$v = \frac{V}{m}$ m^3/kg $\qquad v \simeq v_f @ T$ (in compressed region) $\qquad x \equiv \frac{m_{vap}}{m_{tot}}$ $\qquad v = \frac{V_{tot}}{m_{tot}}$

$W = wm$ $\qquad u \simeq u_f @ T$ (compressed region)

$v = v_f + x v_{fg}$ $\qquad h = h_f + v_f (P - P_{sat}) @ T$ (compressed region) $\qquad v_f = \frac{V_{liq}}{m_{liq}}$ $\qquad v_g = \frac{V_{vap}}{m_{vap}}$

$h \equiv u + Pv$ $\qquad h = u + RT$ (I.G., rev.) $\qquad 1 - x = \frac{m_{liq}}{m_{tot}}$ $\qquad x v_g = \frac{V_{vap}}{m_{tot}}$

For I.G. $h = h(T)$ only & $u = u(T)$ only

$u_2 - u_1 = \int C_v \, dT$ ($u = u(T)$ only)

$h_2 - h_1 = \int C_p \, dT$ ($h = h(T)$ only)

$w = \int P dv$ (closed system, reversible) $\qquad (1-x) v_f = \frac{V_{liq}}{m_{tot}}$

$w = P(V_2 - V_1)$ (closed sys., Rev., P = const.)

$PV = n\bar{R}T$ (I.G., rev.) $\qquad R = \frac{\bar{R}}{m}$

$PV = mRT$ (I.G., rev.)

$Pv = RT = \text{const.}$ (I.G., rev.) $\qquad M = \frac{m}{n}$

$w = \frac{P_2 V_2 - P_1 V_1}{1 - n}$ (closed system, Rev., $T \neq$ const., I.G.)

$w = P_1 V_1 \ln\left(\frac{V_2}{V_1}\right) = RT \ln\left(\frac{P_1}{P_2}\right)$ (closed sys. Rev., T = const. I.G.)

$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$ (I.G., Rev.)

$q - w = u_2 - u_1$ (closed system, $\Delta KE \approx 0$, $\Delta PE \approx 0$)

$C_p - C_v = R$ $\qquad C_p = \frac{kR}{k-1}$

$k \equiv \frac{C_p}{C_v}$ $\qquad C_v = \frac{R}{k-1}$

$$\dot{Q} + \sum \dot{m}_i \left(h_i + \frac{\vec{V}_i^2}{2} + g z_i\right) = \dot{W} + \sum \dot{m}_e \left(h_e + \frac{\vec{V}_e^2}{2} + g z_e\right)$$

$\frac{\dot{Q}}{\dot{m}} = q$ $\qquad \dot{m} = \rho \vec{V} A = \frac{\vec{V}A}{v}$ $\qquad \rho \overset{I.G}{=} \frac{P}{RT}$ $\qquad \frac{\dot{W}}{\dot{m}} = w$

$Pv^n = \text{const.}$ = polytropic process

- $n = 0 \Rightarrow P = \text{const.}$
- $n = 1 \Rightarrow T = \text{const.}$
- $n = k \Rightarrow s = \text{const.}$
- $n \Rightarrow \infty \Rightarrow v = \text{const.}$

$q - w = h_2 - h_1$ (S.F., $\Delta KE \approx 0$, $\Delta PE \approx 0$)

$w = Pv \ln \frac{V_2}{V_1} = RT \ln \frac{P_1}{P_2}$ (Pv^n = const. $n = 1$, T = const. I.G.)

$Pv^k = \text{const}$ (Isentropic, I.G. C_p = const.)

$w = n\left(\frac{P_2 V_2 - P_1 V_1}{1 - n}\right)$ ($n \neq 1$, I.G., Pv^n = const.)

$$\left.\begin{aligned} &\frac{P_1}{P_2} = \left(\frac{V_2}{V_1}\right)^k \qquad \left(\frac{P_2}{P_1}\right)^k = \frac{V_2}{V_1} \\ &\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} \qquad \left(\frac{T_2}{T_1}\right)^{\frac{k}{k-1}} = \frac{P_2}{P_1} \end{aligned}\right\} (\Delta s = 0, \text{I.G.}, C_p = \text{const})$$

$w = \frac{kR(T_2 - T_1)}{1 - k} = C_p (T_1 - T_2)$ ($n = k$, $\Delta s = 0$, I.G.)

$q = \int T \cdot ds$ (reversible)

Throttling process implies $h_1 = h_2$ (adiabatic)

$T \cdot ds = du + Pdv$ (pure simple compressible subst.)

$$\left.\begin{aligned} T \cdot ds &= dH - VdP \\ T \cdot ds &= dU + Pdv \end{aligned}\right\}$$

$$\left.\begin{aligned} s_2 - s_1 &= C_v \ln \frac{T_2}{T_1} + R \ln \frac{V_2}{V_1} \\ s_2 - s_1 &= C_p \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1} \end{aligned}\right\} \text{I.G. } C_p = \text{const.}$$

$w = -\int VdP - \frac{\vec{V}_2^2 - \vec{V}_1^2}{2} - g(Z_2 - Z_1)$ (Rev. S.F.)

$\Delta s = \underbrace{\int C_p \frac{dT}{T}}_{= s_2^\circ - s_1^\circ} - R \ln \frac{P_2}{P_1}$ (I. G.)

$w = -\int VdP$ (Rev., $\Delta KE \approx 0$, S.F., $\Delta PE \approx 0$)

$\frac{P_1}{\rho} + \frac{\vec{V}_1^2}{2} + g z_1 = \frac{P_2}{\rho} + \frac{\vec{V}_2^2}{2} + g z_2$ (Rev., S.F., w = 0, ρ = const, v = const.)

$w = -\underset{v_f @ T}{v}(P_2 - P_1)$ (Rev., $\Delta KE \approx 0$, v = const. S.F., $\Delta PE \approx 0$ (Pump))

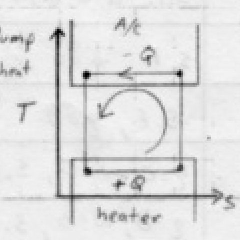
$\eta_{TH} = \frac{W_{net}}{Q_H} = \frac{Q_H - Q_L}{Q_H} = 1 - \frac{Q_L}{Q_H}$ (heat engine) $\qquad \eta_{TH} = 1 - \frac{T_L}{T_H}$ (Carnot H.E.)

$COP_C = \beta = \frac{Q_L}{W_{net}} = \frac{Q_L}{Q_H - Q_L} = \overset{\text{carnot only}}{\frac{T_L}{T_H - T_L}}$ $\qquad 0 < \beta < \infty$ $\qquad \frac{Q_L}{Q_H} = \frac{T_L}{T_H}$ (carnot)

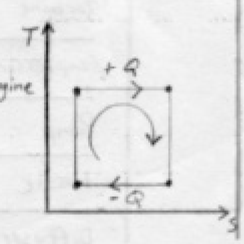
$COP_H = \gamma = \frac{Q_H}{W_{net}} = \frac{Q_H}{Q_H - Q_L}$ $\qquad 1 < \gamma < \infty$

$\gamma - \beta = 1$

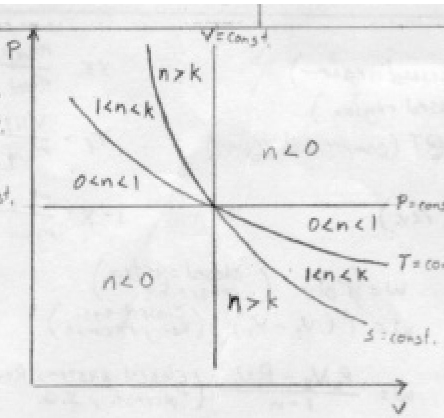
Heat Pump (rejects more heat than it adds)

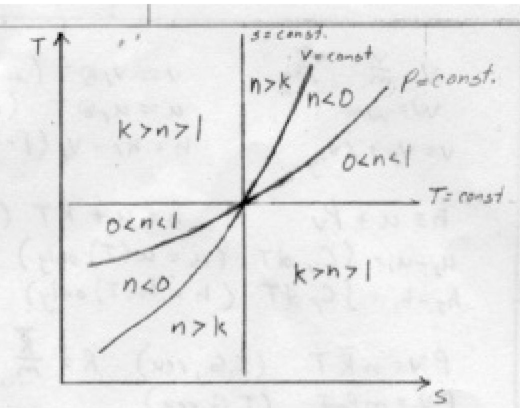


Heat Engine



$n=0 \Rightarrow P=\text{const.}$
$n=1 \Rightarrow T=\text{const.}$
$n=k \Rightarrow s=\text{const.}$
$n \to \infty \Rightarrow v=\text{const.}$





Isothermal => T = const.
Isobaric => P = const.
Adiabatic => $q = 0$
Polytropic => Pv^n = const. (I.G., c_p = const.)
Isentropic => $\Delta S = 0$ (reversible, adiabatic)
C_p = pressure specific heat
C_v = volume specific heat
q = heat transfer
u = internal energy
h = enthalpy
M = molecular weight
n = # kmols / # lbmols
s = entropy
$\bar{s}$ = s per mole

Turbines
Compressors
Pumps
Nozzles
Difussers

} Isentropic

$°R = °F + 459.67$
$°k = °C + 273.15$

$$\bar{R} = \begin{cases} 8.314 \ kJ/kmol \cdot °k \\ 1.986 \ BTU/lbmol \cdot °R \\ 1545 \ ft \cdot lbf/lbmol \cdot °R \end{cases}$$

$$\left(\frac{ft^2}{s^2}\right) = \left(\frac{ft^2}{s^2}\right)\left(\frac{1 \ BTU}{778 \ ft \ lbf}\right)\left(\frac{1 \ lbf}{32.2 \ lbm (ft/s^2)}\right) = \frac{BTU}{lbm} = \left(\frac{BTU}{lbf}\right)\left(\frac{32.2 \ lbm \ ft/s^2}{lbf}\right)\left(\frac{778 \ ft \ lbf}{BTU}\right) = \frac{ft^2}{s^2}$$

$$\left(\frac{m^2}{s^2}\right) = \left(\frac{m^2}{s^2}\right)\left(\frac{1 N}{1 \ kg \ m/s^2}\right)\left(\frac{1 J}{1 N \cdot m}\right) = J/kg \div 1000 = kJ/kg$$

$$P_r = \frac{P}{P_{crit}}$$
$$T_r = \frac{T}{T_{crit}}$$
$$Pv = ZRT$$

$-w$ if outside does work on system
if Q goes in its pos.
if w leaves its pos.

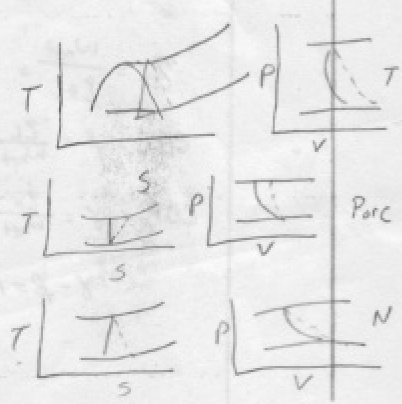
S.F. No change at a point w/respect to time

Device	η_{TH}	assumptions
Turbine	$\eta_T = \frac{W}{W_s}$	S.F., Q=0 (+) net work
Compressor	$\eta_C = \frac{W_s}{W}$	S.F., q=0
Pump	$\eta_p = \frac{W_s}{W}$	S.F., q=0
Nozzle	$\eta_N = \frac{\vec{V}^2}{\vec{V}_s^2}$	q=0, w=0, S.F.
Diffuser	$\eta_D = \frac{\Delta P}{\Delta P_s}$	q=0, w=0, S.F.

$\dot{V} = \vec{V} A$

$\frac{P_{r2}}{P_{r1}} = \frac{P_2}{P_1}$ isentropic

$\frac{V_{r2}}{V_{r1}} = \frac{V_2}{V_1}$ isentropic



$(m_2 - m_1)_{cv} + m_e - m_i = 0$

$$Q + m_i\left(h_i + \frac{\vec{V}_i^2}{2} + gz_i\right) = W + m_e\left(h_e + \frac{\vec{V}_e^2}{2} + gz_e\right) + m_2\left(u_2 + \frac{\vec{V}_2^2}{2} + gz_2\right) - m_1\left(u_1 + \frac{\vec{V}_1^2}{2} + gz_1\right) \quad U.S.U.F$$