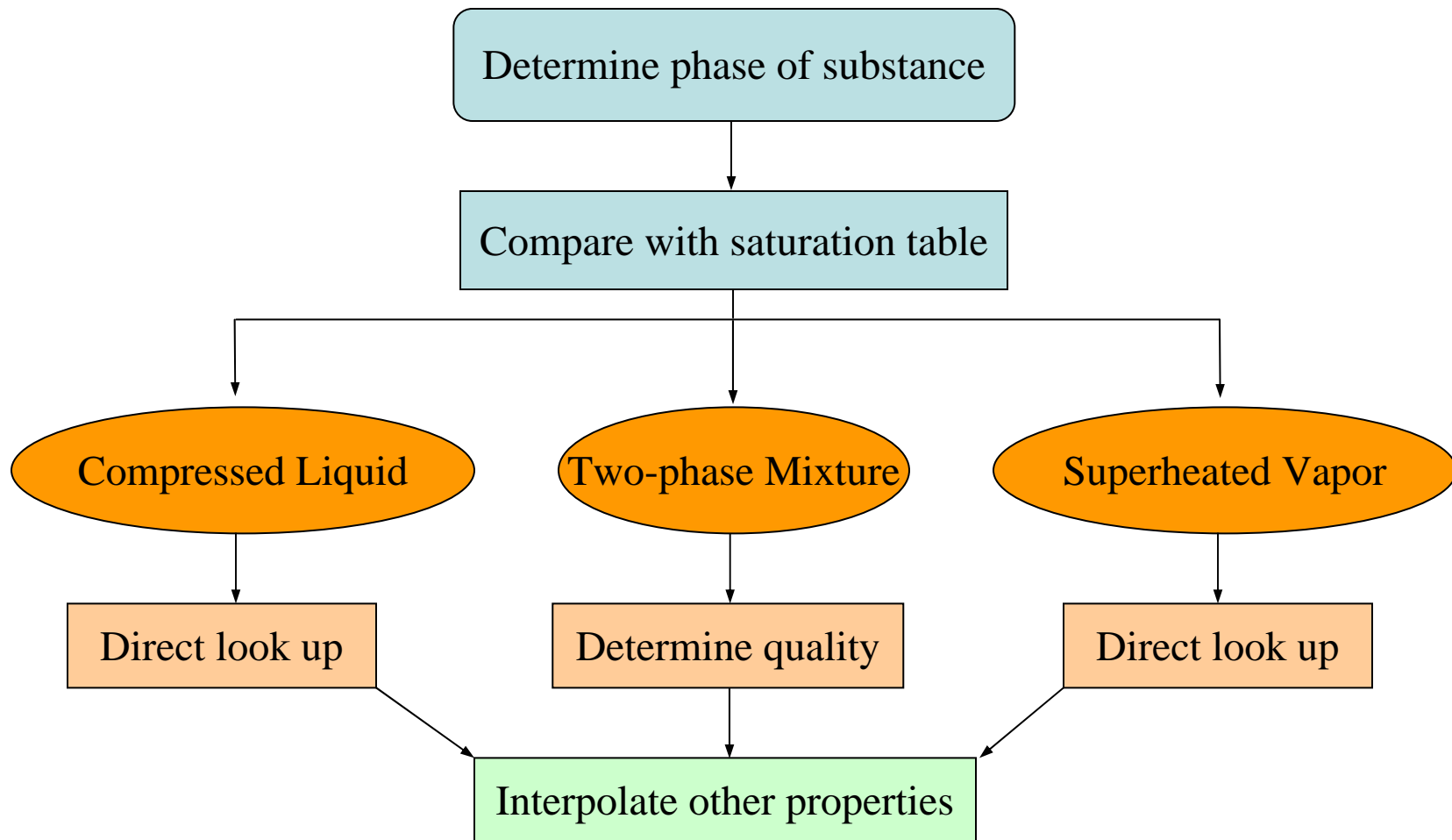


We will cover,

- ***Phase Diagrams***
- ***Enthalpy***
- ***Specific Heat Constant***
- ***Incompressible Fluid***
- ***Compressed Liquid (subcooled)***
- ***Molar Base and Universal Gas Constant***
- ***Critical State and Reduced Coordinate***
- ***Compressibility***

Flow Chart



For a processes conducted at constant pressure ($dP=0$), balance of energy is:

$$dE = \delta Q - \delta W$$

$$dE = \delta Q - p dV \quad \text{considering only P - V work}$$

$$\int_1^2 dE = \int_1^2 dQ - p \int_1^2 dV$$

$$E_2 - E_1 = Q_p - p(V_2 - V_1)$$

$$(E_2 + PV_2) - (E_1 + PV_1) = Q_p$$

Since E , P , and V are state variables, $(E + PV)$ must also be a state variable.

Define *Enthalpy* (H): $H \equiv E + PV$

$$H_2 - H_1 = Q_p$$

$\Delta H = Q_p$ The enthalpy change of the system is equal to the heat absorbed at constant pressure. Thus, ΔH is often referred to as the "heat of reaction."

$$h = \frac{H}{m}, \quad h = e + Pv = u + Pv \quad \text{and} \quad h = (1 - x) h_f + x h_g$$

Specific Heat Constants

energy required to raise the temperature of a system by one degree (at constant pressure or constant volume).

$$c_v = \left(\frac{\partial u}{\partial T} \right)_v$$

$$c_p = \left(\frac{\partial h}{\partial T} \right)_p$$

Specific Heat Ratio

$$k = \frac{c_p}{c_v}$$

Incompressible Flow

When density is assumed to be constant throughout a process the process is called “incompressible” and the fluid is called “incompressible fluid.”

$$h(T, P) = u(T) + Pv$$

$$\left(\frac{\partial h}{\partial T} \right)_p = \left(\frac{\partial u}{\partial T} \right)_v \rightarrow c_p = c_v = c$$

$$c_v = \left(\frac{\partial u}{\partial T} \right)_v \rightarrow du = cdT \rightarrow u_2 - u_1 = \int_{T_1}^{T_2} cdT$$

$$h_2 - h_1 = \int_{T_1}^{T_2} cdT + P(v_2 - v_1)$$

Compressed Liquid Approximation

- If the substance is a compressed (subcooled) liquid and the compressed liquid table is unavailable or inadequate, you may invoke the compressed liquid approximation:

$$u(T, P) \cong u_f(T)$$

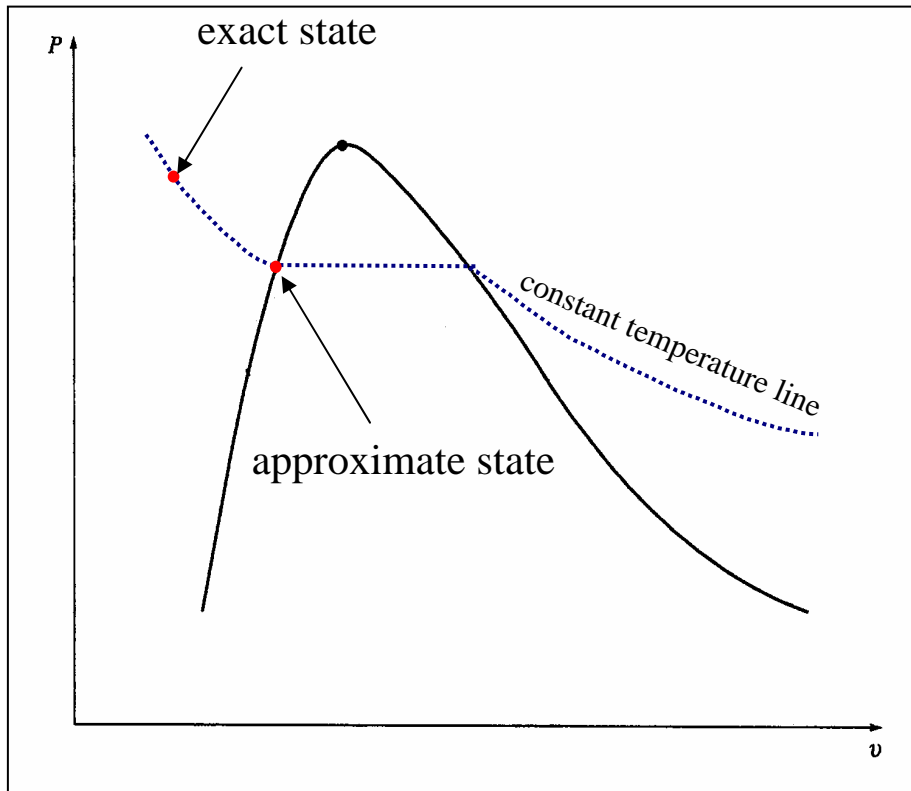
$$v(T, P) \cong v_f(T) \quad (\text{weak function of } P)$$

$$h(T, P) \cong u_f(T) + Pv_f(T) = h_f(T) + [P - P_{sat}(T)]v_f(T)$$

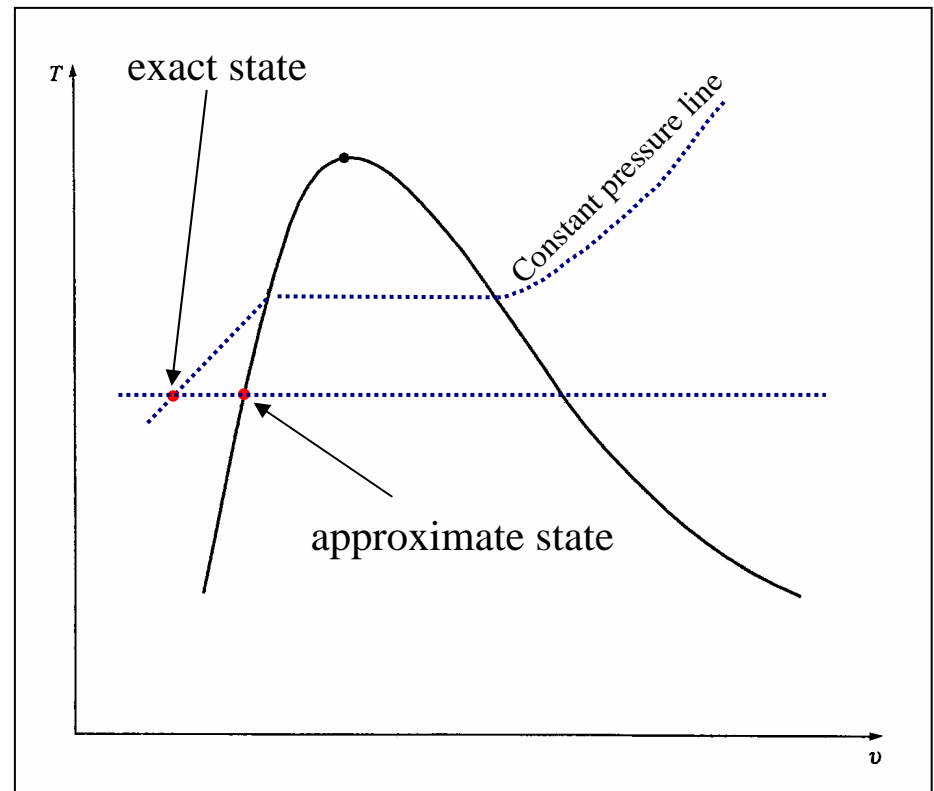
- It can be interpreted as weak dependency of most properties on pressure in the compressed liquid region.
- Hence, most properties can be simply approximated by their saturated liquid values at the specified temperature, except specific enthalpy.

Interpretation of Compressed Liquid Approximation

P - v diagram



T - v diagram



Compressed Liquid Approximation

- However, the compressed liquid approximation for enthalpy is exceptional. It is due to the intrinsic definition of enthalpy being explicitly dependent on pressure:

$$h = u + Pv$$

- It is incorrect to neglect the pressure variation in enthalpy evaluation. Hence,

$$h(T, P) = u(T, P) + Pv(T, P)$$

$$\cong u_f(T) + Pv_f(T)$$

$$= \underbrace{u_f(T) + P_{sat}(T)v_f(T)}_{h_f(T)} + Pv_f(T) - P_{sat}(T)v_f(T)$$

$$= h_f(T) + (P - P_{sat}(T))v_f(T)$$

Molar Base and Universal Gas Constant

If molecular weight of a substance is M

$$\bar{v} = Mv$$

\bar{v} is molar specific volume

$$\bar{u} = Mu, \bar{h} = Mh, \bar{c}_p = Mc_p$$

Universal Gas Constant

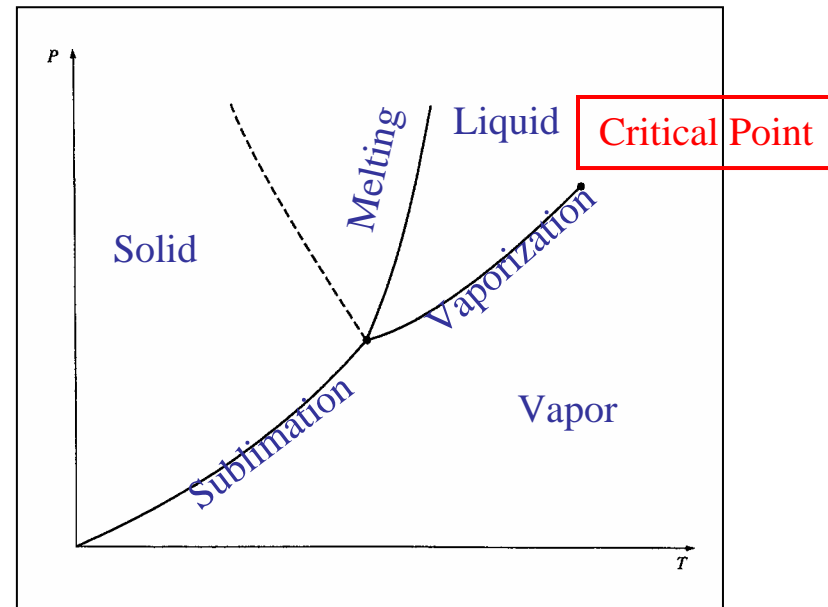
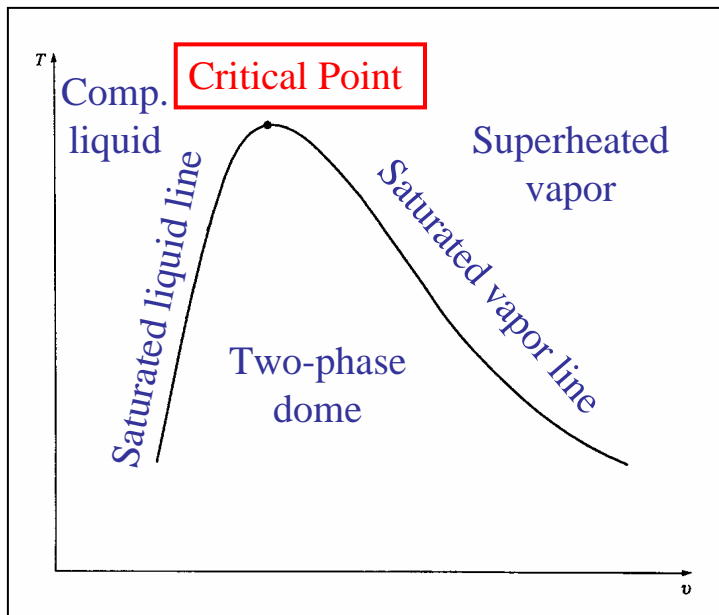
$$\bar{R} = M.R = 8.314 \frac{\text{kJ}}{\text{kmol.K}}$$

R is called “Gas Constant” which is tabulated for different fluids.

Critical State and Reduced Coordinate

The critical temperature is the maximum temperature at which liquid and vapor phases can coexist in equilibrium.

- Recall the phase diagrams of a general substance:



- Based on the thermodynamic properties associated with the critical point, a non-dimensional reduced coordinate can be defined for each substance:

$$\text{reduced pressure: } P_R = \frac{P}{P_{cr}} \quad , \quad \text{reduced temperature: } T_R = \frac{T}{T_{cr}}$$

Compressibility Chart

Compressibility Factor:

$$Z = \frac{Pv}{RT} = \frac{P\bar{v}}{\bar{R}T}$$

Ideal Gas:

$$Z = 1$$

Good for:

- low pressure
- high temperature

