Thermodynamics I

Lecture 11

Property Tables (Ch-3)

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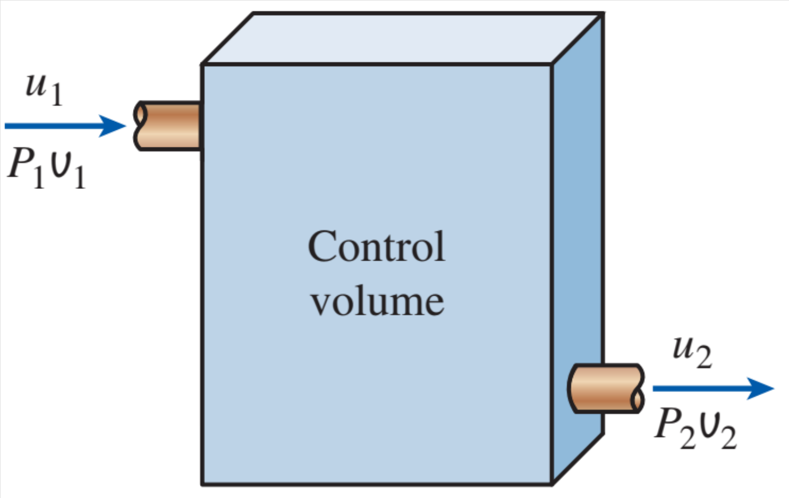
PROPERTY TABLES

- 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.
- Some thermodynamic properties can be measured easily, but others cannot and are calculated by using the relations between them and measurable properties.
- The results of these measurements and calculations are presented in tables in a convenient format.

Enthalpy—A Combination Property

$$h = u + Pv \qquad \text{(kJ/kg)}$$

$$H = U + PV \qquad \text{(kJ)}$$



The combination $u + Pv$ is frequently encountered in the analysis of control volumes.

$$\text{kPa} \cdot \text{m}^3 \equiv \text{kJ}$$
$$\text{kPa} \cdot \text{m}^3/\text{kg} \equiv \text{kJ/kg}$$
$$\text{bar} \cdot \text{m}^3 \equiv 100 \text{ kJ}$$
$$\text{MPa} \cdot \text{m}^3 \equiv 1000 \text{ kJ}$$
$$\text{psi} \cdot \text{ft}^3 \equiv 0.18505 \text{ Btu}$$

The product *pressure* × *volume* has energy units.

Saturated Liquid and Saturated Vapor States

- **Table A–4**: Saturation properties of water under temperature.
- **Table A–5**: Saturation properties of water under pressure.

Temp. °C T	Sat. press. kPa P_{sat}	Specific volume m^3/kg Sat. liquid v_f	Sat. vapor v_g
85	57.868	0.001032	2.8261
90	70.183	0.001036	2.3593
95	84.609	0.001040	1.9808

Temperature

Corresponding saturation pressure

Specific volume of saturated liquid

Specific volume of saturated vapor

v_f = specific volume of saturated liquid

v_g = specific volume of saturated vapor

v_{fg} = difference between v_g and v_f (that is, $v_{fg} = v_g - v_f$)

Enthalpy of vaporization, h_{fg} **(Latent heat of vaporization):** The amount of energy needed to vaporize a unit mass of saturated liquid at a given temperature or pressure.

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.

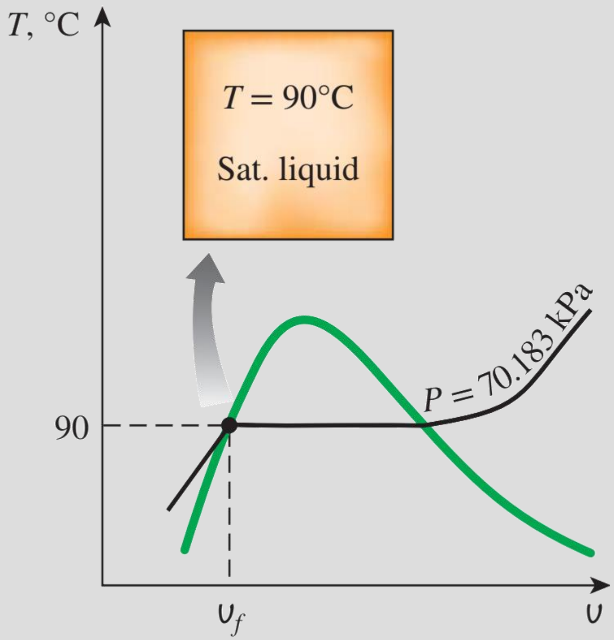
$$P = P_{\text{sat @ 90°C}} = \mathbf{70.183\ kPa}$$

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

$$v = v_{f\text{ @ 90°C}} = 0.001036\ \text{m}^3/\text{kg}$$

Then the total volume of the tank becomes

$$V = mv = (50\ \text{kg})(0.001036\ \text{m}^3/\text{kg}) = \mathbf{0.0518\ m^3}$$

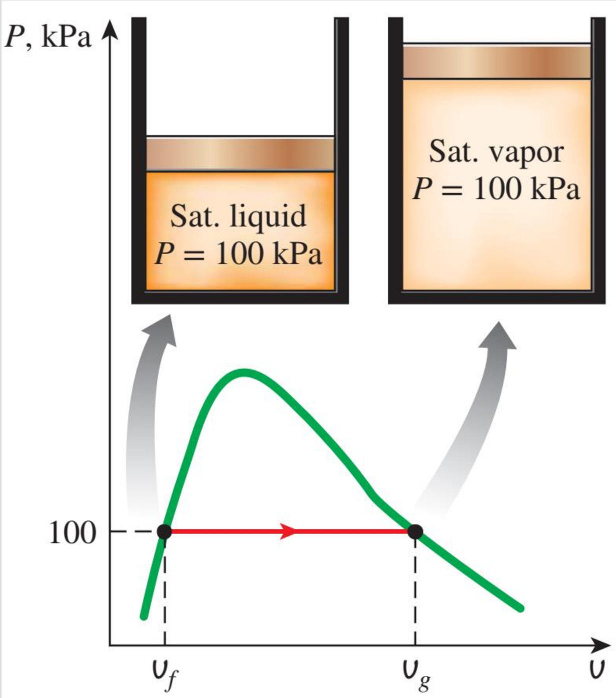


EXAMPLE 3–3 Volume and Energy Change during Evaporation

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 transferred to the water.

The volume change per unit mass during a vaporization process is v_{fg}

$$\upsilon_{fg} = \upsilon_g - \upsilon_f = 1.6941 - 0.001043 = 1.6931\ \mathrm{m^3/kg}$$



Thus,

$$\Delta V = m\upsilon_{fg} = (0.2\ \mathrm{kg})(1.6931\ \mathrm{m^3/kg}) = \mathbf{0.3386\ m^3}$$

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} = 2257.5 kJ/kg for water at 100 kPa.

$$mh_{fg} = (0.2\ \mathrm{kg})(22575.5\ \mathrm{kJ/kg}) = \mathbf{451.5\ kJ}$$

Saturated Liquid–Vapor Mixture

Quality, *x* : The ratio of the mass of vapor to the total mass of the mixture.

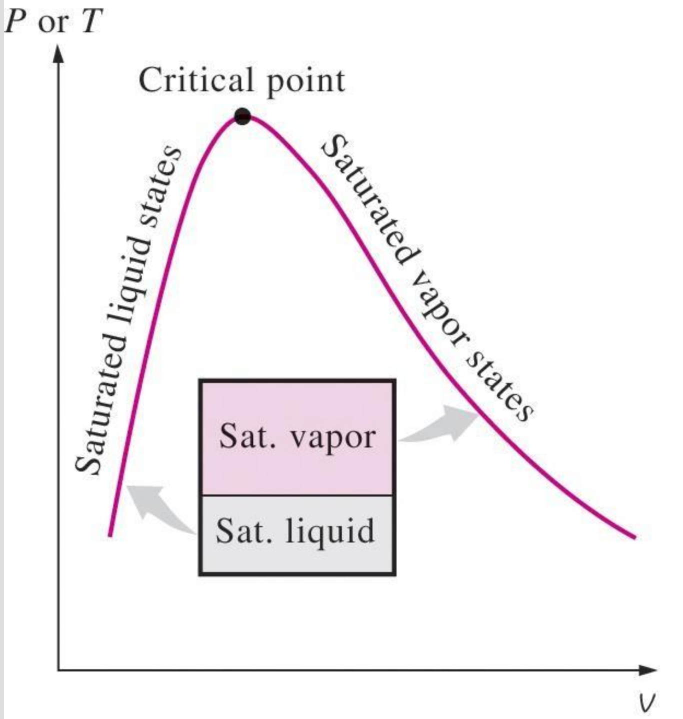
Quality is between 0 and 1 → 0: sat. liquid, 1: sat. vapor.

The properties of the saturated liquid are the same whether it exists alone or in a mixture with saturated vapor.

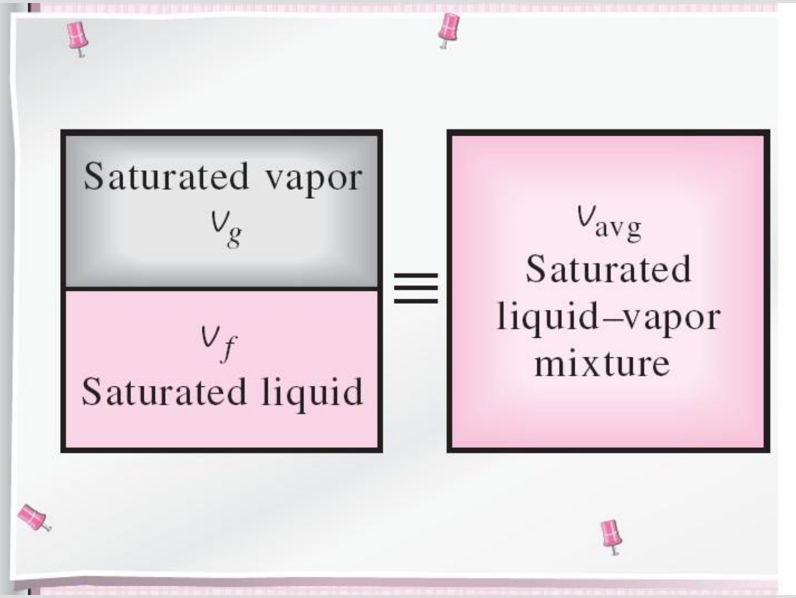
$$x = \frac{m_{\text{vapor}}}{m_{\text{total}}}$$

$$m_{\text{total}} = m_{\text{liquid}} + m_{\text{vapor}} = m_f + m_g$$

Temperature and pressure are dependent properties for a mixture.



The relative amounts of liquid and vapor phases in a saturated mixture are specified by the ***quality x***.



A two-phase system can be treated as a homogeneous mixture for convenience.

Saturated Liquid–Vapor Mixture

$$V = V_f + V_g$$

$$V = m\upsilon \longrightarrow m_t\upsilon_{\text{avg}} = m_f\upsilon_f + m_g\upsilon_g$$

$$m_f = m_t - m_g \longrightarrow m_t\upsilon_{\text{avg}} = (m_t - m_g)\upsilon_f + m_g\upsilon_g$$

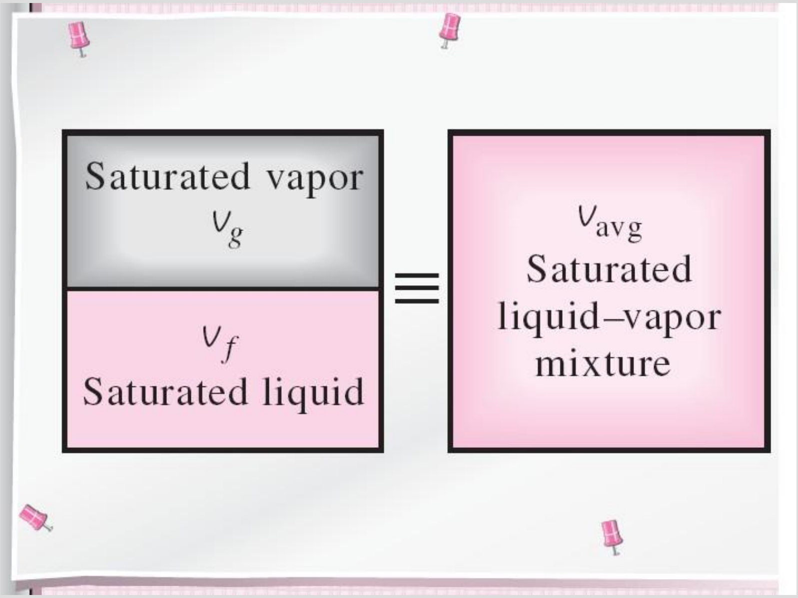
Dividing by m_t yields $\quad x = m_g/m_t$

$$\boxed{\upsilon_{\text{avg}} = (1 - x)\upsilon_f + x\upsilon_g}$$

$$\upsilon_{fg} = \upsilon_g - \upsilon_f$$

$$\upsilon_{\text{avg}} = \upsilon_f + x\upsilon_{fg} \qquad (\text{m}^3/\text{kg})$$

$$x = \frac{\upsilon_{\text{avg}} - \upsilon_f}{\upsilon_{fg}}$$



A two-phase system can be treated as a homogeneous mixture for convenience.

$$\upsilon_{avg} = \upsilon_f + x\upsilon_{fg} \qquad (\text{m}^3/\text{kg}) \qquad x = \frac{\upsilon_{avg} - \upsilon_f}{\upsilon_{fg}}$$

$$x = m_g/m_t$$

$$u_{avg} = u_f + xu_{fg} \qquad (\text{kJ/kg})$$

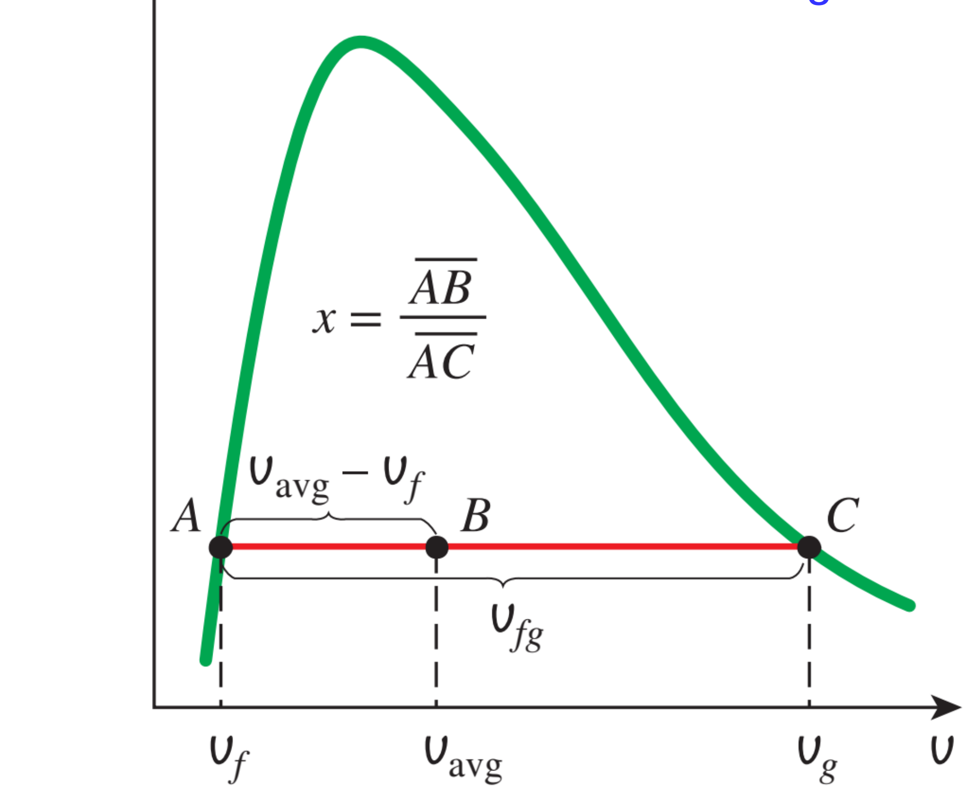
$$h_{avg} = h_f + xh_{fg} \qquad (\text{kJ/kg})$$

y → *v*, *u*, or *h*.

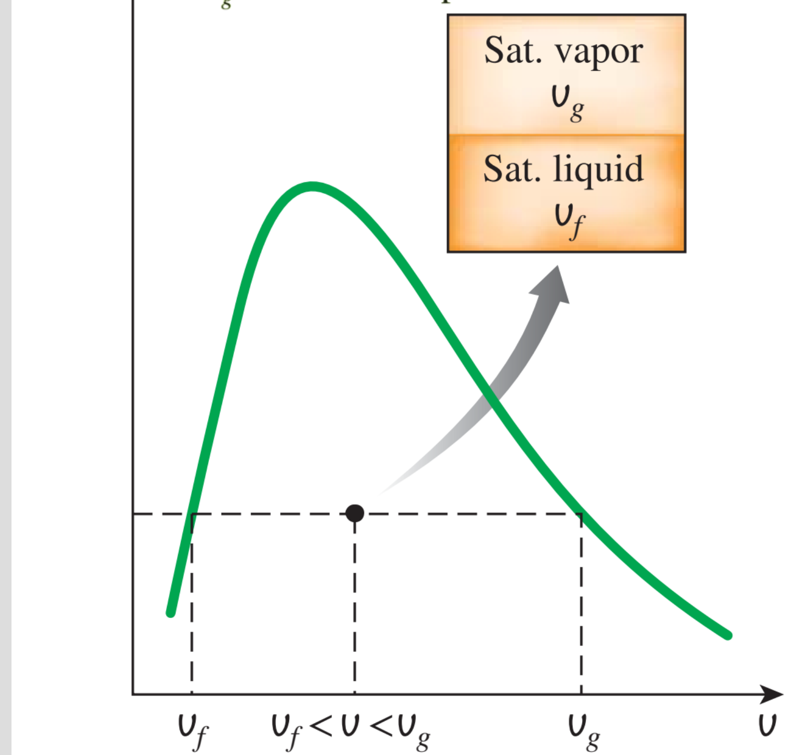
$$y_{avg} = y_f + xy_{fg}$$

$$y_f \le y_{avg} \le y_g$$

Quality is related to the horizontal distances on *P*-*v* and *T*-*v* diagrams.

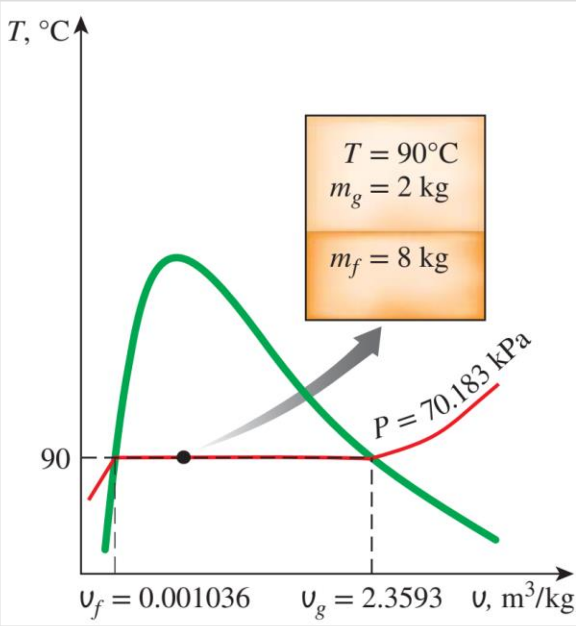


The υ value of a saturated liquid–vapor mixture lies between the υ_f and υ_g values at the specified *T* or *P*.



EXAMPLE 3–4 Pressure and Volume of a Saturated Mixture

A rigid tank contains 10 kg of water at 90°C. If 8 kg of the water is in the liquid form and the rest is in the vapor form, determine (*a*) the pressure in the tank and (*b*) the volume of the tank.



Analysis (*a*) The state of the saturated liquid–vapor mixture is shown in Fig. 3–35. Since the two phases coexist in equilibrium, we have a saturated mixture, and the pressure must be the saturation pressure at the given temperature:

$$P = P_{\text{sat @ 90°C}} = \mathbf{70.183\ kPa} \qquad \text{(Table A–4)}$$

(*b*) At 90°C, we have $\upsilon_f = 0.001036\ \text{m}^3/\text{kg}$ and $\upsilon_g = 2.3593\ \text{m}^3/\text{kg}$ (Table A–4). One way of finding the volume of the tank is to determine the volume occupied by each phase and then add them:

$$\begin{aligned} V &= V_f + V_g = m_f\upsilon_f + m_g\upsilon_g \\ &= (8\ \text{kg})(0.001036\ \text{m}^3/\text{kg}) + (2\ \text{kg})(2.3593\ \text{m}^3/\text{kg}) \\ &= \mathbf{4.73\ m^3} \end{aligned}$$

$$\boxed{x = \frac{m_g}{m_t} = \frac{2\ \text{kg}}{10\ \text{kg}} = 0.2}$$

$$\downarrow$$

$$\boxed{\upsilon = \upsilon_f + x\upsilon_{fg}}$$

$$\downarrow$$

$$\boxed{V = m\upsilon}$$

EXAMPLE 3–5 **Properties of Saturated Liquid–Vapor Mixture**

An 80-L vessel contains 4 kg of refrigerant-134a at a pressure of 160 kPa. Determine (*a*) the temperature, (*b*) the quality, (*c*) the enthalpy of the refrigerant, and (*d*) the volume occupied by the vapor phase.

$$v = \frac{V}{m} = \frac{0.080 \text{ m}^3}{4 \text{ kg}} = 0.02 \text{ m}^3/\text{kg}$$

At 160 kPa, we read

$$v_f = 0.0007435 \text{ m}^3/\text{kg}$$
$$v_g = 0.12355 \text{ m}^3/\text{kg} \qquad \text{(Table A–12)}$$

Obviously, $v_f < v < v_g$, and the refrigerant is in the saturated mixture region. Thus, the temperature must be the saturation temperature at the specified pressure:

$$T = T_{\text{sat @ 160 kPa}} = \mathbf{-15.60°C}$$

Quality can be determined from

$$x = \frac{v - v_f}{v_{fg}} = \frac{0.02 - 0.0007435}{0.12355 - 0.0007435} = \mathbf{0.157}$$

(*c*) At 160 kPa, we also read from Table A–12 that $h_f = 31.18$ kJ/kg and $h_{fg} = 209.96$ kJ/kg. Then,

$$\begin{aligned} h &= h_f + x h_{fg} \\ &= 31.18\ \text{kJ/kg} + (0.157)(209.96\ \text{kJ/kg}) \\ &= \mathbf{64.1\ kJ/kg} \end{aligned}$$

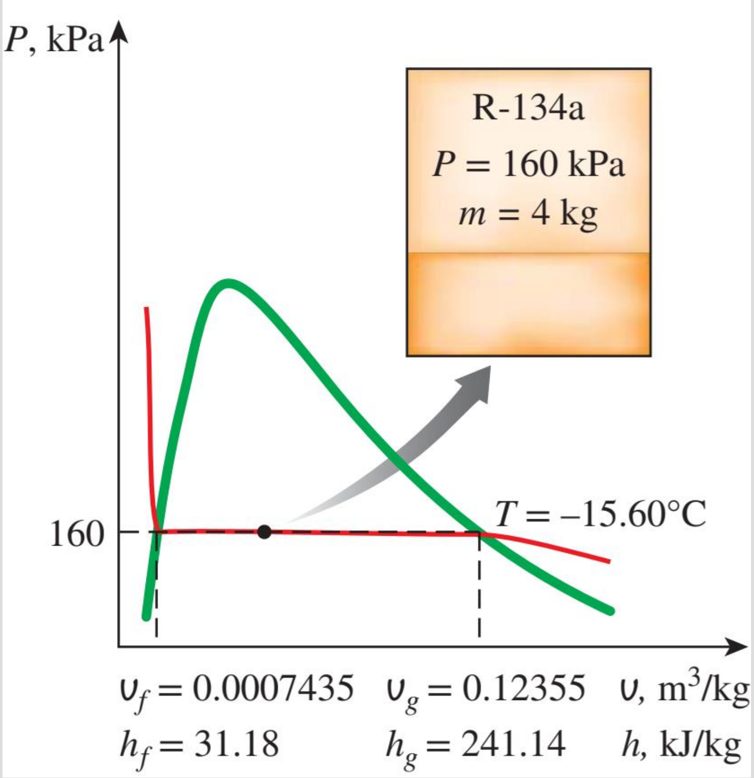
(*d*) The mass of the vapor is

$$m_g = x m_t = (0.157)(4\ \text{kg}) = 0.628\ \text{kg}$$

and the volume occupied by the vapor phase is

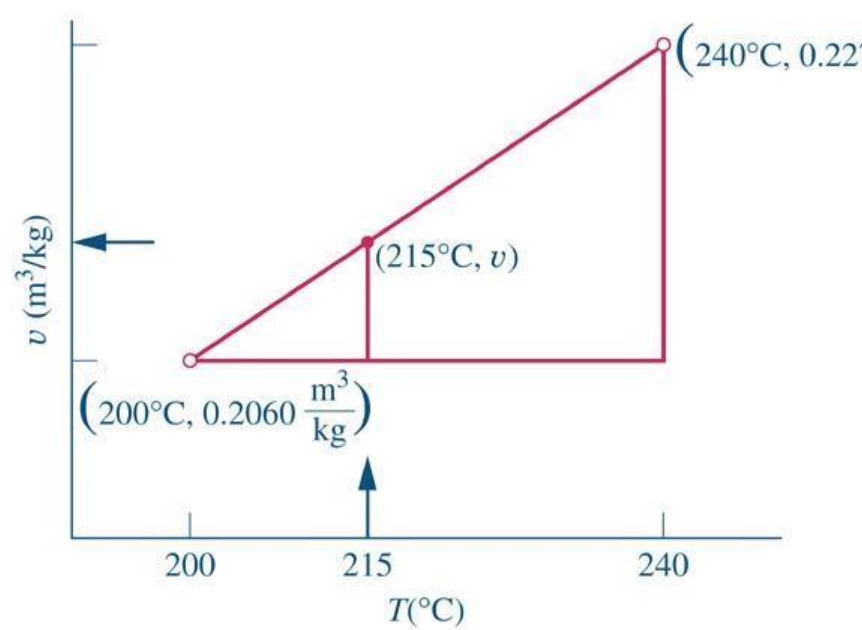
$$V_g = m_g v_g = (0.628\ \text{kg})(0.12355\ \text{m}^3/\text{kg}) = \mathbf{0.0776\ m^3}\ (\text{or } 77.6\ \text{L})$$

The rest of the volume (2.4 L) is occupied by the liquid.



Practice Example

What is the *v* at 10.0 bar (maintained in a tank) and T = 215 °C



p = 10 bar	
T(°C)	v (m^3/kg)
200	**0.2060**
215	v = ?
240	**0.2275**

Interpolation:

$$slope = \frac{(0.2275 - 0.2060)\ \mathrm{m^3/kg}}{(240 - 200)^\circ\mathrm{C}} = \frac{(v - 0.2060)\ \mathrm{m^3/kg}}{(215 - 200)^\circ\mathrm{C}}$$

Solving for v, the result is $v = 0.2141\ \mathrm{m^3/kg}$.