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Mass:

$$\underbrace{\frac{dm}{dt}}_{\text{Rate of increase of mass}} = \underbrace{\sum_{i} \dot{m}_{i}}_{\text{Mass flow rate}} - \underbrace{\sum_{e} \dot{m}_{e}}_{\text{Mass flow rate}} \begin{bmatrix} \frac{kg}{s} \end{bmatrix}; \quad (1)$$
where, $\dot{m} = \rho AV = \frac{AV}{v} \begin{bmatrix} \frac{kg}{K} \end{bmatrix}$
Energy:
$$\underbrace{\frac{dE}{dt}}_{\text{Rate of increase}} = \underbrace{\sum_{i} \dot{m}_{i} j_{i}}_{\text{Energy transported}} - \underbrace{\sum_{e} \dot{m}_{e} j_{e}}_{\text{Energy transported}} + \underbrace{\dot{Q}}_{\text{Rate of heat}} - \underbrace{\dot{W}_{ext}}_{work transfer into} \begin{bmatrix} kW \end{bmatrix} \quad (2)$$
where, $j = h + ke + pe = h + \frac{V^{2}}{V} + \frac{gz}{V} = \begin{bmatrix} \frac{kJ}{k} \end{bmatrix}$

and
$$\dot{W}_{\text{ext}} = \dot{W}_{\text{sh}} + \dot{W}_{\text{el}} + \dot{W}_{B};$$
 $\dot{W}_{\text{sh}} = 2\pi \frac{N}{60}T;$ $\dot{W}_{\text{el}} = \frac{VI}{1000}$ [kW]
 $W_{B} = \int p d\Psi$ [kJ]; $\dot{W}_{B} = \lim_{\Delta t \to 0} \frac{W_{B}}{\Delta t};$ [kW]

Entropy:

$$\underbrace{\frac{dS}{dt}}_{\text{an open system.}} = \underbrace{\sum_{i} \dot{m}_{i} s_{i}}_{\text{Entropy}} - \underbrace{\sum_{e} \dot{m}_{e} s_{e}}_{\text{Entropy}} + \underbrace{\frac{\dot{Q}}{T_{B}}}_{\text{Entropy}} + \underbrace{\frac{\dot{S}_{\text{gen}}}{T_{B}}}_{\text{Entropy transported by}} \begin{bmatrix} \frac{kW}{K} \end{bmatrix}$$
(3)

where, according to the second law, $\dot{S}_{\text{gen}} \ge 0$

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Closed Steady Systems (Wall, Light bulb, Laptop adapter, Gear box, closed cycles)

Mass Equation: $m = \text{constant}$	(1)
Energy Equation: $0 = \dot{Q} - \dot{W}_{ext}$ [kW] where, $\dot{W}_{ext} = \dot{W}_B + \dot{W}_{sh} + \dot{W}_{el}$	(2)
Entropy Equation: $0 = \frac{\dot{Q}}{T_B} + \dot{S}_{gen} \left[\frac{kW}{K}\right]$; Second law asserts: $\dot{S}_{gen} \ge 0$	(3)

Single-Flow Open-Steady Systems (pumps, turbines, nozzles, valves, pipes, etc.)

Mass:
$$\dot{m}_{e} = \dot{m}_{i} = \dot{m}$$
 $\left[\frac{\mathrm{kg}}{\mathrm{s}}\right]$ (1)
Energy: $\dot{m}j_{e} = \dot{m}j_{i} + \dot{Q} - \dot{W}_{\mathrm{ext}}$ $[\mathrm{kW}]$
where, $j = h + \mathrm{ke} + \mathrm{pe} = h + \frac{V^{2}}{2000} + \frac{gz}{1000}$ $[\mathrm{kJ/\mathrm{kg}}], \quad \dot{W}_{\mathrm{ext}} = \dot{W}_{B} + \dot{W}_{\mathrm{sh}} + \dot{W}_{\mathrm{el}}$ $[\mathrm{kW}]$ (2)
Entropy: $\dot{m}s_{e} = \dot{m}s_{i} + \frac{\dot{Q}}{T_{B}} + \dot{S}_{\mathrm{gen}}$ $\left[\frac{\mathrm{kW}}{\mathrm{K}}\right]$ where, by second law, $\dot{S}_{\mathrm{gen}} \ge 0$ (3)

Closed Processes (Heating water in a tank, piston-cylinder compression)

Mass:
$$m = \text{constant} [kg]$$
 (1)
Energy: $\Delta E = E_f - E_b = Q - W_{\text{ext}}$ or, $m\Delta e = Q - W_{\text{ext}}$ [kJ]
where, $e = u + \text{ke} + \text{pe} = u + \frac{V^2}{2000} + \frac{gz}{1000}$ [kJ/kg]; $W_{\text{ext}} = W_B + W_{\text{sh}} + W_{\text{el}}$ [kJ] (2)
Entropy: $\Delta S = S_f - S_b = Q/T_B + S_{\text{gen}}$ or, $m\Delta s = Q/T_B + S_{\text{gen}}$ [kJ/K] where, $S_{\text{gen}} \ge 0$ (3)

Open Processes (Filling an evacuated tank, filling a propane cylinder, discharge from a tank)

Mass:
$$\Delta m = m_f - m_b = m_i - m_e \quad [kg]$$
 (1)
Energy: $\Delta E = E_f - E_b = m_i j_i - m_e j_e + Q - W_{ext} \quad [kJ]$
where, $e = u + ke + pe = u + \frac{V^2}{2000} + \frac{gz}{1000}, \ j = h + ke + pe = h + \frac{V^2}{2000} + \frac{gz}{1000} \quad [kJ/kg]$ (2)
and $W_{ext} = W_B + W_{sh} + W_{el} \quad [kJ]$
Entropy: $\Delta S = S_f - S_b = m_i s_i - m_e s_e + Q/T_B + S_{gen}$ where, $S_{gen} \ge 0$ (3)

Manual State Evaluation thermofluids.net>Tables

General State Related Equations: (applies to any substance)

$$m = \rho \forall; \ \rho = \frac{1}{v}; \ \text{ke} = \frac{V^2}{2000}; \ \text{pe} = \frac{gz}{1000}; \ e \equiv u + ke + pe; \ j \equiv h + ke + pe; \ h \equiv u + pv \tag{1}$$

$$E = me_{jj} \quad S = ms_{j} \quad KE = m(ke)_{j} \quad PE = m(pe)$$
⁽²⁾

$$\dot{m} = \rho AV; \quad \dot{\mathcal{V}} = AV; \quad \dot{E} = \dot{m}e; \quad \dot{S} = \dot{m}s; \tag{3}$$

$$Tds = du + pdv = dh - vdp; \quad c_v \equiv \left(\frac{\partial u}{\partial T}\right)_v; \quad c_p \equiv \left(\frac{\partial h}{\partial T}\right)_p \tag{4}$$

SL Model: (Assumptions: $\rho = \text{constant} \ c_v = \text{constant}$: see Tables>Table-A)

$$\Delta u \equiv u_2 - u_1 = c(T_2 - T_1); \qquad c_v = c_p = c; \tag{5}$$

$$\Delta h \equiv h_2 - h_1 = \Delta(u + pv) = \Delta u + \Delta(pv) = c(T_2 - T_1) + v(p_2 - p_1)$$
(6)

$$\Delta s = c_p \ln \frac{I_2}{T_1} \tag{7}$$

PG Model: (Assumptions: $p = \rho RT$; c_v =constant: see Tables>Table-C)

$$p\Psi = n\overline{R}T; \ p\Psi = mRT; \ p = \rho RT; \ pv = RT; \ \text{where, } R = \frac{\overline{R}}{\overline{M}} \left(\overline{R} = 8.314 \ \frac{\text{kJ}}{\text{kmol} \cdot \text{K}}\right),$$
 (8)

$$\Delta u \equiv u_2 - u_1 = c_v (T_2 - T_1), \quad \Delta h \equiv h_2 - h_1 = c_p (T_2 - T_1), \quad \text{where} \quad c_p = (c_v + R)$$
(9)

$$\Delta s = c_p \ln \frac{T_2}{T_1} - R \ln \frac{p_2}{p_1}; \quad \Delta s = c_v \ln \frac{T_2}{T_1} + R \ln \frac{v_2}{v_1}; \text{ also, } k \equiv \frac{c_p}{c_v}, \quad c_p = \frac{kR}{k-1}; \quad \text{and} \quad c_v = \frac{R}{k-1}$$
(10)

$$s = \text{con process:} \frac{p_2}{p_1} = \left(\frac{\rho_2}{\rho_1}\right)^k = \left(\frac{T_2}{T_1}\right)^{\frac{k}{k-1}} = \left(\frac{v_1}{v_2}\right)^k = \left(\frac{V_1}{V_2}\right)^k; \quad \frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{k-1}{k}} = \left(\frac{v_1}{v_2}\right)^{k-1}; \quad \frac{p_2}{p_1} = \left(\frac{v_1}{v_2}\right)^k; \quad (11)$$

For polytropic process replace k with n

IG Model: (Assumptions: $p = \rho RT$; c_v is function of T: see Tables>Table-D)

$$p = \rho RT = \frac{RT}{\nu} = \frac{m}{\Psi} RT = \frac{m}{\Psi} \frac{\bar{R}}{\bar{M}} T = \frac{m}{\bar{M}} \bar{R} \frac{T}{\Psi} = n\bar{R} \frac{T}{\Psi}$$
(12)

$$h = h(T), u = u(T) \quad s = s(p,T) \quad \text{(use ideal gas tables);} \quad c_p = c_v + R \tag{13}$$

The temperature dependent part of entropy is separated from the pressure dependent part:

$$\Delta s = \int_{T_1}^{T_2} c_p \frac{dT}{T} - R \ln \frac{p_2}{p_1} = s^o(T_2) - s^o(T_1) - R \ln \frac{p_2}{p_1}, \text{ where } s^0(T) \text{ is tabulated against } T. (14)$$

- **PC Model:** (see Tables>Table-B) Determine the phase, L, V or M, of the fluid. For vapor use superheated Table. For mixture, use saturation table (if the quality is not known, your goal should be to evaluate the quality first which is the key to finding all specific properties of a mixture). For liquid use the **CL sub-model**. **CL Sub-Model:** v, u and s depend on T only. Therefore, use the temperature-sorted saturation table to obtain $v = v_{f@T}$, $u = u_{f@T}$ or $s = s_{f@T}$. To find h, use $h = u + pv = u_{f@T} + pv_{f@T}$.
- **RG Model:** (see Tables>Table-E) $p = Z(p_r, T_r)\rho RT$ where Z, the compressibility factor, is obtained from a chart. p_r and T_r are pressure and temperature normalized by the corresponding critical properties. Just like entropy in the PG or IG model, h and u also have two parts, one temperature dependent and another pressure dependent, in the RG model. The departure of these values from the corresponding IG values are tabulated in the enthalpy and entropy departure charts as functions of p_r and T_r . Therefore, the complete state can be evaluated if p_r and T_r are given.