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



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

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

$$dE = \delta Q - pdV \text{ considering only P-V work}$$

$$\int_{1}^{2} dE = \int_{1}^{2} dQ - p \int_{1}^{2} dV$$

$$E_{2} - E_{1} = Q_{p} - p(V_{2} - V_{2})$$

$$(E_{2} + PV_{2}) - (E_{1} + PV_{1}) = Q_{p}$$

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."

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

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."

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

$$\left(\frac{\partial h}{\partial T}\right)_{p} = \left(\frac{\partial u}{\partial T}\right)_{v} \rightarrow c_{p} = c_{v} = c$$
$$c_{v} = \left(\frac{\partial u}{\partial T}\right)_{v} \rightarrow du = cdT \rightarrow u_{2} - u_{1} = \int_{T_{1}}^{T_{2}} cdT$$
$$h_{2} - h_{1} = \int_{T_{1}}^{T_{2}} cdT + P(v_{2} - v_{1})$$

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

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

 $v(T, P) \cong v_f(T)$ (weak function of T)

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

- It can be interpreted as <u>weak dependency</u> 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.



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

$$h = u + Pv$$

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

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

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

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

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

If molecular weight of a substance is M

$$\overline{v} = Mv$$

 \overline{v} is molar specific volume

$$\overline{u} = Mu, \overline{h} = Mh, \overline{c}_{p} = Mc_{p}$$

Universal Gas Constant

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

R is called "Gas Constant" which is tabulated for different fluids.

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

• Recall the phase diagrams of a general substance:



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

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

