

THERMODYNAMICS

PROPERTIES OF SINGLE-COMPONENT SYSTEMS

Nomenclature

1. Intensive properties are independent of mass.
2. Extensive properties are proportional to mass.
3. Specific properties are lowercase (extensive/mass).

State Functions (properties)

Absolute Pressure, P (lb/in² or Pa)

Absolute Temperature, T (°R or K)

Volume, V (ft³ or m³)

Specific Volume, $v = V/m$ (ft³/lbm or m³/kg)

Internal Energy, U (Btu or kJ)

Specific Internal Energy, $u = U/m$ (usually in Btu/lbm or kJ/kg)

Enthalpy, H (Btu or kJ)

Specific Enthalpy, $h = u + Pv = H/m$ (usually in Btu/lbm or kJ/kg)

Entropy, S (Btu/°R or kJ/K)

Specific Entropy, $s = S/m$ [Btu/(lbm·°R) or kJ/(kg·K)]

Gibbs Free Energy, $g = h - Ts$ (usually in Btu/lbm or kJ/kg)

Helmholtz Free Energy, $a = u - Ts$ (usually in Btu/lbm or kJ/kg)

Heat Capacity at Constant Pressure, $c_p = \left(\frac{\partial h}{\partial T}\right)_p$

Heat Capacity at Constant Volume, $c_v = \left(\frac{\partial u}{\partial T}\right)_v$

Quality x (applies to liquid-vapor systems at saturation) is defined as the mass fraction of the vapor phase:

$$x = m_g / (m_g + m_f), \text{ where}$$

m_g = mass of vapor, and

m_f = mass of liquid.

Specific volume of a two-phase system can be written:

$$v = xv_g + (1 - x)v_f \text{ or } v = v_f + xv_{fg} \text{ where}$$

v_f = specific volume of saturated liquid,

v_g = specific volume of saturated vapor, and

$$v_{fg} = \text{specific volume change upon vaporization,} \\ = v_g - v_f$$

Similar expressions exist for u , h , and s :

$$u = xu_g + (1 - x)u_f \text{ or } u = u_f + xu_{fg}$$

$$h = xh_g + (1 - x)h_f \text{ or } h = h_f + xh_{fg}$$

$$s = xs_g + (1 - x)s_f \text{ or } s = s_f + xs_{fg}$$

For a simple substance, specification of any two intensive, independent properties is sufficient to fix all the rest.

For an ideal gas, $Pv = RT$ or $PV = mRT$, and

$$P_1 v_1 / T_1 = P_2 v_2 / T_2, \text{ where}$$

P = pressure,

v = specific volume,

m = mass of gas,

R = gas constant, and

T = absolute temperature.

V = volume

R is specific to each gas but can be found from

$$R = \frac{\bar{R}}{(\text{mol. wt})}, \text{ where}$$

$\bar{R}$ = the universal gas constant

$$= 1,545 \text{ ft-lbf/(lbmol}\cdot^\circ\text{R)} = 8,314 \text{ J/(kmol}\cdot\text{K)}.$$

For ideal gases, $c_p - c_v = R$

Also, for ideal gases:

$$\left(\frac{\partial h}{\partial P}\right)_T = 0 \quad \left(\frac{\partial u}{\partial v}\right)_T = 0$$

For cold air standard, heat capacities are assumed to be constant at their room temperature values. In that case, the following are true:

$$\Delta u = c_v \Delta T, \quad \Delta h = c_p \Delta T$$

$$\Delta s = c_p \ln (T_2/T_1) - R \ln (P_2/P_1); \text{ and}$$

$$\Delta s = c_v \ln (T_2/T_1) + R \ln (v_2/v_1).$$

For heat capacities that are temperature dependent, the value to be used in the above equations for Δh is known as the mean heat capacity ($\bar{c}_p$) and is given by

$$\bar{c}_p = \frac{\int_{T_1}^{T_2} c_p dT}{T_2 - T_1}$$

Also, for constant entropy processes:

$$\frac{P_2}{P_1} = \left(\frac{v_1}{v_2}\right)^k; \quad \frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{1}{k-1}}$$

$$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{k-1}, \text{ where } k = c_p/c_v$$

For real gases, several equations of state are available; one such equation is the van der Waals equation with constants based on the critical point:

$$\left(P + \frac{a}{v^2}\right)(\bar{v} - b) = RT$$

$$\text{where } a = \left(\frac{27}{64}\right)\left(\frac{R^2 T_c^2}{P_c}\right), \quad b = \frac{RT_c}{8P_c}$$

where P_c and T_c are the pressure and temperature at the critical point, respectively, and $\bar{v}$ is the molar specific volume.

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Kathleen E. Murphy



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