_1 = 0.02 \text{ m}^3$ to $P_2 = 0.42 \text{ MPa}$. Process 2-3 : Constant pressure cooling. Process 3-1 : Isothermal heating to the initial state. Employing the ideal gas model with $C_p = 1 \text{ kJ/kgK}$, evaluate the change of entropy for each process. Sketch the cycle on p-v and T-s coordinates. APRIL/MAY 2017 (15 MARK)

Given:

$$P_1 = 0.1 \text{ MPa} = 0.1 \times 10^3 \text{ kN/m}^2$$

$$T_1 = 15^\circ \text{C} = 298 \text{ K}$$

$$V_1 = 0.02 \text{ m}^3$$

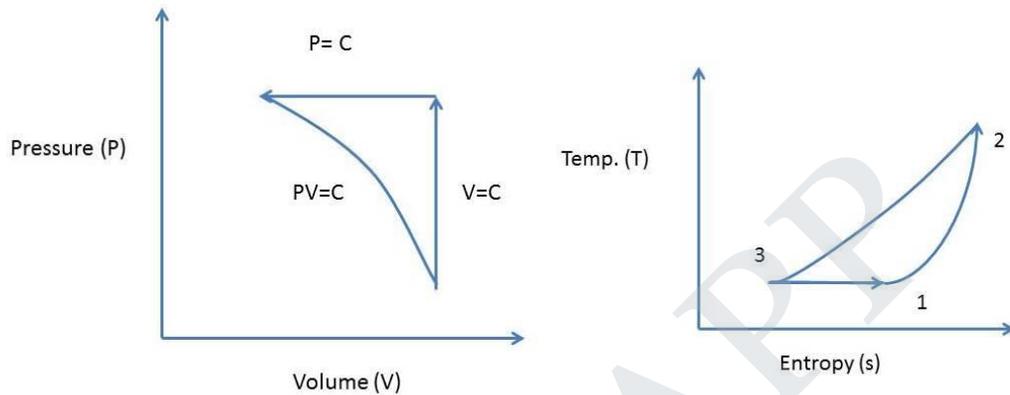
$$P_2 = 0.42 \text{ MPa} = 0.42 \times 10^3$$

$$C_p = 1 \text{ kJ/kgK}$$

To Find:

1. Change of entropy for each process
2. Sketch on p-v and T-s coordinates

Solution:



From Ideal gas equation

$$P_1 V_1 = mRT_1$$

$$m = \frac{0.1 \times 10^3 \times 0.02}{0.287 \times 298}$$

$$m = 0.023 \text{ kg}$$

Process 1-2 : Constant Volume

Change in entropy during constant volume process

$$S_2 - S_1 = mC_v \ln \left(\frac{P_2}{P_1} \right)$$

$$= 0.023 \times 0.718 \times \ln \left(\frac{0.42 \times 10^3}{0.1 \times 10^3} \right)$$

$$S_2 - S_1 = 0.0256 \text{ kJ/K}$$

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

$$T_2 = \frac{0.42 \times 10^3 \times 298}{0.1 \times 10^3}$$

$$T_2 = 1251.6K$$

Process 2-3 Constant Pressure

$$P_2 = P_3 = 0.42 \times 10^3 \text{ kN/m}^2$$

$$\frac{V_2}{T_2} = \frac{V_3}{T_3} \quad T_3 = T_1, V_1 = V_2$$

$$V_3 = \frac{298 \times 0.02}{1251.6}$$

$$V_3 = 0.00467 \text{ m}^3$$

$$\begin{aligned} S_3 - S_2 &= mC_p \ln \left(\frac{V_3}{V_2} \right) \\ &= 0.023 \times 1 \times \ln \left(\frac{0.00467}{0.02} \right) \end{aligned}$$

$$S_3 - S_1 = -0.033 \text{ kJ/K}$$

Negative Sign indicate there is a decrease in entropy

Process 3-1 Constant Temperature

$$\begin{aligned} S_1 - S_3 &= mR \ln \left(\frac{V_1}{V_3} \right) \\ &= 0.023 \times 0.287 \ln \left(\frac{0.02}{0.00467} \right) \end{aligned}$$

$$S_1 - S_2 = 0.0096 \text{ kJ/K}$$

UNIT III

PROPERTIES OF PURE SUBSTANCE AND STEAM POWER CYCLE

PART - A

1. Define a pure substance (May/June 2016 R 8)

A pure substance is a substance of constant chemical composition (homogeneous) throughout its mass. It is a one component system. It may exist in one or more phases. eg. water, ice

2. Define critical temperature and pressure for water.

Critical point is the point in the p-v diagram above which, a liquid upon heating suddenly flashes into vapour or vapour upon cooling suddenly condenses to liquid. There is no distinct transition zone from liquid to vapour and vice versa.

For water

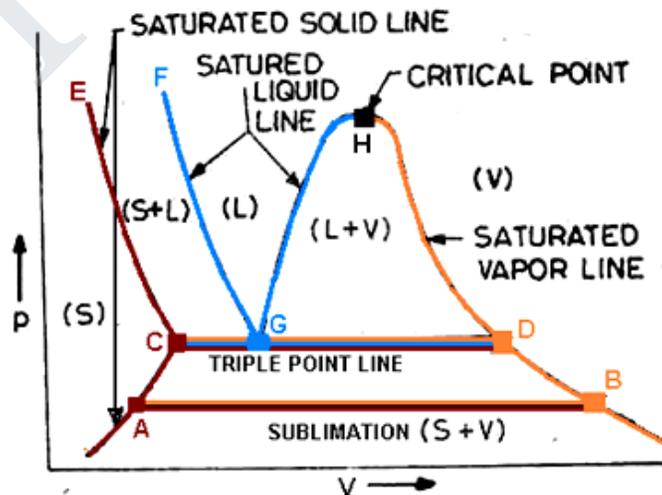
$$p_c = 221.2 \text{ bar}$$

$$t_c = 374.5 \text{ }^\circ\text{C}$$

$$v_c = 0.00317 \text{ m}^3/\text{kg}$$

3. How is the triple point represented in the p-V diagram? (May/June 2016 R 8)

The triple point of a substance is the temperature and pressure at which the three phases gas, liquid, and solid of that substance coexist in thermodynamic equilibrium. The triple point is represented as a line in the p-v diagram.



4. State the phase rule for pure substance (May/June 2016 R 13)

The Gibbs phase rule describes the degrees of freedom (F) available to describe a particular system with various phases and species. This will depend on the number of chemical species, C, and number of phases, P, present. In the absence of chemical reaction, the Gibbs phase rule is simply:

$$F=2+C-P$$

For a pure substance (C=1), the Gibbs phase rule can be applied as follows:

$$\text{For } P=1 \rightarrow F=[2+1-1]=2 ; \quad \text{For } P=2 \rightarrow F=[2+1-2] =1; \quad \text{For } P= 3 \rightarrow F=[2+1-3] =0$$

5. Mention the two working fluids used in binary vapour cycle (May/June 2016 R 13)

Mercury and steam is the most commonly used pair or fluid in binary vapour cycle. Apart from Mercury, Diphenyl ether, Aluminium bromide are also used along with steam.

6. A vessel of 2 m³ contains a wet steam of quality 0.8 at 210 °C. Determine the mass of liquid and vapour present in the vessel. (Nov/ Dec 2015 R 8)

Given:

$$V = 2 \text{ m}^3$$

$$x = 0.8$$

$$T = 210 \text{ }^\circ\text{C}$$

Find:

$$1. m_f \quad 2. m_g$$

FORMULAE USED :

$$m = m_f + m_g$$

$$v = v_f + v_g$$

$$\text{Dryness fraction } x = \frac{m_g}{m}$$

$$v = v_f + x v_{fg} = v_f + x[v_g - v_f]$$

$$V_g = v_g \cdot m_g$$

$$V_f = v_f \cdot m_g$$

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

At 210°C, from steam tables,

$$V_g = 0.10441 \text{ m}^3 / \text{kg}$$

$$V_f = 0.001173 \text{ m}^3 / \text{kg}$$

$$v = v_f + x v_{fg} = v_f + x[v_g - v_f] = 0.0837 \text{ m}^3 / \text{kg}$$

$$m = \frac{V}{v} = \frac{2}{0.0837} = 23.89 \text{ kg}$$

$$x = \frac{m_g}{m} = \frac{m_g}{23.89} \rightarrow m_g = 19.11 \text{ kg} \Leftarrow$$

$$m = m_f + m_g \rightarrow m_f = m - m_g = 4.77 \text{ kg} \Leftarrow$$

7. What is normal boiling point? (Nov/ Dec 2015 R 8)

The normal boiling point (also called the atmospheric boiling point or the atmospheric pressure boiling point) of a liquid is the special case in which the vapor pressure of the liquid equals the defined atmospheric pressure at sea level, 1 atmosphere.

8. What is reheat Rankine cycle and when is it recommended in a steam power plant? What is regeneration in Rankine cycle?

Reheat cycle: In reheat cycle, the steam after expansion in a high pressure turbine is brought back to the boiler and reheated by the combustion gases and then fed back to the low pressure turbine for further expansion. This increases the mean temperature of heat addition. Higher the mean temperature higher will be the cycle efficiency. The purpose of a reheating cycle is to remove the moisture carried by the steam at the final stages of the expansion process.

Regeneration cycle: In regenerative Rankine cycle, the condensate water from the condenser is heated by the steam extracted from the intermediate stages of turbine. Therefore the feedwater entering the boiler is preheated. This increases the work output and hence improves the thermal efficiency of the system.

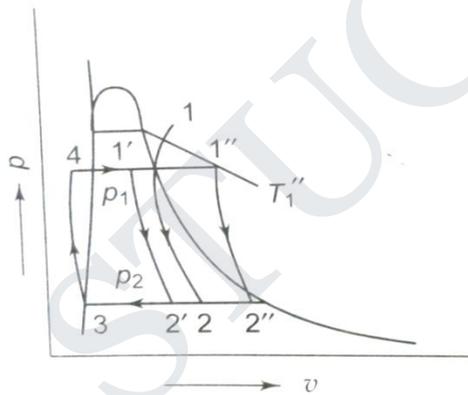
9. What is meant by dryness fraction or quality of steam? What are the methods of determining the quality of steam. (Apr/May 2015)

Dryness fraction is also known as steam quality. It is defined as the ratio of the mass of steam (vapour) in a mixture of saturated liquid and saturated vapour to the total mass of the liquid vapour mixture. It is indicated by x .

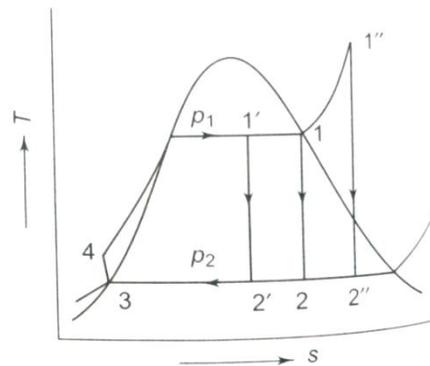
$$\text{Dryness fraction } x = \frac{\text{mass of vapour}}{\text{mass of vapour} + \text{mass of liquid}} = \frac{m_g}{m} \text{ where } m = m_f + m_g$$

The quality of steam can be measured using a throttling calorimeter or an electrical calorimeter.

10. Draw the standard Rankine cycle on p-v and T-s coordinates. (Apr/ May 2015)



Rankine cycle on p-v diagram



Rankine cycle on T-s diagram

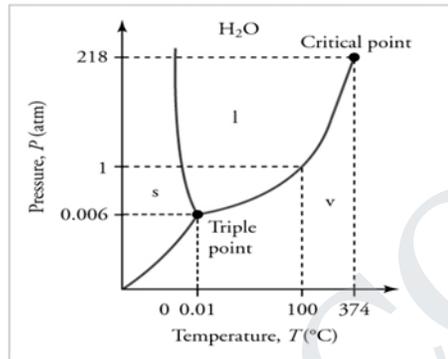
1. 1- 2 --- Reversible Adiabatic expansion process
 2. 2-3 --- Reversible constant pressure heat rejection
 3. 3- 4 --- Reversible Adiabatic compression
 4. 4 - 1 --- Reversible constant pressure heat addition
- 1 – wet steam , 1' – Saturated steam, 1'' – superheated steam

11. State the advantages of using superheated steam in turbines.(Nov/Dec 2014)

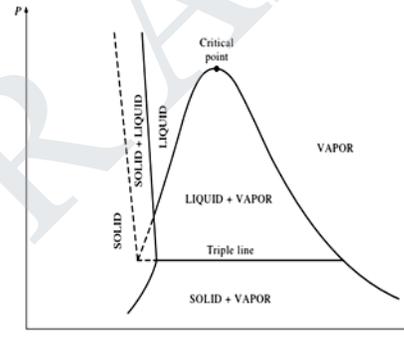
The advantages of using superheated steam in turbines are

1. The mechanical power output can be increased.
2. Thermal efficiency of the system is increased.
3. Small size condenser can be used.
4. Damages caused to by corrosion of turbine blades can be prevented.

12. Draw the p-T and p-v diagram for water or any pure substance and label all salient points. (Nov/Dec 2014)



p-T diagram for water



p-v diagram for water

13. Mention the possible ways to increase the thermal efficiency of Rankine cycle.(May/June 2014, 2017)

1. Decreasing the condenser pressure
2. Increasing the boiler pressure
3. Superheating the steam to a higher temperature
4. Reheating and regeneration in Rankine cycle

14. When will you call a vapour superheated and define degree of superheat, and when will you call a liquid subcooled or compressed liquid and define degree of subcooling

Superheated steam or vapour: When the temperature of the vapour is greater than the saturation temperature corresponding to the given pressure, the vapour is said to be superheated vapour

Degree of superheat: The difference between the temperature of the superheated vapour and the saturated temperature at that pressure is called degree of superheat or superheat.

Subcooled liquid or compressed liquid: When the temperature of the liquid is lower than the saturated temperature corresponding to the given pressure, the liquid is said to be compressed liquid or subcooled liquid. When the liquid is cooled below its saturation temperature at a certain pressure it is said to be subcooled.

Degree of subcool: The difference between the temperature of the compressed liquid and the saturated temperature at that pressure is called degree of subcool or subcooling.

15. What is a p v T surface? What do you mean by specific steam rate? State its units

P v T surface:

The variables of the ideal gas equation p, v and T are plotted along three mutually perpendicular axes. Such a surface is called p-v-T surface. These surfaces represent the fundamental properties of a substance and provide a tool to study the thermodynamic properties and processes of a substance.

Specific steam rate:

It is defined as the quantity of steam flow required for producing unit power. It is also known as steam rate (kg/ kW hr). It defines the capacity of the boiler

PART B

1. Discuss the different zones of T-s diagram for water when the temperature rises from -20°C to 200°C at 1 atm pressure [May/ June 2016 R 8, Nov/Dec 2015] (16 marks)

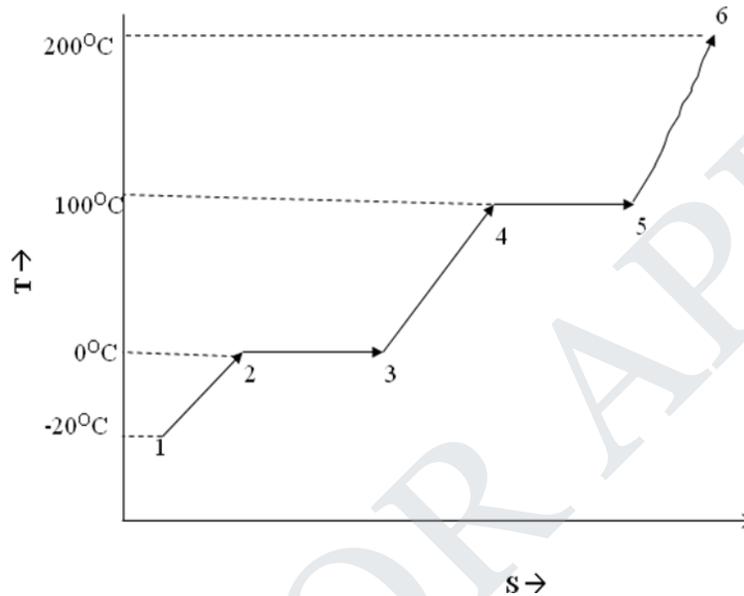


Figure 1 T-s diagram for heating of ice from -20°C to 200°C

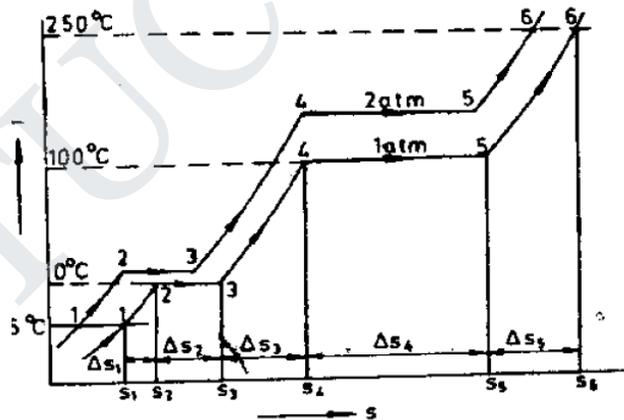


Figure 2 T-s diagram for heating of ice from -20°C to 200°C at different pressures

The state changes of water upon slow heating at different constant pressures are shown on the T - s diagrams at different pressure levels. If the heating of ice at -10°C to steam at 250°C at the constant pressure of 1 atm is considered, 1-2 is the solid (ice) heating, 2-3 is the melting of ice at 0°C , 3-4 is the liquid heating upto 100°C , 4-5

is the vapourisation of water at 100°C, and 5-6 is the heating of vapour phase upto 200°C. The process will be reversed from 6 to state 1 upon cooling. The curve passing through the 2, 3 points is called *fusion curve*, and the curve passing through the 4,5 points (which indicate the vaporisation or condensation at different temperatures and pressures) is called *vaporisation curve*. If the vapour pressure of a solid is measured at different temperatures and these are plotted, *sublimation curve* will be obtained. The fusion curve, the vaporisation curve, and the sublimation curve meet at the triple point.

The slopes of the sublimation and vaporisation curves for all substances are positive. The slope of the fusion curve for most substances is positive, but for water, it is negative, The temperature at which a liquid boils is very sensitive to pressure, as indicated by the vaporisation curve which gives the saturation temperatures at different pressures, but the temperature at which the solid melts is not such a strong function of pressure, as indicated by the small slope of the fusion curve.

2. A vessel of volume 0.04 m³ contains a mixture of saturated water and saturated steam at a temperature of 250°C. The mass of the liquid present is 9 kg. Find the pressure, the mass, the specific volume, the enthalpy, the entropy, and the internal energy. [May/ June 2016 R 8, Nov/Dec 2015, April/May 2017] (16 marks)

Given:

$$V = 0.04 \text{ m}^3$$

$$T = 250^\circ\text{C}$$

$$m_f = 9 \text{ kg}$$

Find:

$$p, m, v, h, s, u$$

Solution From steam tables, at 250°C, $p_{sat} = 3.973 \text{ Mpa}$

$$v_f = 0.0012512 \text{ m}^3/\text{kg}, \quad v_g = 0.05013 \text{ m}^3/\text{kg}$$

$$h_f = 1085.36 \text{ kJ/kg} \quad h_{fg} = 1716.2 \text{ kJ/kg}$$

$$s_f = 2.7927 \text{ kJ/kgK} \qquad s_{fg} = 3.2802 \text{ kJ/kgK}$$

Volume of liquid,

$$V_f = m_f v_f$$

$$= 9 \times 0.0012512 = 0.01126 \text{ m}^3$$

Volume of vapour,

$$V_g = 0.04 - 0.01126 = 0.02874 \text{ m}^3$$

∴ Mass of vapour

$$m_g = \frac{V_g}{v_g} = \frac{0.02874}{0.05013} = 0.575 \text{ kg}$$

∴ Total mass of mixture,

$$m = m_f + m_g = 9 + 0.575 = 9.575 \text{ kg}$$

Quality of mixture,

$$x = \frac{m_g}{m_f + m_g} = \frac{0.575}{9.575} = 0.06$$

$$v = v_f + x v_{fg}$$

$$= 0.0012512 + 0.06 (0.05013 - 0.0012512)$$

$$= 0.00418 \text{ m}^3/\text{kg}$$

$$h = h_f + x h_{fg}$$

$$= 1085.36 + 0.06 \times 1716.2 = 1188.32 \text{ kJ/kg}$$

$$s = s_f + x s_{fg}$$

$$= 2.7927 + 0.06 \times 3.2802 = 2.9895 \text{ kJ/kgK}$$

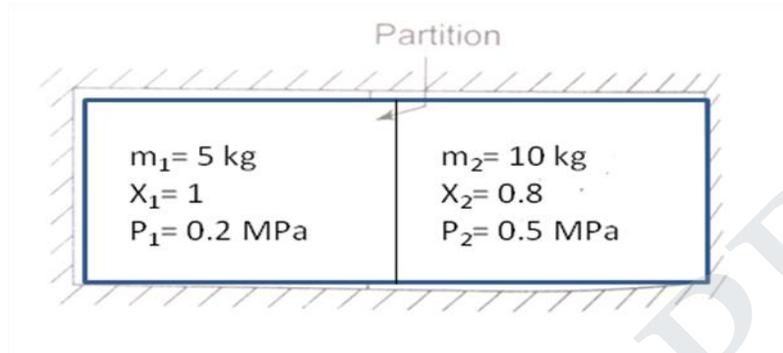
$$u = h - p v$$

$$= 1188.32 - 3.973 \times 10^3 \times 0.00418 = 1171.72 \text{ kJ/kg}$$

4. A large insulated vessel is divided into two chambers one containing 5 kg of dry saturated steam at 0.2 MPa and the other 10 kg of steam 0.8 quality at 0.5 MPa. If the partition between the chambers is removed and the steam is mixed

thoroughly and allowed to settle, find the final pressure, steam quality and entropy change in the process. [May/ June 2016 R 13] (16 marks)

Given:



Find: p_2, x_2, ds

Solution

The vessel is divided into chambers as shown in above figure

At 0.2Mpa, $v_g = v_1 = 0.8857 \text{ m}^3/\text{kg}$

$$V_1 = m_1 v_1 = 5 \times 0.8857 = 4.4285 \text{ m}^3$$

At 0.5Mpa,

$$\begin{aligned} v_2 &= v_f + x_2 v_{fg} \\ &= 0.001093 + 0.8 \times 0.3749 \\ &= 0.30101 \text{ m}^3/\text{kg} \end{aligned}$$

$$\begin{aligned} V_2 &= m_2 v_2 = 10 \times 0.30101 \\ &= 3.0101 \text{ m}^3 \end{aligned}$$

∴ Total volume,

$$V_m = V_1 + V_2 = 7.4386 \text{ m}^3 \text{ (of mixture)}$$

Total mass of the mixture, $m_m = m_1 + m_2$

$$= 5 + 10 = 15 \text{ kg}$$

∴ Specific volume of mixture

$$v_m = \frac{V_m}{m_m} = \frac{7.4386}{15} = 0.496 \text{ m}^3/\text{kg}$$

By energy balance

$$m_1 u_1 + m_2 u_2 = m_3 u_3$$

At 0.2 MPa, $h_g = h_1 = 2706.7 \text{ kJ/kg}$

$$u_1 = h_1 - p_1 v_1 \cong 2706.7 \text{ kJ/kg}$$

At 0.5 Mpa,

$$h_2 = h_f + x_2 h_{fg}$$

$$= 640.23 + 0.8 \times 2108.5 = 2327.03 \text{ kJ/kg}$$

$$u_2 = h_2 - p_2 v_2 \cong h_2 = 2327.03 \text{ kJ/kg}$$

$$h_3 = h_m = \frac{5 \times 2706.7 + 10 \times 2327.03}{15}$$

$$= 2453.6 \text{ kJ/kg} \cong u_3$$

Now for the mixture

$$h_3 = 2453.6 \text{ kJ/kg} = u_3$$

$$v_3 = \frac{0.496 \text{ m}^3}{\text{kg}}$$

From the Mollier diagram, with the given values of h and v, point 3 after mixing is fixed (Fig 9.40)

$$x_3 = 0.870 \quad s_3 = 6.29 \text{ kJ/kgK}$$

$$p_3 = 3.5 \text{ bar Ans.} \quad s_4 = s_{g0.2\text{MPa}} = 7.1271 \text{ kJ/kgK}$$

$$s_2 = s_{f0.5\text{MPa}} + 0.8 s_{fg0.5\text{MPa}}$$

$$= 1.8607 + 0.8 \times 4.9606 = 5.8292 \text{ kJ/kgK}$$

∴ entropy change during the process (ds)

$$= m_3 s_3 - (m_1 s_1 + m_2 s_2)$$

$$= 15 \times 6.298 - (5 \times 7.1271 + 10 \times 5.8292) = 0.43 \text{ kJ/K}$$

5. In a steam power plant the condition of steam at inlet to the steam turbine is 20 bar and 300 °C and the condenser pressure is 0.1 bar. Two feed water heaters operate at optimum temperatures. Determine: (1) the quality of steam at turbine exhaust (2) network per kg of steam (3) cycle efficiency (4) the steam rate. Neglect pump work [May/ June 2016 R 13] (16 marks)

Given:

$$p_1 = 20 \text{ bar}$$

$$T_1 = 300^\circ\text{C}$$

$$p_4 = 0.1 \text{ bar}$$

Find: x_4 , W_{net} , η , steam rate

Solution:

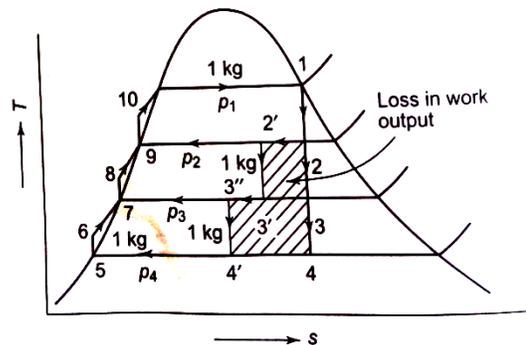
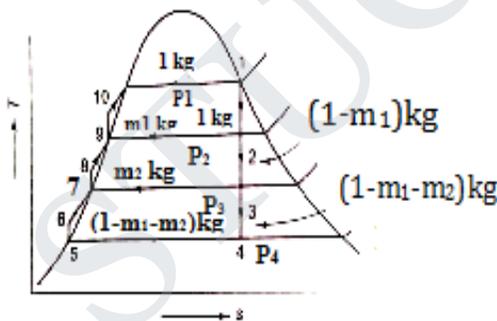
$$h_1 = 3023.5 \text{ kJ/kg}$$

$$s_1 = 6.7664 \text{ kJ/kgK} = s_2 = s_3 = s_4$$

$$t_{sat} \text{ at } 20 \text{ bar} \cong 212^\circ\text{C}$$

$$t_{sat} \text{ at } 0.1 \text{ bar} \cong 46^\circ\text{C}$$

$$\Delta T_{OA} = 212 - 46 = 166^\circ\text{C}$$



$$\text{Temperature rise per heater} = \frac{166}{3} = 55.3^\circ\text{C} \cong 55^\circ\text{C}$$

Temperature at which the first heater operates

$$= 212 - 55 = 157^\circ\text{C} \cong 150^\circ\text{C (approx)}$$

Temperature at which second heater operates = $157 - 55 = 102^\circ\text{C} = 100^\circ\text{C}$ (approx)

At 0.1 bar,

$$h_f = 191.83, \quad h_{fg} = 2392.8, \quad s_f = 0.6493 \quad s_g = 8.1502$$

At 100°C ,

$$h_f = 419.04, \quad h_{fg} = 2257.0, \quad s_f = 1.3069, \quad s_g = 7.3549$$

At 150°C ,

$$h_f = 632.20, \quad h_{fg} = 2114.3, \quad s_f = 1.8418, \quad s_g = 6.8379$$

$$6.7664 = 1.8418 + x_2 \times 4.961 \quad x_2 = 0.986$$

$$h_2 = 632.2 + 0.986 \times 2114.3 = 2716.9 \frac{\text{kJ}}{\text{kg}}$$

$$6.7664 = 1.3069 + x_3 \times 6.0480 = x_3 = 0.903$$

$$\therefore h_3 = 419.04 + 0.903 \times 2257.0 = 2457.1 \text{ kJ/kg}$$

$$6.7664 = 0.6493 + x_4 \times 7.5010 \quad x_4 = 0.816$$

$$\therefore h_4 = 191.83 + 0.816 \times 2392.8 = 2144.3 \text{ kJ/kg}$$

Since pump work is neglected, $h_{10} = h_9, h_8 = h_7, h_6 = h_5$. By making an energy balance for the hp heater

$$(1 - m_1)(h_9 - h_8) = m_1(h_2 - h_9)$$

Rearranging

$$m_1 = \frac{h_9 - h_7}{h_2 - h_7} = \frac{213.16}{2297.86} = 0.093 \text{ kg}$$

By making an energy balance for the lp heater,

$$(1 - m_1 - m_2)(h_7 - h_6) = m_2(h_3 - h_7)$$

$$(1 - 0.093 - m_2)(419.04 - 191.83) = m_2(2457.1 - 419.04)$$

$$m_2 = 0.091 \text{ kg}$$

$$\begin{aligned} W_T &= 1(h_1 - h_2) + (1 - m_1)(h_2 - h_3) + (1 - m_1 - m_2)(h_3 - h_4) \\ &= (3023.5 - 2716.9) + (1 - 0.093)(2716.9 - 2457.1) + (1 - 0.093 - 0.091) \\ &\quad (2457.1 - 2144.3) = 797.48 \text{ kJ/kg} \end{aligned}$$

$$Q_1 = h_1 - h_9 = 3023.5 - 632.2 = 2391.3 \text{ kJ/kg}$$

$$\therefore \eta_{\text{cycle}} = \frac{W_T - W_P}{Q_1} = \frac{797.48}{2391.3} = 0.3334 \text{ or } 33.34\%$$

$$\text{Steam rate} = \frac{3600}{W_{\text{net}}} = \frac{3600}{797.48} = 4.51 \text{ kg/kWh}$$

6. A steam power plant operates on a theoretical Rankine reheat cycle. Steam at boiler at 150 bar and 550 °C expands through the high pressure turbine. It is reheated at a constant pressure of 40 bar to 550 °C and expands through the low pressure turbine to a condenser at 0.1 bar. Draw the T-s and h-s diagrams, Find: 1) Quality of steam at turbine exhaust 2) cycle efficiency 3) steam rate in kg/kW hr [May/June 2014 R 8 April/May 2017] (16 marks)

Given:

$$P_1 = 150 \text{ bar}$$

$$T_1 = 550^\circ\text{C}$$

$$P_2 = 40 \text{ bar}$$

$$T_3 = 550^\circ\text{C}$$

$$P_4 = 0.1 \text{ bar}$$

Find:

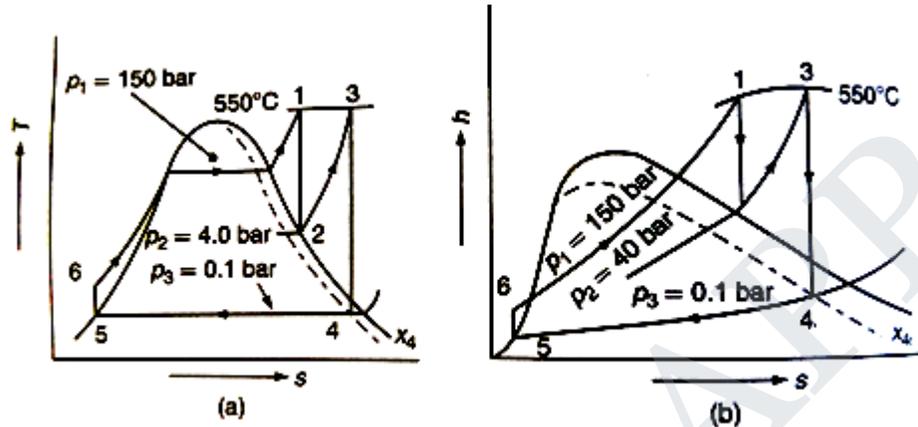
1. Quality of steam at exit x_{4s}
2. Cycle efficiency
3. Steam rate in kg/kW hr

Solution:

The property values at different states are read from the Mollier chart.

$$h_1 = 3465 \text{ kJ/kg}, h_2 = 3065 \text{ kJ/kg}, h_3 = 3565 \text{ kJ/kg}$$

$$h_4 = 2300 \text{ kJ/kg}, x_4 = 0.88, h_5 \text{ (steam table)} = 191.83 \text{ kJ/kg}$$



Quality at turbine exhaust = 0.88

$$W_p = v \Delta p = 10^{-3} \times 150 \times 150 \times 10^2 = 15 \text{ kJ/kg}$$

$$h_6 = 206.83 \text{ kJ/kg}$$

$$Q_1 = (h_1 - h_6) + (h_3 - h_2)$$

$$= (3465 - 206.83) + (3565 - 3065) = 3758.17 \text{ kJ/kg}$$

$$W_T = (h_1 - h_2) + (h_3 - h_4)$$

$$= (3465 - 3065) + (3565 - 2300) = 1665 \text{ kJ/kg}$$

$$W_{Net} = W_T - W_p = 1665 - 15 = 1650 \text{ kJ/kg}$$

$$\eta = \frac{w_{net}}{Q_1} = \frac{1650}{3758.17} = 0.4390 = 43.9\%$$

$$\text{Steamrate} = \frac{3600}{w_{net}} = \frac{3600}{1650} = 2.18 \text{ kg/kWhr}$$

7. Steam initially at 0.3 MPa, 250 °C is cooled at constant volume. At what temperature will the steam become saturated vapour? What is the steam quality at 80 °C. Also find what is the heat transferred per kg of steam in cooling from 250 °C to 80 °C [Nov/Dec 2013 R 8] (16 marks)

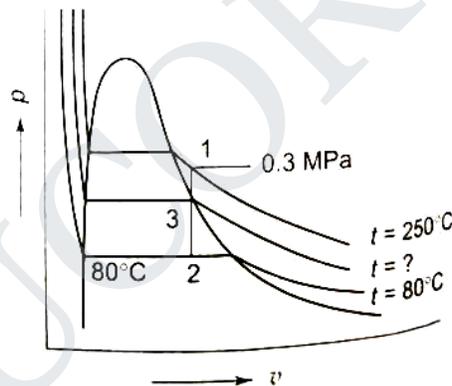
Given:

$$p_1 = 0.3 \text{ MPa}$$

$$T_1 = 250^\circ\text{C}$$

Find:

1. T_{sat} when cooled at constant volume
2. x when cooled to 80°C
3. Q when cooled from 250°C to 80°C



Solution

At 0.3 Mpa, $t_{\text{sat}} = 133.55^\circ\text{C}$

Since $t > t_{\text{sat}}$, the state would be in superheated . From steam table A.2for properties of superheated steam at 0.3 Mpa, 250°C

$$v_1 = 0.7964 \text{ m}^3/\text{kg}$$

$$h_1 = 2967.6 \frac{\text{kJ}}{\text{kg}}$$

$$\therefore v_1 = v_3 = v_2 = 0.7964 \text{ m}^3/\text{kg}$$

From Steam tables,

When $v_g = 0.8919$, $t_{sat} = 120^\circ\text{C}$

Therefore, when $v_g = 0.7964$, t_{sat} , by linear interpolation, would be 123.9°C . Steam would become saturated vapour at $t = 123.9^\circ\text{C}$

At 80°C , $v_f = 0.001029 \text{ m}^3/\text{kg}$, $v_g = 3.407 \text{ m}^3/\text{kg}$

$h_f = 334.91 \text{ kJ/kg}$, $h_{fg} = 2308.8 \text{ kJ/kg}$, $p_{sat} = 47.39 \text{ kPa}$

$$v_1 = v_2 = 0.7964 \frac{\text{m}^3}{\text{kg}} = v_{f80^\circ\text{C}} + x_2 v_{fg80^\circ\text{C}}$$

$$0.001029 + x_2 (3.407 - 0.001029)$$

$$\therefore x_2 = \frac{0.79539}{3.40597} = 0.234$$

$$h_2 = 334.91 + 0.234 \times 2308.8 = 875.9 \text{ kJ/kg}$$

$$h_1 = 2967.6 \frac{\text{kJ}}{\text{kg}}$$

From the first law of thermodynamics

$$dQ = du + pdv$$

$$\therefore (dQ)_v = du$$

$$\begin{aligned} \text{Or } Q_{1-2} &= u_2 - u_1 = (h_2 - p_2 v_2) - (h_1 - p_1 v_1) \\ &= (h_2 - h_1) + v(p_1 - p_2) \\ &= (875.9 - 2967.6) + 0.7964(300 - 47.39) \\ &= -2091.7 + 201.5 = -1890.2 \text{ kJ/kg} \end{aligned}$$

PART - C

8.A regenerative cycle utilizes steam as a working fluid . Steam is supplied to the turbine at 40 bar and 450°C and the condenser pressure is 0.03bar. After

expansion is the turbine to 3 bar, some of the stream is extracted from the turbine for heating feed water from the condenser in an open heater. The pressure in the boiler is 40 bar and the state of the fluid leaving the heater is saturated liquid water at 3 bar. Assuming isentropic heat drop in the turbine and pumps, compute the efficiency of the cycle. NOV/DEC 2016 (13 MARK)

Given data:

$$p_1 = 40 \text{ bar}$$

$$T_1 = 450^\circ\text{C}$$

$$p_2 = 3 \text{ bar}$$

$$p_3 = 0.03 \text{ bar}$$

To find:

$$\eta \text{ regenerative}$$

Solution:

From super heated steam table

At $p_1 = 40 \text{ bar}$ and $T_1 = 450^\circ\text{C}$

$$h_1 = 3330.3 \text{ kJ/kg} \quad s_1 = 6.9363 \text{ kJ/kgk}$$

From saturated steam table, $p_2 = 3 \text{ bar}$

$$h_{f2} = 561.47 \text{ KJ/kg} \quad h_{fg2} = 2163.8 \text{ kJ/kg}$$

$$s_{f2} = 1.68 \text{ KJ/kg k} \quad s_{fg2} = 5.320 \text{ kJ/kg k}$$

$$v_{f2} = 0.001073 \text{ m}^3/\text{kg}$$

At $p_3 = 0.03 \text{ bar}$

$$h_{f3} = 101.05 \text{ KJ/kg} \quad h_{fg3} = 2444.5 \text{ kJ/kg}$$

$$s_{f3} = 0.3545 \text{ KJ/kg k} \quad s_{fg3} = 8.223 \text{ kJ/kg k}$$

$$v_{f3} = 0.001003 \text{ m}^3/\text{kg}$$

We know that ,

$$\begin{aligned} s_1 = s_2 &= s_{f2} + x_2 * s_{fg2} \\ &= 6.9363 = 1.6718 + x_2 * 5.321 \\ &= 0.9895 \end{aligned}$$

$$\begin{aligned} h_2 &= h_{f2} + x_2 * h_{fg2} \\ &= 561.47 + 0.9895 * 2163.8 \\ &= 2702.65 \text{ kJ/kg} \end{aligned}$$

Similarly,

$$\begin{aligned} s_1 = s_3 &= s_{f3} + x_3 * s_{fg3} \\ 6.9363 &= 0.3545 + x_3 * 8.2231 \\ &= 0.8 \end{aligned}$$

$$\begin{aligned} h_3 &= h_{f3} + x_3 * h_{fg3} \\ &= 101.05 + 0.8 * 2444.5 \\ &= 101.35 \text{ kJ/kg} \end{aligned}$$

Pump work during 4- 5 processes

$$W_{p4-5} = (1- m) (h_5-h_4) = (1- m) * v_{f3} (p_2-p_3)$$

$$h_5-h_4 = v_{f3} (p_2-p_3)$$

$$= 0.001003(300-3)$$

$$= 0.2989 \text{ kJ/kg}$$

$$h_5 = 0.29789 + 101.05$$

$$= 101.35 \text{ kJ/kg}$$

Amount of steam bleed

$$m = \frac{h_{f2} - h_5}{h_2 - h_5}$$

$$= \frac{561.47 - 101.35}{2702.65 - 101.35}$$

$$= 0.117 \text{ kg}$$

$$W_{p_{6-7}} = h_7 - h_6 = v_{f2} (p_1 - p_2)$$

$$= 0.001073 (4000 - 300)$$

$$= 3.9701 \text{ kJ/kg}$$

$$h_7 = 3.9701 + h_6 = 3.9701 + h_{f2}$$

$$= 3.9701 + 561.47 \text{ kJ}$$

$$= 565.44 \text{ kJ/kg}$$

Regenerative rankine cycle efficiency

$$\eta_{\text{regenerative}} = \frac{(h_1 - h_7) - (1 - m)(h_3 - h_{f3})}{(h_1 - h_7)}$$

$$= \frac{(3330.3 - 565.44) - (1 - 0.177)(2057.63 - 101.05)}{(3330.3 - 565.44)}$$

$$\eta_{\text{regenerative}} = 41.75\%$$

9.A steam initially contains 5 m³ of steam and 5 m³ of water at 1Mpa. Steam is taken out at constant pressure until 4 m³ of water is left. What is the heat transferred during the process? NOV/DEC 2016 (13 MARK)

Given data:

$$V_{s1} = 5 \text{ m}^3$$

$$V_{w1} = 5 \text{ m}^3$$

$$P = 1 \text{ Mpa} = 10 \text{ bar}$$

$$V_{s2} = 4 \text{ m}^3$$

Solution:

From steam tables corresponding to 10 bar,

$$V_f = V_w = 0.001127 \text{ m}^3 / \text{kg}$$

$$V_g = 0.1944 \text{ m}^3 / \text{kg}$$

$$\begin{aligned} \text{Initial mass of water and steam, } m_1 &= \frac{V_s}{v_s} + \frac{V_w}{v_w} \\ &= \frac{5}{0.001127} + \frac{5}{0.1944} = 4462.28 \text{ kg} \end{aligned}$$

$$\begin{aligned} \text{Final mass of water and steam, } m_2 &= \frac{V_s}{v_s} + \frac{V_w}{v_w} \\ &= \frac{4}{0.001127} + \frac{6}{0.1944} = 3580.11 \text{ kg} \end{aligned}$$

$$\text{Mass of steam taken out, } m = m_1 - m_2 = 4462.28 - 3580.11 = 882.17 \text{ kg}$$

Making an energy balance,

Initial energy stored in saturated water and steam + heat transferred from the external source = final energy stored in saturated water and steam + energy leaving with steam.

$$U_1 + Q = U_2 + m_s h_g$$

Corresponding to 1 Mpa = 10 bar

$$h_f = 761.68 \text{ kJ/kg}$$

$$h_{fg} = 2583.6 \text{ kJ/kg}$$

$$h_g = 2778.1 \text{ kJ/kg}$$

Assuming that the steam is taken at dry condition.

$$m_{1w} = \frac{V_w}{v_w} = \frac{5}{0.1944} = 25.72 \text{ kg}$$

Similarly,

$$m_{2w} = \frac{V_w}{v_w} = \frac{6}{0.1944} = 30.86 \text{ kg}$$

Final mass of water and steam

$$m_2 = \frac{V_s}{v_s} + \frac{V_w}{v_w} = \frac{4}{0.001127} + \frac{6}{0.1944} = 3580.11 \text{ kg}$$

$$m_1 h_f + m_{1w} h_{fg} + Q = m_2 h_f + m_{2w} h_{fg} + m h_g \quad (m_s = m_1)$$

$$4462.28 \times 761.68 + 25.72 \times 2583.6 + Q = 3580.11 \times 761.68 + 30.86 \times 2583.6 + 882.17 \times 2778.1$$

$$Q = 1792104.94 \text{ kJ}$$

$$= 1792.11 \text{ MJ.}$$

UNIT IV

IDEAL AND REAL GASES, THERMODYNAMIC RELATIONS

1. Define Avogadro's law. (NOV/DEC 2013)

Avogadro's law states that 'Equal volumes of all perfect gases at the same temperature and pressure contain equal number of molecules'.

2. What is a real gas? Give example. (NOV/DEC 2013)

The gas which does not obey the law of equation of state is known as real gas. All practical gases are real gas.

3. Using Clausius-Clapeyrons equation, estimate the enthalpy of vapourization at 200°C, $v_g=0.127\text{m}^3/\text{kg}$, $v_f= 0.001157\text{m}^3/\text{kg}$, $dp/dT=32\text{kPa/K}$. (MAY/JUNE 2014)

By Clausius-Clapeyron equation.

$$\frac{dp}{dT} = \frac{h_{fg}}{T v_{fg}}$$

$$\frac{dp}{dT} = \frac{h_{fg}}{T(v_g - v_f)}$$

$$32 = \frac{h_{fg}}{473 * (0.1274 - 0.001157)}$$

$$h_{fg} = 1910.814 \text{ kJ/kg}$$

4. What are the assumptions made to derive ideal gas equation analytically using the kinetic theory of gases? (MAY/JUNE 2014)

- There is no intermolecular force between particles.
- The volume of the molecules is negligible in compression with the gas.

5. What is known as equation of state and when it can be used for engineering calculations?. (NOV/DEC 2014)

The relationship which exists for the state variables such as pressure, volume and temperature of the system in equilibrium is called equation of state.

The equation of state for ideal is given by $pV = mRT$

The equations of state are used in process engineering problems when the operating pressure is low or temperature is high

6. What are known as thermodynamic gradients? (NOV/DEC 2014)

Thermodynamic gradients are mathematical interrelations which are used to determine the change in thermodynamic properties ex. Pressure, temperature and volume, for the system having constant chemical composition. Thermodynamic gradients are partial derivatives.

7. What is Joule-Thomson coefficient? Why is it zero for an ideal gas? (APRIL/MAY 2015)

Joule-Thomson coefficient is defined as the change in temperature with change in pressure, keeping the enthalpy constant. It is denoted by

$$\mu = \left[\frac{\partial T}{\partial p} \right]_h = \frac{1}{c_p} \left[\left[\frac{\partial v}{\partial T} \right]_p - v \right]$$

We know that the equation of state as

$$pV = RT$$

Differentiating the above equation of state with respect to T by keeping pressure, p constant

$$\left[\frac{\partial v}{\partial T} \right]_p = \frac{R}{p} = \frac{v}{T}$$

$$\mu = \frac{1}{c_p} \left(T \cdot \frac{v}{T} - v \right) \quad \mu = 0$$

It implies that the Joule Thomson coefficient is zero for ideal gas.

8. What is the law of corresponding states? (APRIL/MAY 2015)

The law of corresponding states the relation among the reduced properties p_r , T_r and v_r . It can be derived from the various equations of state. This indicates that deviation from ideal gas behavior for all gases is about the same degree.

9. State Gibbs- Daltons law. (NOV/DEC 2015)

The law states that the pressure of mixture of gases is equal to the sum of the pressure of individual gas.

10. Write the Clausius- Claperyan equation and label all the variables.

Clausius equation which involves in the relationship between the saturation pressure, saturation temperature, the enthalpy of evaporation and the specific volume of the two phases involved.

$$\frac{dp}{dT} = \frac{h_{fg}}{T_{vfg}}$$

Where,

dp =change in pressure

dT =Change in Temp.

h_{fg} =Enthalpy of vaporization

T =Absolute temp

V_{fg} =Specific volume of vaporization

11. Define volume expansivity.(MAY/JUNE 2016)

Volume expansivity or co-efficient of volume expansion is defined as the change in volume with change in temperature per unit volume by keeping the pressure constant.

$$\beta = \frac{1}{v} \left[\frac{\partial v}{\partial T} \right]_p$$

12. What are the properties of Ideal gas? (NOV/DEC 2014)

An imaginary gas which obeys the equation of states as $PV = RT$ at all pressures and temperatures is known as ideal gas. If the pressure of real gas tends to zero or temperature tends to infinity, the real gas behaves as an ideal gas. In equation of states, the volume may remain constant or pressure may remain constant. But the minimum possible temperature is zero Kelvin.

13. State the Vander Walls equation of state. (NOV/DEC 2014)

The Vander walls equation of real gases is given by

$$\left[\frac{p + a}{v^2} \right] [v - b] = RT$$

$$a = 27R^2(T_c)^2/64P_c$$

$$b = RT_c/8P_c$$

p_c = Critical pressure, T_c = Critical Temperature

14. State the main reasons for the deviation of behaviour of real gases from ideal gases. (NOV/DEC 2014)

At high pressure, the gases start to deviate from ideal gas behaviour as intermolecular forces become significant. This occurs at low temperature as well. This deviation needs to be taken into account. For accounting this deviation, a factor called compressibility is introduced. So, the state equation for real gases is given by.

$$Pv = ZRT$$

Z is known as compressibility factor.

PART- B

1. Derive the Clausius - Clapeyron equation and discuss its significance. (NOV/DEC 2013, MAY/JUNE 2016, NOV/DEC 2016)

Clausius-Clapeyron equation is a relationship between the saturation pressure, temperature, the enthalpy of evaporation, and the specific volume of the two phases involved. This equation provides a basis for calculations of properties in a two-

phase region. It gives the slope of a curve separating the two phases in the p-T diagram.

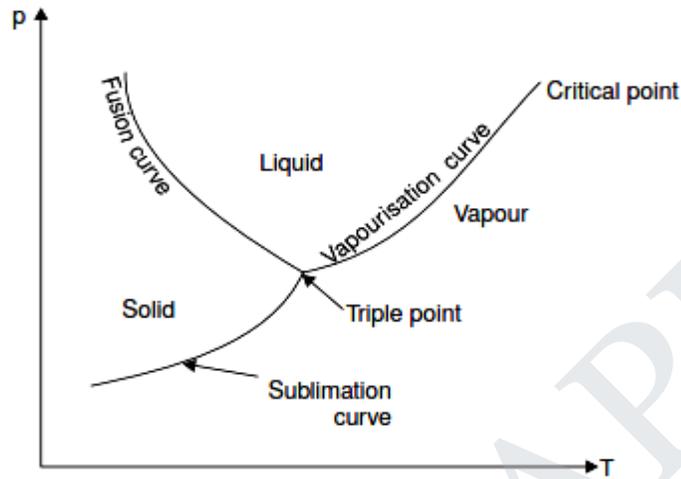


Fig. 7.4. p-T diagram.

The Clausius-Claperyon equation can be derived in different ways. The method given below involves the use of the Maxwell relation.

$$\left(\frac{\partial p}{\partial T}\right)_v = \left(\frac{\partial s}{\partial v}\right)_T$$

Let us consider the change of state from saturated liquid to saturated vapour of a pure substance which takes place at constant temperature. During the evaporation, the pressure and temperature are independent of volume.

$$\left(\frac{dp}{dT}\right) = \frac{s_g - s_f}{v_g - v_f}$$

- where,
- s_g = Specific entropy of saturated vapour,
 - s_f = Specific entropy of saturated liquid,
 - v_g = Specific volume of saturated vapour, and
 - v_f = Specific volume of saturated liquid.

$$s_g - s_f = s_{fg} = \frac{h_{fg}}{T}$$

$$v_g - v_f = v_{fg}$$

where s

f_g = Increase in specific entropy,

v_{fg} = Increase in specific volume, and

h = Latent heat added during evaporation at saturation temperature T.

$$\frac{dp}{dT} = \frac{s_g - s_f}{v_g - v_f} = \frac{s_{fg}}{v_{fg}} = \frac{h_{fg}}{T \cdot v_{fg}}$$

This is known as Clausius-Claperyon or Claperyon equation for evaporation of liquids. The derivative dp/dT is the slope of vapour pressure versus temperature curve. Knowing this slope and the specific volume v_g and v_f from experimental data, we can determine the enthalpy of evaporation, $(h_g - h_f)$ which is relatively difficult to measure accurately

It is also valid for the change from a solid to liquid, and from solid to a vapour. At very low pressures, if we assume $v_g \sim v$ and the equation of the vapour are taken as $pv = RT$, then becomes f_g

$$\frac{dp}{dT} = \frac{h_{fg}}{Tv_g} = \frac{h_{fg}P}{RT^2}$$

$$h_{fg} = \frac{RT^2}{p} \frac{dp}{dT}$$

It may be used to obtain the enthalpy of vaporization. This equation can be rearranged as follows:

$$\frac{dp}{p} = \frac{h_{fg}}{R} \cdot \frac{dT}{T^2}$$

Integrating the above equation, we get

$$\int \frac{dp}{p} = \frac{h_{fg}}{R} \int \frac{dT}{T^2}$$

$$\ln \frac{p_2}{p_1} = \frac{h_{fg}}{R} \left[\frac{1}{T_1} - \frac{1}{T_2} \right]$$

2. Derive the Maxwell relations and explain their importance in thermodynamics. (MAY/JUNE,NOV/DEC 2014, NOV/DEC 2013,APRIL/MAY 2015, MAY/JUNE 2016)

The first law applied to a closed system undergoing a reversible process states that

$$dQ = du + pdv$$

According to second law,

$$ds = \left(\frac{dQ}{T} \right)_{\text{rev.}}$$

Combining these equations, we get

$$\begin{aligned} Tds &= du + pdv \\ du &= Tds - pdv \end{aligned}$$

The properties h, f and g may also be put in terms of T, s, p and v as follows :

$$dh = du + pdv + vdp = Tds + vdp$$

Helmholtz free energy function,

$$\begin{aligned} df &= du - Tds - sdT \\ &= -pdv - sdT \end{aligned}$$

Gibb's free energy function,

$$dg = dh - Tds - sdT = vdp - sdT$$

Each of these equations is a result of the two laws of thermodynamics. Since du, dh, df and dg are the exact differentials, we can express them as

$$du = \left(\frac{\partial u}{\partial s}\right)_v ds + \left(\frac{\partial u}{\partial v}\right)_s dv,$$

$$dh = \left(\frac{\partial h}{\partial s}\right)_p ds + \left(\frac{\partial h}{\partial p}\right)_s dp,$$

$$df = \left(\frac{\partial f}{\partial v}\right)_T dv + \left(\frac{\partial f}{\partial T}\right)_v dT,$$

$$dg = \left(\frac{\partial g}{\partial p}\right)_T dp + \left(\frac{\partial g}{\partial T}\right)_p dT.$$

Above these equations we may equate the corresponding co-efficients. For example, from the two equations for du, we have

$$\left(\frac{\partial u}{\partial s}\right)_v = T \text{ and } \left(\frac{\partial u}{\partial v}\right)_s = -p$$

The complete group of such relations may be summarised as follows :

$$\left(\frac{\partial u}{\partial s}\right)_v = T = \left(\frac{\partial h}{\partial s}\right)_p$$

$$\left(\frac{\partial u}{\partial v}\right)_s = -p = \left(\frac{\partial f}{\partial v}\right)_T$$

$$\left(\frac{\partial h}{\partial p}\right)_s = v = \left(\frac{\partial g}{\partial p}\right)_T$$

$$\left(\frac{\partial f}{\partial T}\right)_v = -s = \left(\frac{\partial g}{\partial T}\right)_p$$

$\left(\frac{\partial T}{\partial v}\right)_s = -\left(\frac{\partial p}{\partial s}\right)_v$
$\left(\frac{\partial T}{\partial p}\right)_s = \left(\frac{\partial v}{\partial s}\right)_p$
$\left(\frac{\partial p}{\partial T}\right)_v = \left(\frac{\partial s}{\partial v}\right)_T$
$\left(\frac{\partial v}{\partial T}\right)_p = -\left(\frac{\partial s}{\partial p}\right)_T$

The above equations are known as Maxwell relations.

3. Draw a neat schematic of a compressibility chart and indicate its salient features. (NOV/DEC 2013, MAY/JUNE 2016)

The perfect gas equation is given by

$$Pv = RT$$

But for real gas a correction factor has to be introduced in the perfect gas equation to take into account the deviation of the real gas from the perfect gas equation. This factor is known as compressibility factor (Z) and is denoted by

$$Z = \frac{pv}{RT}$$

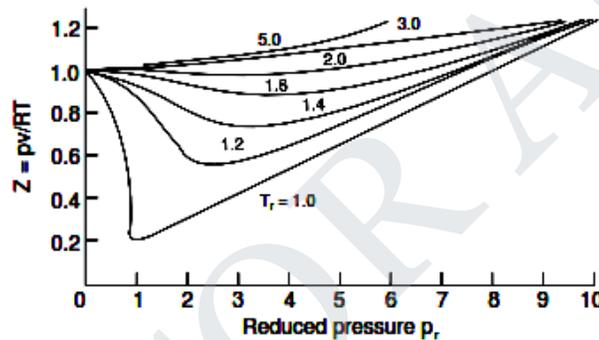


Fig. 8.10. Generalised compressibility chart.

4. Determine the pressure of nitrogen gas at $T = 175 \text{ K}$ and $v = 0.00375 \text{ m}^3/\text{kg}$ on the basis of

- i. The ideal gas equation of state
- ii. The van der Waals equation of state.

The Van der Waals constants for nitrogen are $a = 0.175 \text{ m}^6 \text{ kPa}/\text{kg}^2$, $b = 0.00138 \text{ m}^3/\text{kg}$. (APRIL/MAY 2015, MAY/JUNE 2016)

Given data:

Volume, $v = 0.00375 \text{ m}^3/\text{kg}$

Temp. $T = 175 \text{ K}$

$a = 0.175 \text{ m}^6 \text{ kPa}/\text{kg}^2$

$b = 0.00138 \text{ m}^3/\text{kg}$

Nitrogen Molecular Weight = 28

To Find:

- i. The ideal gas equation of state
- ii. The vander Waals equation of state.

Solution:

(i). The ideal gas equation of state

$$pv = mRT$$

$$p = mRT/v \quad (R \text{ for air is } 8314 \text{ Nm/kgmolK})$$

$$R = R_o/M = 8314/28 = 296.92 \text{ Nm/kgK}$$

$$p = 296.92 \times 175 / 0.00375$$

$$\mathbf{p = 138.5 \times 10^5 \text{ N/m}^2}$$

(ii) The vander Waals equation of state.

$$\left[\frac{p+a}{v^2} \right] [v-b] = R_o T \quad v = 28 \times 0.00375 = 0.105 \text{ m}^3/\text{kg-mol}$$

$$\left[\frac{p+0.175}{(0.105)^2} \right] [0.105 - 0.00138] = 8314 \times 175$$

$$\mathbf{p = 154.83 \times 10^3 \text{ N/m}^2}$$

5. Derive the entropy equations. (NOV/DEC 2015, MAY/JUNE 2016)

Since entropy may be expressed as a function of any other two properties, e.g. temperature T and specific volume v ,

$$s = f(T, v)$$

$$ds = \left(\frac{\partial s}{\partial T} \right)_v dT + \left(\frac{\partial s}{\partial v} \right)_T dv$$

$$Tds = T \left(\frac{\partial s}{\partial T} \right)_v dT + T \left(\frac{\partial s}{\partial v} \right)_T dv$$

But for a reversible constant volume change

$$dq = c_v (dT)_v = T(ds)_v$$

$$c_v = T \left(\frac{\partial s}{\partial T} \right)_v$$

$$\left(\frac{\partial s}{\partial v} \right)_T = \left(\frac{\partial p}{\partial T} \right)_v$$

Hence, substituting in eqn. we get

$$Tds = c_v dT + T \left(\frac{\partial p}{\partial T} \right)_v dv$$

This is known as the first form of entropy equation or the first Tds equation. Similarly, writing

$$s = f(T, p)$$

$$Tds = T \left(\frac{\partial s}{\partial T} \right)_p dT + T \left(\frac{\partial s}{\partial p} \right)_T dp$$

where

$$c_p = T \left(\frac{\partial s}{\partial T} \right)_p$$

Also

$$\left(\frac{\partial s}{\partial p} \right)_T = - \left(\frac{\partial v}{\partial T} \right)_p$$

$$Tds = c_p dT - T \left(\frac{\partial v}{\partial T} \right)_p dp$$

This is known as the second form of entropy equation or the second Tds equation.

6. One kmol of methane is stored in a rigid vessel of volume 0.6m³ at 20°C. Determine the pressure developed by the gas by making use of the compressibility chart. (NOV/DEC 2015, MAY/JUNE 2016)

Given data:

Volume v = 0.6m³

Temp. $T = 20^{\circ}\text{C} + 273 = 293\text{K}$

To Find:

Pressure $p = ?$

Solution:

The critical constants of methane are $T_c = 190.70\text{ K}$ and $P_c = 46.41\text{ bar}$

$$\text{Reduced temperature } T_r = T/T_c = 293/190.7 = 1.537$$

To calculate the compressibility factor Z both T_r and P_r values are needed.

$$\text{Reduced Pressure, } p_r = p/p_c = p/46.41$$

$$\text{Pressure developed by the gas, } p = 46.41 p_r$$

We know that compressibility factor,

$$Z = p v/RT$$

$$Z = 46.41 \times 10^5 \times P_r \times 0.6/1000 \times 8.314 \times 293$$

$$Z = 1.143 P_r$$

The corresponding compressibility value is read from chart which is taken as 0.93 at intersection point.

$$\text{Pressure, } p = ZRT/v$$

$$P = 1000 \times 0.93 \times 8.314 \times 293/0.6$$

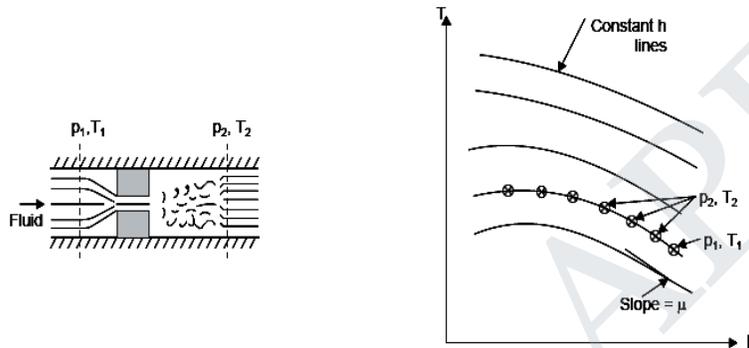
$$P = 3.778\text{MPa}$$

7. Deduce the expression for Joule Thomson co efficient and draw the inversion curve. (NOV/DEC 2014, NOV/DEC 2016)

Let us consider the partial differential co-efficient $(\partial T/\partial P)_h$ We know that if a fluid is flowing through a pipe, and the pressure is reduced by a throttling process, the enthalpies on either side of the restriction may be equal.

The throttling process is illustrated in Fig. 7.3 (a). The velocity increases at the restriction, with a consequent decrease of enthalpy, but this increase of kinetic

energy is dissipated by friction, as the eddies die down after restriction. The steady-flow energy equation implies that the enthalpy of the fluid is restored to its initial value if the flow is adiabatic and if the velocity before restriction is equal to that downstream of it. These conditions are very nearly satisfied in the following experiment which is usually referred to as the Joule-Thomson experiment.



Joule Thompson coefficient

By keeping the upstream pressure and temperature constant at p_1 and T_1 , the downstream pressure p_2 is reduced in steps and the corresponding temperature T_2 is measured. The fluid in the successive states defined by the values of p_2 and T_2 must always have the same value of the enthalpy, namely the value of the enthalpy corresponding to the state defined by p_1 and T_1 . From these results, points representing equilibrium states of the same enthalpy can be plotted on a T-s diagram, and joined up to form a curve of constant enthalpy. The curve does not represent the throttling process itself, which is irreversible. During the actual process, the fluid undergoes first a decrease and then an increase of enthalpy, and no single value of the specific enthalpy can be ascribed to all elements of the fluid. If the experiment is repeated with different values of p_1 and T_1 , a family of curves may be obtained (covering a range of values of enthalpy) as shown in figure. The slope of a curve at any point in the field is a function only of the state of the fluid. The slope of a curve in figure shown above at any point in the field is a function only of the state of the fluid, it is the Joule-Thomson co-efficient μ , defined by $\mu = (\partial T / \partial P)_h$

The change of temperature due to a throttling process is small and, if the fluid is a gas, it may be an increase or decrease. At any particular pressure there is a temperature, the temperature of inversion, above which a gas can never be cooled by a throttling process. Both c_p and μ , as it may be seen, are defined in terms of p , T and h . The third partial differential co-efficient based on these three properties is given as follows :

$$\left(\frac{\partial h}{\partial p}\right)_T \left(\frac{\partial p}{\partial T}\right)_h \left(\frac{\partial T}{\partial h}\right)_p = -1$$

$$\left(\frac{\partial h}{\partial p}\right)_T = -\mu c_p$$

μ may be expressed in terms of C_p , p , v and T as follows :

The property relation for dh is $dh = T ds + v dp$

From second $T ds$ equation, we have

$$T ds = c_p dT - T \left(\frac{\partial v}{\partial T}\right)_p dp$$

$$dh = c_p dT - \left[T \left(\frac{\partial v}{\partial T}\right)_p - v \right] dp$$

For a constant enthalpy process $dh = 0$. Therefore,

$$0 = (c_p dT)_h + \left[v - T \left(\frac{\partial v}{\partial T}\right)_p \right] dp$$

$$(c_p dT)_h = \left[T \left(\frac{\partial v}{\partial T}\right)_p - v \right] dp$$

$$\therefore \mu = \left(\frac{\partial T}{\partial p}\right)_h = \frac{1}{c_p} \left[T \left(\frac{\partial v}{\partial T}\right)_p - v \right]$$

For an ideal gas,

$$pv = RT ; \quad v = \frac{RT}{p}$$

$$\left(\frac{\partial v}{\partial T}\right)_p = \frac{R}{p} = \frac{v}{T}$$

$$\mu = \frac{1}{c_p} \left(T \times \frac{v}{T} - v \right) = 0.$$

Therefore, if an ideal gas is throttled, there will not be any change in temperature.

Let $h = f(p, T)$

Then
$$dh = \left(\frac{\partial h}{\partial p}\right)_T dp + \left(\frac{\partial h}{\partial T}\right)_p dT$$

But
$$\left(\frac{\partial h}{\partial T}\right)_p = c_p$$

\therefore
$$dh = \left(\frac{\partial h}{\partial p}\right)_T dp + c_p dT$$

For throttling process, $dh = 0$

\therefore
$$0 = \left(\frac{\partial h}{\partial p}\right)_T \left(\frac{\partial p}{\partial T}\right)_h + c_p$$

$$c_p = -\frac{1}{\mu} \left(\frac{\partial h}{\partial p}\right)_T$$

$\left(\frac{\partial h}{\partial p}\right)_T$ is known as the *constant temperature co-efficient*.

PART - C

8. One kg of CO₂ has volume of 1 m³ at 100° C. compute the pressure by

- Vander waal's equation
- Perfect gas equation

The vander waal's constant $a = 362850 \text{ Nm}^4/(\text{kg-mol})^2$ and $b = 0.0423 \text{ m}^3/(\text{kg-mol})$.

NOV/DEC 2016

Given

Mass, $m = 1 \text{ kg}$

Volume, $V = 1 \text{ m}^3$

Temperature, $T = 100^\circ\text{C} = 273 + 100 = 373\text{K}$

$a = 362850 \text{ Nm}^4/(\text{kg-mol})^2$

$b = 0.0423 \text{ m}^3/(\text{kg-mol})$

solution

- **Vander waal's equation**

Molar mass of CO₂, M = 12 + 16 x 2 = 44 kg/kmol

Molar specific volume, v = 1x44 = 44 m³/kgmol

$$\text{Vander equation } \left(P + \frac{a}{v^2} \right) (v - b) = RT$$

$$\left(P + \frac{362850}{44^2} \right) (44 - 0.0423) = 8314 \times 373$$

$$P = 70360.45 \text{ N/m}^2$$

- **Perfect gas equation**

$$Pv = RT$$

$$p = \frac{RT}{v}$$

$$p = \frac{8314 \times 373}{44}$$

$$P = 70480.05 \text{ N/m}^2.$$

Write the berthelot and dieterici equations of state.

- 1. Berthelot equation of state**

$$\left(p + \frac{a}{v^2 T} \right) (v - b) = RT$$

- 2. First dieterici equation of state**

$$p(v - b) = RT e^{\frac{a}{RTv}}$$

- 3. Second dieterici equation**

$$\left(p + \frac{a}{v^3} \right) (v - b) = RT$$

Where a and b are constant

P = pressure

V = volume

R = gas constant, T = temperature.

UNIT-V

GAS MIXTURES AND PSYCHROMETRY

PART-A

1. Define dew point temperature. (Nov/Dec 2015) ,(May/June 2009)

It is the temperature at which condensation of water vapour present in moist air just begins. Difference between the dew point temperature and dry bulb temperature is called Dew point depression.

2. What is chemical dehumidification? (Nov/Dec 2015)

Many salts and liquids are hygroscopic in nature and liberate heat during adsorption or absorption of moisture from air. Such chemicals can be used for dehumidification and heat of air in insulated chamber. This process is known as Chemical dehumidification.

3. Define adiabatic saturation temperature.(May/June 2014), (May/June 2009)

The temperature at which the air attains the saturation point, when thermal equilibrium exists with respect to water , water vapour is known as adiabatic saturation temperature.

4. What is by-pass factor? (May/June 2014)

The by-pass factor is defined as the ratio of the difference between the mean surface temperature of the coil and having air temperature to the difference between the mean surface temperature and the entering air temperature.

5. Why do wet clothes dry in the sun faster? (Nov/Dec 2013)

The heat energy from the sun and the humidity in the air helps the dry cloth to dry faster.

6. Define degree of saturation. (Nov/Dec 2013)

It is the ratio of the mass of water vapour associated with unit mass of dry air to the mass of water vapour associated with saturated unit mass of dry saturated air.

7. What is the relative humidity of air if the DPT and DBT are 25°C and 30°C at 1 atmospheric pressure? (Nov/Dec 2012)

For the given data

DPT = 25°C

DBT = 30°C

P = 1 atm

From the psychometric chart

Relative humidity = 74.48%

8. What is adiabatic evaporative cooling? (Nov/Dec 2012)

If unsaturated air is passed through a spray of continuously recirculated water, the specific humidity will increase while the dry bulb temperature decreases. This is the process of adiabatic saturation or evaporative cooling

9. Define mass fraction.

Mass fraction of individual constituents of a mixture is defined as the ratio of mass of a given constituent to the mass of the whole mixture.

10. What is meant by volume fraction?

It is the ratio of number of moles of each constituent gas to the total number of moles of the gas mixture.

11. State the Gibbs law.

It states that the internal energy, enthalpy and entropy of a gaseous mixture are respectively equal to the sums of the internal energies, enthalpies and entropies of the constituents

12. Define 'Mole fraction'.

It is the ratio of the number of moles of each constituent gas to the total number of moles of the gas mixture.

PART-B

1. The sling psychrometer in a laboratory test recorded the following readings.

Dry bulb temperature = 35 °C

Wet bulb temperature = 25 °C

Calculate the following

- (i) Specific humidity**
- (ii) Relative humidity**
- (iii) Vapour density in air**
- (iv) Dew point temperature**
- (v) Enthalpy of mixture per kg of dry air.**

Take atmospheric pressure = 1.0132 bar

(Nov/Dec 2015)

Given data:

DBT = 35 °C

WBT = 25 °C

Atmospheric pressure = 1.0132 bar

To find:

- (i) Specific humidity**
- (ii) Relative humidity**
- (iii) Vapour density of air**
- (iv) Dew point temperature**
- (v) Enthalpy of mixture per kg of dry air.**

Solution:

Partial pressure of vapour, using the equation

$$P_v = (P_{vs})_{wb} - \frac{[P_t - (P_{vs})_{wb}](T_{ab} - T_{wb})}{1527.4 - 1.3T_{wb}}$$

Corresponding to 25 °C (from steam tables)

$$(P_{vs})_{wb} = 0.0317 \text{ bar}$$

Substituting the values in the above equation, we get

$$P_v = 0.0317 - \frac{[1.0132 - 0.0317][35.25]}{1527.4 - (1.3 \times 25)}$$

$$= 0.0317 - 0.0065 = 0.0252 \text{ bar}$$

(i) Specific humidity

$$W = \frac{0.622 P_v}{P_t - P_v} = \frac{0.622 \times 0.0252}{(1.0312 - 0.0252)}$$

$$= 0.01586 \text{ kg/ kg of dry air}$$

(ii) Relative humidity

$$\phi = \frac{P_v}{P_{vs}} = \frac{0.0252}{0.0563} = 0.447 = 44.7\%$$

(iii) Vapour density

$$P_v V_v = m_v R_v T_v$$

$$P_v = \frac{m_v}{V_v} R_v T_v$$

$$= \rho_v R_v T_v$$

$$P_v = \frac{0.0252 \times 10^5}{8314.3 \times 308} = 0.0177 \text{ kg/m}^3$$

(iv) Dew point temperature

Corresponding to 0.0252 bar, from steam tables

$$T_{dp} = 21 + (22-21) \times \frac{(0.0252-0.0249)}{(0.0264-0.0249)}$$

$$= 21.2^\circ\text{C}$$

(v) Enthalpy of mixture per kg of dry air, h

$$h = C_p t_{db} + W h_{\text{vapour}}$$

$$= 1.005 \times 35 + 0.01586 [h_g + 1.88 (t_{db} - t_{dp})]$$

$$= 35.175 + 0.01586 [2565.3 + 1.88 [35 - 21.2]]$$

Where $h_g = 2565.3 \text{ kJ/kg}$ corresponding to 35°C (T_{db})

$$= 76027 \text{ kJ/kg of dry air}$$

2. An air-water vapour mixture enters an air conditioning unit at a pressure of 1.0 bar 38°C DBT and a relative humidity of 75 %. The mass of dry air entropy is 1 Kg/Sec. The air vapour mixture leaves the air-conditioning unit at 1.0 bar, 18°C , 85% relative humidity. The mixture condensed leaves at 18°C . Determine the heat transfer rate for the process. (May/June 2014)

Given data :

$$P_1 = 1 \text{ bar,}$$

$$T_{d1} = 38^\circ\text{C}$$

$$\phi_1 = 75\%$$

$$m = 1 \text{ kg/Sec}$$

$$P_2 = 1 \text{ bar}$$

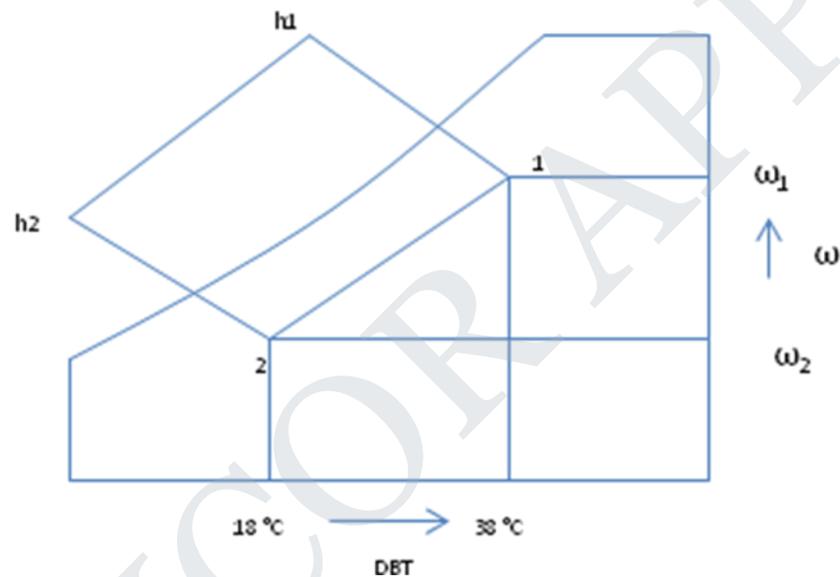
$$\phi_2 = 85\%$$

To find :

Heat transfer rate $Q = ?$

Solution:

For the dry air at 38°C and 75% relative humidity is shown on the psychrometric chart at point 1. The dry air (i.e.) 18°C DBT and 85% relative humidity is marked on the psychrometric chart at point 2.



➤ Join the point 1 and 2.

Enthalpy at point 1

$$h_1 = 122 \text{ KJ/Kg}$$

Enthalpy at Point 2

$$h_2 = 45 \text{ KJ/Kg}$$

Heat added $Q = m (h_1 - h_2)$

$$= 1 \times (122 - 45) = 77 \text{ KW}$$

3. It is required to design an air conditioning system for an industrial process for the following hot and wet summer conditions. Outdoor condition 32°C DBT and 65% RH. Required indoor condition 25°C and 60% RH. Amount of free air circulated 250m³/min coil dew temperature 13°C. The required condition is first achieved by first cooling and de-humidifying and then by heating. Calculate the following with the use of psychrometric chart

- (i) Cooling capacity of the cooling coil
- (ii) Heating capacity of the heating coil in kW and surface temperature of the heating coil if the by-pass factor is 0.3
- (iii) Mass of water vapour removed per hour. (May/June 2014)

Given data

Outdoor condition : DBT = 32° C, RH = 65%

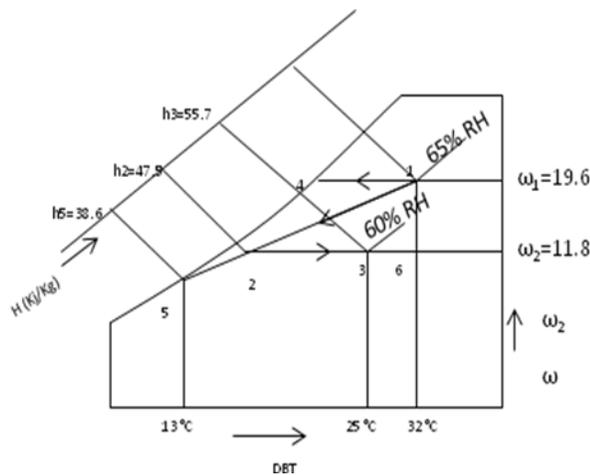
Indoor condition : DBT = 25° C, RH = 60%.

DPT = 13 ° C

To find:

- (i) Cooling capacity of the cooling coil
- (ii) Heating capacity of the heating coil in kW and surface temperature of the heating coil if the by-pass factor is 0.3
- (iii) Mass of water vapour removed per hour.

Solution:



- Locate the points 1,5 and 3 on the psychometric chart
- Join the line 1-5
- Draw constant specific humidity line through 3 which cuts the line 1-5 at point 2

From psychometric chart

$$h_1 = 82.5 \text{ kJ/Kg}, \quad h_2 = 47.5 \text{ kJ/Kg}, \quad h_3 = 55.7 \text{ kJ/Kg}, \quad h_4 = 36.6 \text{ kJ/Kg}$$

$$\omega_1 = 19.6 \text{ gm/kg}, \quad \omega_3 = 11.8 \text{ gm/kg},$$

$$\text{DBT}_2 = 17.6^\circ \text{C} \quad V_{s1} = 0.892 \text{ m}^3/\text{kg}$$

$$\text{Mass of air supplied per minute} = m_a = \frac{250}{0.892} = 280.26 \text{ kg/min}$$

(i) Capacity of the cooling coil

$$= \frac{m_a(h_1 - h_2) \times 60}{14000}$$

$$= \frac{280.26(82.5 - 47.5) \times 60}{14000} = 42.04 \text{ kW}$$

By -pass factor of the cooling coil is given by

$$\text{B.F} = \frac{h_2 - h_5}{h_1 - h_5} = \frac{47.5 - 36.6}{82.5 - 36.6} = 0.237$$

(ii) Heating capacity of the heating coil

$$= m_a (h_3 - h_2)$$

$$= 280.26 (55.7 - 47.5)$$

$$= 2298.13 \text{ kJ/min}$$

$$= \frac{2298.13}{60} = 38.3 \text{ kW}$$

By -pass factor of the heating coil is given by

$$B.F = \frac{tdb_5 - tdb_3}{tdb_5 - tdb_2}$$

$$0.3 = \frac{tdb_5 - 25}{tdb_5 - 17.6}$$

$$tdb_5 = 28.2^\circ \text{C}$$

(iii) Mass of water removed per hour

$$= \frac{280.26 (W_1 - W_2) \times 60}{1000}$$

$$= \frac{280.26 (19.6 - 11.8) \times 60}{1000}$$

$$= 131.16 \text{ kg/h}$$

4. Atmospheric air at 1.0132 bar has 20°C DBT and 65% RH. Find the humidity ratio, wet bulb temperature, dew point temperature, degree of saturation, enthalpy of the mixture, density of air and density of vapour in the mixture (Nov/Dec 2012)

Given data

$$P_b = 1.0132 \text{ bar, DBT} = 20^\circ \text{C, RH} = 65\%$$

To find:

- (i) humidity ratio
- (ii) wet bulb temperature
- (iv) dew point temperature,
- (v) degree of saturation ,
- (vi) enthalpy of the mixture,
- (vii) density of air
- (viii) density of vapour in the mixture

Solution:

From steam tables corresponding to 20°C

$$P_s = 0.02337 \text{ bar}$$

Humidity ratio

$$\phi = \frac{P_v}{P_s}$$

$$0.65 = \frac{P_v}{0.02337}$$

$$P_v = 0.0151 \text{ bar}$$

$$P_b = P_v + P_a$$

$$1.132 = 0.0151 + P_a$$

$$P_a = 0.998 \text{ bar}$$

Specific volume of air

$$V_a = \frac{R_a T_a}{P_a}$$

$$R_a = 0.287 \text{ kJ/kg}, T_a = t_d + 273$$

$$T_a = 20 + 273 = 293$$

$$P_a = 0.0151 \times 293 = 4.45 \text{ bar}$$

$$V_a = \frac{0.287 \times 293}{0.998 \times 100} = \frac{84.09}{99.8} = 0.842 \text{ m}^3/\text{kg}$$

Dew point temperature (T_{dp})

For $P_v = 0.0151$ bar from steam tables

$$T_{dp} = 13^\circ\text{C}$$

$$\text{Specific humidity } (\omega) = 0.622 \frac{P_v}{P_b - P_v}$$

$$0.622 \times \frac{0.0151}{(1.0132 - 0.0151)} = 0.00941 \text{ kg/kg of dry air}$$

Degree of saturation

$$\mu = \frac{P_v}{P_s} \left[\frac{P_b - P_s}{P_b - P_v} \right] = \frac{0.0151}{0.02337} \left[\frac{1.0132 - 0.02337}{1.0132 - 0.0151} \right]$$

$$= 0.64$$

Density of air in the mixture $P_a V_a = R_a T_a$

$$P_a = \frac{1}{V_a} = \frac{1}{0.842}$$

$$P_a = 1.187 \text{ kg/m}^3$$

Density of vapour in the mixture

$$P_v V_v = R_v T_v$$

$$0.0151 \times 10^2 V_v = 0.0462 \times 293$$

$$V_v = 89.64 \text{ m}^3/\text{kg}$$

$$\rho_v = 0.0111 \text{ kg/m}^3$$

5. Two streams of moist air, one having flow rate of 3 kg/sec at 30°C and 30 % relative humidity, other having flow rate of 2 kg/sec at 35°C and 65% relative humidity get mixed adiabatically. Determine specific humidity and partial pressure of water vapour after mixing. Take C_p for stream = 1.86 kJ/kg K (April/May 2011)

Given data

$$m_1 = 3 \text{ kg/sec}$$

$$m_2 = 2 \text{ kg/sec}$$

$$\text{DBT}_1 = 30^\circ\text{C}, \phi_1 = 30\%$$

$$\text{DBT}_2 = 35^\circ\text{C} \quad \phi_2 = 65\%$$

To find

- (i) Specific humidity
- (ii) Partial pressure of water vapour after mixing

Solution:

For adiabatic mixing

$$\frac{m_1}{m_2} = \frac{\omega_3 - \omega_2}{\omega_1 - \omega_3}$$

$$m_1 = 3 \text{ kg/sec}$$

$$m_2 = 2 \text{ kg/sec}$$

By using $DBT_1 = 30^\circ\text{C}$ and $\phi = 30\%$ from psychrometric chart

$$\omega_1 = 0.008 \text{ kg moisture/kg dry air}$$

By using $DBT_2 = 35^\circ\text{C}$ $\omega_2 = 0.024$ from psychrometric chart

$$\frac{3}{2} = \frac{\omega_3 - 0.024}{0.008 - \omega_3} \rightarrow 1.5 = \frac{\omega_3 - 0.024}{0.008 - \omega_3}$$

$$\omega_3 = 0.0144 \text{ kg moisture/kg dry air}$$

The specific humidity after mixing = 0.0144 kg/kg of dry air

Vapour pressure (P_v) from ω_3 is found out from the Psychrometric chart

$$P_v = 16.5 \text{ mm of Hg}$$

$$760 \text{ mm of Hg} = 1.013 \text{ bar}$$

Partial pressure of water vapour = 0.02189 bar

6. Two vessels, A and B, both containing nitrogen, are connected by a valve which is opened to allow the components to mix and achieve an equilibrium temperature of 27°C . Before mixing the following information is known about the gases in two vessels.

Vessel A	Vessel B
$P = 1.5 \text{ MPa}$	$P = 0.6 \text{ MPa}$
$T = 50^\circ\text{C}$	$T = 20^\circ\text{C}$
Contents = 0.5 kg mol	Contents = 2.5 kg mol

Calculate the final equilibrium pressure, and the amount of heat transferred to the surroundings. If the vessel had been perfectly insulated, calculate the final temperature and pressure which would have been reached. Take $\gamma=1.4$

Given data: $\gamma=1.4$

Vessel A	Vessel B
P = 1.5 MPa	P = 0.6 MPa
T = 50°C	T = 20 °C
Contents = 0.5 kg mol	Contents = 2.5 kg mol

To find:

- (i) Final equilibrium pressure
- (ii) Amount of heat transferred

Solution :

For the gases in vessel A

$$P_A V_A = m_A R T_A$$

Where V_A is the volume of vessel A

$$1.5 \times 10^3 \times V_A = 0.5 \times 8.3143 \times 323$$

$$V_A = 0.895 \text{ m}^3$$

The mass of gas in vessel A

$$m_A = n_A \mu_A$$

$$= 0.5 \text{ kg mol} \times 28 \text{ kg/kg mol} = 14 \text{ kg}$$

Characteristic gas constant R of nitrogen

$$R = \frac{8.3143}{28} = 0.297 \text{ kJ/kgK}$$

For the vessel B

$$P_B V_B = m_B R T_B$$

$$0.6 \times 10^3 \times V_B = 2.5 \times 0.297 \times 293$$

$$V_B = 0.363 \text{ m}^3$$

Total volume of A and B

$$V = V_A + V_B = 0.895 + 0.363 = 1.258 \text{ m}^3$$

Total mass of gas (m)

$$m = m_A + m_B = 14 + 2.5 = 16.5 \text{ kg}$$

Final temperature after mixing

$$T = 27 + 273 = 300 \text{ K}$$

For the final condition after mixing

$$PV = mRT$$

where P is the final equilibrium pressure

$$P \times 1.258 = 16.5 \times 0.297 \times 300$$

$$P = \frac{16.5 \times 0.297 \times 300}{1.258}$$

$$= 1168.6 \text{ MPa}$$

$$C_v = \frac{R}{\gamma - 1} = \frac{0.297}{0.4} = 0.743 \text{ kJ/kg K}$$

Since there is no work transfer, the amount of heat transfer

Q = change in internal energy

$$= U_2 - U_1$$

Measuring the internal energy above the datum of absolute zero (at T = 0 K,
u = 0 kJ/kg)

$$\begin{aligned} \text{Initial internal energy } U_1 &= m_A C_v T_A + m_B C_v T_B \\ &= (14 \times 323 + 2.5 \times 293) \times 0.743 \\ &= 3904.1 \text{ kJ} \end{aligned}$$

$$\begin{aligned} \text{Final internal energy } U_2 (\text{after mixing}) &= m c_v T \\ &= 16.5 \times 0.743 \times 300 \\ &= 3677.9 \text{ kJ} \end{aligned}$$

$$Q = 3677.9 - 3904.1 = - 226.2 \text{ kJ}$$

If the vessels were insulated

$$U_1 = U_2$$

$$m_A C_v T_A + m_B C_v T_B = m c_v T$$

where T would have been the final temperature

$$\begin{aligned} T &= \frac{m_A T_A + m_B T_B}{m} \\ &= \frac{14 \times 323 + 2.5 \times 293}{16.5} = 318.5 \text{ K} \end{aligned}$$

$$T = 45.5^\circ\text{C}$$

$$\text{The final pressure; } P = \frac{mRT}{V} = \frac{16.5 \times 0.297 \times 318.5}{1.258} = 1240.7 \text{ kPa} = 1.24 \text{ MPa}$$

7. A mixture of ideal gases consist of 3 kg of nitrogen and 5 kg of carbon dioxide at a pressure of 300K Pa and a temperature of 20 °C. Find (a) the mole fraction of each constituents, (b) the equivalent molecular weight of the mixture (c) The equivalent gas constant of the mixture (d) the partial pressure and partial volumes, (e) the volume and density of the mixture and (f) the c_p and c_v of the mixture.

If the mixture is heated at constant volume to 40 °C, find the changes in they internal energy, enthalpy and entropy of the mixture. Find the changes in internal energy, enthalpy and entropy of the mixture if the heating is done at constant pressure. Take γ for CO_2 and N_2 to be 1.28 and 1.4 respectively.

Given data:

$$P = 300 \text{ kPa}$$

$$T = 20 \text{ }^\circ\text{C},$$

$$\gamma \text{ for } \text{CO}_2 = 1.28$$

$$\gamma \text{ for } \text{N}_2 = 1.4$$

To find:

- (a) The mole fraction of each constituents,
- (b) The equivalent molecular weight of the mixture
- (c) The equivalent gas constant of the mixture
- (d) The partial pressure and partial volumes,
- (e) The volume and density of the mixture and
- (f) The c_p and c_v of the mixture.

(g) changes in internal energy, enthalpy and entropy of the mixture if the heating is done at constant pressure

Solution:

(a) Since mole fraction $X_i = \frac{n_i}{\sum n_i}$

$$X_{N_2} = \frac{\frac{3}{28}}{\frac{3}{28} + \frac{5}{44}} = 0.485$$

$$X_{CO_2} = \frac{\frac{5}{44}}{\frac{3}{28} + \frac{5}{44}} = 0.515$$

(b) Equivalent molecular weight of the mixture

$$M = x_1 \mu_1 + x_2 \mu_2$$

$$= 0.485 \times 28 + 0.515 \times 44$$

$$= 36.25 \text{ kg/kg mol}$$

(c) Total mass

$$m = m_{N_2} + m_{CO_2} = 3 + 5 = 8 \text{ kg}$$

(d) Equivalent gas constant of the mixture

$$R = \frac{m_{N_2} R_{N_2} + m_{CO_2} R_{CO_2}}{m}$$

$$= \frac{3 \times \frac{8.3143}{28} + 5 \times \frac{8.3143}{44}}{8}$$

$$= \frac{.89 + 0.94}{8}$$

$$= 0.229 \text{ kJ/kg K}$$

$$P_{N_2} = x_{N_2} p = 0.485 \times 300 = 145.5 \text{ kPa}$$

$$P_{CO_2} = x_{CO_2} p = 0.515 \times 300 = 154.5 \text{ kPa}$$

$$V_{N_2} = \frac{m_{N_2} R_{N_2} T}{p} = \frac{3 \times \frac{8.3143}{28} \times 293}{300} = 0.87 \text{ m}^3$$

$$V_{CO_2} = \frac{m_{CO_2} R_{CO_2} T}{p} = \frac{5 \times \frac{8.3143}{44} \times 293}{300} = 0.923 \text{ m}^3$$

(e) **Total volume of the mixture**

$$V = \frac{mRT}{p} = \frac{m_{N_1} R_{N_1} T}{P_{N_1}} = \frac{m_{CO_2} R_{CO_2} T}{P_{CO_2}}$$

$$V = \frac{8 \times 0.229 \times 293}{300} = 1.79 \text{ m}^3$$

Density of the mixture

$$\rho = \rho_{N_2} + \rho_{CO_2} = \frac{m}{v} = \frac{8}{1.79}$$

$$= 4.46 \text{ kg/m}^3$$

$$C_{pN_2} - C_{vN_2} = R_{N_2}$$

$$C_{vN_2} = \frac{R_{N_2}}{\gamma - 1} = \frac{8.3143}{28 \times (1.4 - 1)}$$

$$= 0.742 \text{ kJ/kg K}$$

$$C_{pN_2} = 1.4 \times 0.742$$

$$= 1.039 \text{ kJ/kg K}$$

For $CO_2 = \gamma = 1.286$

$$C_{vCO_2} = \frac{RCO_2}{\gamma - 1} = \frac{8.3143}{44 \times 0.286} = 0.661 \text{ kJ/kg K}$$

$$C_{pCO_2} = 1.286 \times 0.661 = 0.85 \text{ kJ/kg K}$$

For the mixture

$$C_p = \frac{m_{N_2} C_{pN_2} + m_{CO_2} C_{pCO_2}}{m_{N_2} + m_{CO_2}}$$

$$= 3/8 \times 1.039 + 5/8 \times 0.85 = 0.92 \text{ kJ/kg K}$$

$$C_v = \frac{m_{N_2} C_{vN_2} + m_{CO_2} C_{vCO_2}}{m}$$

$$= 3/8 \times 0.742 + 5/8 \times 0.661 = 0.69 \text{ kJ/kgK}$$

If the mixture is heated at constant volume;

$$U_2 - U_1 = mC_v (T_2 - T_1)$$

$$= 8 \times 0.69 \times (40 - 20) = 110.4 \text{ kJ}$$

$$H_2 - H_1 = mC_p (T_2 - T_1)$$

$$= 8 \times 0.92 \times 20 = 147.2 \text{ kJ}$$

$$S_2 - S_1 = mC_v \ln \frac{T_2}{T_1} = mR \ln \frac{V_2}{V_1}$$

$$= mC_v \ln \frac{T_2}{T_1} = 8 \times 0.69 \times \ln \frac{313}{293}$$

$$= 0.368 \text{ kJ/kg K}$$

If the mixture is heated at constant pressure ΔU and ΔH will remain the same.

The change in entropy will be

$$S_2 - S_1 = mC_p \ln \frac{T_2}{T_1} - mR \ln \frac{P_2}{P_1}$$

$$= mC_p \ln \frac{T_2}{T_1} = 8 \times 0.92 \ln \frac{313}{293}$$

$$= 0.49 \text{ kJ/ K}$$

8. An air conditioning system is designed under the following conditions:

Outdoor conditions 15°C DBT and 10°C WBT

Required conditions 20°C DBT and 50% RH

Amount of free air circulated 0.25 m³/min person

Seating capacity – 50 persons

The required condition is achieved first by heating and then by adiabatic humidifying . Determine the following

1. Capacity of heating coil in kw

2. Capacity of humidifier

NOV/DEC 2016 (13 MARK)

Given data:

Dry bulb temperature $td_1 = 15^\circ\text{C}$

Wet bulb temperature $tw_1 = 10^\circ\text{C}$

Required Indoor conditions:

Dry bulb temperature $td_2 = 20^\circ\text{C}$

Relative humidity, $\phi_2 = 50\%$

$v = 4.17 \times 10^{-3} \text{ m}^3/\text{s} / \text{person}$

Seating capacity = 50 persons

So, amount of free air circulated , $V = 4.17 \times 10^{-3} \times 50 = 0.21 \text{ m}^3/\text{s}$

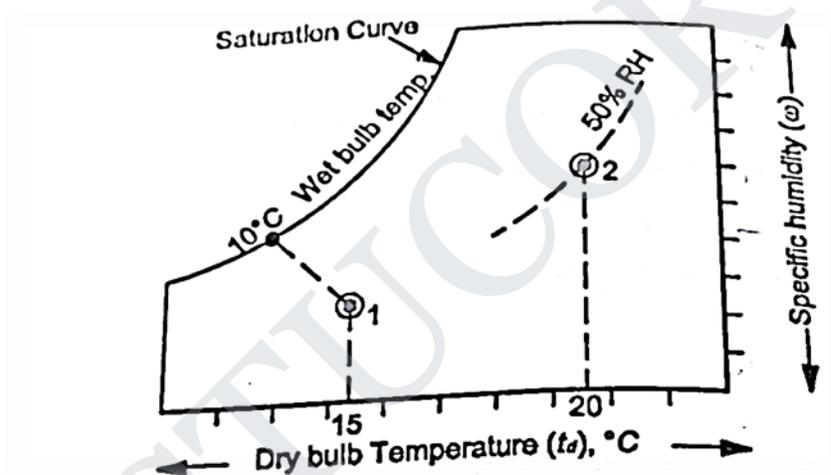
Solution:

Step 1:

Outdoor conditions of air i.e 15°C dry bulb temperature 10°C wet bulb temperature are marked on the psychrometric chart at point 1. The required indoor conditions of air 20°C dry bulb temperature and 50% relative humidity is marked outdoor the psychrometric chart at point 2.

Step 2:

Draw an inclined line through point 1 along constant wet bulb temperature till it cuts the total enthalpy line. Draw a horizontal line from point 2 both the intersect at point 3.



Step 3:

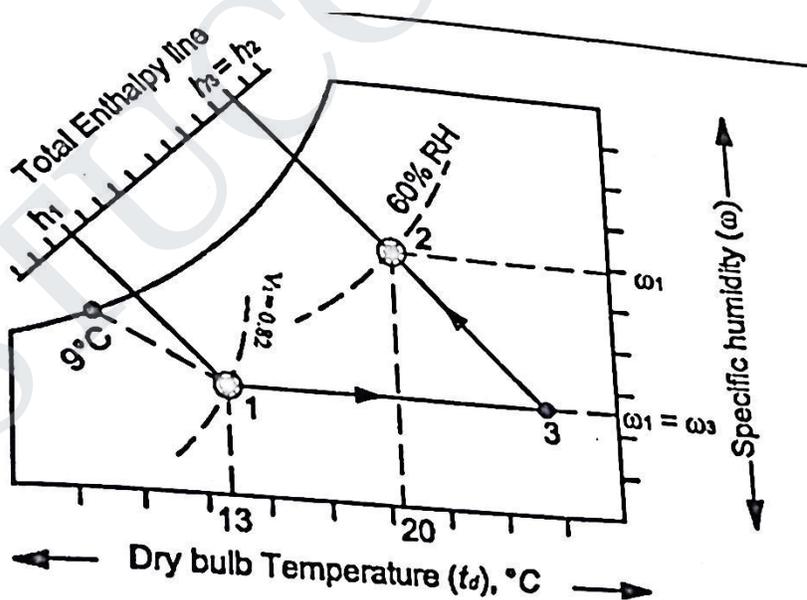
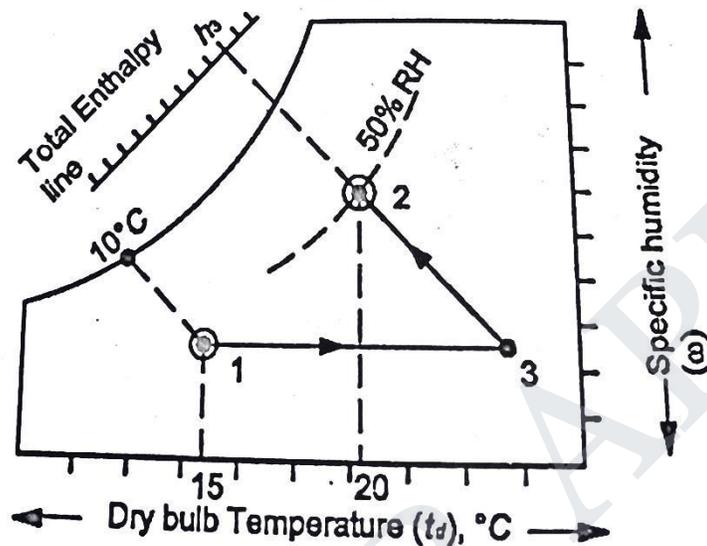
From psychrometric chart,

$$h_1 = 30 \text{ kJ/kg}$$

$$h_2 = h_3 = 40 \text{ kJ/kg}$$

$$w_1 = w_3 = 0.0055 \text{ kg/kg of dry air}$$

$w_2 = 0.0075 \text{ kg/kg of dry air}$



Specific volume passing through point 1 is $0.85 \text{ m}^3/\text{kg}$

$$i.e v_1 = 0.85 \text{m}^3/\text{kg}$$

$$m_a = V_1/v_1 = 0.210.835 = 0.25 \text{kg/s}$$

$$\text{Heating coil capacity} = m_a (h_3 - h_1)$$

(i.e 1-3 line , dry bulb temp increases)

$$= 0.25(40-30) = 2.5 \text{kW}$$

$$\text{Capacity of humidifier} = m_a (w_2 - w_1)$$

$$= 0.25(0.0075 - 0.0055) = 5 \times 10^{-4} \text{kg/s}$$

PART - C

9. How do you minimize the energy consumed by your domestic refrigerator?

NOV/DEC 2016 (7 MARK)

- The compressor in the refrigerator is the most power consuming part but it is not always on. The fan on the other hand is switches on frequently and consumes more power.
- The temperature adjustment and the air temperature in the room determines the duty cycle of refrigerator. So, the power consumption in the refrigerator will be high in summer season and if it is kept in kitchen.
- Use a double door refrigerator because the freezer compartment is not opening frequently. When it open frequently, there will be more power consumption. So, keep the freezer clean and remove the old food items from it.
- Set the temperature wisely. There are mainly 3 temperature adjustments for the seasons. Normal, cold and summer seasons. Set the knob accordingly.
- Check the gasket. It is the rubber lining on the door. If it is loose or broken fridge will switch on continuously because the temperature inside rises.
- Keep the refrigerator in a well-ventilated area with minimum 30cm gap from the wall.
- Clean the compressor and coil once in a month. Unplug the refrigerator, and turn it. Use a vacuum cleaner or brush to remove dust that accumulated.

- Voltage drop is the most common cause of increased power consumption in fridge. When the voltage drops current use increases. So, check the line voltage.
- Temperature of the food to be stored. Always cool hot food to room temperature before storing in the fridge/freezer as hot food would take in the cold air from the fridge/freezer causing the unit to work harder in order to maintain its temperature.
- Do not stuff the refrigerator full as it will hinder the flow of cold air thereby decreasing its efficiency. Adequate space will increase the cooling efficiency of the refrigerator.
- Keeping the vegetables in polythene bags will reduce the job of fridge because there will be some cold air inside the bag. Which keeps the vegetables fresh.
- Even though stabilizer is a must for fridge, it also takes current considerably.
- Unless you have noticeable condensation, keep power-saver switch on the energy –saving seting.
- Do not open refrigerator door unnecessarily as every time it is opened, some heat enters which decreases its efficiency.
- Always cover any liquids kept in the refrigerator as moisture lost from the liquids can impact condenser performance.
- Make sure that the refrigerator remains tightly closed when not open. Any open space will cause heat to get into the refrigerator causing motor to work harder thereby consuming more electricity.

10.The interior lighting of refrigerators is provided by incandescent lamps whose switches are actuated by the opening of the refrigerator door. Consider a refrigerators whose 40 W light bulb remains on continuously as a result of performance of 1.3 and the cost of electricity is Rs. 5 per kWh, determine the increase in the energy consumption of the refrigerator and its cost per year if the switch is not fixed. Assume the refrigerator is opened 20 times a day for an average of 30 s.

NOV/DEC 2016 (8 MARK)

Given data:

Heat to be removed, $Q = 40 \text{ W}$

$\text{COP} = 1.3$

Cost of electricity = Rs. 5 per kWh

The refrigerator is opened 20 times a day for an average of 30 s

Solution:

$$\text{COP of refrigerator} = \frac{\text{refrigeration effect}}{\text{power input}}$$

$$1.3 = \frac{40}{\text{power input}}$$

$$\text{Power input} = 30.77 \text{ W}$$

$$\text{Total power consumed by the refrigerator} = 30.77 + 40 = 70.77 \text{ W}$$

$$\text{Total number of hours in a year} = 365 \times 24 = 8760 \text{ hrs.}$$

Assume the refrigerator is opened 20 times a day for an average of 30 s.

$$\text{So, normal operating hours in a year} = 20 \times \frac{30}{3600} \times 365 = 60.83 \text{ hrs}$$

Extra hours of light on due to malfunction,

$$= 8760 - 60.83 = 8699.17 \text{ hrs}$$

$$\text{Increase in power consumption} = \frac{70.77}{1000} \times 8699.17$$

$$= 615.64 \text{ kWh/year}$$

$$\text{Increase in cost of power consumption} = 615.64 \times 5 = \text{Rs. } 3078.20 \text{ kw.}$$

- 13. A household refrigerator that has a power input of 450 W and a COP of 1.5 is to cool 5 large watermelons, 10 kg each, to 8°C. If the watermelons are initially at 28°C, determine how long it will take for the refrigerator to cool them. The watermelons can be treated as water whose specific heat is 4.2 kJ/kg K. Is your answer realistic or optimistic? Explain.**

NOV/DEC 2016 (5 MARK)

Given

Power input, $P = 450\text{W}$

$\text{COP} = 1.5$

No. of watermelons, $N = 5$

Mass of watermelons, $m = 10\text{kg}$

$T_i = 28^\circ\text{C} = 273 + 28 = 301\text{K}$

$T_f = 8^\circ\text{C} = 273 + 8 = 281\text{K}$

Solution

$$\begin{aligned} \text{Heat removed from watermelons, } Q &= NmC_{p\text{water}}(T_i - T_f) \\ &= 5 \times 10 \times 4.2(301 - 281) = 4200\text{kJ} \end{aligned}$$

$$\text{COP of refrigerator} = \frac{\text{refrigeration effect}}{\text{power input}}$$

$$1.5 = \frac{\text{refrigeration effect}}{450}$$

Refrigeration effect = $675\text{ W} = 675\text{ kJ/min}$

$$\text{Time to cool watermelons, } t = \frac{\text{heat removed}}{\text{refrigeration effect}}$$

$$= \frac{4200}{675} = 6.22\text{ min}$$

Approximation is an under estimate primarily because of assuming uniform cooling of watermelon, ideal process with no heat transfer, ideal source and sink.

B.E/B.Tech. DEGREE EXAMINATION, APRIL/MAY 2017.

Third Semester

Mechanical Engineering

ME 6301 – ENGINEERING THERMODYNAMICS

(Common to Automobile Engineering, Mechanical and Automation Engineering)

(Regulations 2013)

Time : Three hours

Maximum : 100 marks

Answer ALL questions.

PART A – (10 x 2 = 20 marks)

1. State and explain the Zeroth law and its application.(P3, Q9)
2. Apply steady flow energy equation for a nozzle and state the assumptions made.
3. What is PMM2 and why is it impossible?
4. What do you understand by high grade energy and low grade energy?
5. What are compressed solid and compressed liquid?
6. What are the methods for improving the performance of the Rankine cycle?(P58, Q13)
7. What is meant by generalized compressibility chart? And what are its features?
8. What is the value of Joule – Thomson coefficient for an ideal gas? Why?(P77,Q7)
9. State and prove the Amagats law of partial volume.
10. What is sensible cooling?

PART B – (5 x 13 = 65 marks)

- 11 (a) A gas occupies 0.3 m^3 at 2 bar. It executes a cycle consisting of processes:
- (i) 1 - 2, constant pressure with work interaction of 15kJ

- U_2 and
- (ii) 2 - 3, compression process which follows the law $pV = C$ and $U_3 =$
- (iii) 3 - 1, constant volume process, and reduction in internal energy is 40kJ

Neglecting the changes in Kinetic energy and Potential energy. Draw pV diagram for the process and determine net work transfer for the cycle. Also show that first law is obeyed by the cycle. (P17, Q8)

Or

- (b) In a gas turbine, the gases enter the turbine at the rate of 5 kg/s with a velocity of 50 m/s and the enthalpy of 900 kJ/kg and leaves the turbine with 150 m/s and the enthalpy of 400 kJ/kg. The loss of heat from the gas to the surroundings is 25 kJ/kg. Assume $R = 0.285$ kJ/kg K, $C_p = 1.004$ kJ/kg K and the inlet conditions to be at 100 kPa and 27°C. Determine the work done and diameter of the inlet pipe. (P 18, Q9)
- 12 (a) A heat pump working on the carnot cycle takes in heat from a reservoir at 5 °C and delivers heat to a reservoir at 60 °C. The heat pump is driven by a reversible heat engine which takes in heat from reservoir at 840 °C and rejects to a reservoir at 60 °C. The reversible heat engine also drives a machine that absorbs 30 kW. If the heat pump extracts 17 kJ/s from 5 °C reservoir, determine
- (i) the rate of heat supply from the 840 °C source, and
- (ii) the rate of heat rejection to the 60 °C sink (P46 , Q8)

Or

- (b) Air flows through an adiabatic compressor at 2 kg/s. The inlet conditions are 1 bar and 310 K and the exit conditions are 7 bar and 560 K. Compute the net rate of energy transfer and the irreversibility. Take $T_0 = 298$ K
- 13 (a) A vessel of volume 0.04 m³ contains a mixture of saturated water and saturated steam at a temperature of 250 °C. The mass of the liquid

present is 9 kg. Find the pressure, the mass, the specific volume, the enthalpy, the entropy, and the internal energy. (P61, Q2)

Or

- (b) A reheat Rankine cycle receives steam at 35 bar and 0.1 bar. Steam enters the first stage steam turbine 350 °C. If reheating is done at 8 bar to 350 °C; calculate the specific steam consumption and reheat Rankine cycle efficiency. (P67, Q6)
- 14 (a) 10 kmol of methane gas is stored in 5 m³ container at 300 K. Calculate the pressure by
- (i) ideal gas equation and
 - (ii) van der Waals equation.
- Use the following constants $a = 228.296 \text{ kPa}\cdot\text{m}^6/\text{kmol}^2$ and $b = 0.043 \text{ m}^3/\text{kmol}$ for the Vander Waals equation.

Or

- (b) The latent heat of vaporization at 1 bar pressure is 2258 kJ/kg and the saturation temperature is 99.4 °C. Calculate the saturation temperature at 2 bar pressure using Clausius – Clapeyron equation. Verify the same from the steam table data.
15. (a) Atmosphere air at 101.325 kPa and 288.15 K contains 21% oxygen and 79% nitrogen, by volume. Calculate the
- (i) mole fractions, mass fractions and partial pressures of oxygen and nitrogen and
 - (ii) molar mass, gas constant and density of air.
- Take Molar mass of oxygen and nitrogen as 32 and 28 kg/kmol.

Or

- (b) Air at 20 °C, 40% RH is mixed adiabatically with air at 40 °C, 40% RH in the ratio of 1 kg of the former with 2 kg of the latter (on dry basis). Determine the specific humidity and the enthalpy of the mixed stream.

PART C – (1 x 15 = 15 marks)

16. (a) A quantity of air undergoes a thermodynamic cycle consisting of three processes. Process 1 – 2 : Constant volume heating from $P_1 = 0.1 \text{ MPa}$,

$T_1 = 15\text{ }^\circ\text{C}$, $V_1 = 0.02\text{ m}^3$ to $P_2 = 0.42\text{ MPa}$. Process 2-3 : Constant pressure cooling. Process 3-1 : Isothermal heating to the initial state. Employing the ideal gas model with $C_p = 1\text{ kJ/kgK}$, evaluate the change of entropy for each process. Sketch the cycle on p-v and T-s coordinates. (P51,Q13)

Or

- (b) Air at 80 kpa, 27 °C and 220 m/s enters a diffuser at a rate of 2.5 kg/s and leaves at 42 °C. The exit area of the diffuser is 400cm². The air is estimated to lose heat at a rate of 18 kJ/s during this process.
- (i) the exit velocity and
 - (ii) the exit pressure of the air.(P23,Q12)

B.E./B.Tech. DEGREE EXAMINATION, NOVEMBER/ DECEMBER 2016.

Third Semester

Mechanical Engineering

ME 6301 - ENGINEERING THERMODYNAMICS

(Regulation 2013)

Answer ALL Questions

PART - A (10 x 2 = 20 Marks)

1. Should the automobile radiator be analyzed as a closed system or as an open system? Explain.
2. What are intensive and extensive properties?(P1,Q2)
3. A heat engine with thermal efficiency of 45 percent rejects 500KJ/Kg of heat. How much heat does it receive?
4. When system is adiabatic what can be said about the entropy change of the substance in the system?
5. Is iced water a pure substance ? why?(P54,Q1)
6. What is the effect of reheat on (a)the network output (b) the cycle efficiency and (c)steam rate of steam power plant?
7. What are reduced properties?
8. Write down the Two Tds equations
9. State the Dalton's law of partial pressures.
10. What is dew point temperature?(P92,Q1)

PART B (5 x 13 = 65 Marks)

11. (a) A Piston -cylinder device contains 0.15kg of air initially at 2 MPa and 3500C. The air is first expanded isothermally to 500KPa, then compressed polytropically with a polytropic exponent of 1.2 to the initial pressure and finally compressed at the constant pressure to the initial state .Determine the boundary work for each process and the network of the cycle.(P20,Q10)

(OR)

(b) Air enters the compressor of a gas-turbine plant at ambient conditions of 100 kPa and 25°C with a low velocity and exits at 1 MPa and 347°C with a velocity of 90 m/s. The compressor is cooled at a rate of 1500 kJ/min and the power input to the compressor is 250 kW. Determine the mass flow rate of air through the compressor. Assume $C_p = 1.005 \text{ kJ/kgK}$ (P22, Q11)

12. (a) (i) A heat pump operates on a Carnot heat pump cycle with a COP of 8.7. It keeps a space at 24°C by consuming 2.15 kW of power. Determine the temperature of the reservoir from which the heat is absorbed and the heating load provided by the heat pump. (P46, Q8)

(ii) An inventor claims to have developed a refrigeration system that removes heat from the closed region at -12°C and transfers it to the surrounding air at 25°C while maintaining a COP of 6.5. Is this claim reasonable? (P50, Q11)

(OR)

(b) (i) A 30 kg iron block and a 40 kg copper block, both initially at 80°C. Thermal equilibrium is established after a while as a result of heat transfer between the blocks and the lake water. Determine the total entropy change for this process. (P47, Q9)

(ii) How much of the 100 kJ of thermal energy at 650 K can be converted to useful work? Assume the environment to be at 25°C. (P51, Q12)

13. (a) A steam initially contains 5 m³ of steam and 5 m³ of water at 1 MPa. Steam is taken out at constant pressure until 4 m³ of water is left. What is the heat transferred during the process? (P74, Q9)

(OR)

(b) A regenerative cycle utilizes steam as a working fluid. Steam is supplied to the turbine at 40 bar and 450°C and the condenser pressure is 0.03 bar. After expansion in the turbine to 3 bar, some of the steam is extracted from the turbine for heating feed water from the condenser in an open heater. The pressure in the boiler is 40 bar and the state of the fluid leaving the heater is saturated liquid water at 3 bar. Assuming isentropic heat drop in the turbine and pumps, compute the efficiency of the cycle. (ii) When will you call a vapour superheated? Give example. Also when will you call a liquid as compressed liquid? Give example. (P43, Q14)

14. (a) (i) One kg of CO₂ has volume of 1 m³ at 100o C. compute the pressure by Vander waal's equation

Perfect gas equation

The vander waal's constant $a = 362850 \text{ Nm}^4/(\text{kg-mol})^2$ and $b=0.0423\text{m}^3/(\text{kg-mol})$.

(ii) Write the berthelot and dieterici equations of state. (P90,Q8)

(OR)

(b) (i) What is Joule-Thomson coefficient? Why is it zero for an ideal gas?(P87,Q7)

(ii) Derive an expression for clausius Clapeyron equation applicable to fusion and vapourization.(P79,Q1)

15. (a) A rigid tank that contains 2 kg of N₂ at 25 C and 550kpa is connected to another rigid tank that contains 4 kg of O₂ at 25 C and 50 kpa. The valve connecting the two tanks is opened and the two gases are allowed to mix. If the final mixture temperature is 25 C, determine the volume of each tank and the final mixture pressure.

(OR)

(b) An air conditioning system is designed under the following conditions:

Outdoor conditions 15oC DBT and 10oC WBT

Required conditions 20oC DBT and 50% RH

Amount of free air circulated 0.25 m³/min person

Seating capacity – 50 persons

The required condition is achieved first by heating and then by adiabatic humidifying . Determine the following

1. Capacity of heating coil in kw

2. Capacity of humidifier (P111,Q8)

PART C (1 x 15 = 15 Marks)

16. (a) (i) A household refrigerator that has a power input of 450 W and a COP of 1.5 is to cool 5 large watermelons, 10 kg each, to 8°C. If the watermelons are initially at 28°C, determine how long it will take for the refrigerator to cool them. The watermelons can be treated as water whose specific heat is 4.2 kJ/kg K. Is your answer realistic or optimistic? Explain. (P116, Q13)

(ii) What are the desirable characteristics of a working fluid most suitable for vapour power cycles?

(OR)

(b) (i) How do you minimize the energy consumed by your domestic refrigerator? (P114, Q9)

(ii) The interior lighting of refrigerators is provided by incandescent lamps whose switches are actuated by the opening of the refrigerator door. Consider a refrigerator whose 40 W light bulb remains on continuously as a result of performance of 1.3 and the cost of electricity is Rs. 5 per kWh, determine the increase in the energy consumption of the refrigerator and its cost per year if the switch is not fixed. Assume the refrigerator is opened 20 times a day for an average of 30 s. (P115, Q10)

Question Paper code: 51845

B.E / B.TECH DEGREE EXAMINATION, MAY/JUNE 2016

Third Semester

Mechanical Engineering

ME 2202 – ENGINEERING THERMODYNAMICS

REGULATION 2008/2010

Answer ALL Questions

PART – A (10 x 2 =20 Marks)

1. Define the Zeroth Law of thermodynamics. Why is it so called?
2. List any five physical properties of matter which can be used for measurement of temperature.
3. List the limitations of first law of Thermodynamics. (P21, Q12)
4. In an isothermal process 1000 kJ of work is done by the system at a temperature of 200°C. What is the entropy change in this process? (P21, Q13)
5. Define a pure substance. (P 39, Q1)
6. How is triple point represented in a P-v diagram? (P39, Q3)
7. Why do the specific heats of an ideal gas depend only on the atomic structure of the gas?
8. Define volumetric expansivity. (P 58, Q11)
9. When is humidification of air necessary?
10. How does the wet bulb temperature differ from the dry bulb temperature?

PART B (5 x 16 = 80 Marks)

11. (a) A thermodynamic system operates under steady flow conditions, the fluid entering at 2 bar and leaving at 10 bar. The entry velocity is 30 m/s and exit velocity is 10 m/s. During the process 25 MJ/hr of heat from an external source is supplied and the increase in enthalpy is 5 kJ/kg. The exit point is 20

m above the entry point. Determine the flow work from the system if the fluid flow rate is 45 kg/min

(OR)

(b) A vessel of constant volume 0.3 m^3 contains air at 1.5 bar and is connected via a valve to a large main carrying air at a temperature of 38°C and high pressure. The valve is opened allowing air to enter the vessel and raising the pressure therein to 7.5 bar. Assuming the vessel and valve to be thermally insulated, find the mass of air entering the vessel.

12. (a) (i) Define the terms “ Irreversible process” and “ Reversible process”. Give an example of each.

(ii) In a Carnot cycle the maximum pressure and temperature are limited to 18 bar and 410°C . The volume ratio of isentropic compression is 6 and isothermal expansion is 1.5. Assume the volume of the air at the beginning of isothermal expansion as 0.18 m^3 . Show the cycle on p-V and T-s diagrams and determine

(1) Pressure and temperature at main points

(2) Thermal efficiency of the cycle (P 22, QI a)

(OR)

(b) (i) State and prove Clausius inequality.

(ii) A metal block with $m= 5 \text{ kg}$, $C = 0.4 \text{ kJ/kg K}$ at 40°C is kept in a room at 20°C . It is cooled in the following two ways:

(1) Using a Carnot engine (executing integral number of cycles) with the room itself as the cold reservoir;

(2) Naturally (P32, Q V a)

13. (a) (i) Discuss the different zones of T-V diagram for water when the temperature rises from -20°C to 200°C at 1 atm pressure. (P 45, Q I)

(ii) A vessel of volume 0.04 m^3 contains a mixture of saturated water and saturated steam of 250°C . The mass of the liquid present is 9 kg. Find

the pressure, the mass, the specific volume, the enthalpy, the entropy and the internal energy (P 46, Q II)

(OR)

(b) Steam at 90 bar and 480 °C is supplied to a steam turbine. The steam is reheated to its original temperature by passing the steam through reheater at 12 bar. The expansion after reheating takes place to condenser pressure of 0.07 bar. Find the efficiency of the reheat cycle and work output if the flow of steam is 5 kg/s. Neglect the pressure loss in the system and assume expansions through the turbine are isentropic. Do not neglect pump work.

14. (a) (i) Derive the Clausius- Clapeyron equation and discuss its significance.
(ii) Write down two Tds relations (P 65, Q 5)

(OR)

(b) (i) Derive any two Maxwell's relation (P 62, QII)
(ii) Draw a neat schematic of compressibility chart and indicate its salient features. (P 64, Q III)

15. (a) (i) Derive the sensible heat factor for cooling and dehumidification process. Also explain the process.
(ii) One kg of air at 40 °C dry bulb temperature and 50% relative humidity is mixed with 2 kg of air at 20 °C dry bulb temperature and 20 °C dew point temperature. Calculate the temperature and specific humidity of the mixture.

(OR)

(b) (i) Prove the specific humidity of air is $w=0.622 \frac{P_v}{P_b - P_v}$

b(ii)with the aid of a model psychrometric chart explain the following processes

- (1) Adiabatic mixing
- (2) Evaporative cooling

Question Paper code: 57539

B.E / B.TECH DEGREE EXAMINATION, MAY/JUNE 2016

Third Semester

Mechanical Engineering

ME 6301 – ENGINEERING THERMODYNAMICS

REGULATION 2013

Answer ALL Questions

PART – A (10 x 2 =20 Marks)

1. Write down the equation for the first law for a steady flow process.
2. Give the energy equation applicable for an adiabatic nozzle and an adiabatic turbine.
3. A reversible heat engine operates between a source at 800 °C and a sink at 30 °C. What is the least rate of heat rejection per kW network output of the engine. (P27,Q10)
4. Define Irreversibility. (P27, Q11)
5. State the phase rule for pure substance. (P 55, Q4)
6. Mention the working fluids used in binary vapour cycle. (P 55, Q 5)
7. What are reduced properties? Give their significance.
8. What is the importance of Joule –Thomson coefficient?.
9. State Dalton's law of partial pressure. On what assumptions this law is based.
10. What is adiabatic mixing and write the equation for that.

PART B (5 x 16 = 80 Marks)

11. (a) A mass of air is initially at 260 °C and 700 kPa and occupies 0.028m³. The air is expanded at constant pressure to 0.084 m³. A polytropic process with $n = 1.5$ is then carried out followed by a constant temperature process which completes a cycle. All the process are reversible.

- (1) Sketch the cycle in T-S and p-V planes
- (2) Find the heat received and heat rejected in the cycle
- (3) Find the efficiency of the cycle (P3, QI)

(OR)

(b) (i) A room for four persons has 2 fans each consuming 0.18 kW power and three 100 W lamps. Ventilation air at the rate of 80 kg/hr enters with an enthalpy of 84 kJ/kg and leaves with an enthalpy of 59 kJ/kg. If each person puts out heat at the rate of 630 kJ/hr, determine the rate at which heat is removed by a room cooler, so that a steady state is maintained in the room

(P6, QII a)

(ii) An insulated rigid tank of 1.5 m³ of air at a pressure of 6 bar and 100 °C discharges air into the atmosphere which is at 1 bar through a discharge pipe till its pressure becomes 1 bar.

- (1) Calculate the velocity of air in the discharge pipe
- (2) Evaluate the work that can be obtained from the frictionless turbine using the kinetic energy of that air. (P7, QII b)

12. A heat engine operating between two reservoirs at 1000 K and 300 K is used to drive a heat pump which extracts heat from the reservoir at 300 K at a rate twice that at which the engine rejects heat to it. If the efficiency of the engine is 40% of the maximum possible and the COP of the heat pump is 50% of the maximum possible, what is the temperature of the reservoir to which the heat pump rejects heat? What is the rate of heat rejection from the heat pump if the rate of heat supply to the engine is 50 kW. (P 45, Q VII b)

(OR)

(b) (i) 50 kg of water is at 313 K and enough ice at -5 °C is mixed with water in an adiabatic vessel such that at the end of the process all the ice melts and water at 0 °C is obtained. Find the mass of ice required and the entropy change of water and ice. Given C_p of water = 4.2 kJ/kg K and C_p of ice = 2.1 kJ/kg K and the latent heat of ice = 335 kJ/kg (P41, Q Vb)

(ii) A heat engine receives 800 kJ of heat from a reservoir at 1000 K and rejects 400 kJ at 400 K. If the surrounding is at 300 K, calculate the first and second law efficiency and the relative efficiency of the heat engine.

13. (a) A large insulated vessel is divided into two chambers, one containing 5 kg of dry saturated steam at 0.2 MPa and the other 10 kg of steam, 0.8 quality at 0.5 MPa. If the partition between the chambers is removed and the steam is mixed thoroughly and allowed to settle, find the final pressure, steam quality and entropy change in the process. (P 62, Q IV)

(OR)

(b) (i) Why is Carnot cycle not practicable for a steam powerplant?

(ii) In a steam power plant the condition of steam at inlet to the turbine is 20 bar and 300 °C and the condenser pressure is 0.1 bar. Two feed water heaters operate at optimum temperatures. Determine (1) The quality of steam at turbine exhaust (2) network per kg of steam (3) cycle efficiency (4) the steam rate. Neglect pump work. (P 65, Q V)

14. (a) (i) A vessel of volume 0.28 m³ contains 10 kg of air at 320 K. Determine the pressure exerted by the air using a) Perfect gas equation b) Vander Waals equation c) Generalized compressibility chart (Take critical temperature of air as 132.8 K and critical pressure as 37.7 bar) .

(ii) Draw the neat schematic of a compressibility chart and indicate the salient features.

(OR)

(b) What is meant by phase change process? Derive Clausius – Clapeyron equation for a phase change process. Give the significance of this equation (P 79, Q I)

15. (a) A rigid tank of 5 m³ contains gas mixture comprising 3 kg of O₂ and 4 kg of N₂ and 5 kg of CO₂ at 290 K. Calculate the molar specific volume, initial pressure of the gas. If it is heated to 350 K, calculate the heat transfer and change in enthalpy. Also verify the Gibbs theorem for entropy

(OR)

(b) A room 7m x 4m x 4m is occupied by an air – water vapour mixture at 38°C. The atmospheric pressure is 1 bar and the relative humidity is 70%. Determine the humidity ratio, dew point, mass of dry air and mass of water vapour. If the mixture of air – water vapour is further cooled at constant pressure until the temperature is 10°C. Find the amount of water vapour condensed.

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B.E/B.Tech. DEGREE EXAMINATION, NOV/DEC 2015

Third Semester

Mechanical Engineering

ME 6301 – ENGINEERING THERMODYNAMICS

(Regulation 2013)

Time: Three hours

Maximum: 100 marks

Answer ALL Questions

PART-A (10x2=20 marks)

1. State the thermodynamics definition of work. ((P3, Q11)
2. Classify the following properties as intensive or extensive or neither. (a) Pressure (b) Temperature (c) Volume (d) Internal energy (e) volume per mole (f) Enthalpy per unit mass. (P3, Q12)
3. What is triple point? For a pure substance, how many degrees of freedom are there at triple point?
4. A vessel of 2 m³ contains a wet steam of quality 0.8 at 210°C. Determine the mass of the liquid and vapour present in the vessel. (P 55, Q 6)
5. Define degree of saturation.
6. State Gibbs-Dalton's law. (P 78, Q9)
7. Express Clausius inequality for various processes. . (P25, Q3)
8. Define second law efficiency. . (P25, Q4)
9. What is known as equation of state?
10. Write the Clausius-Clapeyron equation and label all the variables.

PART- B (5x16=80)

- 11 (a) A piston-cylinder assembly contains air (ideal gas with $\gamma = 1.4$) at 200kPa and occupies a volume of 0.01m³. The piston is attached to one end of a spring and the other end of the spring is fixed to a wall. The force exerted by the spring on the piston is proportional to the decrease in the length of the spring from its natural length. The ambient atmospheric pressure is 100 kPa. Now, the air in the cylinder is heated till the volume is doubled and at this instant it is found

that the pressure of the air in the cylinder is 500 kPa. Calculate the work done by the gas.

Or

(b) An insulated rigid tank having 5kg of air at 3 atm and 30°C is connected to an air supply line at 8 atm and 50°C through a valve. The valve is now slowly opened to allow the air from the supply line to flow into the tank until the tank pressure reaches 8 atm, and then the valve is closed. Determine the final temperature of the air in the tank. Also find the amount of air added to the tank.

12. (a) One kmol of methane is stored in a rigid vessel of volume 0.6m³ at 20°C. Determine the pressure developed by the gas by making use of the compressibility chart. (P 86, Q VI)

Or

(b) Derive the entropy equations. (P 85, Q V) (16)

13. (a) State the Carnot principles and prove the first principle with relevant sketches. (16)

Or

(b) One kilogram of water at 273 K is brought into contact with a heat reservoir at 373 K.

(i) When the water has reached 373 K, find the change in entropy of the water, of the heat reservoir, and of the universe. (ii) If the water had been heated from 273 K to 373 K by first bring it in contact with a reservoir at 323 K and then with a reservoir at 373K, what would have been the change in entropy of the universe?

14. (a) Draw the p-V, T-S, h-S diagrams and theoretical layout for Rankine cycle and hence deduce the expression for its efficiency. (16)

Or

(b) (i) State the advantages of using super heated steam in vapour power cycle. (6)

(ii) A vessel with a capacity of 0.05 m³ contains a mixture of saturated water and saturated steam at a temperature of 245°C. The mass of the liquid present is 10 kg. Find the following:

- (1) The pressure
- (2) The mass
- (3) The specific volume
- (4) The specific enthalpy
- (5) The specific entropy and
- (6) The specific internal energy. (10)

15. (a) In an engine cylinder a gas has a volumetric analysis of 13% CO₂, 12.5 % O₂ and 74.5% N₂. The temperature at the beginning of expansion is 950°C and the gas mixture expands reversibly through a volume ratio of 8:1, according to the law $pv^{1.2} = \text{constant}$. Calculate per kg of gas:

- (i) The work done:
- (ii) The heat flow:
- (iii) Change of entropy per kg of mixture.

The values of c_p for the constituents CO₂, O₂ and N₂ are 1.235 kJ/kg K, 1.088 kJ/kg K and 1.172 kJ/kg K respectively.

Or

(b) (i) The sling psychrometer in a laboratory test recorded the following readings:

Dry bulb temperature = 35°C
Wet bulb temperature = 25°C

Calculate the following :

- (1) Specific humidity
- (2) Relative humidity
- (3) Vapour density in air
- (4) Dew point temperature
- (5) Enthalpy of mixture per kg of dry air take atmospheric pressure = 1.0132

bar. (P 94, Q I)

- (ii) Write a short note on mixing of air steams in psychrometry. (8)

B.E/B.Tech. DEGREE EXAMINATION, NOV/DEC 2015

Third Semester

Mechanical Engineering

ME2202- ENGINEERING THERMODYNAMICS

(Regulation 2008/2010)

Time: Three hours

maximum: 100 marks

Answer ALL Questions

PART-A (10x2=20 marks)

1. Show how zeroth law of thermodynamics is used for temperature measurement.
2. Show that the energy of an isolated system remains constant.
3. What are the causes of irreversibility?
4. What is entropy principle?
5. What is normal boiling point? (p 56, Q7)
6. When is reheat recommended in a steam power plant? (P 56, Q8)
7. Why do the specific heats of an ideal gas depend only on the atomic structure of the gas?
8. Define volume expansivity.
9. Define dew point temperature. (P 92, Q 1)
10. What is chemical dehumidification? (P 92, Q 2)

PART B (5x16=80 marks)

11. (a) (i) A mass of gas is compressed in a quasi-static process from 80 kPa, 0.1 m³ to 0.04 MPa, 0.03 m³. Assuming that the pressure and volume are related by $pv^{1.35} = \text{constant}$, find the work done by the gas system. (5)
- (ii) A milk chilling unit can remove heat from the milk at the rate of 41.87 MJ/h. Heat leaks into the milk from the surrounding at an average rate of

4.187 MJ/h. Find the time required for cooling a batch of 500kg of milk from 45°C to 5°C. Take c_p of milk to be 4.187 KJ/kgK. (11)

Or

(b) (i) Write the steady flow energy equation for a boiler. (6)

(ii) Air flows steadily at the rate of 0.04kg/s through an air compressor, entering at 6 m/s with a pressure of bar and a specific volume of 0.85m³/kg and leaving at 4.5 m/s with a pressure of 6.9 bar and a specific volume of 0.16 m³ /kg. The internal energy of the air leaving is 88 kJ/kg greater than that of entering air. Cooling water surrounding the cylinder absorbs heat from the air at the rate of 59W. Calculate the power required to drive the compressor and the inlet and outlet cross sectional areas. (10) (P13, QVI)

12. (a) (i) What is a reversed Carnot heat engine? (5)

(ii) A heat pump working on a reversed carnot cycle taken in energy from reservoir maintained at 3°C and delivers it to another reservoir where temperature is 77°C. the heat pump drivers power for its operation from a reversible heat engine operating with in the higher and lower temperature limits of 1077°C and 77°C. For 100 kJ/s of energy supplied to the reservoir at 77°C, estimate the energy taken from the reservoir at 1077°C. (11) (P36, QIII)

Or

(b) (i) What is available energy and unavailable energy with reference to a thermodynamic cycle? (4)

(ii) A fluid undergoes a reversible adiabatic compression from 0.5 MPa, 0.2 m³ to 0.05 m³, according to the law $p v^{1.3} = \text{constant}$. Determine the change in enthalpy, internal energy and entropy and the heat transfer and work transfer during the process. (12)

13. (a) (i) Discuss the different zones of T-V diagram for water when the temperature rises from -20°C to 200°C at 1 atm pressure (8)

(ii) A Vessel of volume 0.04m³ contains a mixture of saturated water and saturated steam at a temperature of 250°C. The mass of the liquid present is 6 kg. Find the pressure, the mass, the specific volume, the enthalpy, the entropy and the internal energy. (8)

Or

(b) Steam at 90 bar and 480° C is supplied to a steam turbine. The steam is reheated to its original temperature by passing the steam through reheater at 12 bar. The expansion after reheating taken place to condenser pressure of 0.07 bar. Find the efficiency of the reheat cycle and work output if the flow of steam is 5 kg/sec. Neglect the pressure loss in the system and assume expansions through the turbine are isentropic. Do not neglect pump work.

14. (a) A mass of 0.25 kg of an ideal gas has a pressure of 300 kPa, a temperature of 80°C and a volume of 0.07 m³. The gas undergoes an irreversible adiabatic process to a final pressure of 300 kPa and final volume of 0.10 m³, during which work done on the gas is 25 kJ. Evaluate c_p and c_v of the gas the increase in entropy of the gas. (16)

Or

(b) The gas neon has a molecular weight of 20.183 and its critical temperature, pressure and volume are 44.5 K, 2.73 MPa and 0.0416 m³/kg mol. Reading from a compressibility factor z is 0.7. What are the corresponding specific volume, Pressure, temperature and reduced volume? (16)

15. (a) (i) The sling psychrometer reads 40°C DBT and 28°C WBT. Calculate, specific humidity, relative humidity, vapour density in air, dew point temperature and enthalpy of mixture per kg of dry air. Assume atmospheric pressure to be 1.03 bar.

(ii) What is wet bulb depression and where is it equal to zero? (4)

(b) (i) Explain adiabatic evaporative cooling. (6)

Or

(ii) Air at 20°C, 40% relative humidity is mixed adiabatically with air at 40°C, 40% relative humidity in the ratio of 1 kg of the former with 2 kg of the latter (on dry basis). Find the condition of air. (10)

B.E. / B.Tech. DEGREE EXAMINATION, APRIL/MAY 2015

ME6301 – ENGINEERING THERMODYNAMICS

(Regulation 2013)

Time : Three hours

Maximum : 100 marks

PART A – (10 X 2 = 20 Marks)

1. State the first law for a closed system undergoing a process and a cycle. (P2, Q7)
2. Why does free expansion have zero work transfer? (P2, Q8)
3. What is a thermal energy reservoir? Explain the term 'source' and 'sink'. (P25, Q1)
4. What is a reversed heat engine? . (P25, Q2)
5. What is meant by dryness fraction of steam? (P 57, Q9)
6. Draw the standard Rankine cycle on P-V and T-S coordinates. (P57, Q 10)
7. What is joule-Thomson coefficient? Why is it zero for an ideal gas? (P 77, Q7)
8. What is the law of corresponding states? (P 78, Q8)
9. What is Amagat's law?
10. What is sensible heating?

PART B – (5 x 16 = 80 Marks)

11. (a) A gas undergoes a thermodynamic cycle consisting of the following process:
 - i. Process 1-2: Constant pressure $P_1 = 1.4$ bar, $V_1 = 0.028$ m³, $W_{12} = 10.5$ KJ.
 - ii. Process 2-3: Compression with $PV = \text{constant}$, $U_3 = U_2$.
 - iii. Process 3-1: Constant volume, $U_1 - U_3 = -25.4$ KJ

There are no significant changes in KE and PE.

- 1) Sketch the cycle on P-V diagram

- 2) Calculate the network for the cycle in KJ
- 3) Calculate the heat transfer for process 1-2
- 4) Show that $\sum Q_{\text{cycle}} = \sum W_{\text{cycle}}$ (P15, QVII)
11. (b) A turbine operating under steady flow conditions receive steam at the following state: Pressure 13.8 bar; specific volume $0.143 \text{ m}^3/\text{Kg}$; internal energy 2590 KJ/Kg ; Velocity 30 m/s . The state of the stream leaving the turbine is: Pressure 0.35 bar; Specific Volume $4.37 \text{ m}^3/\text{Kg}$; Internal energy 2360 KJ/Kg ; Velocity 90 m/s . Heat is lost to the surrounding at the rate of 0.25 KJ/s . If the rate of steam flow is 0.38 Kg/s , What is the power developed by the turbine?
12. (a) A reversible heat engine operates between two reservoirs at temperature of 600°C and 40°C . The engine drives a reversible refrigerator which operates between reservoirs at temperature of 40°C to -20°C . The heat transfer to the hear engine is 2000 KJ and the network output for the combined engine refrigerator is 360 KJ . Calculate the heat transfer to the refrigerator and net heat transfer to the reservoir at 40°C .
12. (b) Two kg of air at 500 Kpa , 80°C expands adiabatically in a closed system until its volume is doubles and its temperature become equal to that of the surrounding which is at 100 Kpa . 5°C . For this process determine: (i) the maximum work (ii) the change in availability (iii) the irreversibility (P 43, Q VI a)
13. (a) A vessel of volume 0.04 m^3 contains a mixture of saturated water and saturated steam at a temperature of 250°C . the mass of the liquid present is 9 Kg . Find the pressure, the mass, the specific volume, the enthalpy and entropy and internal energy of the mixture.
13. (b) A steam power plant operates on a simple rankine cycle between the pressure limits of 3 MPa and 50 Kpa . The temperature of the steam at the turbine inlet is 300°C and the mass flow rate of steam through the cycle is 35 Kg/s . Show the cycle on a T-S diagram with respect to saturation lines, and determine (i) the thermal efficiency of the cycle (ii) the net power output of the power plant.
14. (a) Derive any three of the Maxwell relation.
14. (b) Determine the pressure of nitrogen gas at $T=175 \text{ K}$ and $v = 0.00375 \text{ m}^3/\text{Kg}$ on the basis of (i) the ideal-gas equation of state (ii) the Vander Walls equation of

state. The Vander walls constants for nitrogen are $a=0.175\text{m}^6\text{kpa/Kg}^2$,
 $b=0.00138\text{m}^3/\text{Kg}$. (P 84, Q IV)

15. (a) A gas mixture consists of 7 Kg nitrogen and 2 Kg oxygen, at 4 bar and 27°C . Calculate the mole fraction, partial pressure, molar mass, gas constant, volume and density.

15. (B) Atmospheric air at 1.0132 bar has a DBT of 30°C and WBT of 25°C . Compute (i) the partial pressure of water vapour (ii) specific humidity (iii) the dew point temperature (iv) the relative humidity (v) the degree of saturation (vi) the density of air in the mixture (vii) the density of vapour in the mixture (viii) the enthalpy of the mixture. Use the thermodynamics tables only.

B.E. / B.Tech. DEGREE EXAMINATION, APRIL/MAY 2015

ME2202 – ENGINEERING THERMODYNAMICS

(Regulation 2008)

Time : Three hours

Maximum : 100 marks

Answer all question

PART A – (10 X 2 = 20 Marks)

1. Define the Zeroth law of thermodynamics. Why is it so called? (P2, Q9)
2. List any five physical properties of matter which can be used for measurement of temperature. (P3, Q10)
3. A closed insulated vessel contains 200 Kg of water. A paddle wheel immersed in the water is driven at 400 rev/min with an average torque of 500 Nm. If the test run is made for 30 minute, determine rise in the temperature of water. Take specific heat of water 4.18 KJ/Kg K. (P28, Q14)
4. A heat engine is supplied with 2512 KJ/min of heat at 650°C, heat rejection take place at 100°C. Specify which of the following heat rejection represents a reversible, irreversible or impossible result (a) 867 KJ/min (ii) 1015 KJ/min. (P28, Q15)
5. Superheated steam at 30 bar and 300°C enter a turbine is expanded to 5 bar and quality 0.974 dryness, compute the loss in availability for the adiabatic process if the atmospheric temperature is 270°C.
6. Define second law of thermodynamics.
7. A domestic food freezer maintains a temperature of -15°C. The ambient air temperature is 30°C. If the heat leaks into freezer 1.75 KJ/s continuously. What is the least power necessary to pump this heat continuously?
8. One kg of an ideal gas is heated from 18°C to 93°C. Taking $R=269 \text{ Nm/Kg K}$ and $\gamma=1.2$ for gas. Find the change in internal energy.
9. Carnot refrigerator require 1.25 KW per ton of refrigeration to maintain the temperature of 243 K. Find the COP of Carnot refrigerator.

10. Ice is formed 0°C from water at 20°C . The temperature of the brine is -10°C . Find the ice formed per KW hour. Assume that refrigeration cycle used is perfect reversed Carnot cycle. Latent heat of ice = 80 Kcal/Kg.

PART B – (5 x 16 = 80 Marks)

11. (a) A thermodynamics system operates under steady state flow condition, the fluid entering at 2 bar and leaving at 10 bar. The entry velocity is 30 m/s and exit velocity is 10 m/s. During the process 25 MJ/hr of heat from an external source is supplied and the increase in enthalpy is 5 KJ/Kg. The exit point is 20 m above the entry point. Determine flow work from the system if the fluid flow rate is 45 Kg/min.
11. (b) A vessel of constant volume 0.3 m^3 contains air at 1.5 bar and it is connected via a valve, to a large main carrying air at a temperature of 33°C and high pressure. The valve is opened allowing air to enter the vessel and raising the pressure therein to 7.5 bar. Assuming the vessel and valve to be thermally insulated. Find the mass of air entering the vessel.
12. (a) Three Carnot engines A, B and C working between the temperature of 1000 K and 300 K are in a series combination. The work produced by these engines are in the ratio of 5:4:3. Make calculation of temperature for intermediate reservoirs.
12. (b) A reversible engine operates between temperatures T_1 and T ($T_1 > T$). The energy rejected from this engine is received by a second reversible engine at the same temperature T . The second engine rejects energy at temperature T_2 ($T_2 < T$). Prove that $T = (T_1 + T_2)/2$ if the engine produce same work output.
13. (a) A power generation plant uses steam as a working fluid and operates at a boiler pressure of 50 bar, dry saturated and a condenser pressure of 0.05 bar. Determine the cycle efficiency, work ratio and specific steam consumption for Rankine cycle.
13. (b) A steam power plant operates on a theoretical reheat cycle. Steam at 25 bar pressure and 400°C is supplied to the high pressure turbine. After its expansion to dry state the steam is reheated at a constant pressure to its original temperature. Subsequent expansion occurs in the low pressure turbine to a condenser pressure of 0.01 bar. Considering feed pump work,

Make calculation to determine (i) Quality of steam at entry to condenser (ii) Thermal efficiency (iii) specific steam consumption.

- 14.(a) A tank of 0.2 m^3 capacity contains O_2 at 15 bar and 400°C . A second tank of 0.5 m^3 contains N_2 at 20 bar and 300°C . the two tanks are connected together and allow to mix. The heat lost during mixing is 50 KJ. Determine the final pressure, final temperature of the mixture and net entropy change due to mixing.
- 14.(b) Five moles of gas mixture contains 45% N_2 , 27% He and 28% C_6H_6 by mass. Find (i) the analysis by volume and number of moles of each constituent (ii) the volume of mixture at 3.5 bar pressure and 20°C .
- 15.(a) A certain sample of moist air exit at 35°C DBT and 20°C dew point temperature the atmospheric pressure is 760 mm of mercury. Calculate the relative humidity and saturation ratio.
- 15.(b) (i) explain the process of cooling dehumidification of air (8)
(ii) Draw the psychometric chart and show any two psychometric process.(4)
(iii) What is moist air and saturated air. (4)

B.E./B.Tech. DEGREE EXAMINATION, NOVEMBER/DECEMBER 2014.

Third Semester - Mechanical Engineering

ME 6301 - ENGINEERING THERMODYNAMICS

(Regulation 2013)

Answer ALL Questions

PART - A (10x2=20marks)

1. Define thermodynamic equilibrium
2. Enlist the similarities between work and heat. (P1, Q5)
3. An inventor claims to have developed an engine which absorbs 100KW of heat from a reservoir at 1000K produces 60KW of work and rejects heat to a reservoir at 500K. Will you advise investment in its development? (P19, Q 8)
4. A turbine gets a supply of 5 kg/s of steam at 7 bar, 250°C and discharges it at 1 bar. Calculate the availability. (P27, Q9)
5. Draw the p-T diagram for water and, label all salient points. (P 58, Q 12)
6. State the advantages of using super heated steam in turbines. (P 58, Q11)
7. What is known as equation of state and when it can be used for engineering calculations? (P 77, Q 5)
8. What are known as thermodynamic gradients? (P 77, Q6)
9. Define molar mass.
10. Define sensible heat factor.

PART B - (5 x 16 = 80 marks)

11.(a) Three grams of nitrogen gas at 6 atm and 160°C in a frictionless piston cylinder device is expanded adiabatically to double its initial volume, then compressed at constant pressure to its initial volume and then compressed again at constant volume to its initial state. Calculate the net work done on the gas. Draw the P-V diagram for the processes. (P9, QIV)

Or

(b) 90 kJ of heat is supplied to a system at a constant volume. The system rejects 95 kJ of heat at constant pressure and 18 kJ of work is done on it. The system is brought to original state by adiabatic process. Determine

- (i) The adiabatic work
- (ii) The values of internal energy at all states if initial value is 105KJ
(P11, QV)

12. (a) Two heat engines operating in series are equal amount of work. The total work is 50 kJ/cycle. If the reservoirs are at 1000K and 250K, find the intermediate temperature and the efficiency of each engine. Also find the heat extracted from (16)

Or

(b) 5 kg of air at 550 K and 4 bar is enclosed in a closed vessel.

- (i) Determine the availability of the system if the surrounding pressure and temperature are 1bar and 290 K (8)
- (ii) If the air is cooled at constant pressure to the atmospheric temperature determine the availability and effectiveness. (P 44, Q VII a)

13. (a) (i) State the conditions under which the equation of state will hold good for a gas.

(ii) State the main reasons for the deviation of behavior of real gases from ideal gas. (4)

(iii) Explain irreversibility with respect to flow and non flow processes. (4)

(iv) Explain the effectiveness of a system. (4)

Or

(b) Derive Maxwell relations. (16)

14. (a) Explain steam formation with relevant sketch and label all salient points and explain every point in detail. (16)

Or

(b) In a Rankine cycle, the steam at inlet to turbine is saturated at a pressure of 35 bar and the exhaust pressure is 0.2 bar. Determine

- (i) The pump work
- (ii) The turbine work
- (iii) The Rankine efficiency
- (iv) The condenser heat flow
- (v) The dryness at the end of expansion. Assume flow rate

15. (a) A mixture of hydrogen (H_2) and Oxygen (O_2) is to be made so that the ratio of H_2 to O_2 is 2: 1 by volume. If the pressure and temperature are 1 bar and $25^\circ C$ respectively, Calculate

- (i) The mass of O_2 required (8)
- (ii) The volume of the container. (8)

Or

(b) 120 m^3 of air per minute at $35^\circ C$ DBT and 50% relative humidity is cooled to $20^\circ C$ DBT by passing through a cooling coil. Determine the following

- (i) Relative humidity of Out coming air and its wet bulb temperature (6)
- (ii) Capacity of cooling coil in tones of refrigeration (5)
- (iii) Amount of water vapour removed per hour (5)

B.E./B.Tech. DEGREE EXAMINATION, NOVEMBER/DECEMBER 2014.

Third Semester

Mechanical Engineering

ME 6301 - ENGINEERING THERMODYNAMICS

(Regulation 2008/2010)

Answer ALL Questions

PART - A (10x2=20marks)

1. What is zeroth law of thermodynamics? (P1, Q3)
2. Compare heat transfer with work transfer. (P2, Q6)
3. State Kelvin Planck's statement
4. What is the entropy principle?
5. What is flow and non-flow process?
6. Write the methods for improving the performance of the Rankine cycle.
7. What are the properties of ideal gas? (P79, Q 12)
8. State the Vander Waal's equation of state. (P 79, Q13)
9. What is adiabatic evaporative cooling?
10. What is the use of sling psychrometer?

Part -B (5 x16 = 80 marks)

11. (a) (i) Derive an expression for the work transfer, heat transfer and change in internal energy for an isobaric and isochoric process (8)
- (ii) Define enthalpy. How is it related to internal energy? (8)

Or

(b) Air at a temperature of 15° c Passes through a heat exchanger at a velocity of 30 m/s where its temperature is raised to 800° C. It then enters a turbine with the same velocity of 30 m/s and expands until the temperature falls to 650°C. On leaving the turbine, the air is taken at a velocity of 60 m/s to a nozzle where its expands until the temperature has fallen to 500°C. If the air flow rate is 2kg/s, calculate (i) the rate of heat transfer to the air in the heat

exchanger, (ii) the power output from the turbine assuming no heat loss, and (iii) the velocity at exit from nozzle, assuming no heat loss. Take the entropy of air as $h=c_p t$, where c_p is the specific heat equal to 1.005 KJ/kg K and t the temperature.

12. (a) (i) State and prove Clausius inequality. (4)

(ii) A reversible heat engine operates between two reservoirs at temperature of 600°C and 40°C. The engine drives a reversible refrigerator which operates between reservoirs at temperature of 40°C and -20°C. The heat transfer to the heat engine is 2000 kJ and the network output of the combined engine refrigerator plant is 360 kJ. (1) Evaluate the heat transfer to the refrigerant and the net heat transfer to the reservoir at 40°C. (2) Reconsider (1) given that the efficiency of the heat engine and the COP of the refrigerator are each 40% of their maximum possible values. (P 37, Q4)

OR

(b) (i) Briefly discuss about the concept of entropy. (6)

(ii) Liquid water of mass 10 kg and temperature 20°C is mixed with 2 kg of ice at -5°C till equilibrium is reached at 1 atm pressure. Find the entropy change of the system. Given: C_p of ice=2.09KJ/kg K and latent heat of ice= 334 kJ/kg. (10)

13. (a) A vessel of volume 0.04m³ contains a mixture of saturated water and saturated steam at a temperature of 250°C. The mass of the liquid present is 9 kg. Find the pressure, the mass, the specific volume, the enthalpy, the entropy and internal energy.

(Or)

(b) Steam at 20 bar, 360°C is expanded in a steam turbine to 0.08 bar. It then enters a condenser, where it is condensed to saturated liquid water. The pump feeds back the water into the boiler. (i) Assuming ideal process, find

per kg of steam the network and the cycle efficiency. (ii) If the turbine and the pump have each 80% efficiency, find the percentage reduction in the network and cycle efficiency.

14. (a) A mixture of ideal gases consists of 3 kg of nitrogen and 5 kg of CO₂ at a pressure of 3 bar and a temperature of 20°C. Find (i) mole fraction of each constituent, (ii) the equivalent molecular weight of the mixture, (iii) the equivalent gas constant of the mixture, (iv) the partial pressures and the partial volumes, (v) the volume and density of the mixture, and (vi) the C_p and C_v of the mixture. Take γ for CO₂ and N₂ to be 1.286 and 1.4 respectively. (P 86, Q VII)

Or

- (b) (i) Derive any two Maxwell's relation.
(ii) Deduce the expression for Joule-Thomson coefficient and draw the inversion curve. (P 87, Q VII)

15. (a) Air at 20°C, 40% RH is mixed adiabatically with air at 40°C, 40% RH in the ratio of 1 kg of the former with 2kg of the latter (on dry basis). Find the final condition of air.

Or

- (b) (i) Explain adiabatic saturation with a schematic diagram. (8)
(ii) A sling psychrometer reads 35° C DBT and 30°C WBT. Find the humidity ratio, relative humidity, dew point temperature, specific volume, and enthalpy of air. (8)

B.E./B.Tech. DEGREE EXAMINATION, MAY/JUNE 2014.

Third Semester

Mechanical Engineering

ME 2202 - ENGINEERING THERMODYNAMICS

(Regulation 2008/2010)

Answer ALL Questions

PART - A (10x2=20marks)

1. Define Thermodynamic Equilibrium(P1, Q3)
2. Differentiate between point function and path function(P1, Q4)
3. State Kelvin plank statement (P 26, Q 6)
4. Write Carnot theorem and its corollaries (P26, Q7)
5. Draw a P-T (pressure temperature) diagram for a pure substance (P 58, Q 12)
6. Mention the possible ways to increase thermal efficiency of Rankine cycle (P 58, Q 13)
7. What are the assumptions made to derive ideal gas equation analytically using the kinetic theory of gases? (P 76, Q 4)
8. Using clausius- claperyon's equation, estimate the enthalpy of vaporization at 200°C, $V_g = 0.1274 \text{ m}^3/\text{kg}$, $V_f = 0.001157 \text{ m}^3/\text{kg}$, $d_p/d_t = 32\text{Kpa/K}$ (P 56, Q 3)
9. Define adiabatic saturation temperature (P 72, Q 3)
10. What is by-pass factor? (P 72, Q 4)

PART B (5 x 16 = 80 Marks)

11. (a) Determine the heat transfer and its direction for a system in which a perfect gas having a molecular weight of 16 is compressed from 101.3kpa, 20°C to a pressure of 600kpa following the law $pV^{1.3} = \text{constant}$. Take specific heat at constant pressure of gas as 1.7KJ/Kg K. (P8, Q III)

(OR)

(b) In a gas turbine installation air is heated inside heat exchanger up to 750°C from ambient temperature of 27°C. Hot air enters in to gas turbine with the velocity of 50m/s. and leaves at 600°C. Air leaving turbine enters nozzle at 60m/s velocity and leaves nozzle at temperature 500°C. For unit mass flow rate of air, determine the following assumptions adiabatic expansion in turbine and nozzle.

- i. Heat transfer to air in heat exchanger
- ii. Power output from turbine
- iii. Velocity at exit of nozzle. Take C_p for air as 1.005KJ/kg°K

12. (a) (i) A reversible heat pump is used to maintain a temperature of 0°C in a refrigerator when it rejects the heat to the surrounding at 25°C. If the heat removal rate from the refrigerator is 1440KJ/min. determine the C.O.P of the machine and work input required.

(ii) If the required input to run the pump is developed by a reversible engine which receives heat at 380°C and rejects heat to atmosphere, then determine the overall C.O.P of the system.

(OR)

(b) 5 m³ of air at 2 bar, 27°C is compressed up to 6 bar pressure following $pV^{1.3} = \text{constant}$. It is subsequently expanded adiabatically to 2 bar. Considering the two processes to be reversible, determine the network, net heat transfer, and change in entropy. Also plat the processes on T-S and P-V diagram. (P 32. Q Ib)

13. (a) A vessel having a capacity of 0.05m³ contains a mixture of saturated water and saturated steam at a temperature of 245°C. The mass of the liquid pressure is 10kg. Find the following

- a. The pressure
- b. The mass
- c. The specific volume
- d. The specific enthalpy
- e. The specific entropy and

f. The specific internal energy

(OR)

(b) A Steam power plant operates on a theoretical reheat cycle. Steam at boiler at 150 bar, 550°C expands through the high pressure of 40bar to 550°C and expands through the low pressure turbine to a condenser at 0.1bar. Draw T-S and h-s diagram. Find:

- i. Quality of steam at turbine exhaust
- ii. Cycle efficiency
- iii. Steam rate in kg/Kwh (P 67, Q VI)

14. (a) Drive the Maxwell relations and explain their importance in thermodynamics.

(OR)

(b) The pressure and temperature of mixture of 4 kg of O₂ and 6kg of N₂ are 4 bar and 27°C respectively. For the mixture determine the following:

The mole fraction of each component

The average molecular weight

The specific gas constant

The volume and density

The partial pressure and partial volume.

15. (a) An air water mixture vapour mixture enters an air conditioning unit at a pressure of 1.0bar, 38°C, DBT, and a relative humidity of 75%. The mass of dry air entering is 1kg/s. The air vapour mixture leaves the air conditioning unit at 1.0 bar, 18°C, 85% relative humidity. The moisture condensed leaves at 18°C. Determine the heat transfer rate for the process. (P 96, Q II)

(OR)

(b) It is required to design an air conditioning system for an industrial process for the following hot and wet summer conditions.

Outdoor conditions 32°C DBT and 65%RH

Required air inlet conditions 25°C DBT and 60%RH

Amount of free air circulated 250m³/min

Coil due temperature 13°C

The required condition is achieved by first cooling and dehumidifying and then by heating. Calculate the following (Solve this problem with the use of psychometric chart)

The cooling capacity of the cooling coil and its by-pass factor.

Heating capacity of the heating coil in kW and surface temperature of the heating coil if by-pass factor is 0.3.

The mass of water vapour removed per hour. (P 98, Q III)

B.E./B.Tech. DEGREE EXAMINATION, NOVEMBER/ DECEMBER 2013.

Third Semester

Mechanical Engineering

ME 2202 - ENGINEERING THERMODYNAMICS

(Regulation 2008/2010)

Answer ALL Questions

PART - A (10x2=20marks)

PART – A (10 x 2 =20 Marks)

1. What is microscopic approach in thermodynamics? (P1, Q1)
2. Define extensive property. (P1, Q2)
3. State Clausius Statement of Second law of thermodynamics
4. Draw the schematic of an heat pump.
5. Define a pure substance
6. How the triple point respected in the p-V diagrams
7. Define Avogadro's law (P76, Q1)
8. What is a real gas? Give example. (P 76, Q 2)
9. Why do wet clothes dry in the sun faster? (P 92, Q 5)
10. Define degree of saturation. (P 93, Q6)

PART B (5 x 16 = 80 Marks)

11. (a) Drive the steady flow energy equation and reduce it for a turbine, pump, nozzle, and heat exchanger.

(OR)

(b) Briefly explain the following:

- i. Point and path function
- ii. Property, state, process, path

iii. Quasi static process

12. (a) (i) Two Carnot engines A and B are operated in series. The first one receives heat at 870 K and reject to a reservoir at T. B receives heat rejected by the first engine and in turn rejects to a sink at 300 K. Find the temperature T for

1. Equal work outputs of both engine
2. Same efficiencies (P34, Q II)

(ii) Mention the clausius inequality for open, closed and isolated systems .

(OR)

(b) (i) 3 kg of air at 500 kpa 90°C expands adiabatically in a closed system until its volume is doubled and its temperature become equal to that the surrounding at 100 kpa and 10°C . Find maximum work, change in availability and the irreversibility.

(ii) Briefly discuss about the concept of entropy

13. (a) Steam at 480°C , 90 bar is supplied to a Rankine cycle. It is reheated to 12 bar and 480°C . The minimum pressure is 0.07 bar. Find the work output and cycle efficiency using steam tables with and without considering pump work.

(OR)

(b) (i) Steam initially at 0.3Mpa, 250°C is cooled at constant volume. At what temperature will the steam become saturated vapour? What is the steam quality at 80°C . Also find what is the heat transferred per kg of steam in cooling from 250°C to 80°C . (P 69, Q VII)

(ii) When will you call a vapour superheated? Give example. Also when will you call a liquid as compressed liquid? Give example. (P58, Q 14)

14. (a) (i) Drive the Clausius Claperyon's equations and discuss its significance

(ii) Write down two Tds relations

(OR)

- (b) (i) Write down two Maxwell's relations.
- (ii) Draw the neat schematic of a compressibility chart and indicate its salient features
15. (a) (i) Air at 20°C 40% R.H is mixed with air at 40°C, 40% R.H in the ratio of (former) 1:2 (later) on dry basis. Determine the final condition of air.
- (ii) Briefly discuss about evaporative cooling process.

(OR)

- (b) (i) Define the terms Relative humidity and Specific humidity.
- (ii) Explain the adiabatic saturation process with a schematic.
- (iii) Represent heating and humidification, cooling and dehumidification processes on a psychometric chart.