Chapter 1:

$$F = ma$$

$$1\ \text{J} = 1\ \text{N}\cdot\text{m}$$

Density: $\rho = \dfrac{m}{V} \quad (\text{kg/m}^3)$

$$v = \frac{V}{m} = \frac{1}{\rho}$$

Specific gravity: $\text{SG} = \dfrac{\rho}{\rho_{H_2O}}$

Specific weight: $\gamma_s = \rho g \quad (\text{N/m}^3)$

$$T = a + bP$$

$$T(\text{K}) = T(^\circ\text{C}) + 273.15$$

$$T(\text{R}) = T(^\circ\text{F}) + 459.67$$

$$T(\text{R}) = 1.8T(\text{K})$$

$$T(^\circ\text{F}) = 1.8T(^\circ\text{C}) + 32$$

$$\Delta T(\text{K}) = \Delta T(^\circ\text{C})$$

$$\Delta T(\text{R}) = \Delta T(^\circ\text{F})$$

$$P_{\text{gage}} = P_{\text{abs}} - P_{\text{atm}}$$

$$P_{\text{vac}} = P_{\text{atm}} - P_{\text{abs}}$$

$$\Delta P = P_2 - P_1 = -\rho g\, \Delta z = -\gamma_s\, \Delta z$$

$$P_{\text{below}} = P_{\text{above}} + \rho g|\Delta z| = P_{\text{above}} + \gamma_s|\Delta z|$$

$$P = P_{\text{atm}} + \rho g h \quad \text{or} \quad P_{\text{gage}} = \rho g h$$

$$\frac{dP}{dz} = -\rho g$$

$$\Delta P = P_2 - P_1 = -\int_1^2 \rho g \, dz$$

$$P_1 = P_2 \quad \rightarrow \quad \frac{F_1}{A_1} = \frac{F_2}{A_2} \quad \rightarrow \quad \frac{F_2}{F_1} = \frac{A_2}{A_1}$$

$$P_{\text{atm}} = \rho g h \qquad P_2 = P_{\text{atm}} + \rho g h$$

$$P_1 + \rho_1 g(a + h) - \rho_2 g h - \rho_1 g a = P_2$$

$$P_1 - P_2 = (\rho_2 - \rho_1) g h$$

Chapter 2:

$$e = \frac{E}{m} \quad \text{(kJ/kg)}$$

$$\text{KE} = m\frac{V^2}{2} \quad \text{(kJ)} \qquad \text{ke} = \frac{V^2}{2} \quad \text{(kJ/kg)}$$

$$\text{PE} = mgz \quad \text{(kJ)} \qquad \text{pe} = gz \quad \text{(kJ/kg)}$$

$$E = U + \text{KE} + \text{PE} = U + m\frac{V^2}{2} + mgz \quad \text{(kJ)}$$

$$e = u + \text{ke} + \text{pe} = u + \frac{V^2}{2} + gz \quad \text{(kJ/kg)}$$

Mass flow rate: $\dot{m} = \rho \dot{V} = \rho A_c V_{\text{avg}}$ (kg/s)

Energy flow rate: $\dot{E} = \dot{m} e$ (kJ/s or kW)

$$e_{\text{mech}} = \frac{P}{\rho} + \frac{V^2}{2} + gz$$

$$\dot{E}_{\text{mech}} = \dot{m} e_{\text{mech}} = \dot{m}\left(\frac{P}{\rho} + \frac{V^2}{2} + gz\right)$$

$$\Delta e_{\text{mech}} = \frac{P_2 - P_1}{\rho} + \frac{V_2^2 - V_1^2}{2} + g(z_2 - z_1) \quad \text{(kJ/kg)}$$

$$\Delta \dot{E}_{\text{mech}} = \dot{m}\Delta e_{\text{mech}} = \dot{m}\left(\frac{P_2 - P_1}{\rho} + \frac{V_2^2 - V_1^2}{2} + g(z_2 - z_1)\right) \quad \text{(kW)}$$

$$q = \frac{Q}{m} \quad \text{(kJ/kg)}$$

$$Q = \int_{t_1}^{t_2} \dot{Q}\, dt \quad \text{(kJ)}$$

$$Q = \dot{Q}\Delta t \quad \text{(kJ)}$$

$$w = \frac{W}{m} \quad \text{(kJ/kg)}$$

$$\int_1^2 dV = V_2 - V_1 = \Delta V$$

$$\int_1^2 \delta W = W_{12} \quad (\textit{not } \Delta W)$$

$$\dot{W}_e = \mathbf{V}I \quad \text{(W)}$$

$$W_e = \int_1^2 \mathbf{V}I\, dt \quad \text{(kJ)}$$

$$W_e = \mathbf{V}I\, \Delta t \quad \text{(kJ)}$$

$$W = Fs \quad \text{(kJ)}$$

$$W = \int_1^2 F\, ds \quad \text{(kJ)}$$

$$\mathrm{T} = Fr \quad \rightarrow \quad F = \frac{\mathrm{T}}{r}$$

$$s = (2\pi r)n$$

$$W_{sh} = Fs = \left(\frac{T}{r}\right)(2\pi rn) = 2\pi nT \quad \text{(kJ)}$$

$$\dot{W}_{sh} = 2\pi\dot{n}T \quad \text{(kW)}$$

$$\delta W_{spring} = F\,dx$$

$$F = kx \quad \text{(kN)}$$

$$W_{spring} = \tfrac{1}{2}k(x_2^2 - x_1^2) \quad \text{(kJ)}$$

$$W_{elastic} = \int_1^2 F\,dx = \int_1^2 \sigma_n A\,dx \quad \text{(kJ)}$$

$$W_{surface} = \int_1^2 \sigma_s\,dA \quad \text{(kJ)}$$

$$\Delta E_{system} = E_{final} - E_{initial} = E_2 - E_1$$

$$\Delta E = \Delta U + \Delta KE + \Delta PE$$

$$\Delta U = m(u_2 - u_1)$$

$$\Delta KE = \tfrac{1}{2}m(V_2^2 - V_1^2)$$

$$\Delta PE = mg(z_2 - z_1)$$

$$E_{in} - E_{out} = (Q_{in} - Q_{out}) + (W_{in} - W_{out}) + (E_{mass,in} - E_{mass,out}) = \Delta E_{system}$$

$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{system}}_{\substack{\text{Change in internal, kinetic,} \\ \text{potential, etc., energies}}} \quad \text{(kJ)}$$

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{dE_{system}/dt}_{\substack{\text{Rate of change in internal,} \\ \text{kinetic, potential, etc., energies}}} \quad \text{(kW)}$$

$$Q = \dot{Q}\,\Delta t, \quad W = \dot{W}\,\Delta t, \quad \text{and} \quad \Delta E = (dE/dt)\,\Delta t \quad \text{(kJ)}$$

$$e_{\text{in}} - e_{\text{out}} = \Delta e_{\text{system}} \quad \text{(kJ/kg)}$$

$$\delta E_{\text{in}} - \delta E_{\text{out}} = dE_{\text{system}} \quad \text{or} \quad \delta e_{\text{in}} - \delta e_{\text{out}} = de_{\text{system}}$$

$$W_{\text{net, out}} = Q_{\text{net, in}} \quad \text{or} \quad \dot{W}_{\text{net, out}} = \dot{Q}_{\text{net, in}} \quad \text{(for a cycle)}$$

$$\text{Efficiency} = \frac{\text{Desired output}}{\text{Required input}}$$

$$\eta_{\text{combustion}} = \frac{Q}{\text{HV}} = \frac{\text{Amount of heat released during combustion}}{\text{Heating value of the fuel burned}}$$

$$\eta_{\text{overall}} = \eta_{\text{combustion}} \eta_{\text{thermal}} \eta_{\text{generator}} = \frac{\dot{W}_{\text{net,electric}}}{\text{HHV} \times \dot{m}_{\text{fuel}}}$$

$$\eta_{\text{mech}} = \frac{\text{Mechanical energy output}}{\text{Mechanical energy input}} = \frac{E_{\text{mech, out}}}{E_{\text{mech, in}}} = 1 - \frac{E_{\text{mech, loss}}}{E_{\text{mech, in}}}$$

$$\eta_{\text{pump}} = \frac{\text{Mechanical energy increase of the fluid}}{\text{Mechanical energy input}} = \frac{\Delta \dot{E}_{\text{mech,fluid}}}{\dot{W}_{\text{shaft,in}}} = \frac{\dot{W}_{\text{pump},u}}{\dot{W}_{\text{pump}}}$$

$$\eta_{\text{turbine}} = \frac{\text{Mechanical energy output}}{\text{Mechanical energy decrease of the fluid}} = \frac{\dot{W}_{\text{shaft, out}}}{|\Delta \dot{E}_{\text{mech,fluid}}|} = \frac{\dot{W}_{\text{turbine}}}{\dot{W}_{\text{turbine},e}}$$

Motor: $$\eta_{\text{motor}} = \frac{\text{Mechanical power output}}{\text{Electric power input}} = \frac{\dot{W}_{\text{shaft, out}}}{\dot{W}_{\text{elect, in}}}$$

Generator: $$\eta_{\text{generator}} = \frac{\text{Electric power output}}{\text{Mechanical power input}} = \frac{\dot{W}_{\text{elect, out}}}{\dot{W}_{\text{shaft, in}}}$$

$$\eta_{\text{pump-motor}} = \eta_{\text{pump}} \eta_{\text{motor}} = \frac{\dot{W}_{\text{pump},u}}{\dot{W}_{\text{elect, in}}} = \frac{\Delta \dot{E}_{\text{mech, fluid}}}{\dot{W}_{\text{elect, in}}}$$

$$\eta_{\text{turbine-gen}} = \eta_{\text{turbine}} \eta_{\text{generator}} = \frac{\dot{W}_{\text{elect, out}}}{\dot{W}_{\text{turbine},e}} = \frac{\dot{W}_{\text{elect, out}}}{|\Delta \dot{E}_{\text{mech, fluid}}|}$$

Chapter 3:

$$h = u + Pv \quad \text{(kJ/kg)}$$

$$H = U + PV \quad \text{(kJ)}$$

$$x = \frac{m_{\text{vapor}}}{m_{\text{total}}}$$

$$v_{\text{avg}} = v_f + xv_{fg} \quad (\text{m}^3/\text{kg})$$

$$x = \frac{v_{\text{avg}} - v_f}{v_{fg}}$$

$$u_{\text{avg}} = u_f + xu_{fg} \quad \text{(kJ/kg)}$$

$$h_{\text{avg}} = h_f + xh_{fg} \quad \text{(kJ/kg)}$$

$$y \cong y_{f\,@\,T}$$

$$h \cong h_{f\,@\,T} + v_{f\,@\,T}(P - P_{\text{sat}\,@T})$$

$$Pv = RT$$

$$m = MN \quad \text{(kg)}$$

$$V = mv \longrightarrow PV = mRT$$

$$mR = (MN)R = NR_u \longrightarrow PV = NR_uT$$

$$V = N\bar{v} \longrightarrow P\bar{v} = R_uT$$

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

Chapter 4:

(1) General $$W_b = \int_1^2 P\,dV$$

(2) Isobaric process

$$W_b = P_0(V_2 - V_1) \qquad (P_1 = P_2 = P_0 = \text{constant})$$

(3) Polytropic process

$$W_b = \frac{P_2V_2 - P_1V_1}{1 - n} \quad (n \neq 1) \qquad (PV^n = \text{constant})$$

(4) Isothernal process of an ideal gas

$$W_b = P_1V_1 \ln\frac{V_2}{V_1}$$

$$= mRT_0 \ln\frac{V_2}{V_1} \qquad (PV = mRT_0 = \text{constant})$$

For a closed system $$Q - W = \Delta U + \Delta\text{KE} + \Delta\text{PE}$$

$$W = W_{\text{other}} + W_b$$

For a constant pressure process $$Q - W_{\text{other}} = \Delta H + \Delta\text{KE} + \Delta\text{PE}$$

$$\Delta u = u_2 - u_1 = \int_1^2 c_v(T)\,dT \cong c_{v,\text{avg}}(T_2 - T_1)$$

$$\Delta h = h_2 - h_1 = \int_1^2 c_p(T)\,dT \cong c_{p,\text{avg}}(T_2 - T_1)$$

For an ideal gas $c_p = c_v + R$

Specific heat ratio $k = \dfrac{c_p}{c_v}$

For incompressible substances (liquids and solids) $c_p = c_v = c$

The Δ*u* and Δ*h* of incompressible substances

$$\Delta u = \int_1^2 c(T)\,dT \cong c_{\text{avg}}(T_2 - T_1)$$

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

Chapter 5

$$m_{in} - m_{out} = \Delta m_{system} \quad \text{and} \quad \dot{m}_{in} - \dot{m}_{out} = dm_{system}/dt$$

$$\dot{m} = \rho V A$$

$$\dot{V} = VA = \dot{m}/\rho$$

$$\theta = h + ke + pe = h + \frac{V^2}{2} + gz$$

$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Rate of net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{dE_{system}/dt}_{\substack{\text{Rate of change in internal, kinetic,}\\ \text{potential, etc., energies}}}$$

$$\sum_{in} \dot{m} = \sum_{out} \dot{m}$$

$$\dot{Q} - \dot{W} = \sum_{out} \underbrace{\dot{m}\left(h + \frac{V^2}{2} + gz\right)}_{\text{for each exit}} - \sum_{in} \underbrace{\dot{m}\left(h + \frac{V^2}{2} + gz\right)}_{\text{for each inlet}}$$

$$\dot{m}_1 = \dot{m}_2 \longrightarrow \frac{1}{v_1} V_1 A_1 = \frac{1}{v_2} V_2 A_2$$

$$\dot{Q} - \dot{W} = \dot{m}\left[h_2 - h_1 + \frac{V_2^2 - V_1^2}{2} + g(z_2 - z_1)\right]$$

General Steady State Energy Equation:

$$0 = \frac{\dot{Q}_{cv}}{\dot{m}} - \frac{\dot{W}_{cv}}{\dot{m}} + (h_1 - h_2) + \frac{(V_1^2 - V_2^2)}{2} + g(z_1 - z_2)$$

General Nozzle Eq: $\dot{W}_{cv} = \dot{m}(h_1 - h_2)$

General Turbine Eq: $\frac{\dot{W}_{out}}{\dot{m}} = (h_1 - h_2) + \left(\frac{V_1^2 - V_2^2}{2}\right)$

General Compressor and Pump Eq: $\dot{W}_{cv} = \dot{m}(h_1 - h_2)$

General Heat Exchanger Eq.: $0 = \sum_i \dot{m}_i h_i - \sum_e \dot{m}_e h_e$

General Throttling and Valves Eq.: $h_1 = h_2$

Chapter 6

$$\eta_{\text{th}} = \frac{W_{\text{net,out}}}{Q_H} \quad \text{or} \quad \eta_{\text{th}} = 1 - \frac{Q_L}{Q_H}$$

$$\text{COP}_{\text{R}} = \frac{Q_L}{Q_H - Q_L} = \frac{1}{Q_H/Q_L - 1}$$

$$\text{COP}_{\text{HP}} = \frac{Q_H}{Q_H - Q_L} = \frac{1}{1 - Q_L/Q_H}$$

$$\eta_{\text{th,rev}} = 1 - \frac{T_L}{T_H} \qquad \text{COP}_{\text{R,rev}} = \frac{1}{T_H/T_L - 1} \qquad \text{COP}_{\text{HP,rev}} = \frac{1}{1 - T_L/T_H}$$

$$\left(\frac{Q_H}{Q_L}\right)_{\text{rev}} = \frac{T_H}{T_L}$$

Chapter 7

$$dS = \left(\frac{\delta Q}{T}\right)_{\text{int rev}} \quad \text{(kJ/K)} \qquad \Delta S = \frac{Q}{T_0} \quad \text{(kJ/K)}$$

$$\Delta S_{\text{sys}} = S_2 - S_1 = \int_1^2 \frac{\delta Q}{T} + S_{\text{gen}}$$

$$\Delta S_{\text{isolated}} \geq 0$$

$$S_{\text{gen}} = \Delta S_{\text{total}} = \Delta S_{\text{sys}} + \Delta S_{\text{surr}} \geq 0$$

$$\Delta S = m\Delta s = m(s_2 - s_1) \quad \text{(kJ/K)}$$

$$\textit{Isentropic process:} \qquad \Delta s = 0 \quad \text{or} \quad s_2 = s_1 \quad \text{(kJ/kg·K)}$$

$$Q_{\text{int rev}} = \int_1^2 T\,dS \quad \text{(kJ)}$$

$$Q_{\text{int rev}} = T_0\,\Delta S \quad \text{(kJ)} \qquad q_{\text{int rev}} = T_0\,\Delta s \quad \text{(kJ/kg)}$$

$$T\,ds = du + P\,dv \quad \text{(kJ/kg)}$$

$$\left.\begin{array}{lll} h = u + Pv & \longrightarrow & dh = du + P\,dv + v\,dP \\ \text{(Eq. 7–23)} & \longrightarrow & T\,ds = du + P\,dv \end{array}\right\} T\,ds = dh - v\,dP$$

$$ds = \frac{du}{T} + \frac{P\,dv}{T} \qquad ds = \frac{dh}{T} - \frac{v\,dP}{T}$$

$$\textit{Liquids, solids:} \quad s_2 - s_1 = \int_1^2 c(T)\frac{dT}{T} \cong c_{\text{avg}} \ln\frac{T_2}{T_1} \quad \text{(kJ/kg·K)}$$

$$\textit{Isentropic:} \quad s_2 - s_1 = c_{\text{avg}} \ln\frac{T_2}{T_1} = 0 \longrightarrow T_2 = T_1$$

For an ideal gas

$$ds = c_v\frac{dT}{T} + R\frac{dv}{v} \qquad s_2 - s_1 = \int_1^2 c_v(T)\frac{dT}{T} + R\ln\frac{v_2}{v_1} \qquad s_2 - s_1 = \int_1^2 c_p(T)\frac{dT}{T} - R\ln\frac{P_2}{P_1}$$

For an ideal gas assuming constant heat capacities

$$s_2 - s_1 = c_{v,\text{avg}} \ln\frac{T_2}{T_1} + R \ln\frac{v_2}{v_1} \quad (\text{kJ/kg·K})$$

$$s_2 - s_1 = c_{p,\text{avg}} \ln\frac{T_2}{T_1} - R \ln\frac{P_2}{P_1} \quad (\text{kJ/kg·K})$$

For an ideal gas with variable heat capacities

$$s_2 - s_1 = s_2^\circ - s_1^\circ - R \ln\frac{P_2}{P_1} \quad (\text{kJ/kg·K})$$

Isentropic process of ideal gases

$$\left(\frac{T_2}{T_1}\right)_{s=\text{const.}} = \left(\frac{v_1}{v_2}\right)^{k-1} \quad (\text{ideal gas})$$

$$\left(\frac{T_2}{T_1}\right)_{s=\text{const.}} = \left(\frac{P_2}{P_1}\right)^{(k-1)/k} \quad (\text{ideal gas})$$

$$\left(\frac{P_2}{P_1}\right)_{s=\text{const.}} = \left(\frac{v_1}{v_2}\right)^{k} \quad (\text{ideal gas})$$

$$s_2^\circ = s_1^\circ + R \ln\frac{P_2}{P_1}$$

$$\left(\frac{P_2}{P_1}\right)_{s=\text{const.}} = \frac{P_{r2}}{P_{r1}} \qquad \left(\frac{v_2}{v_1}\right)_{s=\text{const.}} = \frac{v_{r2}}{v_{r1}}$$

Reversible steady flow work

$$w_{\text{rev}} = -\int_1^2 v\,dP - \Delta\text{ke} - \Delta\text{pe} \quad (\text{kJ/kg})$$

$$w_{\text{rev,in}} = \int_1^2 v\,dP + \Delta\text{ke} + \Delta\text{pe}$$

$$w_{\text{rev}} = -v(P_2 - P_1) - \Delta\text{ke} - \Delta\text{pe} \quad (\text{kJ/kg})$$

Compressor work

Isentropic $$w_{\text{comp,in}} = \frac{kR(T_2 - T_1)}{k - 1} = \frac{kRT_1}{k - 1}\left[\left(\frac{P_2}{P_1}\right)^{(k-1)/k} - 1\right]$$

Polytropic $$w_{\text{comp,in}} = \frac{nR(T_2 - T_1)}{n - 1} = \frac{nRT_1}{n - 1}\left[\left(\frac{P_2}{P_1}\right)^{(n-1)/n} - 1\right]$$

Isothermal $$w_{\text{comp,in}} = RT \ln\frac{P_2}{P_1}$$

$$P_x = (P_1P_2)^{1/2} \quad \text{or} \quad \frac{P_x}{P_1} = \frac{P_2}{P_x}$$

Isentropic efficiency of turbines

$$\eta_T = \frac{\text{Actual turbine work}}{\text{Isentropic turbine work}} = \frac{w_a}{w_s} \qquad \eta_T \cong \frac{h_1 - h_{2a}}{h_1 - h_{2s}}$$

Isentropic efficiency of compressors and pumps

$$\eta_C = \frac{\text{Isentropic compressor work}}{\text{Actual compressor work}} = \frac{w_s}{w_a} \qquad \eta_C \cong \frac{h_{2s} - h_1}{h_{2a} - h_1}$$

Isentropic efficiency of nozzle

$$\eta_N = \frac{\text{Actual KE at nozzle exit}}{\text{Isentropic KE at nozzle exit}} = \frac{V_{2a}^2}{V_{2s}^2} \qquad \eta_N \cong \frac{h_1 - h_{2a}}{h_1 - h_{2s}}$$

$$\Delta S_{\text{system}} = S_{\text{final}} - S_{\text{initial}} = S_2 - S_1$$

Entropy transfer by heat transfer: $$S_{\text{heat}} = \frac{Q}{T} \quad (T = \text{constant})$$

Entropy transfer by work: $$S_{\text{work}} = 0$$

Entropy transfer by mass flow: $$S_{\text{mass}} = ms$$

$$\underbrace{S_{\text{in}} - S_{\text{out}}}_{\substack{\text{Net entropy transfer}\\ \text{by heat and mass}}} + \underbrace{S_{\text{gen}}}_{\substack{\text{Entropy}\\ \text{generation}}} = \underbrace{\Delta S_{\text{system}}}_{\substack{\text{Change}\\ \text{in entropy}}} \quad \text{(kJ/K)}$$

Closed system: $$\sum \frac{Q_k}{T_k} + S_{\text{gen}} = \Delta S_{\text{system}} = S_2 - S_1 \quad \text{(kJ/K)}$$

Adiabatic closed system: $$S_{\text{gen}} = \Delta S_{\text{adiabatic system}}$$

$$\sum \frac{Q_k}{T_k} + \sum m_i s_i - \sum m_e s_e + S_{\text{gen}} = (S_2 - S_1)_{\text{CV}} \quad \text{(kJ/K)}$$

$$\sum \frac{\dot{Q}_k}{T_k} + \sum \dot{m}_i s_i - \sum \dot{m}_e s_e + \dot{S}_{\text{gen}} = dS_{\text{CV}}/dt \quad \text{(kW/K)}$$

Steady-flow: $$\dot{S}_{\text{gen}} = \sum \dot{m}_e s_e - \sum \dot{m}_i s_i - \sum \frac{\dot{Q}_k}{T_k}$$

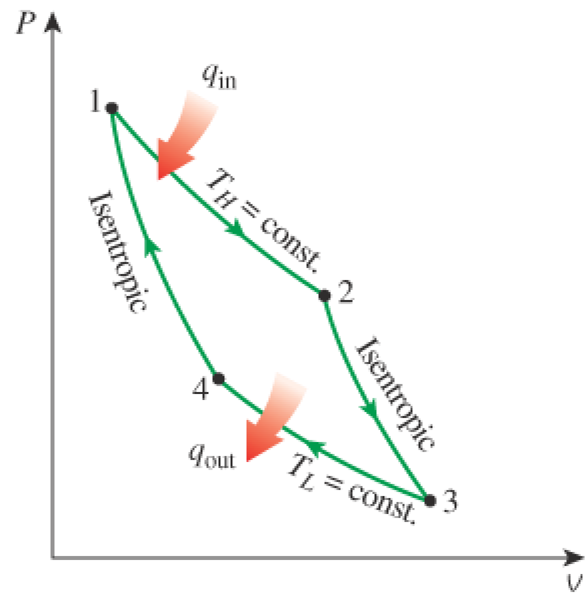
Steady-flow, single-stream: $$\dot{S}_{\text{gen}} = \dot{m}(s_e - s_i) - \sum \frac{\dot{Q}_k}{T_k}$$

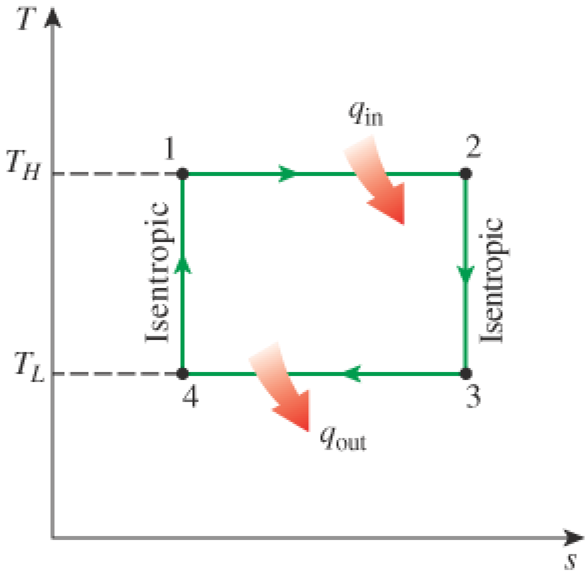
Steady-flow, single-stream, adiabatic: $$\dot{S}_{\text{gen}} = \dot{m}(s_e - s_i)$$

Chapter 9

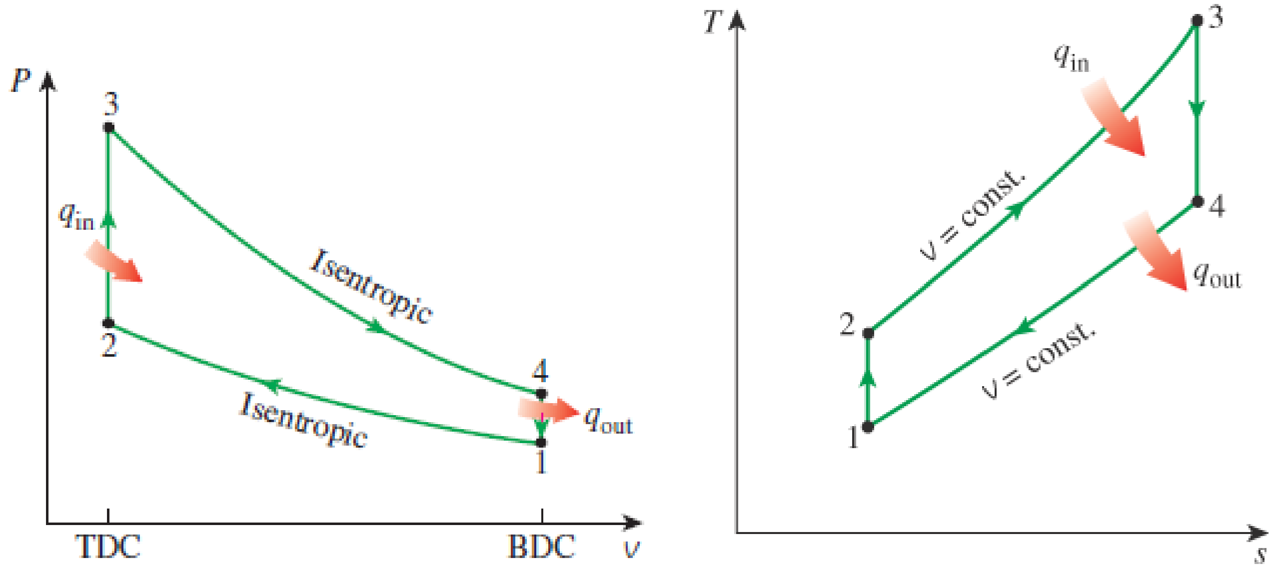
$$\eta_{th,Carnot} = 1 - \frac{T_L}{T_H} \qquad \eta_{th} = \frac{W_{net}}{Q_{in}} \quad \text{or} \quad \eta_{th} = \frac{w_{net}}{q_{in}}$$

Carnot cycle





Otto cycle



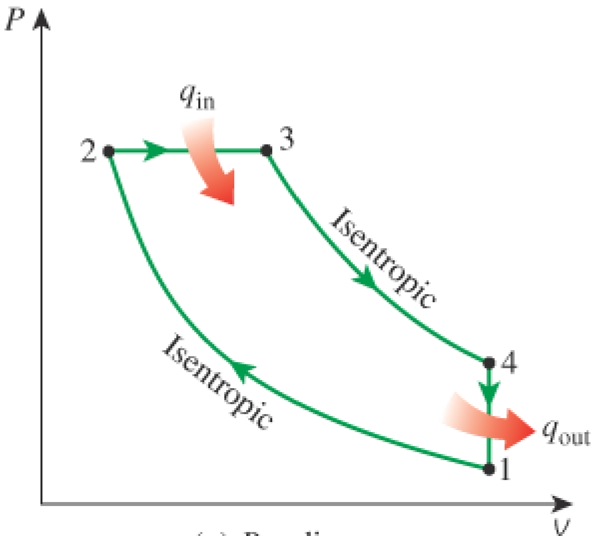
$$r = \frac{V_{max}}{V_{min}} = \frac{V_{BDC}}{V_{TDC}}$$

$$\text{MEP} = \frac{W_{net}}{V_{max} - V_{min}} = \frac{w_{net}}{v_{max} - v_{min}} \qquad (\text{kPa})$$

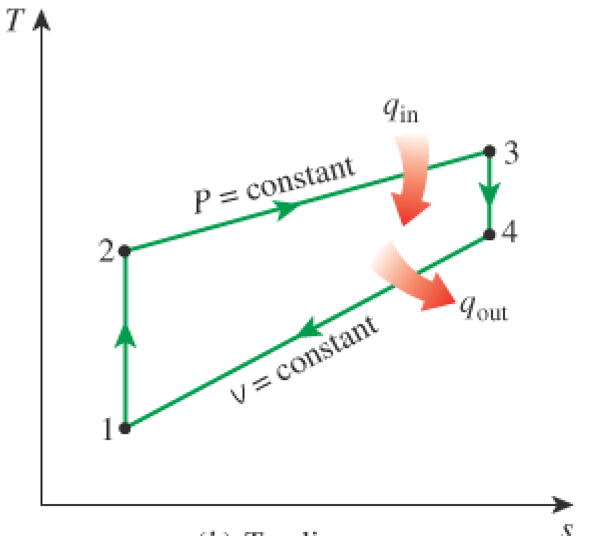
Assuming constant heat capacities

$$\eta_{th,Otto} = 1 - \frac{1}{r^{k-1}}$$

Diesel cycle



(a) P-v diagram

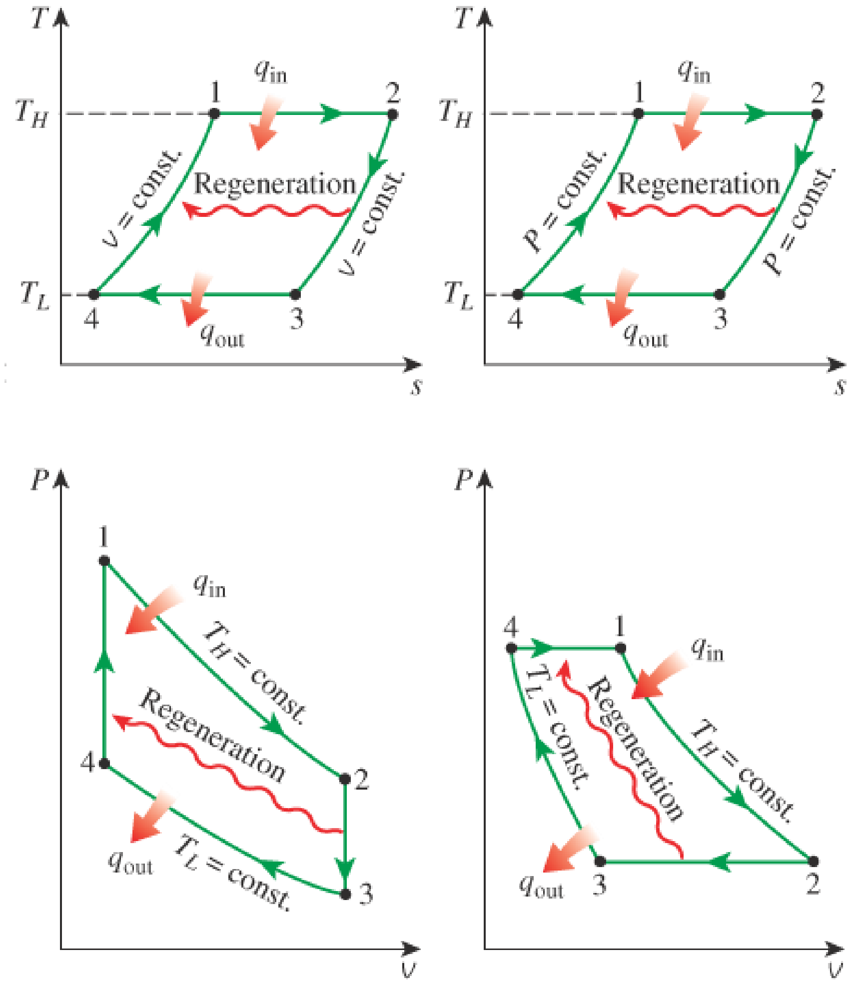


(b) T-s diagram

Assuming constant heat capacities

$$\eta_{\text{th,Diesel}} = 1 - \frac{1}{r^{k-1}}\left[\frac{r_c^k - 1}{k(r_c - 1)}\right] \qquad r_c = \frac{V_3}{V_2} = \frac{v_3}{v_2}$$

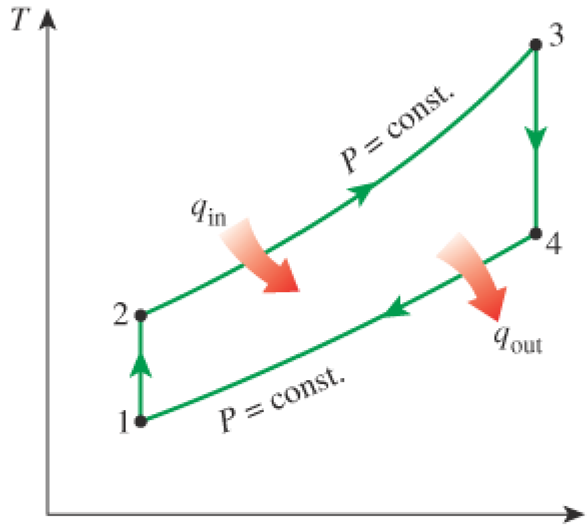
Stirling and Ericsson cycles



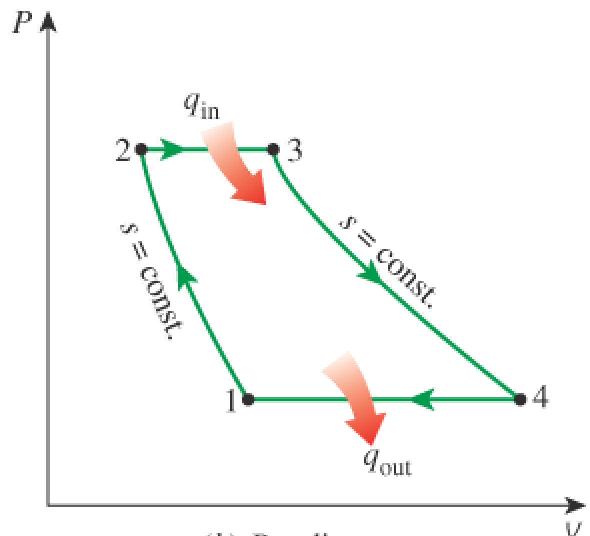
(b) Stirling cycle (c) Ericsson cycle

$$\eta_{\text{th,Stirling}} = \eta_{\text{th,Ericsson}} = \eta_{\text{th,Carnot}} = 1 - \frac{T_L}{T_H}$$

Brayton cycle



(a) T-s diagram



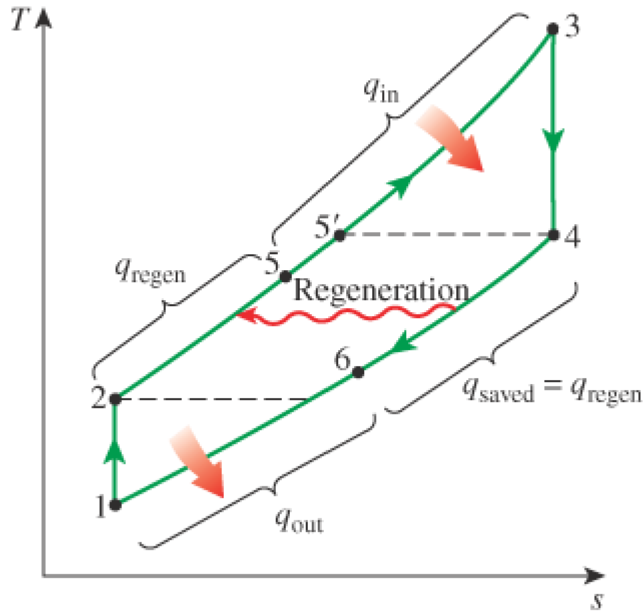
(b) P-v diagram

Assuming constant heat capacities

$$\eta_{\text{th,Brayton}} = 1 - \frac{1}{r_p^{(k-1)/k}}$$

$$r_p = \frac{P_2}{P_1}$$

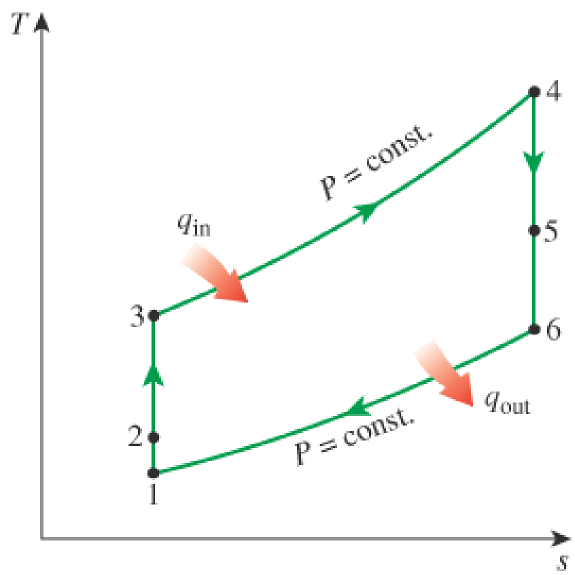
Brayton cycle with regeneration



$$\epsilon = \frac{q_{regen,act}}{q_{regen,max}} = \frac{h_5 - h_2}{h_4 - h_2}$$

$$\eta_{th,regen} = 1 - \left(\frac{T_1}{T_3}\right)(r_p)^{(k-1)/k}$$

Ideal jet-propulsion cycle



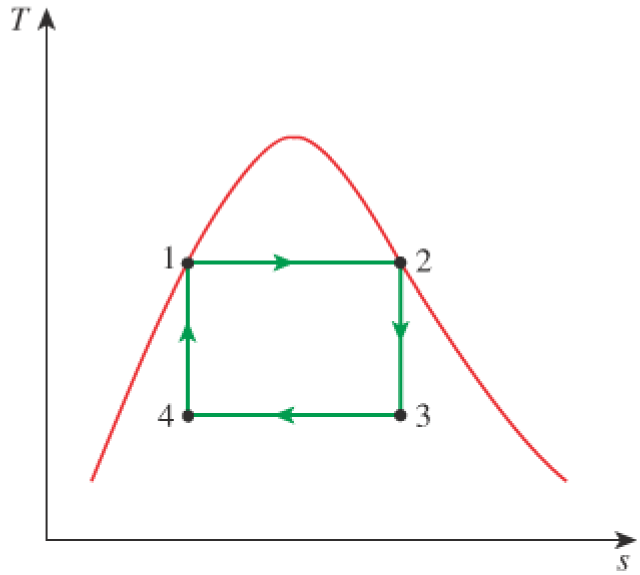
$$F = (\dot{m}V)_{exit} - (\dot{m}V)_{inlet} = \dot{m}(V_{exit} - V_{inlet}) \quad \text{(N)}$$

$$\dot{W}_P = FV_{aircraft} = \dot{m}(V_{exit} - V_{inlet})V_{aircraft} \quad \text{(kW)}$$

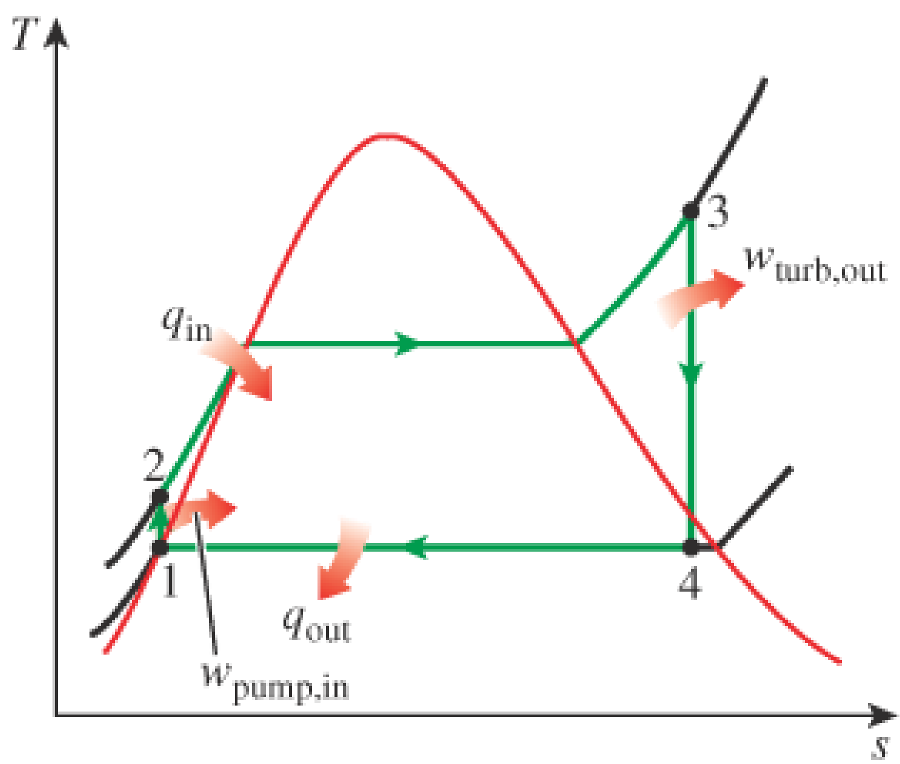
$$\eta_P = \frac{\text{Propulsive power}}{\text{Energy input rate}} = \frac{\dot{W}_P}{\dot{Q}_{in}}$$

Chapter 10

Carnot vapor cycle



Rankine cycle



Pump ($q = 0$): $$w_{\text{pump,in}} = h_2 - h_1$$

or,

$$w_{\text{pump,in}} = v(P_2 - P_1)$$

where

$$h_1 = h_{f\,@\,P_1} \quad \text{and} \quad v \cong v_1 = v_{f\,@\,P_1}$$

Boiler ($w = 0$): $$q_{\text{in}} = h_3 - h_2$$

Turbine ($q = 0$): $$w_{\text{turb,out}} = h_3 - h_4$$

Condenser ($w = 0$): $$q_{\text{out}} = h_4 - h_1$$

$$\eta_{\text{th}} = \frac{w_{\text{net}}}{q_{\text{in}}} = 1 - \frac{q_{\text{out}}}{q_{\text{in}}}$$

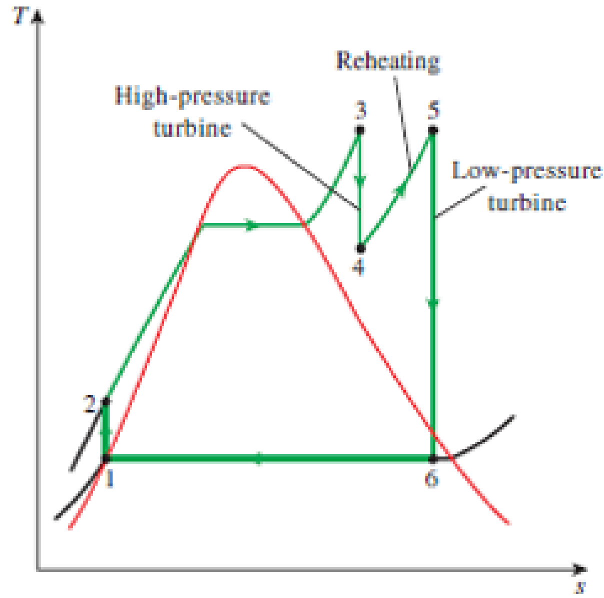
$$w_{\text{net}} = q_{\text{in}} - q_{\text{out}} = w_{\text{turb,out}} - w_{\text{pump,in}}$$

$$\eta_{\text{th}} = \frac{3412\ (\text{Btu/kWh})}{\text{Heat rate (Btu/kWh)}}$$

$$\eta_P = \frac{w_s}{w_a} = \frac{h_{2s} - h_1}{h_{2a} - h_1}$$

$$\eta_T = \frac{w_a}{w_s} = \frac{h_3 - h_{4a}}{h_3 - h_{4s}}$$

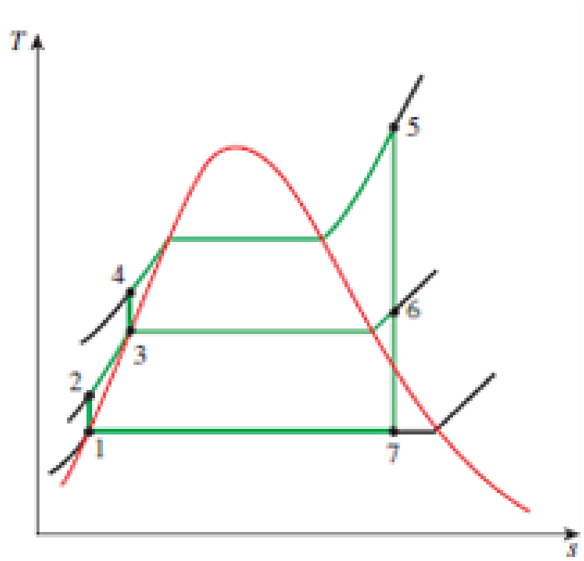
The ideal reheat Rankine cycle



$$q_{in} = q_{primary} + q_{reheat} = (h_3 - h_2) + (h_5 - h_4)$$

$$w_{turb,out} = w_{turb,I} + w_{turb,II} = (h_3 - h_4) + (h_5 - h_6)$$

The ideal regenerative Rankine cycle with an open feedwater heater



$$q_{\text{in}} = h_5 - h_4$$

$$q_{\text{out}} = (1 - y)(h_7 - h_1)$$

$$w_{\text{turb,out}} = (h_5 - h_6) + (1 - y)(h_6 - h_7)$$

$$w_{\text{pump,in}} = (1 - y)w_{\text{pump I,in}} + w_{\text{pump II,in}}$$

$$y = \dot{m}_6/\dot{m}_5 \qquad \text{(fraction of steam extracted)}$$

$$w_{\text{pump I,in}} = v_1(P_2 - P_1)$$

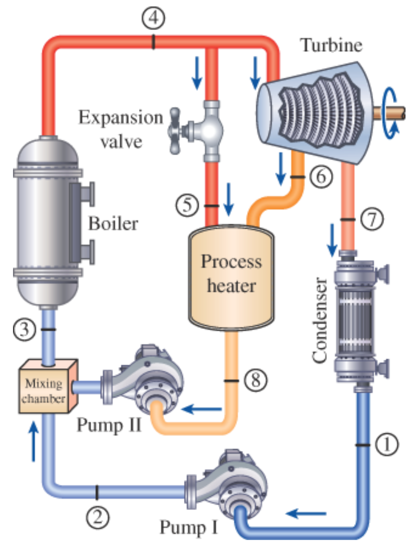
$$w_{\text{pump II,in}} = v_3(P_4 - P_3)$$

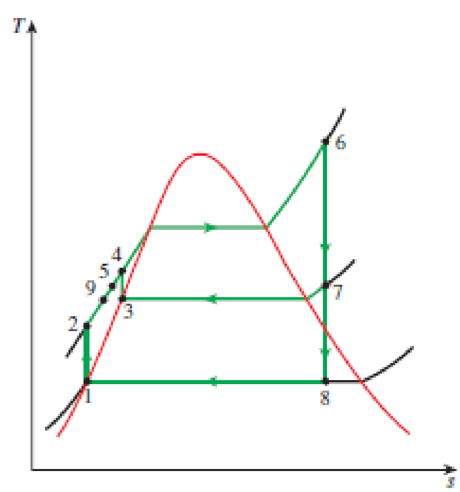
$$\dot{E}_{\text{in}} = \dot{E}_{\text{out}} \longrightarrow \sum_{\text{in}} \dot{m}h = \sum_{\text{out}} \dot{m}h$$

$$yh_6 + (1 - y)h_2 = 1(h_3)$$

$$y = \frac{h_3 - h_2}{h_6 - h_2}$$

The ideal regenerative Rankine cycle with a closed feedwater heater





Cogeneration

$$\dot{Q}_{in} = \dot{m}_3(h_4 - h_3)$$

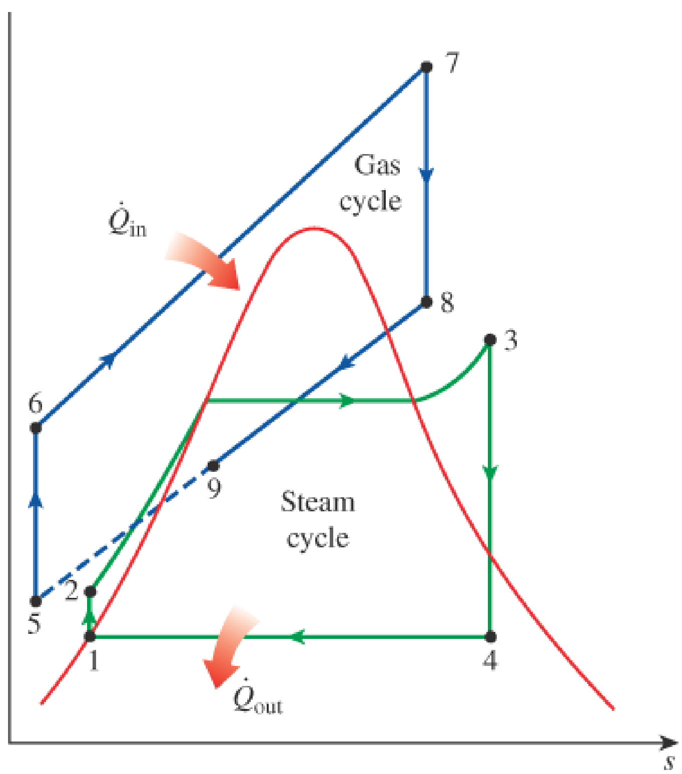
$$\dot{Q}_{out} = \dot{m}_7(h_7 - h_1)$$

$$\dot{Q}_p = \dot{m}_5 h_5 + \dot{m}_6 h_6 - \dot{m}_8 h_8$$

$$\dot{W}_{turb} = (\dot{m}_4 - \dot{m}_5)(h_4 - h_6) + \dot{m}_7(h_6 - h_7)$$

$$\epsilon_u = \frac{\text{Net power output} + \text{Process heat delivered}}{\text{Total heat input}} = \frac{\dot{W}_{net} + \dot{Q}_p}{\dot{Q}_{in}}$$

Combined gas-vapor power cycle

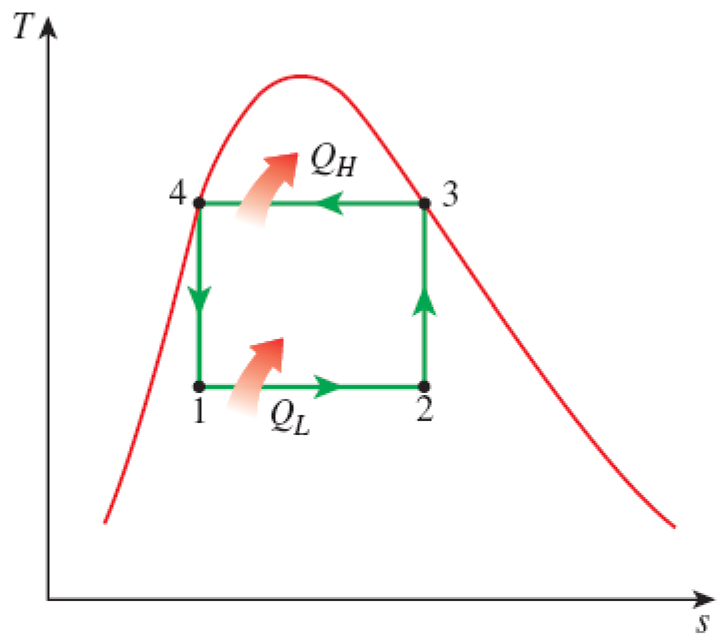


Chapter 11

$$\mathrm{COP_R} = \frac{\text{Desired output}}{\text{Required input}} = \frac{\text{Cooling effect}}{\text{Work input}} = \frac{Q_L}{W_{\text{net,in}}}$$

$$\mathrm{COP_{HP}} = \frac{\text{Desired output}}{\text{Required input}} = \frac{\text{Heating effect}}{\text{Work input}} = \frac{Q_H}{W_{\text{net,in}}}$$

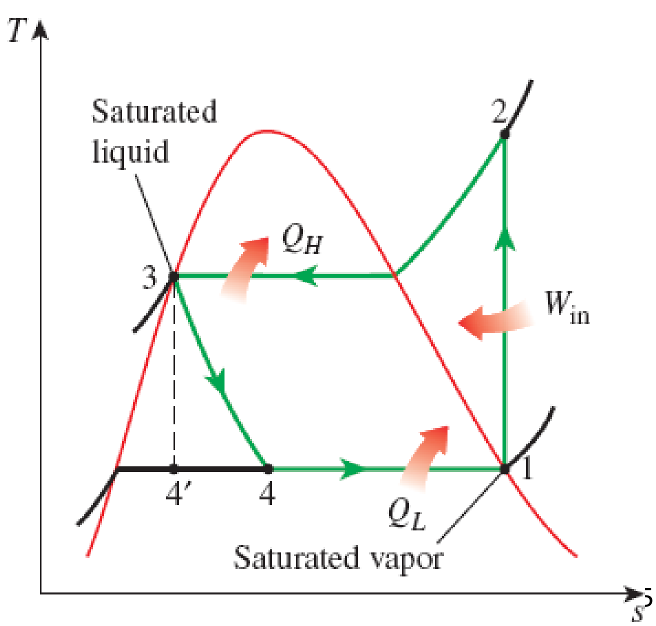
Reversed Carnot cycle



$$\mathrm{COP_{R,Carnot}} = \frac{1}{T_H/T_L - 1}$$

$$\mathrm{COP_{HP,Carnot}} = \frac{1}{1 - T_L/T_H}$$

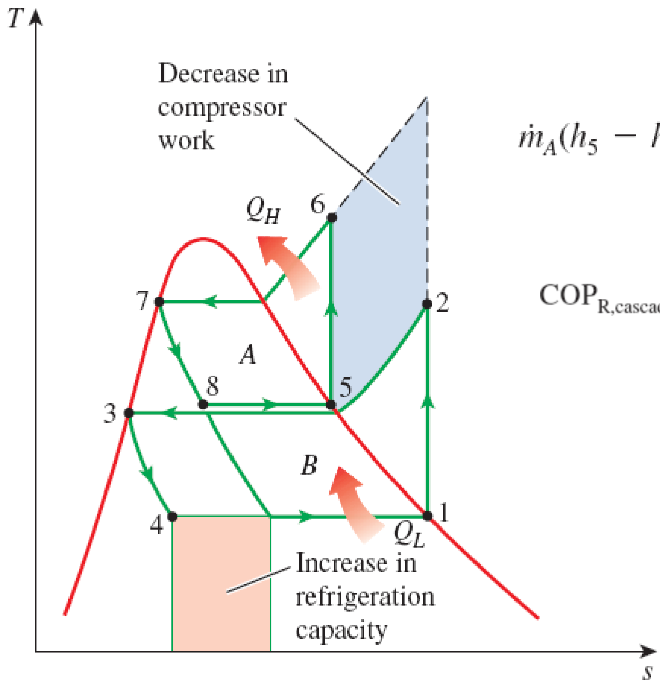
The ideal vapor-compression refrigeration cycle



$$\mathrm{COP_R} = \frac{q_L}{w_{\text{net,in}}} = \frac{h_1 - h_4}{h_2 - h_1}$$

$$\mathrm{COP_{HP}} = \frac{q_H}{w_{\text{net,in}}} = \frac{h_2 - h_3}{h_2 - h_1}$$

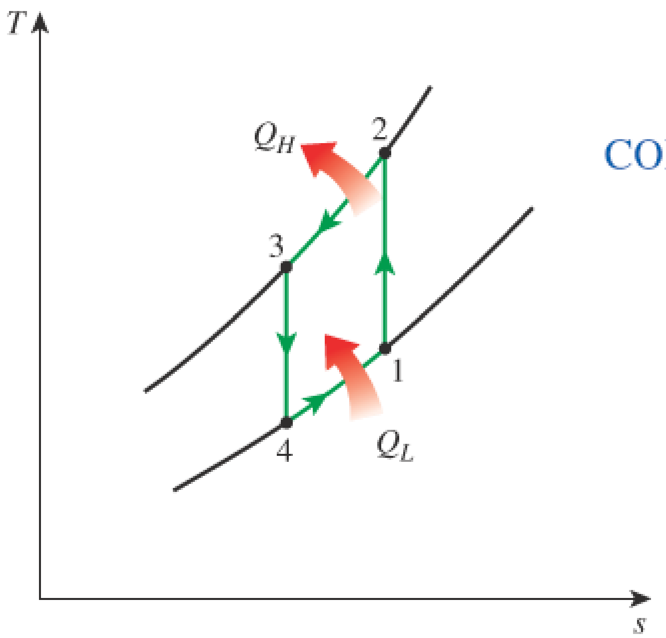
Cascade refrigeration cycles



$$\dot{m}_A(h_5 - h_8) = \dot{m}_B(h_2 - h_3) \longrightarrow \frac{\dot{m}_A}{\dot{m}_B} = \frac{h_2 - h_3}{h_5 - h_8}$$

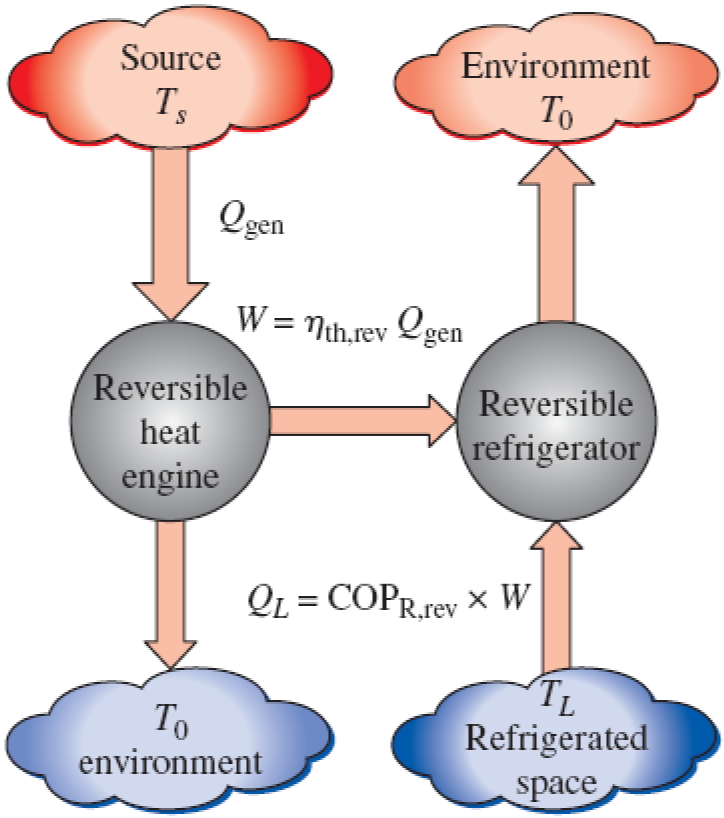
$$\text{COP}_{\text{R,cascade}} = \frac{\dot{Q}_L}{\dot{W}_{\text{net,in}}} = \frac{\dot{m}_B(h_1 - h_4)}{\dot{m}_A(h_6 - h_5) + \dot{m}_B(h_2 - h_1)}$$

Gas refrigeration cycles



$$\text{COP}_\text{R} = \frac{q_L}{w_{\text{net,in}}} = \frac{q_L}{w_{\text{comp,in}} - w_{\text{turb,out}}}$$

Absorption refrigeration cycles



$$W = \eta_{th,\ rev}\, Q_{gen} = \left(1 - \frac{T_0}{T_s}\right) Q_{gen}$$

$$Q_L = COP_{R,rev} W = \left(\frac{T_L}{T_0 - T_L}\right) W$$

$$COP_{rev,absorption} = \frac{Q_L}{Q_{gen}} = \left(1 - \frac{T_0}{T_s}\right)\left(\frac{T_L}{T_0 - T_L}\right)$$

$$COP_{absorption} = \frac{\text{Desired output}}{\text{Required input}} = \frac{Q_L}{Q_{gen} + W_{pump}} \cong \frac{Q_L}{Q_{gen}}$$

$$COP_{rev,absorption} = \frac{Q_L}{Q_{gen}} = \eta_{th,rev} COP_{R,rev} = \left(1 - \frac{T_0}{T_s}\right)\left(\frac{T_L}{T_0 - T_L}\right)$$