Closed System:

1st Law of Thermodynamics

$w := \int P\,dv$ Closed System, Reversible,

$w := P(v_2 - v_1)$ P = Const.

$w := R(T_2 - T_1)$ P = Const. I.G.

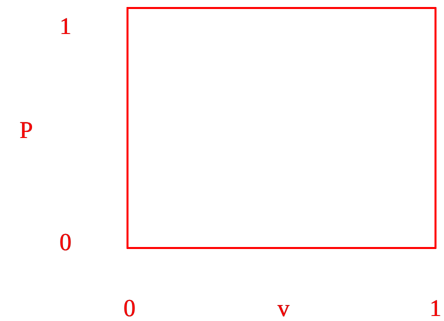
$w := P\cdot v\cdot \ln\left(\frac{v_2}{v_1}\right)$

$w := R\cdot T\cdot \ln\left(\frac{P_1}{P_2}\right)$ $n := 1$

$w := \frac{(P_2\cdot v_2 - P_1\cdot v_1)}{1-n}$ $n \neq 1$

C_p = Const.
T = Const.
Reversible
I.G.
Pv^n = Const.

$q - w := u_2 - u_1$ Closed System, Delta KE ~ 0, Delta PE ~ 0



Heat = Work

$\delta Q := \delta W$

X is Quality

$x := \frac{mass_{vap}}{mass_{total}}$ $1 - x := \frac{mass_{liq}}{mass_{total}}$

$v := v_f + x\cdot v_{fg}$ Saturated

$v \equiv v_f$ @ T Compressed

look up v in charts Superheated

$u := u_f + x\cdot u_{fg}$ Saturated

$u \equiv u_f$ @ T Compressed

look up u in charts Superheated

$h := u + Pv$ Always

look up h in charts Superheated

Steady Flow Systems (St. Fl.):

q's don't change form St. Fl. to Closed System

$w := -\int v\,dP$ Reversible, St. Fl., ΔKE ~ 0, ΔPE ~ 0

$w := -\int v\,dP - \left[\frac{(\upsilon_2{}^2 - \upsilon_1{}^2)}{2}\right] - g\cdot(z_2 - z_1)$ Reversible, St. Fl.

$w := n\cdot\frac{(P_2\cdot v_2 - P_1\cdot v_1)}{1-n}$

Pv^n = Const.
I.G.
n = 0, P = Const.
n = 1, T = Const.
n = κ, S = Const.
n to ∞, v = Const.
St. Fl.

$w := P\cdot v\cdot \ln\left(\frac{v_2}{v_1}\right)$

$w := R\cdot T\cdot \ln\left(\frac{P_1}{P_2}\right)$

Reversible
Isothermal
n = 1

$w := -v\cdot(P_2 - P_1)$ v = Const.

$w := -R\cdot(T_2 - T_1)$ I.G.

$m := \rho\upsilon A$ St. Fl.

$\rho := \frac{P}{R\cdot T}$ I.G.

$m := \frac{\upsilon A}{v}$ not an I.G.

$Q := q\cdot m$

$W := m\cdot w$ St. Fl.

m = mass flow rate (Const.)

1st Law of Thermodynamics

$$Q + \sum_{n=1}^{i} m_i\left[h_i + \frac{(\upsilon_i)^2}{2} + g\cdot z_i\right] = \sum_{n=1}^{i} m_i\left[h_i + \frac{(\upsilon_i)^2}{2} + g\cdot z_i\right]$$ St. Fl.

$q - w := h_2 - h_1$ St. Fl., ΔKE ~ 0, ΔPE ~ 0

Heat Engines:

q_h = heat gained

q_L = heat rejected

$\frac{q_H}{q_L} := \frac{T_H}{T_L}$ For Pumps or Engines

Thermal Efficiency

$\zeta_{th} := 1 - \frac{q_L}{q_H}$

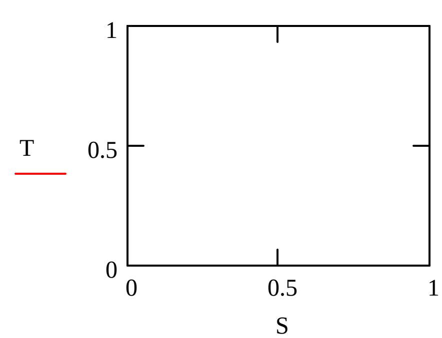
$\zeta_{th} := \frac{W_{net}}{q_H}$

Assume Carnot!

$\zeta_{th} := 1 - \frac{T_L}{T_H}$

$W_{net} := q_H - q_L$

$q := T\cdot(S_2 - S_1)$ reversible isothermal



Heat Pumps:

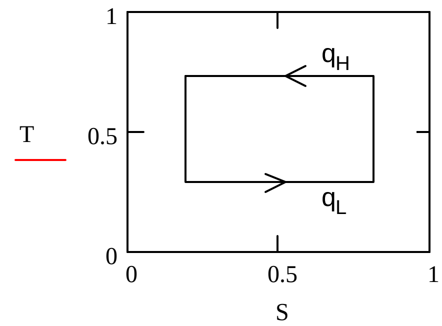
Coefficient of Performance

q_h = heat rejected
q_L = heat gained

$\frac{q_H}{q_L} := \frac{T_H}{T_L}$ For Pumps or Engines

$\alpha := \frac{q_H}{W_{net}}$ $\alpha := \frac{q_H}{q_H - q_L}$ $\alpha - \beta := 1$ $W_{net} := q_H - q_L$

$\beta := \frac{q_L}{W_{net}}$ $\beta := \frac{q_L}{q_H - q_L}$ $\frac{q_H}{q_H - q_L} := \frac{T_H}{T_H - T_L}$



$w := -v \cdot (P_2 - P_1)$

Other Equations:

$\frac{T_2}{T_1} := \left(\frac{P_2}{P_1}\right)^{\frac{(\kappa-1)}{\kappa}}$ Pv^κ = Const. which implies: S = Const. C_p = Const. I.G.

$P \cdot V := nR(bar) T$

$P \cdot V := mRT$

$R := \frac{R(bar)}{M}$ I.G. (all 5)

$\rho := \frac{P}{R \cdot T}$

$Pv := RT$ P < 10 MPa I.G. T > 2 T_{crit}

$q := \int T\, dS$ reversible

$q := T \cdot (S_2 - S_1)$ reversible isothermal

$TdS := du + Pdv$

$TdS := dh - vdP$

$\Delta S := C_v \cdot \ln\left(\frac{T_2}{T_1}\right) + R \cdot \ln\left(\frac{v_2}{v_1}\right)$

$\Delta S := C_p \cdot \ln\left(\frac{T_2}{T_1}\right) - R \cdot \ln\left(\frac{P_2}{P_1}\right)$

C_p = Const. I.G.

$\Delta S := \int C_p \cdot \frac{1}{T} dT - R \cdot \ln\left(\frac{P_2}{P_1}\right)$

$\Delta S := S_2^{\,0} - S_1^{\,0} - R \cdot \ln\left(\frac{P_2}{P1}\right)$

C_p (is not) = Const. I.G.

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

$C_p := \frac{\delta h}{\delta T}$ $\Delta h := C_p \cdot \Delta T$ h(T) only C_p = Const.

It's commonly an I.G.

$C_v := \frac{\delta u}{\delta T}$ $u_2 - u_1 := \int C_v\, dT$ u(T) only

It's commonly an I.G.

$\Delta u := C_v \cdot \Delta T$ u(T) only C_v = Const.

$C_p - C_v := R$ $\frac{C_p}{C_v} := \kappa$

if C_p = Const., then C_v = Const.

$C_p := \frac{(\kappa \cdot R)}{\kappa - 1}$ $C_v := \frac{R}{\kappa - 1}$

$h := u + Pv$ Always

$\frac{P_{r2}}{P_{r1}} := \frac{P_2}{P_1}$ Isentropic Cp is not Const. ΔS = 0

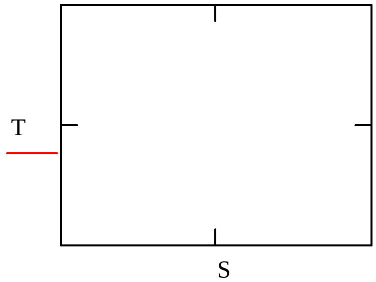
Throttling:

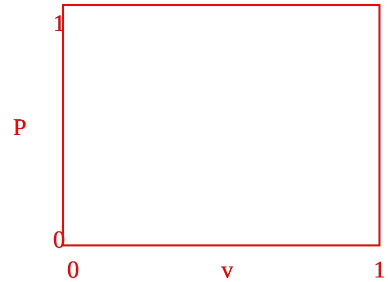
adiabatic
$h_1 = h_2$
absolutely not reversible

$h \sim h_f$ (@ T) + v_f (P - P_{sat}) compressed

or look in compressed tables

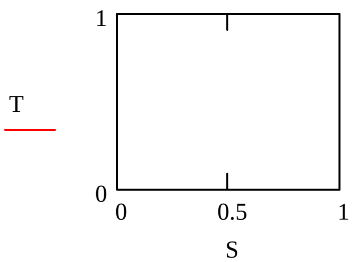
n = 0, P = const.
n = 1, T = const.
n = R, S = const.
n -> ∞, v = const.





Devices:

Turbines



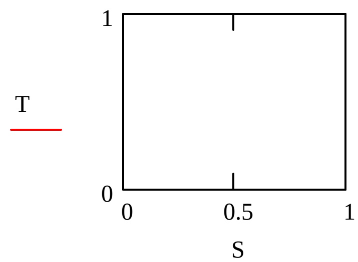
Adiabatic

Steady Flow

in Ideal case, Isentropic

$$\gamma_{tur} := \frac{W_a}{W_s}$$

Compressor



Adiabatic

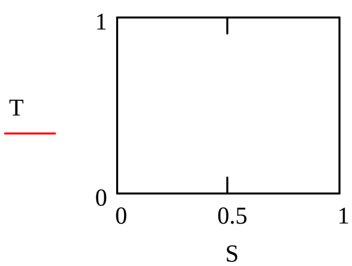
Steady Flow

I.G.

$$\gamma_{comp} := \frac{W_s}{W_a}$$

$$W_s := h_1 - h_{2s}$$

Pump



Adiabatic

Steady Flow

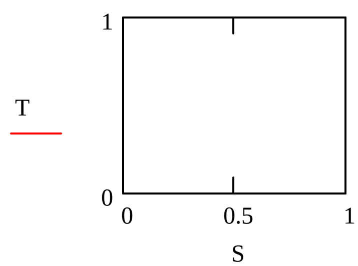
$$\gamma_{pump} := \frac{W_s}{W_a}$$

$$v := .001 \cdot \frac{m^3}{kg}$$

$$W_s := -v \cdot (P_2 - P_1)$$

$v := v_f$ @ T

Nozzle

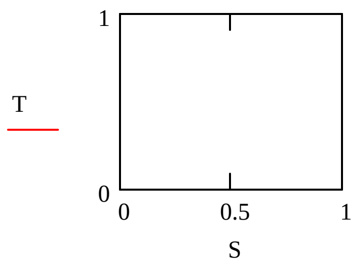


Adiabatic

Steady Flow

$$\gamma_{noz} := \frac{v_a^{\ 2}}{v_s^{\ 2}}$$

Diffuser



Adiabatic

Steady Flow

$\gamma_{diff} := \frac{\Delta P_a}{\Delta P_s}$

$\nu_1 > \nu_2$

$P_2 > P_1$

$$\left(\frac{P_1}{\rho}\right) + \left(\frac{\nu_1^{\,2}}{2}\right) + g \cdot z_1 := \left(\frac{P_2}{\rho}\right) + \left(\frac{\nu_2^{\,2}}{2}\right) + g \cdot z_2$$

for ν is less than .5 moch

3 Part Cycle:

$\frac{P_{r2}}{P_{r1}} := \frac{P_2}{P_1}$ Isentropic
Cp is not Const.
$\Delta S = 0$

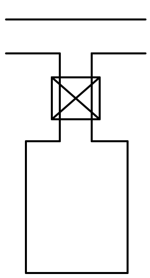
$T_2 := T_1 \cdot \left(\frac{P_2}{P_1}\right)^{\frac{(k-1)}{k}}$ Closed System

$q - w := \Delta u$ Closed System

$P \cdot v := n \cdot R \cdot T$ I.G.

$w := R \cdot T \cdot \ln\left(\frac{P_2}{P_1}\right)$ I.G.

USUF: (uniform state/ uniform flow)



i = in the tank
e = exit the tank
1 = initially in the tank
2 = final in tank

$$Q + m_i \cdot \left[h_i + \left(\frac{\nu_i^{\,2}}{2}\right) + g \cdot z_i\right] := W + m_e \cdot \left[h_e + \left(\frac{\nu_e^{\,2}}{2}\right) + g \cdot z_e\right] + m_2 \cdot \left[u_2 + \left(\frac{\nu_2^{\,2}}{2}\right) + g \cdot z_2\right] + m_1 \cdot \left[u_1 + \left(\frac{\nu_1^{\,2}}{2}\right) + g \cdot z_1\right]$$

Definitions:

Isothermal: T = Const.
Isentropic: S = Const. means (Reversible & Adiabatic)
Adiabatic: q = 0
Reversible: Both the system and surroundings can be returned to their initial state
Heat Engines: Thermo cycle with + net heat transfer and + net work
Heat Pumps: Thermo cycle with - net heat transfer and - net work
Steady Flow: No change @ a point with time
Throttling: Adiabatic, $h_1 = h_2$ (for single inlet, single outlet only), & Absolutely not Reversible
Pumps: Adiabatic
Turbines: Adiabatic
Compressors: Adiabatic
Nozzles: Adiabatic
Diffusers: Adiabatic

Units Conversions:

Charts:

Description	SI	English
Air	p. 840	p. 890
Critical Properties	p. 803	p. 851
Critical Property Graphs	p. 899	p. 851
H_2O	p. 804	p. 852
Propane	p. 832	p. 881
R-22	p. 814	p. 864
I.G. Properties of Selected Gases	p. 842	p. 892
Thermo Properties of selected Subs.	p. 847	p. 897
I.G. Specific Heats of common Gases	p. 838	p. 888

Properties of Various Ideal Gases

SI Units

Gas	Chemical Formula	Molecular Weight	$R(\frac{KJ}{Kg°K})$	$C_p(\frac{KJ}{Kg°K})$	$C_v(\frac{KJ}{Kg°K})$	k
Air	-	28.97	.28700	1.0035	.7165	1.400
Argon	Ar	39.948	.20813	.5203	.3122	1.667
Butane	C_4H_{10}	58.124	.14304	1.7164	1.5734	1.091
Carbon Dioxide	CO_2	44.01	.18892	.8418	.6529	1.289
Carbon Monoxide	CO	28.01	.29683	1.0413	.7445	1.400
Ethane	C_2H_6	30.07	.27650	1.7662	1.4897	1.186
Ethylene	C_2H_4	28.054	.29637	1.5482	1.2518	1.237
Helium	He	4.003	2.07703	5.1926	3.1156	1.667
Hydrogen	H_2	2.016	4.12418	14.2091	10.0819	1.409
Methane	CH_4	16.04	.51835	2.2537	1.7354	1.299
Neon	Ne	20.183	.41195	1.0299	.6179	1.667
Nitrogen	N_2	28.013	.29680	1.0416	.7448	1.400
Octane	C_8H_{18}	114.23	.07279	1.7113	1.6385	1.044
Oxygen	O_2	31.999	.25983	.9216	.6618	1.393
Propane	C_3H_8	44.097	.18855	1.6794	1.4909	1.126
Steam	H_2O	18.015	.46152	1.8723	1.4108	1.327

English Units

Gas	Chemical Formula	Molecular Weight	$R(\frac{ft \cdot lb_f}{lb_m °R})$	$C_p(\frac{Btu}{lb_m °R})$	$C_v(\frac{Btu}{lb_m °R})$	k
Air	-	28.97	53.34	.240	.171	1.400
Argon	Ar	39.94	38.68	.1253	.0756	1.667
Butane	C_4H_{10}	58.124	26.58	.415	.381	1.09
Carbon Dioxide	CO_2	44.01	35.10	.203	.158	1.285
Carbon Monoxide	CO	28.01	55.16	.249	.178	1.399
Ethane	C_2H_6	30.07	51.38	.427	.361	1.183
Ethylene	C_2H_4	28.054	55.07	.411	.340	1.208
Helium	He	4.003	386.0	1.25	.753	1.667
Hydrogen	H_2	2.016	766.4	3.43	2.44	1.404
Methane	CH_4	16.04	96.35	.532	.403	1.32
Neon	Ne	20.183	76.55	.246	.1477	1.667
Nitrogen	N_2	28.016	55.15	.248	.177	1.400
Octane	C_8H_{18}	114.22	13.53	.409	.392	1.044
Oxygen	O_2	32.000	48.28	.219	.157	1.395
Propane	C_3H_8	44.097	35.04	.407	.362	1.124
Steam	H_2O	18.016	85.76	.445	.335	1.329

SI: (C_p, C_v, & κ are at 300 K), English: (C_p, C_v, & κ are at 80 F)