Module

3

Lecture

7

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Department of Mechanical Engineering

Thermodynamics

Properties of Pure Substances

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Properties of Pure Substances

(*Contd…*)

Enthalpy–Entropy Diagram (Mollier Diagram)

- The enthalpy *vs* entropy plot or h–s diagram is found to be valuable in the analysis of steady-flow devices like turbines, compressors, nozzles etc.
- The h–s diagram is popularly known as Mollier diagram as in Fig. 3.13.
- Note the location of the critical point and the appearance of lines of constant temperature and constant pressure. Lines of constant quality are shown in the two-phase liquid–vapor region (some figures give lines of constant percent moisture).
- The figure is intended for evaluating properties at superheated vapor states and for two-phase liquid–vapor mixtures.
- Liquid data are seldom shown.
- In the superheated vapor region, constant-temperature lines become nearly horizontal as pressure is reduced.
- These superheated vapor states are shown, approximately, as the shaded area in Fig. 3.13.

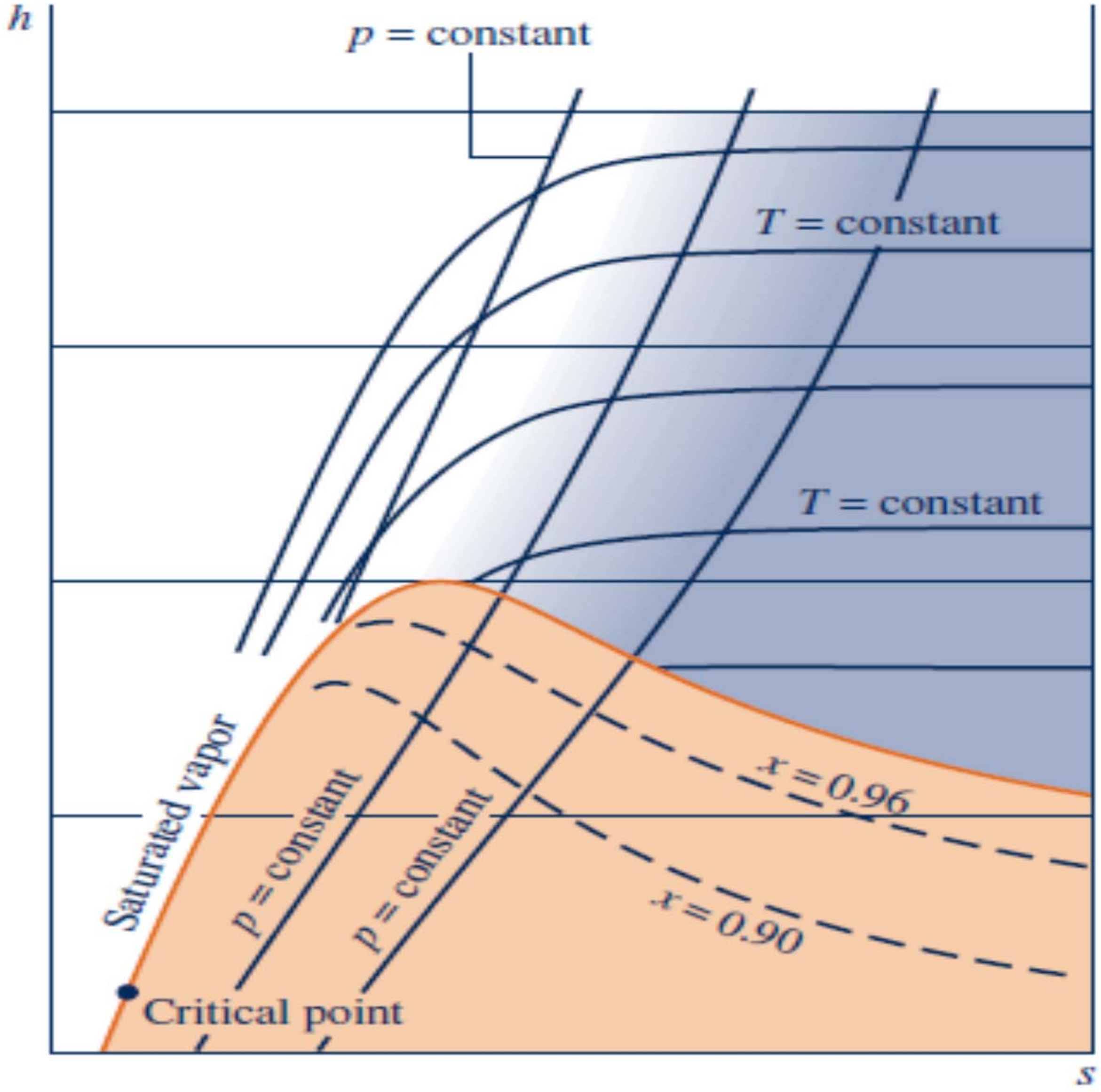


Fig. 3.13: Mollier Diagram

Solved Examples

Example 3.7

Calculate the specific volume, specific enthalpy and specific entropy of wet steam of dryness fraction or quality of 0.9 at 2 MPa pressure.

Solution From the saturated steam table

Specific volume of saturated liquid is $v_f = 0.001177\ \text{m}^3/\text{kg}$

Specific volume of saturated vapour is $v_g = 0.09963\ \text{m}^3/\text{kg}$

Specific enthalpy of saturated liquid is $h_f = 908.8\ \text{kJ/kg}$

Specific enthalpy of saturated vapour $h_g = 2799.5\ \text{kJ/kg}$

Specific entropy of saturated liquid is $s_f = 2.4478\ \text{kJ/kg-K}$

Specific entropy of saturated vapour is $s_g = 6.3417\ \text{kJ/kg-K}$

Dryness fraction of the mixture is given as $x = 0.9$

The specific volume of the wet steam is

$$v = v_f + x(v_g - v_f)$$

$$= 0.001177 + 0.9(0.09963 - 0.001177) = 0.08978 \text{ m}^3/\text{kg}$$

The specific enthalpy of the wet steam is

$$h = h_f + x(h_g - h_f)$$

$$= 908.8 + 0.9(2799.5 - 908.8) = 2610.43 \text{ kJ/kg}$$

The specific entropy of the wet steam is

$$s = s_f + x(s_g - s_f)$$

$$= 2.4478 + 0.9(6.3417 - 2.4478) = 5.9523 \text{ kJ/kg-K}$$

Example 3.8

During an experiment, 1 kg of an unknown gas is heated from 30°C to 130°C. It is observed that 43.6 kJ of heat is required at constant pressure and 14 kJ of heat is needed at constant volume. Find the characteristic gas constant and the molecular weight of the gas.

Solution

Mass of air	$m = 1$ kg
Initial temperature	$T_1 = 30°C$
Final temperature	$T_2 = 130°C$

Heat needed to raise the temperature at constant pressure $Q_{p=const} = 43.6$ kJ

Heat needed to raise the temperature at constant volume $Q_{v=const} = 14$ kJ

From the given conditions, we have

$$Q_{p=const} = mC_p\left(T_2 - T_1\right)$$

$$Q_{v=const} = mC_v\left(T_2 - T_1\right)$$

Substituting the values, we get

$$43.6 = 1 \times C_p\left(130 - 30\right)$$

$$14 = 1 \times C_v\left(130 - 30\right)$$

From the above two equations, we find

$$C_p = 0.436 \text{ kJ/kgK} \text{ and } C_v = 0.14 \text{ kJ/kgK}$$

The characteristic gas constant can be found from equation

$$R = C_p - C_v = 0.436 - 0.14 = 0.296 \text{ kJ/kgK}$$

The molecular weight of the gas is obtained from equation

$$M = \frac{\bar{R}}{R} = \frac{8.3143}{0.296} = 28 \text{ kg/kg mol}$$

Example 3.9

One kg of air is compressed in a closed system from 0.1 MPa, 20°C to 0.4 MPa isothermally. Find the changes in internal energy, enthalpy and entropy. Also find the work done, and the heat transferred. Assume that C_p and C_v are constant over this range of temperature.

Solution

Initial pressure	$P_1 = 0.1$ MPa
Initial temperature	$T_1 = 20°C = 20 + 273 = 293$ K
Final pressure	$P_2 = 0.4$ MPa

Since internal energy and enthalpy of an ideal gas is a function of absolute temperature only, the changes in internal energy and enthalpy both are zero for an isothermal process.

Work done during the isothermal process 1-2 is

$$W_{1-2} = P_1 V_1 \ln \frac{P_1}{P_2}$$

$$= mRT_1 \ln \frac{P_1}{P_2} \qquad [\because P_1 V_1 = mRT_1]$$

$$= 1 \times 0.287 \times 293 RT_1 \ln \frac{0.1}{0.4} = -116.57 \text{ kJ}$$

Negative sign physically signifies that the work is done on the air.

From the first law of thermodynamics, one can write

$$Q_{1\text{-}2} = W_{1-2} + U_2 - U_1$$

$$= W_{1-2} = -116.57 \text{ kJ} \qquad [\because U_2 - U_1 = 0]$$

The heat transferred is same as the work done.

Exercises

1. 4 kg of water is placed in an enclosed volume of $1m^3$. Heat is added until the temperature is 150°C. Find (a) the pressure, (b) the mass of vapor, and (c) the volume of the vapor.

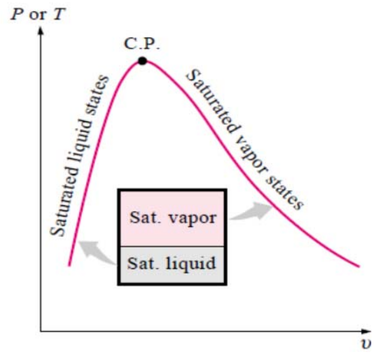
2. A piston-cylinder device contains 0.1 m^3 of liquid water and 0.9 m^3 of water vapor in equilibrium at 800 kPa. Heat is transferred at constant pressure until the temperature reaches 350°C.
   (a) what is the initial temperature of the water,
   (b) determine the total mass of the water,
   (c) calculate the final volume, and
   (d) show the process on a P-v diagram with respect to saturation lines.

Exercises

3. For a specific volume of 0.2 m^3/kg, find the quality of steam if the absolute pressure is (a) 40 kPa and (b) 630 kPa. What is the temperature of each case ?

4. Water is contained in a rigid vessel of 5 m^3 at a quality of 0.8 and a pressure of 2 MPa. If the pressure is reduced to 400 kPa by cooling the vessel, find the final mass of vapor m_g and mass of liquid m_f.

Important definitions



- *Pure substance:* homogeneous and invariable in a chemical composition throughout its mass.

- The pressure and temperature under which two phases can exist in equilibrium are called *saturation pressure and saturation temperature*.

- A liquid existing at a temperature lower than the saturation temperature corresponding to its pressure is called *compressed liquid or sub-cooled liquid.*
- Vapour existing at a temperature higher than the saturation temperature corresponding to its pressure is called *superheated vapour.*

- *Quality or dryness fraction* is defined as the ratio of mass of saturated vapour to the total mass of mixture. That is,

$$x = \frac{m_g}{m} = \frac{m_g}{m_f + m_g}$$

where m_f is the mass of saturated liquid, m_x is the mass of saturated vapour and m is the total mass of liquid-vapour mixture.

Important Definitions (*contd…*)

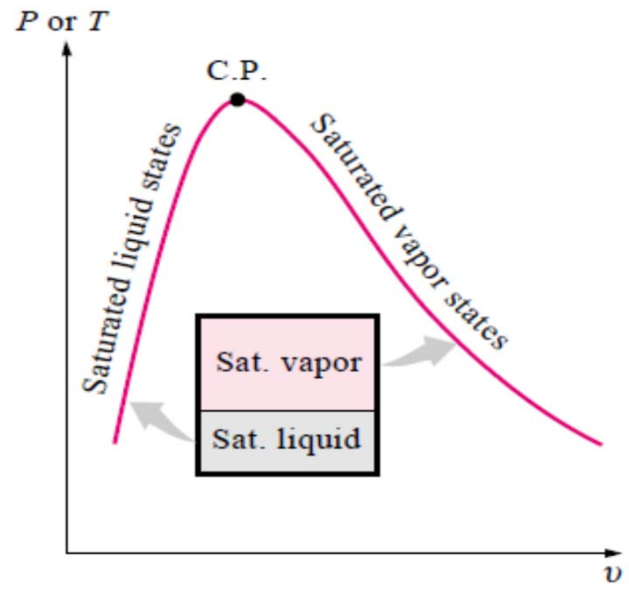
- Properties of a liquid–vapour mixture may be found by relations such as

$$v = v_f + xv_{fg}$$

$$h = h_f + xh_{fg}$$

$$s = s_f + xs_{fg}$$

$$u = u_f + xu_{fg}$$



Important Definitions (*contd…*)

- ***Critical point*** - the temperature and pressure above which there is no distinction between the liquid and vapor phases.
- ***Triple point*** - the temperature and pressure at which all three phases can exist in equilibrium.
- ***Sublimation*** - change of phase from solid to vapor.
- ***Vaporization*** - change of phase from liquid to vapor.
- ***Condensation*** - change of phase from vapor to liquid.
- ***Fusion or melting*** - change of phase from solid to liquid.

Chapter to be discussed in next lecture

First law for flow processes

Thank You