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

Determine phase of substance

Compare with saturation table

Compressed Liquid
  Direct look up

Two-phase Mixture
  Determine quality

Superheated Vapor
  Direct look up

Interpolate other properties
For a processes conducted at constant pressure \((dP=0)\), balance of energy is:

\[
dE = \delta Q - \delta W
\]

\[
dE = \delta Q - pdV \quad \text{considering only } P - V \text{ work}
\]

\[
\int_1^2 dE = \int_1^2 dQ - p\int_1^2 dV
\]

\[
E_2 - E_1 = Q_p - p(V_2 - V_1)
\]

\[
(E_2 + PV_2) - (E_1 + PV_1) = Q_p
\]

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, \(\Delta H\) is often referred to as the "heat of reaction."

\[
h = \frac{H}{m}, \quad h = e + P v = u + P v \quad \text{and} \quad h = (1 - x) h_f + x h_g
\]
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

\[ k = \frac{c_p}{c_v} \]
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:

\[ u(T, P) \approx u_f(T) \]

\[ v(T, P) \approx v_f(T) \quad \text{(weak function of } T) \]

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

- 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**

- *exact state*
- *approximate state*
- *constant temperature line*

**T-v diagram**

- *exact state*
- *approximate state*
- *Constant pressure line*
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,

\[
h(T, P) = u(T, P) + Pv(T, P) \\
\approx u_f(T) + P v_f(T) \\
= u_f(T) + P_{sats}(T)v_f(T) + P v_f(T) - P_{sats}(T)v_f(T) \\
= h_f(T) + (P - P_{sats}(T))v_f(T)
\]
Molar Base and Universal Gas Constant

If molecular weight of a substance is $M$

$$
\bar{v} = M \nu
$$

$\bar{v}$ is molar specific volume

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

Universal Gas Constant

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

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

![Phase Diagram](image)

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

\[
P_R = \frac{P}{P_{cr}}, \quad T_R = \frac{T}{T_{cr}}
\]
Compressibility Chart

Compressibility Factor:

\[ Z = \frac{P \nu}{RT} = \frac{P \bar{\nu}}{R \bar{T}} \]

Ideal Gas:

\[ Z = 1 \]

Good for:

- low pressure
- high temperature

(Taken from Figure 3-56 in Cengel & Turner)