

## ME 209

### Basic Thermodynamics (Lecture-7)

Kannan Iyer  
Kiyer@me.iitb.ac.in



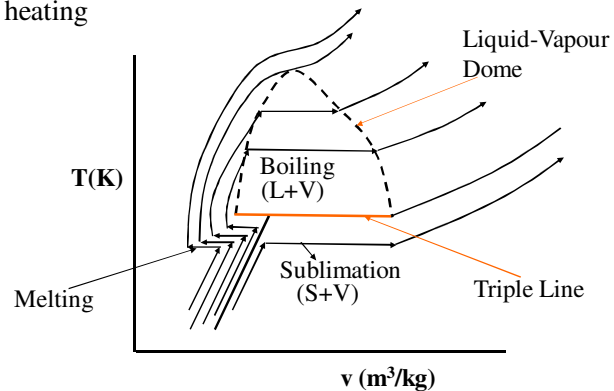
Department of Mechanical Engineering  
Indian Institute of Technology, Bombay

## Review of Lecture 6

- Introduced the various form of first law and the State principle
- Introduced the ideal gas equation of state and the definition of specific heats. Learnt that  $u$ ,  $h$ ,  $c_p$  and  $c_v$  are only functions of temperature
- Derived the process relation for adiabatic frictionless process in ideal gas with constant specific heats
- Solved a few problems illustrating work and first law.
- Today, we shall build the concepts involving properties of water substance.

## Properties of Pure Substances

- Consider a fixed mass of a pure water in a cylinder piston arrangement ( $p = \text{constant}$ ) subjected to heating

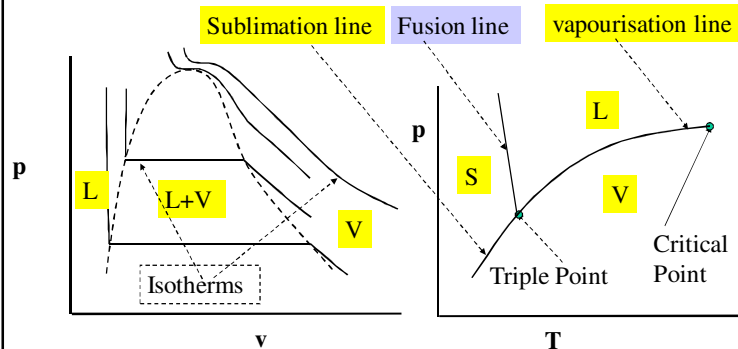


## Properties of Pure Substances - II

- Triple line –  $p = 611 \text{ Pa}$ ,  $T = 0.01 \text{ }^\circ\text{C}$
- Critical Point –  $p = 22.09 \text{ MPa}$ ,  $T = 374.14 \text{ }^\circ\text{C}$
- Water contracts on melting and  $T_{\text{melt}}$  decreases with increase in  $p$
- Other substances that expand on Melting, the  $T_{\text{melt}}$  increases with increase in  $p$
- During phase change,  $p$  and  $T$  are not independent
- The solid-liquid transformation and solid-vapour transformation are not very useful in power generation applications and hence will not be discussed further.

### Properties of Pure Substances - III

- The phase diagram can be plotted in p-v and p-T plane. Only liquid-vapour system is plotted in p-v



### Properties of Pure Substances - IV

#### Definitions

- Saturated temperature** is the temperature at which change of phase occurs at constant pressure. It is a function of pressure.  $T_{\text{sat}} = T_{\text{sat}}(p)$
- Saturated pressure** is the pressure at which change of phase occurs at constant temperature. It is a function of temperature.  $p_{\text{sat}} = p_{\text{sat}}(T)$
- Subcooled Liquid** is the state when  $T < T_{\text{sat}}(p)$
- Superheated vapour** is the state is when  $T > T_{\text{sat}}(p)$
- The state is **wet**,  $T = T_{\text{sat}}$ ,  $p = p_{\text{sat}}$  and a mixture of vapour and liquid is simultaneously present.

### Steam Tables - I

- Ideal gas temperature holds, when  $p \ll p_c$ ,  $T \gg T_{\text{sat}}$
- Equation of state of a real substance is quite complicated.
- These are tabulated in the form of tables.
- Generally this table is in three forms
  - Saturated Tables
  - Superheated vapour Table
  - Compressed liquid Table.
- The last one is often skipped and Incompressible model is used.

### Steam Tables - II

- For every  $T_{\text{triple point}} < T < T_{\text{critical}}$ , there exists a  $p_{\text{sat}}$
- The saturated liquid properties are denoted by the subscript **f** and the saturated vapour properties are denoted by the subscript **g**
- In saturated pressure table, for every  $p_{\text{sat}}$ , the corresponding  $T_{\text{sat}}$ ,  $v_f$ ,  $v_g$ ,  $u_f$ ,  $u_g$ ,  $h_f$ ,  $h_g$ ,  $h_{fg}$ ,  $s_f$ ,  $s_{fg}$  and  $s_g$  are tabulated
- In saturated temperature table, for every  $T_{\text{sat}}$ , the corresponding  $p_{\text{sat}}$ ,  $v_f$ ,  $v_g$ ,  $u_f$ ,  $u_g$ ,  $h_f$ ,  $h_g$ ,  $h_{fg}$ ,  $s_f$ ,  $s_{fg}$  and  $s_g$  are tabulated

### Steam Tables - III

- In superheated steam table, for every pressure, the values of  $v$ ,  $u$ ,  $h$  and  $s$  are tabulated at regular intervals of temperature for  $T > T_{\text{sat}}$
- Thus the properties of the gas and liquid phase in saturated state and the properties of gas at superheated vapour state can be obtained
- When a mixture of two phases exists, we define a parameter  $x$ , which is defined as the fraction of mass of vapour in the mixture. This parameter is called dryness fraction or quality

### Steam Tables - IV

- The properties of two-phase mixture is estimated using the dryness fraction as follows
- Consider, Volume of two-phase mixture,  $V$

$$V = V_f + V_g = m_f v_f + m_g v_g$$

$$\Rightarrow v = \frac{V}{m_f + m_g} = \frac{m_f v_f + m_g v_g}{m_f + m_g}$$

$$\Rightarrow v = \frac{m_f}{m_f + m_g} v_f + \frac{m_g}{m_f + m_g} v_g$$

$$\Rightarrow v = (1 - x)v_f + xv_g$$

### Steam Tables - V

- In a similar fashion all the specific properties will be dryness fraction weighted.

$$u = (1 - x)u_f + xu_g \quad h = (1 - x)h_f + xh_g$$

$$s = (1 - x)s_f + xs_g$$

- From the above we can write,

$$x = \frac{v - v_f}{v_g - v_f} = \frac{u - u_f}{u_g - u_f} = \frac{h - h_f}{h_g - h_f} = \frac{s - s_f}{s_g - s_f}$$

### Incompressible liquid model

- For incompressible substances,  $u = u(T)$ ,  $v = v(T)$  and  $s(T) = s_f(T)$
- Hence we can estimate  $u$ ,  $v$  and  $s$  for liquids as  $u(T) = u_f(T)$ ,  $v(T) = v_f(T)$  and  $s(T) = s_f(T)$
- Finally,  $h(T)$  can be estimated as  $h(p, T) = u_f(T) + pv_f(T)$

For details refer to the original site  
<http://www.lsbu.ac.uk/water/phase.html>

