Module

3

Lecture 4

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Department of Mechanical Engineering

Thermodynamics

Properties of Pure Substances

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Properties of Pure Substances

(*Contd…*)

PROPERTY TABLES

- For most substances, the relationships among thermodynamic properties are too complex to be expressed by simple equations. Therefore, properties are frequently presented in the form of tables.
- For each substance, the thermodynamic properties are listed in more than one table.
- In fact, a separate table is prepared for each region such as the superheated vapor, compressed liquid, and saturated (mixture) regions.
- Before we get into the discussion of property tables, we define a new property called *enthalpy*.

Enthalpy—A Combination Property

- In the analysis of certain types of processes, particularly in power generation and refrigeration, we frequently encounter the combination of properties $U + PV$.
- For the sake of simplicity and convenience, this combination is defined as a new property, *enthalpy*, and given the symbol H:

$$H = U + PV$$

or, per unit mass,

$$h = u + Pv$$

Saturated Liquid and Saturated Vapor States

- The properties of saturated liquid and saturated vapor for water are listed in Saturated water-Temperature Table and Saturated water-Pressure Tables.
- Both tables give the same information. The only difference is that in Saturated water-Temperature Table, the properties are listed under temperature and in Saturated water-Pressure Table, the properties are listed under pressure.
- Therefore, it is more convenient to use Saturated water-Temperature Table when *temperature* is given and Saturated water-Pressure Table when *pressure* is given.

Temp. °C T	Sat. press kPa P_{sat}	Specific volume m^3/kg: Sat. liquid v_f	Specific volume m^3/kg: Sat. vapor v_g
85	57.83	0.001 033	2.828
90	70.14	0.001 036	2.361
95	84.55	0.001 040	1.982

Specific temperature

Corresponding saturation pressure

Specific volume of saturated liquid

Specific volume of saturated vapor

Fig. 3.19: *Saturated water-Temperature Table*

- The subscript *f* is used to denote properties of saturated liquid, and the subscript *g* to denote the properties of saturated vapor.
- These symbols are commonly used in thermodynamics and originated from German.
- Another subscript *fg* is used for the difference between the saturated vapor and saturated liquid values of the same property.
- For example

$$v_f = Specific\ volume\ of\ saturated\ liquid$$
$$v_g = Specific\ volume\ of\ saturated\ vapor$$
$$v_{fg} = Difference\ between\ v_f\ and\ v_g (v_{fg} = v_g - v_f)$$

- The quantity h_{fg} is called the *enthalpy of vaporization* (or *latent heat of vaporization*).
- It represents the amount of energy needed to vaporize a unit mass of saturated liquid at a given temperature or pressure.
- It decreases as the temperature or pressure increases, and becomes zero at the critical point.

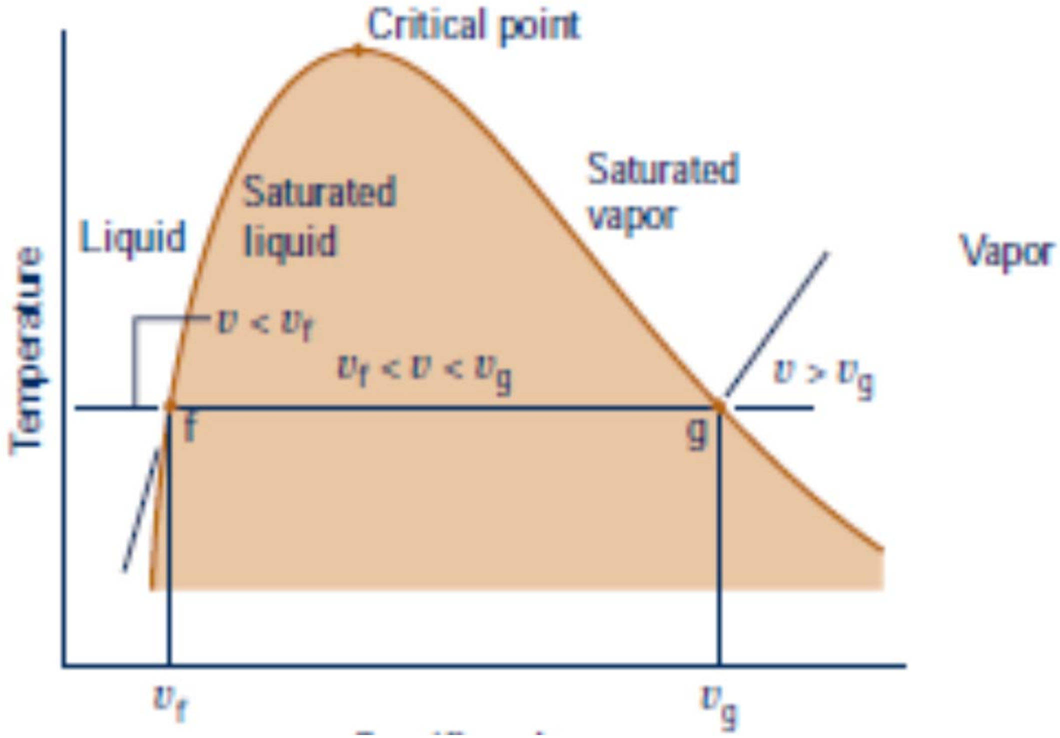

Fig. 3.20: ***Sketch of a T–v diagram for water used to discuss locating states in the tables.***

EXAMPLE 3.1: **Pressure of Saturated Liquid in a Tank**

A rigid tank contains 50 kg of saturated liquid water at 90°C. Determine the pressure in the tank and the volume of the tank.

SOLUTION: A rigid tank contains saturated liquid water. The pressure and volume of the tank are to be determined

Analysis: The state of the saturated liquid water is shown on a *T-v* diagram in Fig. 3.21. Since saturation conditions exist in the tank, the pressure must be the saturation pressure at 90°C:

$P = P_{sat\,@\,90°C} = 70.14\ \mathrm{kPa}$

The specific volume of the saturated liquid at 90°C is

$v = v_{f@90\,C} = 0.001036\ \mathrm{m3/kg}$

Then the total volume of the tank is

$V = mv\ \ (50\ \mathrm{kg})(0.001036\ \mathrm{m3/kg})\ \ 0.0518\ \mathrm{m_3}$

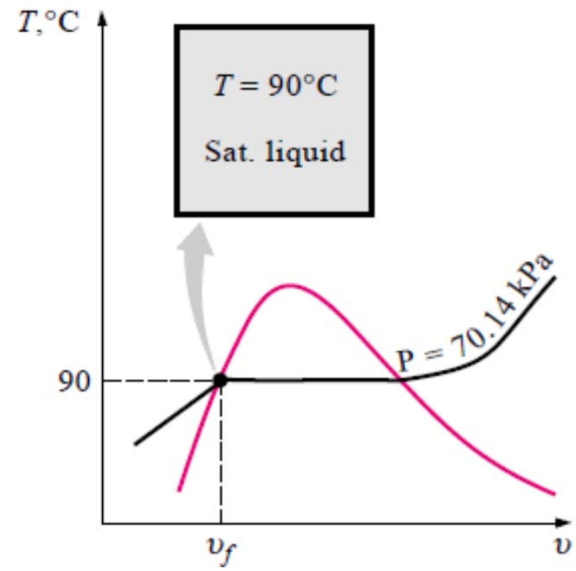

Fig. 3.21: *Schematic and T-v diagram for Example 3.1.*

Latent Heat

- **Latent heat**: The amount of energy absorbed or released during a phase-change process.
- **Latent heat of fusion**: The amount of energy absorbed during melting. It is equivalent to the amount of energy released during freezing.
- **Latent heat of vaporization:** The amount of energy absorbed during vaporization and it is equivalent to the energy released during condensation.
  - *At 1 atm pressure, the latent heat of fusion of water is 333.7 kJ/kg and the latent heat of vaporization is 2256.5 kJ/kg.*

EXAMPLE 3.2: **Volume and Energy Change during Evaporation**

A mass of 200 g of saturated liquid water is completely vaporized at a constant pressure of 100 kPa. Determine (*a*) the volume change and (*b*) the amount of energy added to the water.

SOLUTION: Saturated liquid water is vaporized at constant pressure. The volume change and the energy added are to be determined.

Analysis: (*a*) The process described is illustrated on a *P*-*v* diagram in Fig. 3.21. The volume change per unit mass during a vaporization process is v_{fg}, which is the difference between v_g and v_f.

Reading these values from Saturated water-Pressure Table at 100 kPa.

$$v_{fg} = v_g - v_g = 1.6940 - 0.001043 = 1.6930 \text{ m3/kg}$$

Thus,

$$V = m\, v_{fg} = (0.2 \text{ kg})(1.6930 \text{ m3/kg}) = \mathbf{0.3386\ m3}$$

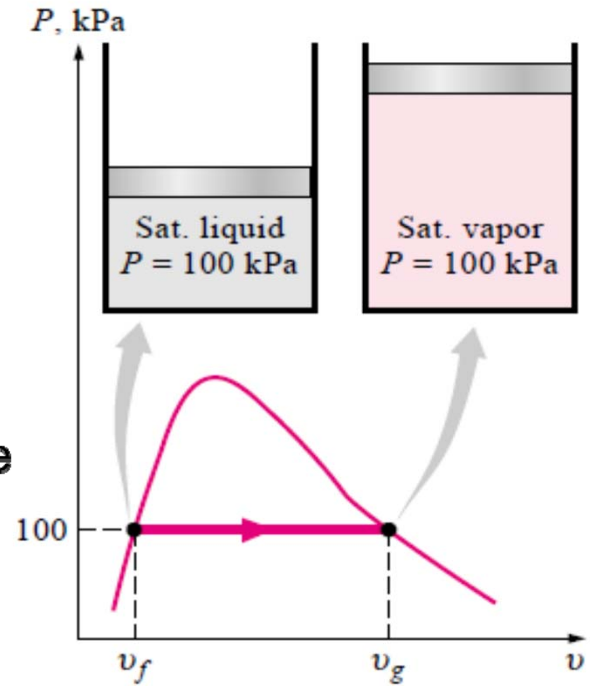

Fig. 3.22: *Schematic and P-v diagram*

(*b*) The amount of energy needed to vaporize a unit mass of a substance at a given pressure is the enthalpy of vaporization at that pressure, which is $h_{fg} = 2258.0$ kJ/kg for water at 100 kPa.

Thus, the amount of energy added is
mh_{fg} = $(0.2kg)(2258)$ kJ/kg = **451.6 kJ**

Saturated Liquid–Vapor Mixture

- During a vaporization process, a substance exists as part liquid and part vapor. That is, it is a mixture of saturated liquid and saturated vapor (Fig. 3.23).
- To analyze this mixture properly, we need to know the proportions of the liquid and vapor phases in the mixture.
- This is done by defining a new property called the *quality x* as the ratio of the mass of vapor to the total mass of the mixture:
- The quality is zero for the saturated liquid and one for the saturated vapor ($0 \leq x \leq 1$)
- For example, if the mass of vapor is 0.2 g and the mass of the liquid is 0.8 g, then the quality is 0.2 or 20%.

$$x = \frac{mass_{saturated\ vapor}}{mass_{total}} = \frac{m_g}{m_f + m_g}$$

Quality

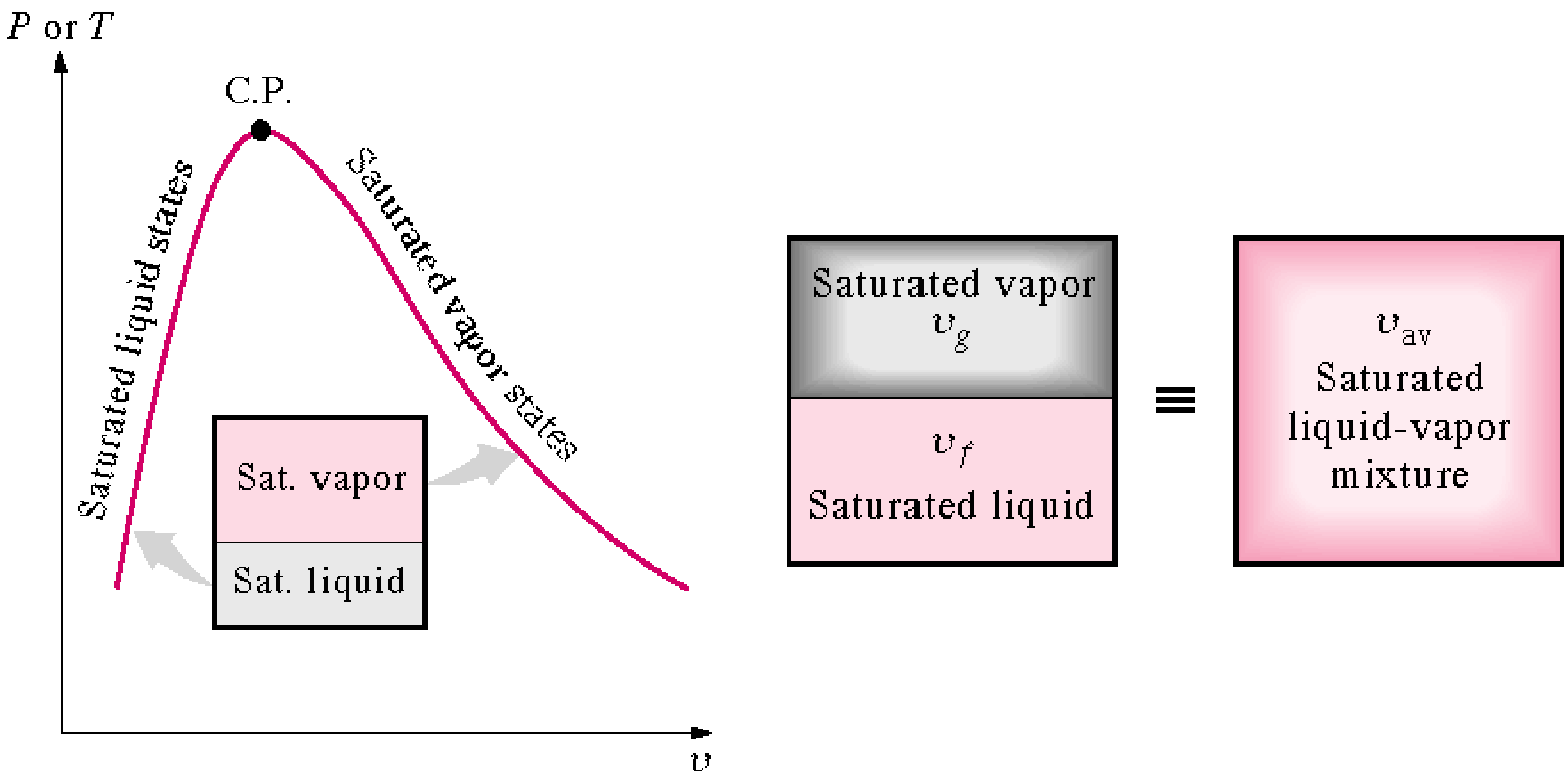

Fig. 3.23: *Mixture of liquid and vapor*

Moisture Content

- The *moisture content* of a substance is the opposite of its quality. Moisture is defined as the ratio of the mass of the liquid to the total mass of both liquid and vapor
- Recall the definition of quality x

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

- Then

$$\frac{m_f}{m} = \frac{m - m_g}{m} = 1 - x$$

Moisture Content

- Take specific volume as an example. The specific volume of the saturated mixture becomes

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

- The form that is most often used

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

- Let Y be any extensive property and let y be the corresponding intensive property, Y/m, then

$$y = \frac{Y}{m} = y_f + x(y_g - y_f)$$

$$= y_f + x\,y_{fg}$$

$$where \quad y_{fg} = y_g - y_f$$

Retrieving *u* and *h* values

- The property tables having pressure, specific volume, and temperature also provide values of specific internal energy u, enthalpy h, and entropy s.
- Data for specific internal energy u and enthalpy h are retrieved from the property tables in the same way as for specific volume. For saturation states, the values of u_f and u_g, as well as h_f and h_g, are tabulated versus both saturation pressure and saturation temperature.
- The specific internal energy for a two-phase liquid–vapor mixture is calculated for a given quality in the same way the specific volume is calculated

$$u = (1 - x)u_f + xu_g = u_f + x(u_g - u_f)$$

Similarly, the specific enthalpy for a two-phase liquid–vapor mixture is given in terms of the quality by

$$h = (1 - x)h_f + xh_g = h_f + x(h_g - h_f)$$

Thank You