

Thermodynamics Cheat Sheet

Ideal gas · quality · first law · steady flow · entropy · Carnot · cycles

Properties

Ideal gas law

$$P \cdot v = R \cdot T; P \cdot V = m \cdot R \cdot T$$

P absolute pressure (kPa); v specific volume (m³/kg); T absolute temperature (K)

Gas constant of a gas

$$R = R_u / M$$

$R_u = 8.314 \text{ kJ/(kmol}\cdot\text{K)}$; M molar mass (kg/kmol); R (kJ/(kg·K))

Two-phase mixture (quality)

$$x = m_g / m; v = v_f + x \cdot v_{fg}$$

Same form for u, h and s; f liquid, g vapour, fg = g - f

Enthalpy

$$h = u + P \cdot v$$

h, u (kJ/kg); P·v in kPa·m³/kg = kJ/kg

Specific heats (ideal gas)

Internal energy and enthalpy change

$$\Delta u = c_v \cdot \Delta T; \Delta h = c_p \cdot \Delta T$$

c_v , c_p (kJ/(kg·K)); constant specific heats

Relations

$$c_p - c_v = R; k = c_p / c_v$$

k specific heat ratio (1.4 for air near room temperature)

Liquids and solids

$$\Delta u \approx \Delta h \approx c \cdot \Delta T$$

Incompressible substance

Work and the first law

Boundary work

$$W_b = \int P \, dv$$

W (kJ); V volume (m³); work done by the system positive

Constant pressure

$$W_b = P \cdot (V_2 - V_1)$$

P (kPa); V (m³); W (kJ)

Isothermal ideal gas

$$W_b = m \cdot R \cdot T \cdot \ln(V_2/V_1)$$

m (kg); R (kJ/(kg·K)); T absolute (K)

Polytropic, $P \cdot V^n = \text{constant}$

$$W_b = (P_2 V_2 - P_1 V_1) / (1 - n), n \neq 1$$

n polytropic exponent

Closed system

$$Q - W = \Delta U + \Delta KE + \Delta PE$$

Q heat in; W work out (kJ)

Steady-flow device, one inlet and exit

$$q - w = (h_2 - h_1) + (V_2^2 - V_1^2)/2 + g(z_2 - z_1)$$

Per kg of flow (J/kg; divide $V^2/2$ by 1 000 for kJ/kg)

Mass flow rate

$$\dot{m}_{\text{rate}} = \rho \cdot A \cdot V = A \cdot V / v$$

$\dot{m}_{\text{rate}}$ (kg/s); A flow area (m²); V velocity (m/s)

Entropy and the second law

Entropy change (Clausius)

$$\Delta S \geq \int \delta Q / T$$

Equality for a reversible process; S (kJ/K)

Ideal gas entropy change

$$\Delta s = c_p \cdot \ln(T_2/T_1) - R \cdot \ln(P_2/P_1)$$

Constant c_p ; s (kJ/(kg·K))

Isentropic ideal gas

$$T_2/T_1 = (P_2/P_1)^{(k-1)/k}; P \cdot v^k = \text{constant}$$

Reversible and adiabatic, constant specific heats

Isentropic efficiency

$$\text{turbine: } \eta = w_{\text{actual}} / w_s; \text{ compressor: } \eta =$$

$$w_s / w_{\text{actual}}$$

w_s isentropic work (kJ/kg)

Cycles

Thermal efficiency

$$\eta = W_{\text{net}} / Q_H = 1 - Q_L / Q_H$$

Q_H heat in; Q_L heat rejected

Carnot (maximum) efficiency

$$\eta_{\text{max}} = 1 - T_L / T_H$$

T_L , T_H absolute reservoir temperatures (K)

Refrigerator and heat pump

$$\text{COP}_R = Q_L / W; \text{COP}_{\text{HP}} = Q_H / W = \text{COP}_R + 1$$

Carnot: $\text{COP}_R = T_L / (T_H - T_L)$

Pump work (liquid)

$$w_p \approx v \cdot (P_2 - P_1)$$

Rankine cycle; v of saturated liquid (m³/kg)