$T_K = T°C + 273,15$

$\rho = \frac{M}{V}$ $\quad v = \frac{1}{\rho}$

$\Delta U = Q^{\leftarrow} - L^{\rightarrow}$

$\nu = \frac{\mu}{\rho}$ $[m^2/s]$ viscosità cinematica

$p = \rho g h$ legge di Stevino

$R = 8,314$ J/kmol $\quad R^*$ [J/kgK]

1 cal = 4,186 J
1 CV = 0,735 kW
1 kWh = 3600 kJ

1 atm = 101325 Pa = 760 mmHg
1 mmHg = 133,322 Pa
1 bar = 10^5 Pa
1 mmH_2O = 9806 Pa
1 ata = 98066,5 Pa

LEGGE DI BOYLE $PV = cost$

LEGGE DI CHARLES $V/T = cost$

LEGGE DI AMONTONS $P/T = cost$

LEGGE DI STATO GAS IDEALE $pV = nRT \rightsquigarrow pV = MR^*T$ $\quad$ $R^* \to R/m_m$

$P/\rho = R^*T$

RELAZIONE DI MAYER $c_p = c_v + R$

GAS MONOATOMICI $c_v = \frac{3}{2}R \quad c_p = \frac{5}{2}R$

GAS BIATOMICI $c_v = \frac{5}{2}R \quad c_p = \frac{7}{2}R$

GAS POLIATOMICI NON LINEARI $c_v = 3R \quad c_p = 4R$

ISOENTROPICHE $\rightsquigarrow$ $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{R/c_p = \gamma - 1/\gamma}$ $\quad \gamma = \frac{c_p}{c_v}$

$\frac{P_2}{P_1} = \left(\frac{T_2}{T_1}\right)^{\gamma/\gamma-1} \left(\frac{v_1}{v_2}\right)^{\gamma}$ $\quad \beta_v = \frac{v_1}{v_2}$ $\quad \beta = \frac{P_2}{P_1} = \left(\frac{T_2}{T_1}\right)^{c_p/R}$

BILANCIO DI MASSA $\frac{dM}{dt} = \sum \dot{m}_i$

BILANCIO DI ENERGIA $\frac{dE}{dt} = \sum \dot{m}_i h_i + \dot{Q}^{\leftarrow} - \dot{L}^{\rightarrow}$

BILANCIO DI ENTROPIA $\frac{dS}{dt} = \sum \dot{m}_i s_i + \dot{S}_Q^{\leftarrow} + \dot{S}_{irr\,gen}$ $\quad S_Q = \frac{Q_0}{T_0}$

$\Delta U = M c_v (T_{fin} - T_{in})$ gas perfetti
$\quad = M c (T_{fin} - T_{in})$ liquidi e solidi

$\Delta S = M\left(c_v \ln \frac{T_2}{T_1} + R \ln \frac{V_2}{V_1}\right)$
$\quad = M\left(c_p \ln \frac{V_2}{V_1} + c_v \ln \frac{P_2}{P_1}\right)$ gas perfetti
$\quad = M\left(c_p \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1}\right)$
$\quad = Mc \ln \frac{T_{fin}}{T_{in}}$ liquidi e solidi

ADIABATICO $\to Q^{\leftarrow} = 0 \wedge S_Q^{\leftarrow} = 0$
\+ REVERSIBILE $\to S_{irr} = 0$
= ISOENTROPICO $\to \Delta S = 0$
ISOLATO $\to Q^{\leftarrow} = 0 \wedge L^{\rightarrow} = 0$

$\Delta H = M c_p (T_{fin} - T_{in})$ gas perfetti
$\quad = U + PV = M[c(T_{fin} - T_{in}) + v(p_{fin} - p_{in})]$ liquidi e solidi

Per processo isobaro: $\Delta H = \Delta U$

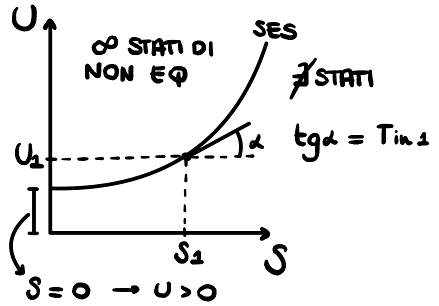
$\dot{M} = \rho W A \quad c = \sqrt{\gamma R T}$

Per liq incomprimibili: $s_i = s_0 + c \ln \frac{T_i}{T_0} = (s_0 - c \ln T_0) + c \ln T_i$

" : $U = U_0 + c_v (T - T_0)$

$\Delta\Omega = -T_R \Delta S + \Delta U \longrightarrow \Delta S = \frac{1}{T_R}(\Delta U - \Delta\Omega)$

per essere SES: $\Psi = 0$



$U_1 - U_2 = \Psi_1 - \Psi_2 \Rightarrow \exists\, PMR_{1\to2}$

$U_1 - U_2 < \Psi_1 - \Psi_2 \Rightarrow \exists\, PM_{1\to2}$

$U_1 - U_2 > \Psi_1 - \Psi_2 \Rightarrow \nexists\, PM_{1\to2}$

$U_1 - U_2 = \Omega_1 - \Omega_2 \Rightarrow \exists\, PMR_{1\to2}$

$U_1 - U_2 < \Omega_1 - \Omega_2 \Rightarrow \exists\, PM_{1\to2}$

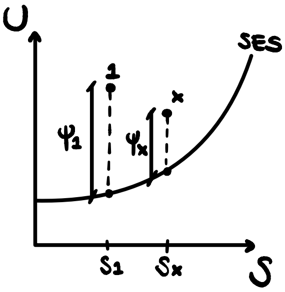
$U_1 - U_2 > \Omega_1 - \Omega_2 \Rightarrow \nexists\, PM_{1\to2}$

EQ DI STATO DEI LIQUIDI: $h = h_0 + c(T - T_0) + v(P - P_0)$

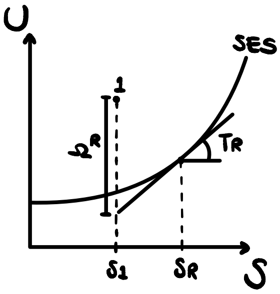
Nei PM: $S_{fin} \geq S_{in}$

PROC ISOBARO: $L_{12}^{A\to} = P\Delta V = \int_1^2 P\,dV$

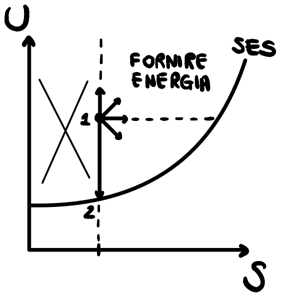
$= L_{FEST} = \int_{H_1}^{H_2} Mg\,d\vec{z} + \int_{H_1}^{H_2} P_{atm} A\,d\vec{z} = Mg\Delta H + P_{atm} A \Delta H$



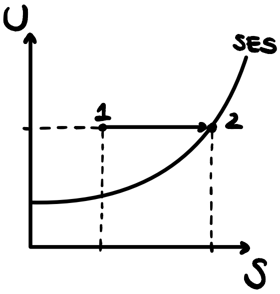
DISP ADIABATICA
$\Psi_x < U_x$ sempre
SES hanno $\Psi = 0$



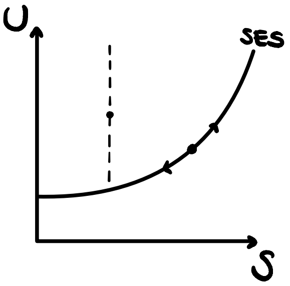
ENERGIA DISP
RISPETTO AD UN
SERBATOIO



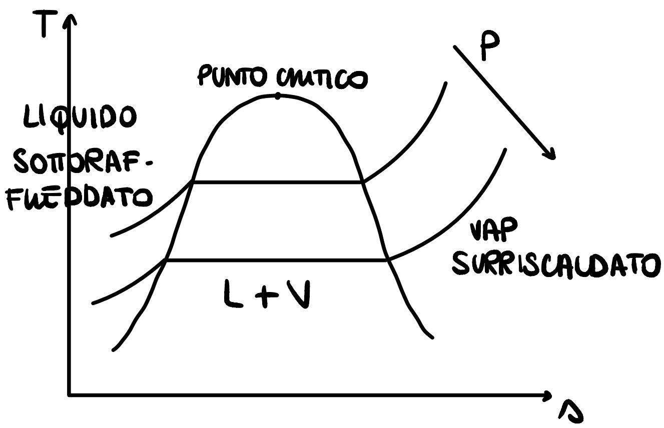
PROC MECCANICO
$L_{1\to2}$: MAX ESTRAIBILE



PROC SPONTANEO
Energia cost
Disp ad diminuisce
Entropia aumenta
In sistemi isolati



PROC QUASISTATICO
sist può evolvere
attraverso SES
scambio di solo calore
proc reversibile



APPROSSIMAZIONE LIQUIDO SOTTORAFFREDDATO

$u = u_{l@T}$

$h_2 = h_{l@T_1} + v_{l@T_1}(P_2 - P_{SAT@T_1})$

$s = s_{l@T} - \alpha_P v_{l@T}(P - P_{SAT@T})$

BIFASE LIQUIDO - VAPORE

$x = \frac{M_v}{M_{TOT}}$ $\quad 0 < x < 1$

$u_l < u < u_v$
h
s

REGOLA DELLA LEVA

$u = (1-x)u_l + x u_v = u_l + \underbrace{(u_v - u_l)}_{u_{lv}} x \sim x = \frac{u - u_l}{u_v - u_l}$

h
s
v

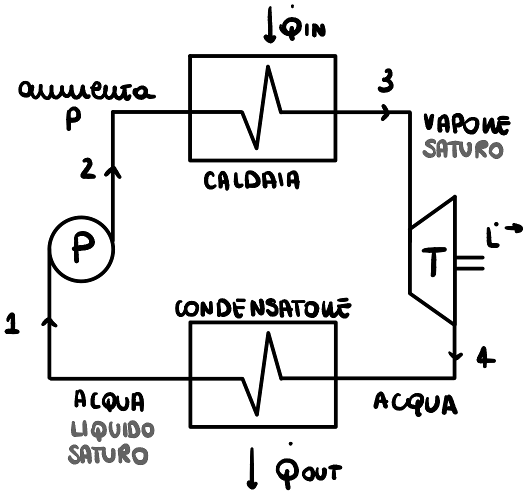
$U = mu$

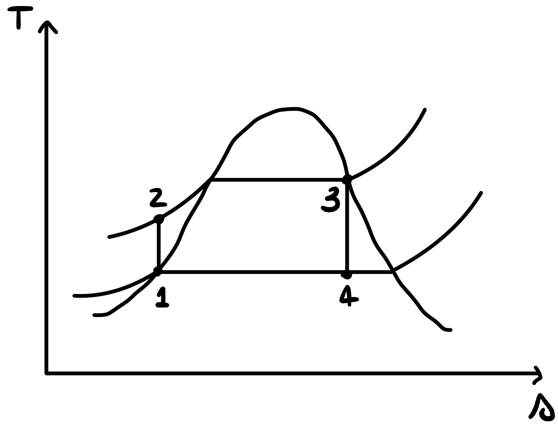
$\Delta P = \frac{\alpha_P}{k_T} \Delta T$

INTERPOLAZIONE LINEARE

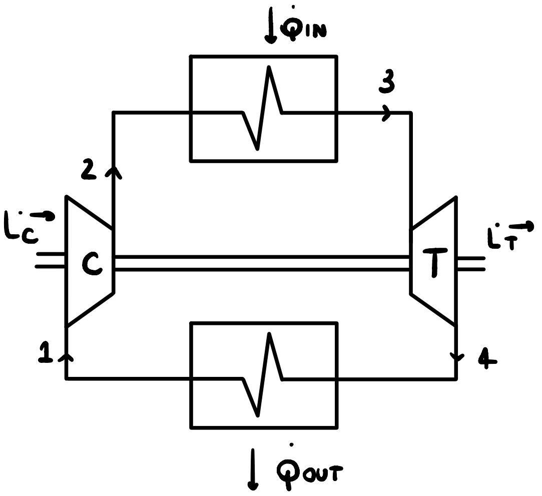
$y = y_1 + \frac{x - x_1}{x_2 - x_1}(y_2 - y_1)$

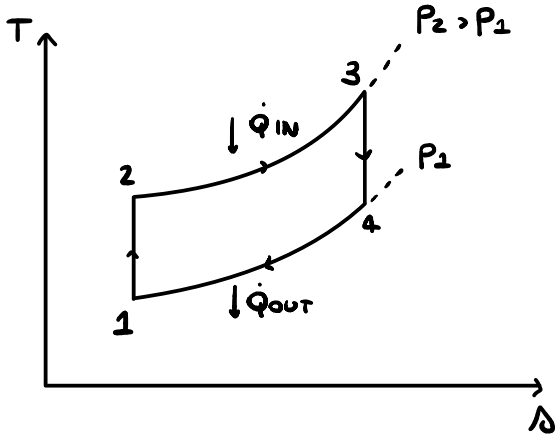
CICLO RANKINE IDEALE





CICLO JOULE - BRYTON





$$\eta_{JB} = \frac{\dot{L}_u}{\dot{Q}_{IN}} = 1 - \frac{q_{OUT}}{q_{IN}} \overset{GP}{=} 1 - \frac{T_4 - T_1}{T_3 - T_2}$$

$$\eta_{JB\,rig} = \frac{l_T - l_C}{q_{H\,rig}}$$

prima di combustore η
temp gas in uscita dal compr = temp gas in uscita dalla turbina prima di immetterli in camera di comb

$$\eta_{CARNOT} = 1 - \frac{T_C}{T_H} \qquad \eta_{OTTO} = 1 - \frac{T_1}{T_2}$$

$$\eta_{I} = \frac{\dot{L}_u}{\dot{Q}_{IN}} \qquad \eta_{II} = \frac{\eta_I}{1 - \frac{T_1}{T_3}}$$

$$\varepsilon^{frigo} = \frac{Q_{IN}}{Q_{OUT} - Q_{IN}} = \frac{T_C}{T_H - T_C} = \frac{Q_{IN}}{L}, \quad L = L_C - L_T$$

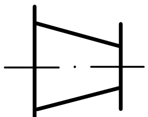
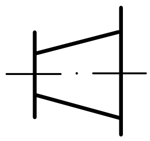
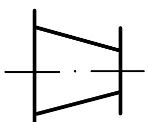
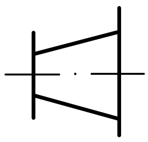
$$COP^{pompa} = \frac{Q_{OUT}}{Q_{OUT} - Q_{IN}} = \frac{T_H}{T_H - T_C} = \frac{Q_{OUT}}{L}$$

$$\eta^{IS}_{COMPR} = \frac{\overleftarrow{\dot{L}}_{IS}}{\overleftarrow{\dot{L}}_{reale}} \qquad \eta^{IS}_{TURB} = \frac{\overrightarrow{\dot{L}}_{reale}}{\overrightarrow{\dot{L}}_{IS}}$$

$$\overleftarrow{\dot{L}}_{rev} = \dot{m}(h_1 - h_2) - \dot{m}T_0(s_1 - s_2) - T_0 S_{irr}$$

$$\eta_{COMPR} = \frac{\overleftarrow{\dot{L}}_{rev}}{\overleftarrow{\dot{L}}} \qquad \eta_{TURB} = \frac{\dot{L}}{\dot{L}_{rev\,max}} = \frac{T_1 - T_2}{T_1' - T_2}$$

$$\eta_{RANK} = \frac{l_T - l_P}{q_{IN}}$$

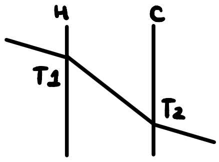
	CONVERGENTI MACH < 1	DIVERGENTI MACH > 1
$W < C$ $\frac{dW}{dA} < 0$ flussi subsonici	 $A\downarrow \Rightarrow W\uparrow$ p_1 $p_2 < p_1$ $W_1 < C$ $C > W_2 > W_1$ $W_2 \le C$	 $A\uparrow \Rightarrow W\downarrow$ p_1 $p_2 > p_1$ $W_1 < C$ $W_2 < W_1 < C$
$W > C$ $\frac{dW}{dA} > 0$ flussi supersonici	 $A\downarrow \Rightarrow W\downarrow$ p_1 $p_2 > p_1$ $W_1 < C$ $W_2 < W_1$	 $A\uparrow \Rightarrow W\uparrow$ p_1 $p_2 < p_1$ $W_1 > C$ $W_2 > W_1 > C$

per errore:

$$\frac{\eta - \eta'}{\eta'} = \frac{\Delta\eta}{\eta'} < 1\%$$

CONDUZIONE

$q = \frac{dQ}{dA}$ flusso termico



PROFILO LINEARE: $\dot{\varphi} = \frac{T_1 - T_2}{\underbrace{\frac{L}{kA}}_{R_k}}$

GEOM CILINDRICA: $\dot{\varphi} = \frac{T_1 - T_2}{\underbrace{\frac{\ln(R_2/R_1)}{2\pi H k}}_{R_{k\,cil}}}$ $\quad R_2 \rightarrow$ EST, $R_1 \rightarrow$ INT

GEOM SFERICA: $\dot{\varphi} = \frac{T_1 - T_2}{\underbrace{\frac{1}{4\pi k}\left(\frac{1}{R_1} - \frac{1}{R_2}\right)}_{R_{cond}}}$

GEOM	R_k	R_{conv}
PIANA	$\frac{L}{kA}$	$\frac{1}{hA}$
CIL	$\frac{\ln(R_o/R_i)}{2\pi H k}$	$\frac{1}{h 2\pi H r}$
SFER	$\frac{1}{4\pi k}\left(\frac{1}{R_i} - \frac{1}{R_o}\right)$	$\frac{1}{h 4\pi r^2}$

$\dot{\varphi}_{convettiva} = \frac{T - T_{rif}}{\underbrace{\frac{1}{hA}}_{R_{conv}}}$

RESISTENZA CONDUTTIVA: $R_k \rightarrow k$

RESISTENZA CONVETTIVA: $R_c \rightarrow h$ $\qquad \sigma = \frac{\varphi}{V}$

GENERAZIONE DI POTENZA (EQ ENERGIA STATO STAZIONARIO MONODIM CON σ)

$\frac{d^2T}{dx^2} = -\frac{\sigma}{k} \qquad T(x) = -\frac{\sigma}{k}\frac{x^2}{2} + C_1 x + C_2 \qquad q(x) = \sigma x - k C_1$

x CIL : $T(r) = -\frac{\sigma}{4k} r^2 + C_1 \ln r + C_2 \qquad q(r) = \frac{\sigma}{2} r - \frac{k C_1}{r}$

$r < r_c$ $Q\uparrow$ se $r\uparrow$

$r > r_c$ $Q\downarrow$ se $r\uparrow$

Raggio che massimizza lo scambio termico: $r_c = k/h$ geom cilindrica; $r_c = 2k/h$ geom sferica

CONDUZIONE IN REGIME VARIABILE $\ln \frac{T - T_\infty}{T_i - T_\infty} = -\frac{hA}{\rho c V} t$ $\quad \frac{A}{V} \rightarrow \frac{1}{L_c}$ $\quad \leftarrow \dot{\varphi} = hA(T - T_\infty)$

$mc\frac{dT}{dt} = -hA(T - T_\infty)$

BIOT $Bi = \frac{hL_c}{k_{sol}}$ $\quad Bi < Bi_{cr} = 0{,}1$

parametri concentrati se $Bi < 0{,}1$

CONVEZIONE

$q_c = h(T_w - T_\infty)$

Diametro idraulico $= \frac{4 \cdot Area}{Perimetro}$

$\nu = \frac{\mu}{\rho}$ viscosità cinematica

$\frac{\mu c_p}{k} = \frac{\nu}{\alpha}$ $\qquad A_{sfera} = 4\pi r^2$

$\alpha = \frac{k}{\rho c_p}$ diffusività termica

NUSSELT $Nu = \frac{hL_c}{k_{fluido}}$ $\qquad Nu_D = \frac{hD}{k}$ $\qquad L_c = \frac{V}{A}$

REYNOLDS $Re = \frac{v L_c}{\nu}$ $\qquad Re_D = \frac{\rho U_\infty D}{\mu}$

PRANDTL $Pr = \frac{\nu}{\alpha} = \frac{\mu c_p}{k}$

GEOM	L_c
PIANA	L
CIL	D/4
SFER	D/6

GRASHOF $Gr = \frac{\rho^2 g \beta (T_w - T) L_c^3}{\mu^2}$ $\quad \beta$ per GP $\rightarrow \frac{1}{T} = \frac{1}{\frac{T_w + T_\infty}{2}}$ $\quad$ vert $L_c = H$, orizz $L_c = \frac{A}{2p}$

RAYLEIGH $Ra = Gr \cdot Pr$

CONVEZIONE NATURALE $Nu = 0{,}55\, Ra^{0{,}25}$

$\frac{Gr}{Re^2}$: $\gg 1$ CONV NAT; $\ll 1$ CONV FORZ; ~ 1 MIST

SCAMBIATORE DI CALORE

$\dot{\varphi} = hA\Delta T_{m,ln} = hA \frac{\theta_{IN} - \theta_{OUT}}{\ln(\theta_{IN}/\theta_{OUT})}$ $\quad A = \pi D_i L$

$\Delta T_{m,ln} < \Delta T_M = \frac{\theta_{IN} + \theta_{OUT}}{2}$

$\Delta P = \frac{1}{2}\rho L f \frac{1}{D} v^2$

$\theta_{IN} = T_W - T_{IN}$

$\theta_{OUT} = T_W - T_{OUT}$

$\dot{Q}_{liq\,inc} = \dot{m} c (\theta_{IN} - \theta_{OUT})$

IRRAGGIAMENTO

$\lim_{A_1/A_2 \to 0} \dot{\varphi}_{12} = \frac{\sigma A_1 \varepsilon_1 (T_1^4 - T_2)}{\frac{1-\varepsilon_1}{\varepsilon_1} + \frac{1}{F_{12}} + 0}$

$\vec{\dot{\varphi}}_{12} = \frac{\sigma(T_1^4 - T_2^4)}{\frac{1-\varepsilon}{\varepsilon_1 A_1} + \frac{1}{F_{12}A_1} + \frac{1-\varepsilon_2}{\varepsilon_2 A_2}} = \sigma A_1 \varepsilon_1 (T_1^4 - T_2^4)$ corpo piccolo in ambiente + grande

α ASSORBANZA

ρ RIFLETTANZA

τ TRASMITTANZA $\rightarrow 0$ in corpi opachi

$\lambda_{MAX} T = 2897{,}6\ \mu m \cdot K \qquad \sigma = 5{,}67 \cdot 10^{-8}\ W/m^2K^4$

$1 = \alpha + \tau + \rho \qquad \alpha = \varepsilon$ corpo grigio

$\rho = 0 \quad \varepsilon = 1$ corpo nero

$F_{12}A_1 = F_{21}A_2 \qquad G = \frac{\dot{\varphi}}{A}$ irradianza