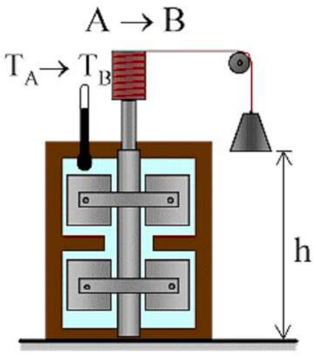
CORSO DI FISICA TECNICA II



Elementi di termodinamica

Parte seconda

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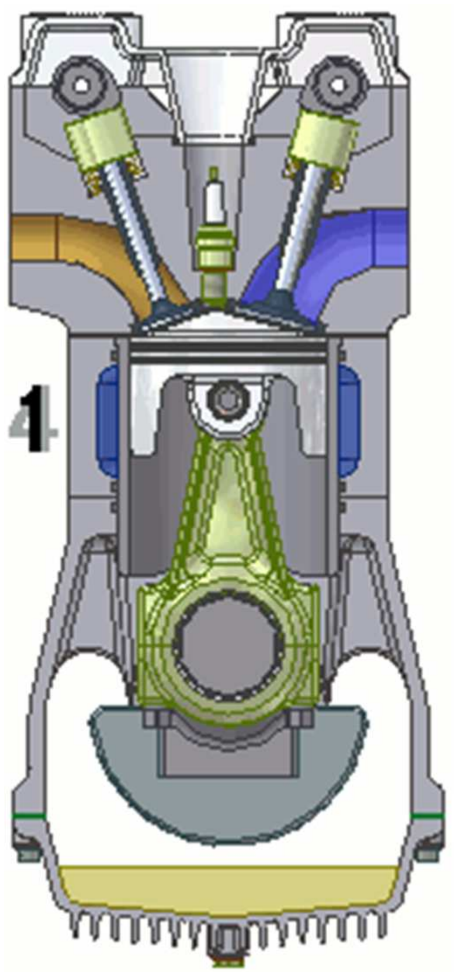
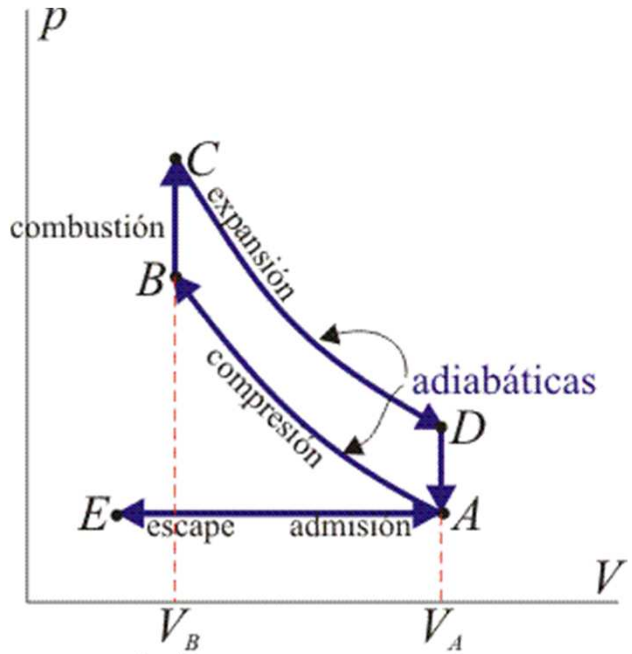
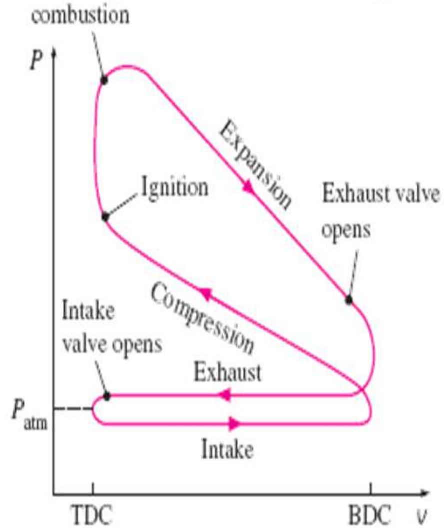
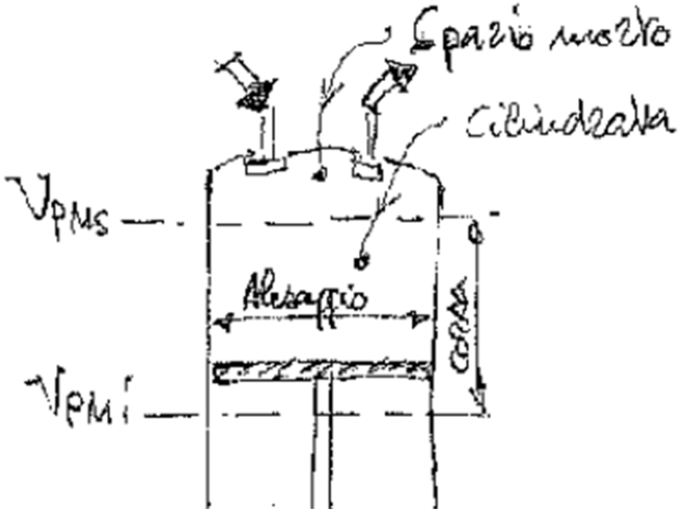
Ciclo OTTO

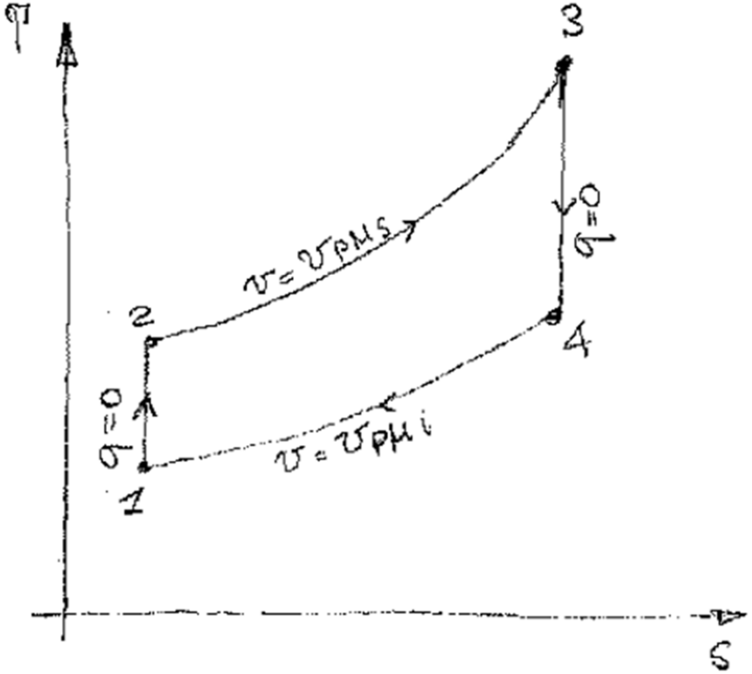
http://www.youtube.com/watch?v=e9-kRh1s18Y&feature=related

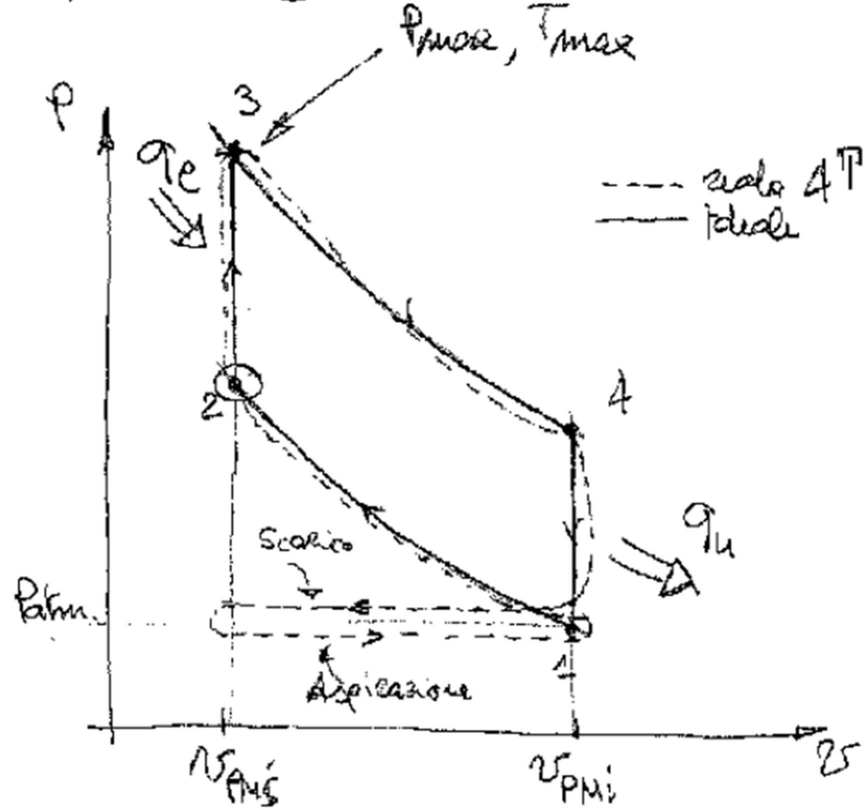







Spazio morto
Cilindrata
V_{PMS}
V_{PMI}
Alesaggio
CORSA


T
s
1
2
3
4
q=0
q=0
$v = v_{PMS}$
$v = v_{PMI}$


p
v
p_{max}, T_{max}
1
2
3
4
q_e
q_u
reale 4T
ideale
Scarico
Aspirazione
Patm.
v_{PMS}
v_{PMI}

ρ = rapporto volumetrico di compressione = $\frac{v_{PMI}}{v_{PMS}}$

$$\eta_i = \frac{l_u}{|q_e|} = 1 - \frac{|q_u|}{|q_e|} = 1 - \frac{T_4 - T_1}{T_3 - T_2}$$

dove $|q_e| = c_v (T_3 - T_2)$ perché $\underbrace{du = \delta q - \delta l}_{\text{ciclo chiuso}}$ ($c_v dT$; $v = \text{cost}$)

$|q_u| = c_v (T_4 - T_1)$

Considerando le due adiabatiche : $T v^{k-1} = \text{cost} \Rightarrow T_1 v_1^{k-1} = T_2 v_2^{k-1}$

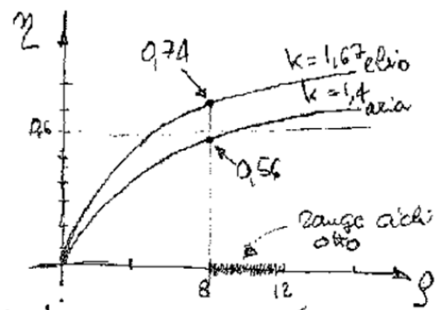
$$\frac{T_1}{T_2} = \left(\frac{v_2}{v_1}\right)^{k-1} \quad \text{e} \quad \frac{T_3}{T_4} = \left(\frac{v_4}{v_3}\right)^{k-1}$$

$$\eta = 1 - \frac{T_1}{T_2} \cdot \frac{\cancel{\frac{T_4}{T_1} - 1}}{\cancel{\frac{T_3}{T_2} - 1}} = \boxed{1 - \frac{1}{\rho^{k-1}}}$$

Rendimento termico ciclo OTTO

ma $v_3 = v_2$ e $v_1 = v_4$

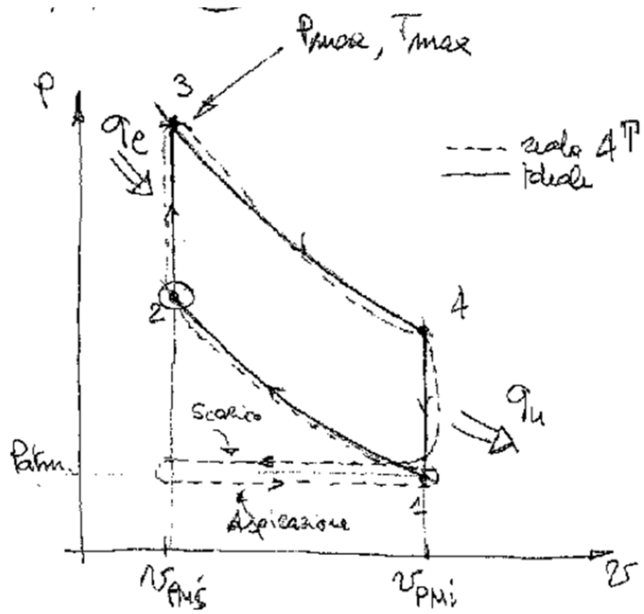
$$\frac{T_1}{T_2} = \left(\frac{v_2}{v_1}\right)^{k-1} = \left(\frac{v_3}{v_4}\right)^{k-1} = \frac{T_4}{T_3} = \left(\frac{1}{\rho}\right)^{k-1}$$



Notare che in 2 inizia la combustione della miscela; $T_2 = T_1 \cdot \rho^{k-1}$

se $\rho \uparrow \Rightarrow T_2 \uparrow$

Ci sono dei limiti per ρ, affinché non si inneschi l'autocombustione, quindi η_c non può essere aumentato migliorando sempre ρ.

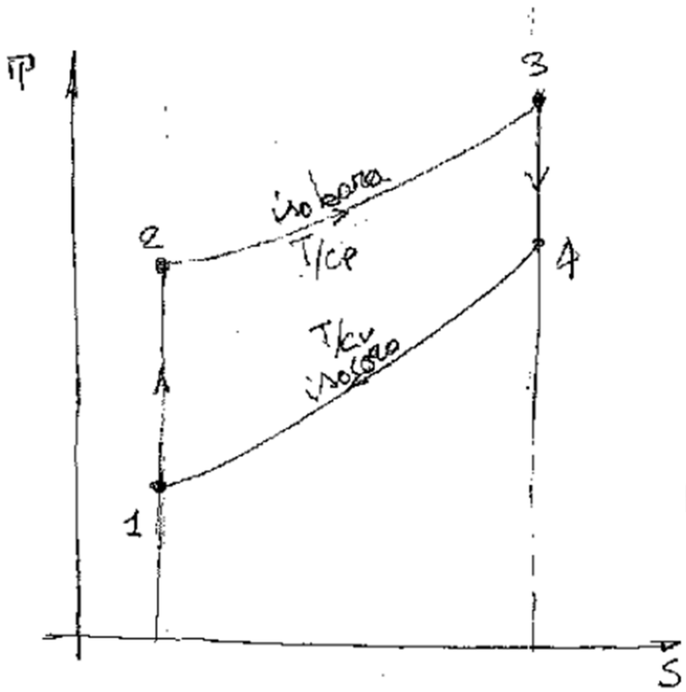


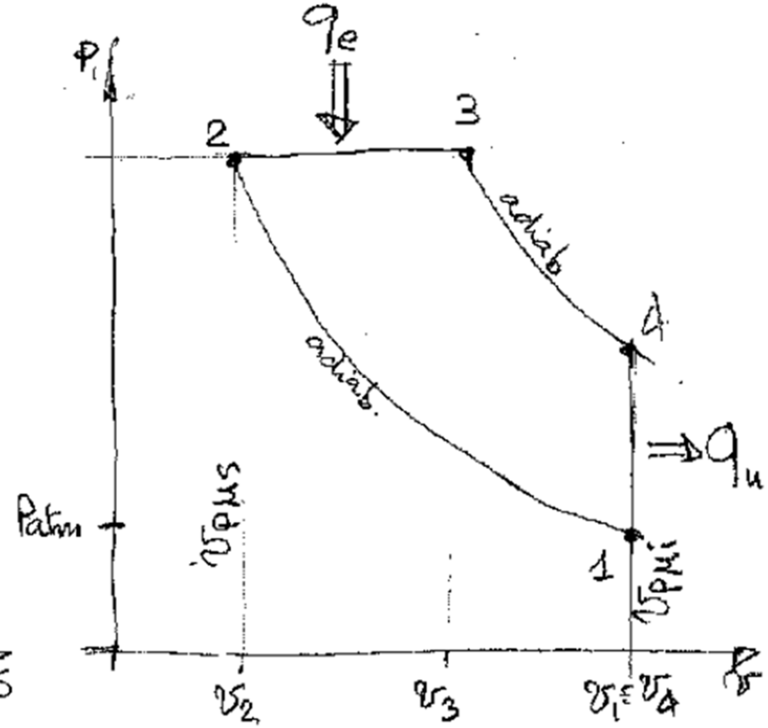
$$\ell_M = q - c_v\left(T_4 - T_1\right) = q\cdot\left(1 - \frac{1}{\rho^{k-1}}\right)$$

$$p_{m,eff} = \frac{\ell_M}{V_{PMI} - V_{PMS}}$$

IDEALE	T	v	p
1	T_1	v_1 PMI	p_1
2	$T_1 \cdot \rho^{k-1}$	$\frac{v_1}{\rho}$ PMS	$\frac{R T_1}{v_1}\rho^k$
3	$T_1\rho^{k-1} + \frac{q_e}{c_v}$	$\frac{v_1}{\rho}$ PMS	$\frac{R T_1 \rho^k}{v_1} + \frac{R \rho q_e}{c_v \cdot v_1}$
4	$T_1 + \frac{q_e}{c_v \cdot \rho^{k-1}}$	v_1 PMI	$\frac{R T_1}{v_1} + \frac{R q_e}{c_v v_1 \cdot \rho^{k-1}}$

Ciclo DIESEL





Analoghe ipotesi fatte per il ciclo Otto, al posto della prima isocora, ho una isobara che rappresenta la combustione della miscela in fase di espansione.

$$|q_e| = \Delta h = c_p (T_3 - T_2)$$

$$|q_u| = \Delta u = c_v (T_4 - T_1)$$

$$\eta = 1 - \frac{|q_u|}{|q_e|} = 1 - \frac{c_v (T_4 - T_1)}{c_p (T_3 - T_2)}$$

Lungo le due isoentropiche vale come per il ciclo OTTO, ovvero ricordando $T v^{k-1} = cost$

$$\frac{T_4}{T_1} = \frac{T_3 \cdot \left(\frac{v_3}{v_4}\right)^{k-1}}{T_2 \cdot \left(\frac{v_2}{v_1}\right)^{k-1}} = \frac{T_3}{T_2} \cdot \frac{\left(\tau \frac{v_2}{v_1}\right)^{k-1}}{\left(\frac{v_2}{v_1}\right)^{k-1}} = \tau \cdot \tau^{k-1} = \tau^k$$

come isobara $\frac{T_3}{v_3} = \frac{T_2}{v_2} \Longrightarrow \frac{T_3}{T_2} = \frac{v_3}{v_2} = \tau$

$$\eta = 1 - \frac{1}{k} \cdot \frac{T_1}{T_2} \cdot \frac{\frac{T_4}{T_1} - 1}{\frac{T_3}{T_2} - 1}$$

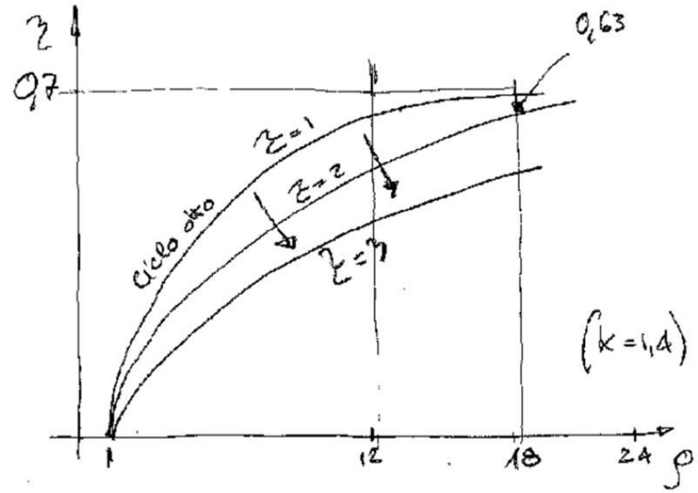
← posto τ = rapporto volumetrico di introduzione = v_3/v_2

$$= 1 - \frac{1}{k} \cdot \frac{1}{\rho^{k-1}} \cdot \frac{\tau^k - 1}{\tau - 1}$$

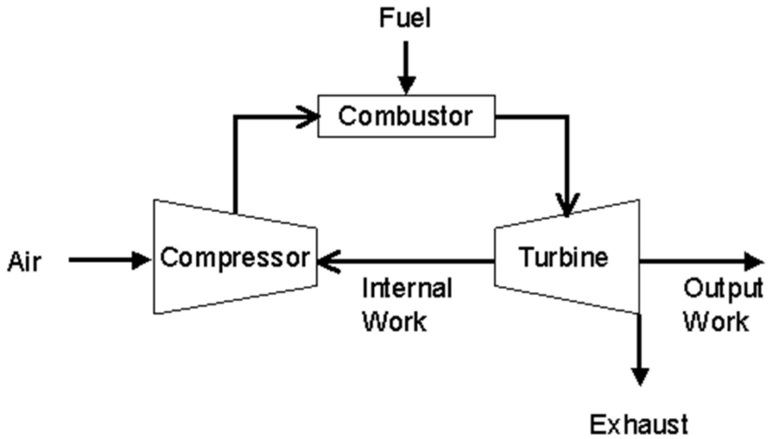
$\eta_{Diesel} < \eta_{OTTO}$ a parità di rapporto volumetrico di compressione

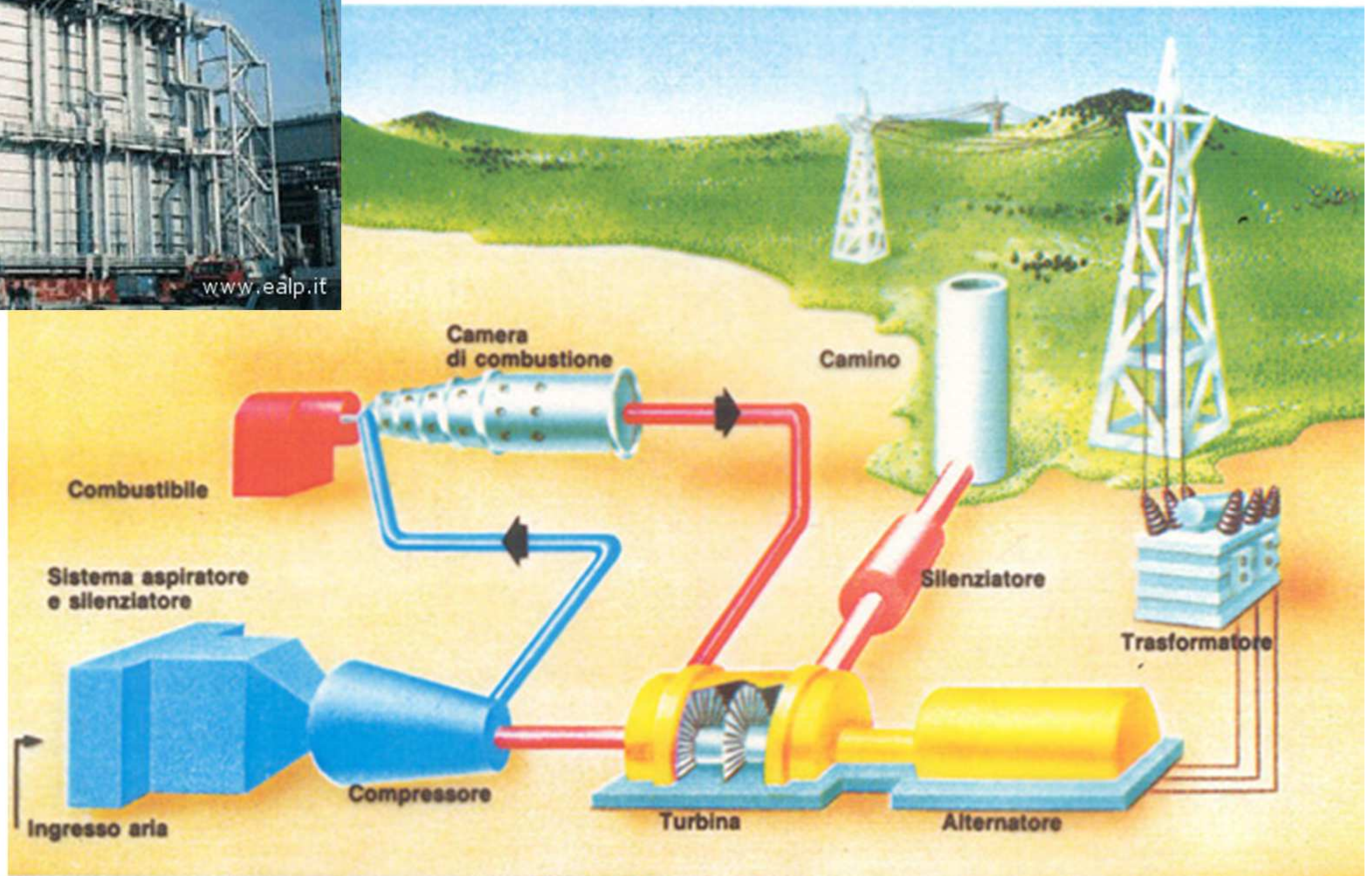
Siccome però $\rho_{Diesel} > \rho_{OTTO} \Longrightarrow \eta_{Diesel} > \eta_{OTTO}$

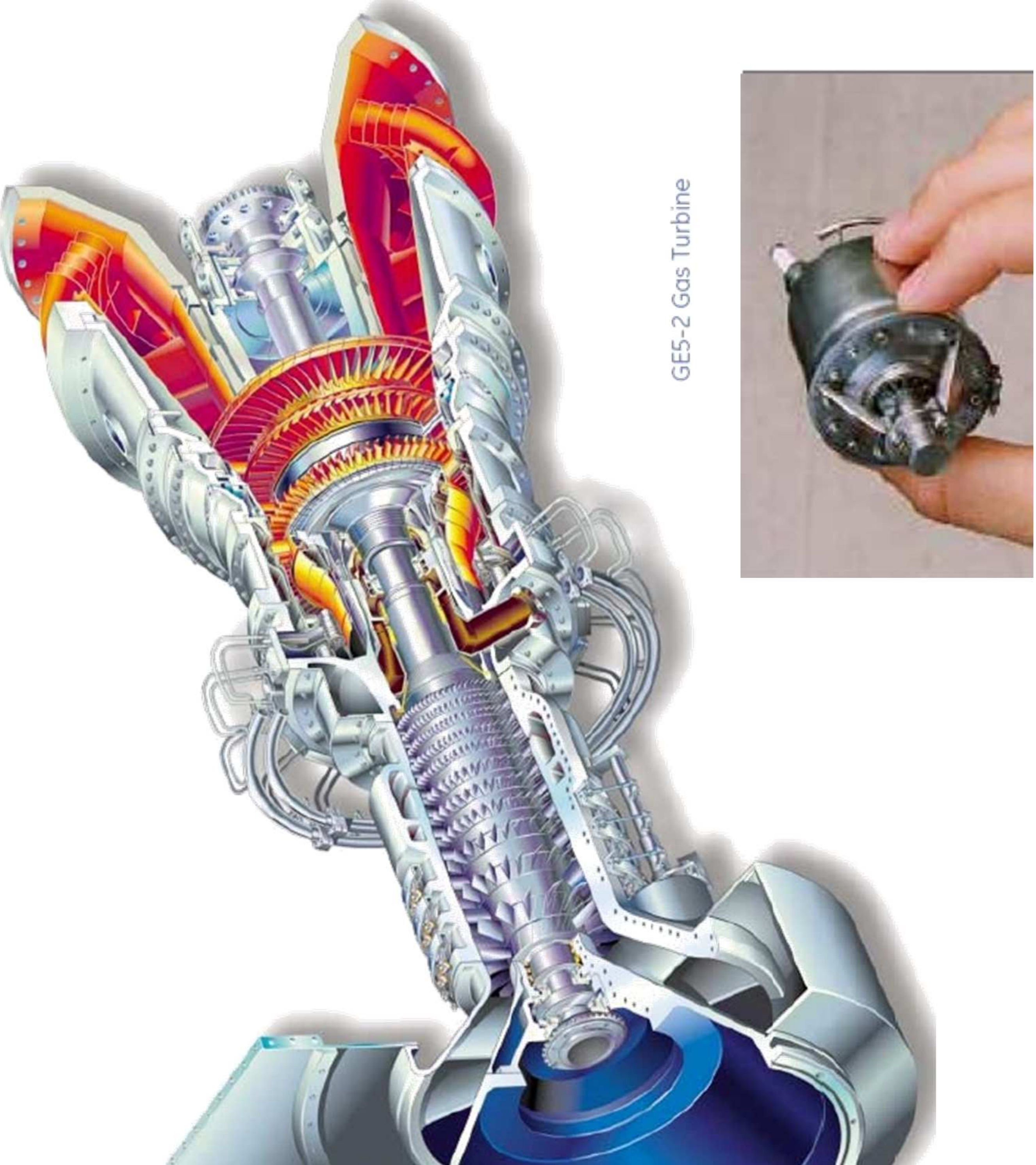
ρ_{Diesel}: $12 \div 24$; ρ_{OTTO}: $8 \div 12$



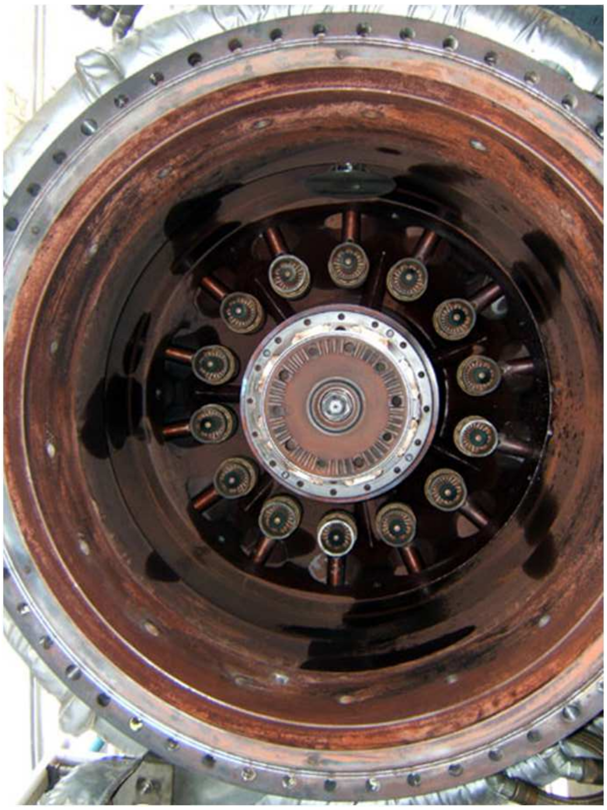
Ciclo BRAYTON

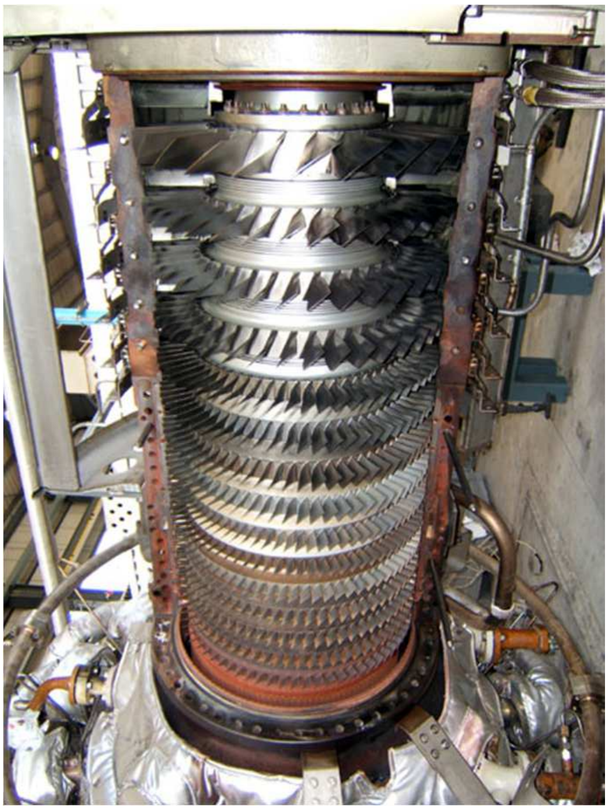


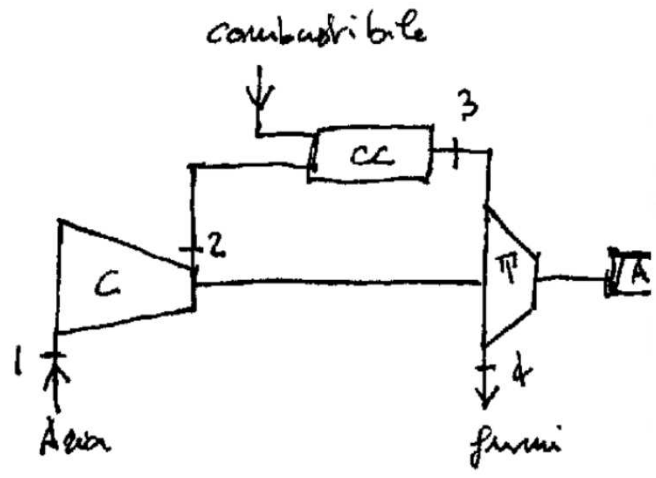


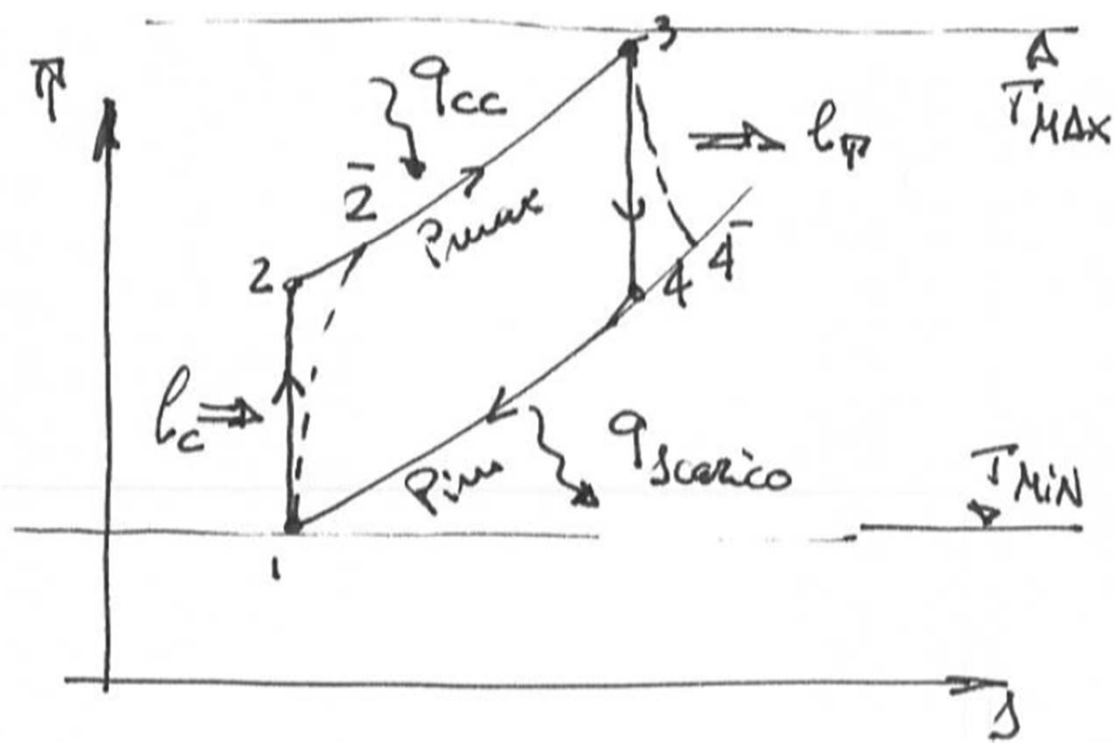


GE5-2 Gas Turbine









$$\eta = 1 - \frac{q_{scarico}}{q_{cc}}$$

$$= \frac{l_T - l_C}{q_{cc}}$$

$$q_{scarico} = c_p \left(T_4 - T_1\right)$$

$$q_{cc} = c_p \left(T_3 - T_2\right) = PCI \, \dot{m} \, . \, \Delta t$$

$$\eta = 1 - \frac{\cancel{c_p}\left(T_4 - T_1\right)}{\cancel{c_p}\left(T_3 - T_2\right)} = 1 - \frac{T_1}{T_2} \cdot \frac{\frac{T_4}{T_1} - 1}{\frac{T_3}{T_2} - 1}$$

dalle due adiabatiche $1 \to 2$ e $3 \to 4$

$$\frac{T_1}{T_2} = \left(\frac{P_2}{P_1}\right)^{\frac{1-\gamma}{\gamma}} \quad e \quad \frac{T_3}{T_4} = \left(\frac{P_4}{P_3}\right)^{\frac{1-\gamma}{\gamma}}$$

$$P\left(\frac{RT}{P}\right)^{\gamma} = \text{cost}$$

$$P^{1-\gamma} \cdot T^{\gamma} = \text{cost}'$$

$$T \cdot P^{\frac{1-\gamma}{\gamma}} = \text{cost}''$$

ma $P_1 = P_4$ e $P_2 = P_3$

$$\Rightarrow \frac{T_1}{T_2} = \left(\frac{P_2}{P_1}\right)^{\frac{1-\gamma}{\gamma}} = \left(\frac{P_3}{P_4}\right)^{\frac{1-\gamma}{\gamma}} = \frac{T_4}{T_3} \Leftrightarrow \frac{T_4}{T_1} = \frac{T_3}{T_2}$$

ne segue che:

$$\eta = 1 - \frac{T_1}{T_2} = 1 - \beta^{\frac{1-\gamma}{\gamma}} \quad \text{dove} \quad \beta = \frac{P_2}{P_1} = \frac{P_{max}}{P_{min}}$$

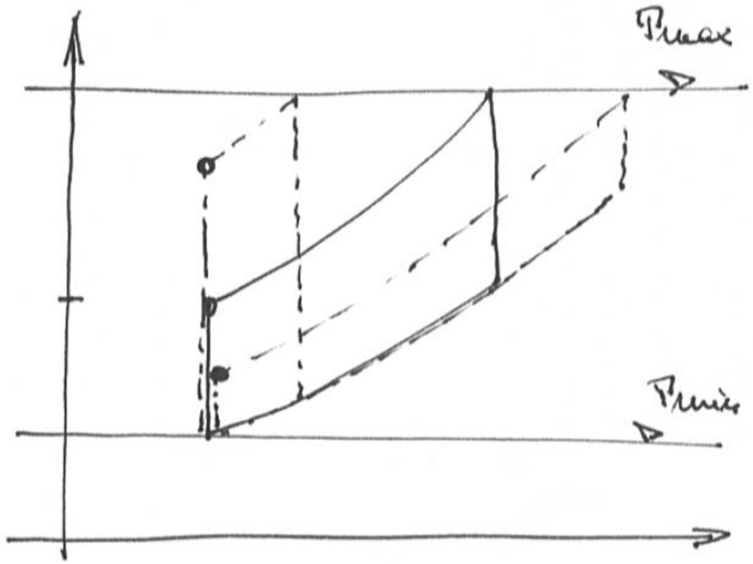
= rapporto di compressione

Notare che $T_2 = T_1 \cdot \beta^{\frac{\gamma-1}{\gamma}}$

e $T_3 = T_2 + \dfrac{q_{cc}}{c_p}$

$$l_{netto} = l_T - l_C = c_p^{fumi}(T_3 - T_4) - c_p^{aria}(T_2 - T_1)$$

Per quale T_2 ho $l_{netto} = \max$?



$$l^* = \frac{l}{c_p T_1} = \frac{T_3}{T_1} - \frac{T_4}{T_1} - \frac{T_2}{T_1} + 1$$

$$= \frac{T_3}{T_1} - \frac{T_4}{T_3} \cdot \frac{T_3}{T_1} - \frac{T_2}{T_1} + 1$$

$$= \frac{T_3}{T_1} - \frac{T_1}{T_2} \cdot \frac{T_3}{T_1} - \frac{T_2}{T_1} + 1$$

pongo $x = \frac{T_2}{T_1}$ (la mia variabile)

$\gamma = \frac{T_3}{T_1}$ una costante

$\Rightarrow l^* = \gamma - \frac{\gamma}{x} - x + 1$

per definizione di max $\frac{d\,l^*}{dx} = 0 \Leftrightarrow 0 = +\frac{\gamma}{x^2} - 1 \Leftrightarrow x = \sqrt{\gamma} \Leftrightarrow \frac{T_2}{T_1} = \sqrt{\frac{T_3}{T_1}}$

Poiché $\quad 1 - \frac{T_1}{T_2} = 1 - \frac{1}{\beta^{\frac{\gamma-1}{\gamma}}}$

con la condizione di massimizzazione del lavoro specifico:

$$\frac{T_1}{\sqrt{T_1 \cdot T_3}} = \frac{1}{\beta^{\frac{\gamma-1}{\gamma}}} \iff \beta^{\frac{\gamma-1}{\gamma}} = \sqrt{\frac{T_3}{T_1}}$$

ovvero

$$\boxed{\beta_{l_{max}} = \frac{p_2}{p_1} = \left(\frac{T_3}{T_1}\right)^{\frac{\gamma}{2\cdot(\gamma-1)}}}$$

Se $T_3 \cong 1500\ K$ e $T_1 \cong 300\ K$, segue che $\beta_{l_{max}} = \frac{p_2}{p_1} \cong 17$

Quindi :

+ Fissate T_{max} e T_{min}, nonché $P_1 \cong P_{atm}$, rimane determinato il valore di P_2 che massimizza il lavoro specifico ottenibile all'asse, ma che però non massimizza il rendimento. Più in generale diviene fissato $\beta_{l_{max}}$

+ Più aumenta β, più aumenta il rendimento termico, ma diminuisce il lavoro. Si tratta quindi di eseguire una scelta :

$\beta = \beta_{l_{max}}$ per macchine di potenza (produzione EE, EM)

$\beta > \beta_{l_{max}}$ $\left(\Rightarrow \eta > \eta_{l_{max}}\right)$ per macchine ad alto rendimento (aerei)

Al limite, il massimo rendimento tra T_3 e T_1 è ~~la~~ quella della macchina di CARNOT

$$\eta_c = 1 - \frac{T_1}{T_3}$$

caso ideale

$$\eta \rightarrow \eta_c \iff T_2 \rightarrow T_3 \Rightarrow l_{turbina} = l_{compressore}$$

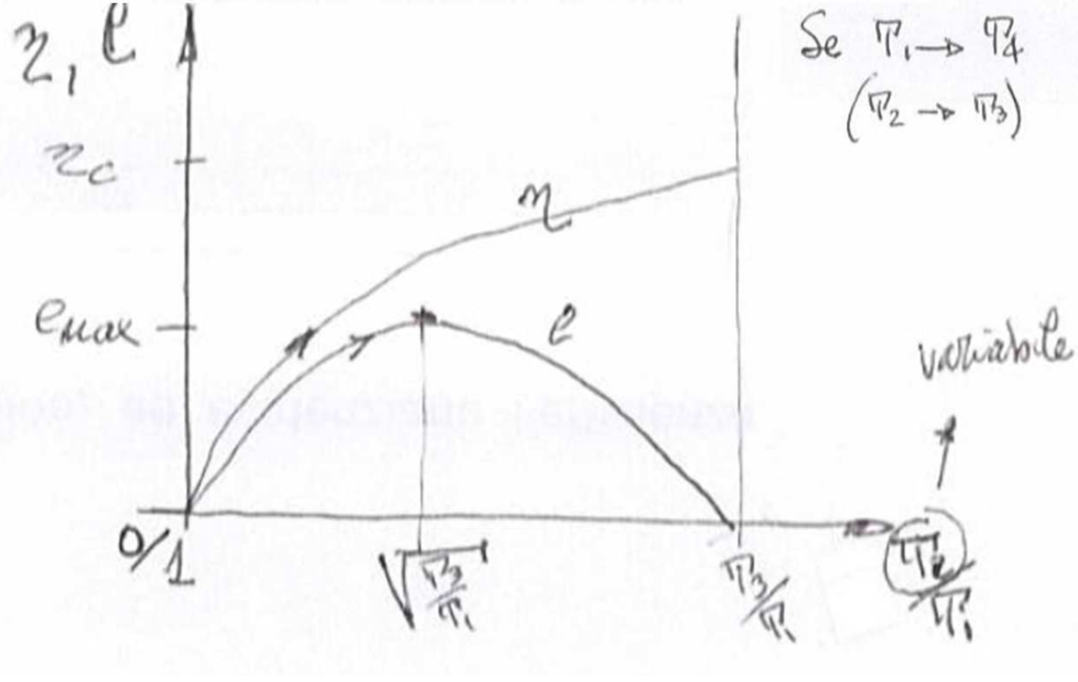
$$\eta = 1 - \frac{T_4 - T_1}{T_3 - T_2} = 1 - \frac{T_1}{T_3} \cdot \frac{T_4/T_1 - 1}{1 - T_2/T_3} \; ;$$

$$\frac{T_2}{T_3} = \frac{T_1 \cdot (P_1/P_2)^{\frac{1-\gamma}{\gamma}}}{T_4 \cdot (P_4/P_3)^{\frac{1-\gamma}{\gamma}}} = \frac{T_1}{T_4} \cdot \frac{\cancel{(P_1/P_2)^{\frac{1-\gamma}{\gamma}}}}{\cancel{(P_1/P_2)^{\frac{1-\gamma}{\gamma}}}}$$

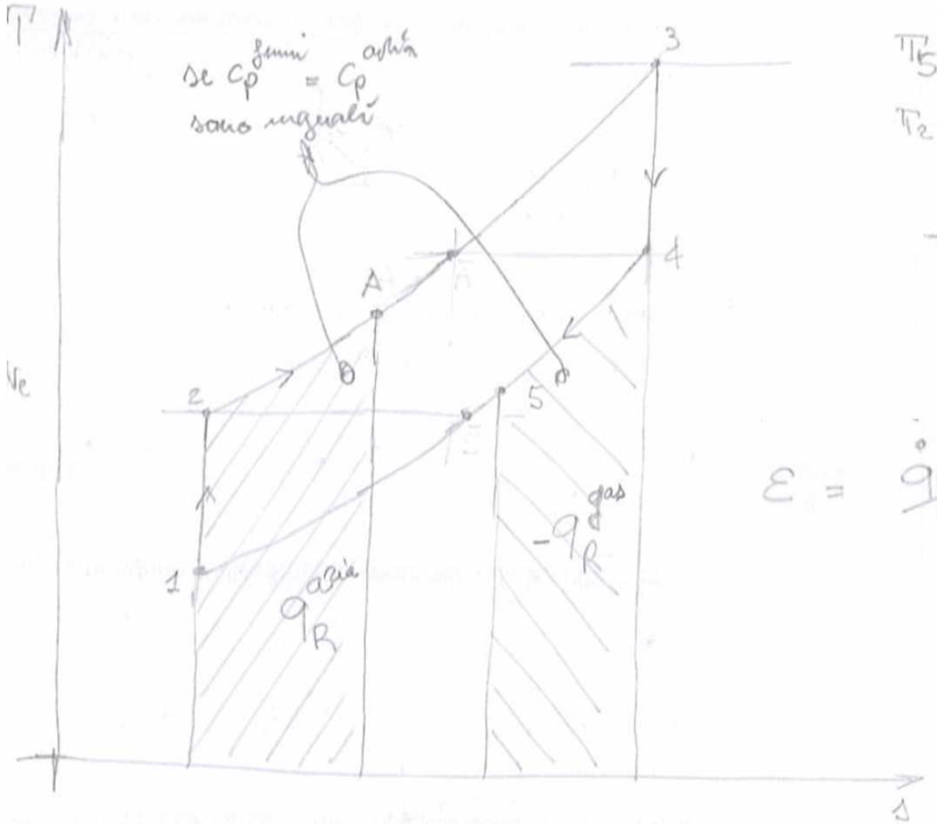
$$\Rightarrow \; = 1 - \frac{T_1}{T_3} \cdot \frac{T_4/T_1 - 1}{1 - T_1/T_4}$$

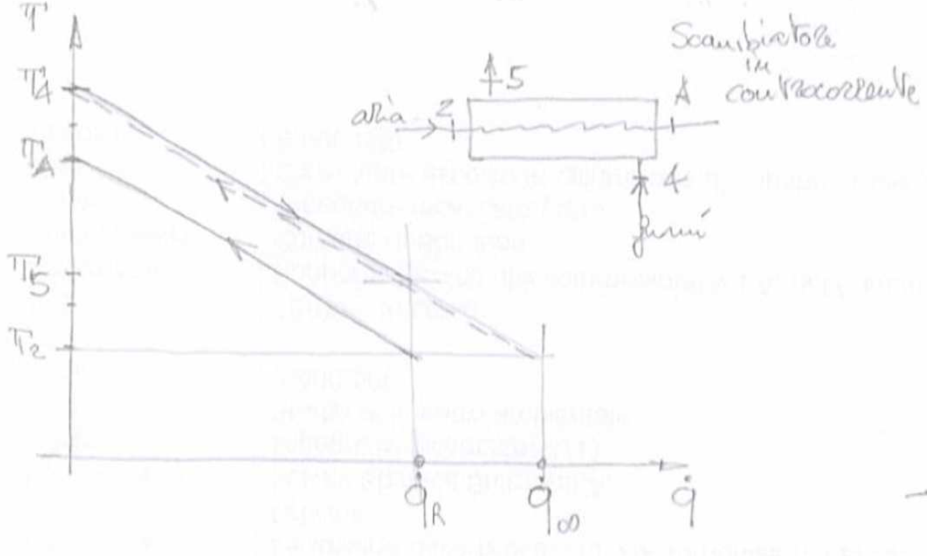
$$= 1 - \frac{T_1}{T_3} \cdot \frac{T_1}{T_4} \cdot \frac{\cancel{1 - T_1/T_4}}{\cancel{1 - T_1/T_4}}$$

$$= 1 - \frac{T_1}{T_3} \cdot \frac{T_1}{T_4}$$



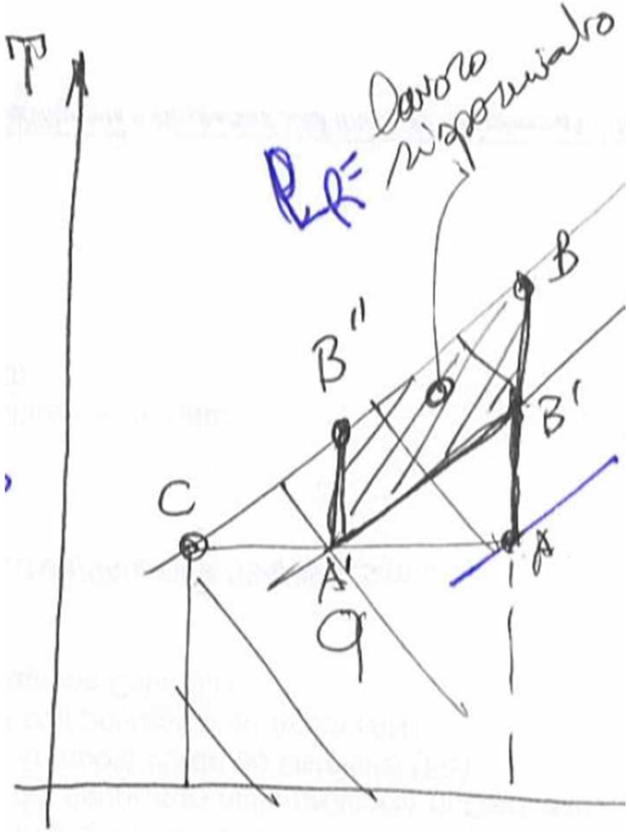
Se $T_1 \to T_4$ $(T_2 \to T_3)$ $\Rightarrow \eta = 1 - \frac{T_1}{T_3} = \eta_c$





$$\varepsilon = \frac{\dot{q}_R}{\dot{q}_\infty} = \frac{\cancel{c_p^g \dot{m}_g} \cdot (T_4 - T_5)}{\cancel{c_p^g \dot{m}_g} \cdot (T_4 - T_2)} = \frac{T_4 - T_5}{T_A - T_2}$$

$$\eta_R = \frac{\dot{\ell}}{\dot{q} - \dot{q}_R^a} \quad \dot{\ell} = \dot{\ell}_T - \dot{\ell}_c \quad \text{dove } \dot{q}_R^a > 0 \Rightarrow \eta_R > \eta(\dot{q}_R^a = 0)$$

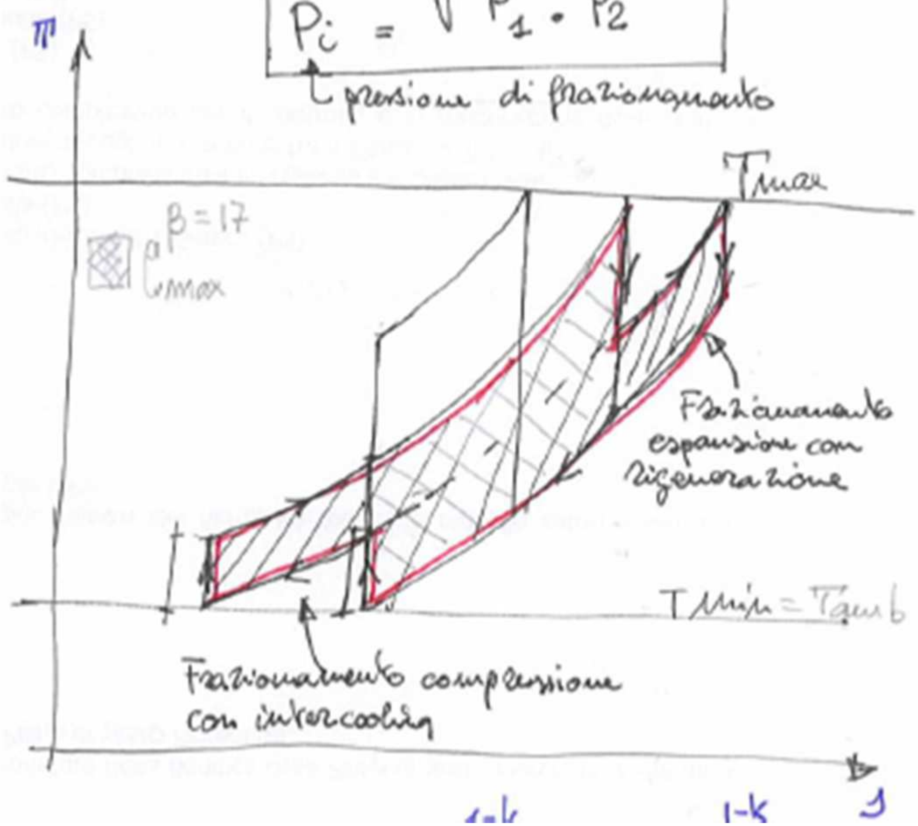


$$\ell_{AB} = \Delta h = c_p\,(T_B - T_A) = c_p\,(T_B - T_C) = q_{CB}$$

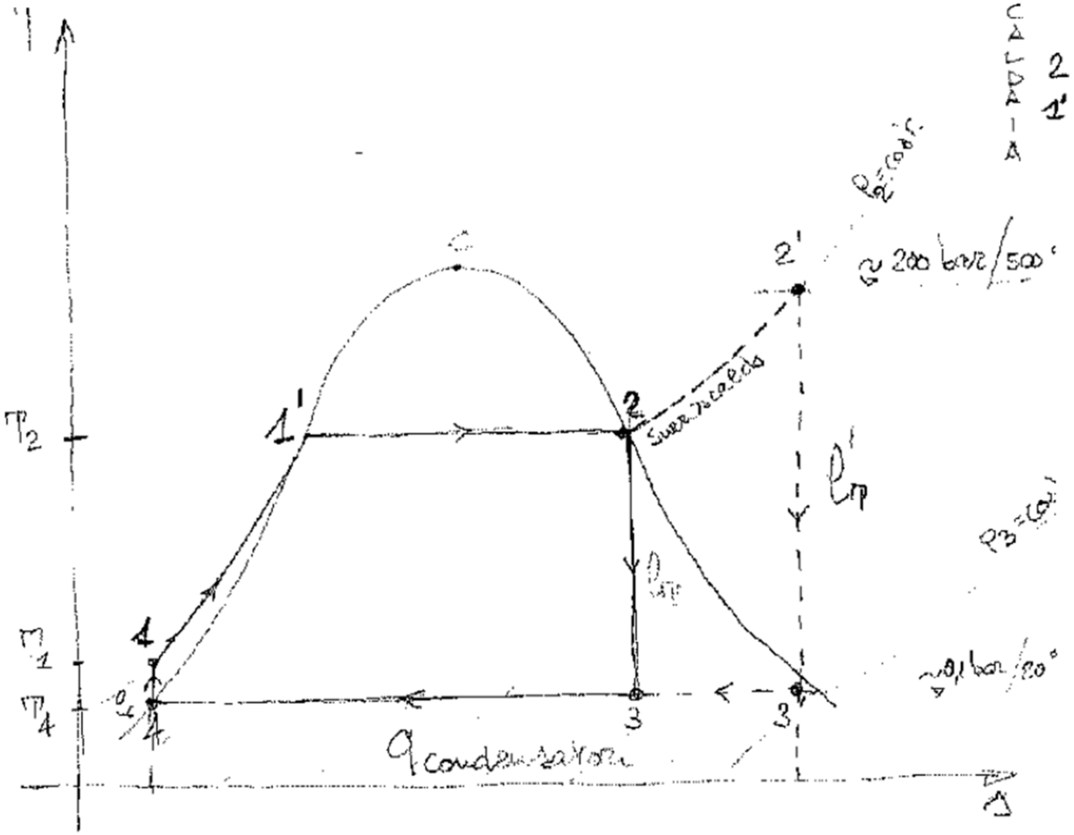
numero di frazionamenti

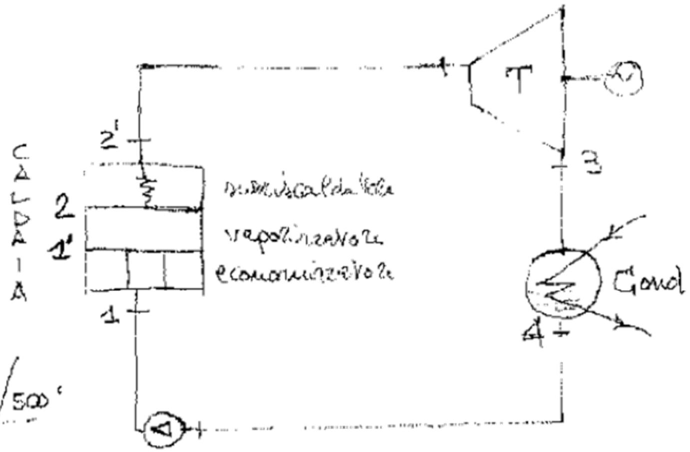
$$\boxed{P_i = \sqrt[n]{P_1 \cdot P_2}}$$

pressione di frazionamento



CICLO RANKINE





generalmente trascurabile

$$\eta = \frac{|l_T| - |l_c|}{|q_{12}|} = 1 - \frac{|q_{34}|}{|q_{12}|} = \frac{(h_{2'} - h_{3'}) - (h_1 - h_4)}{h_{2'} - h_1}$$

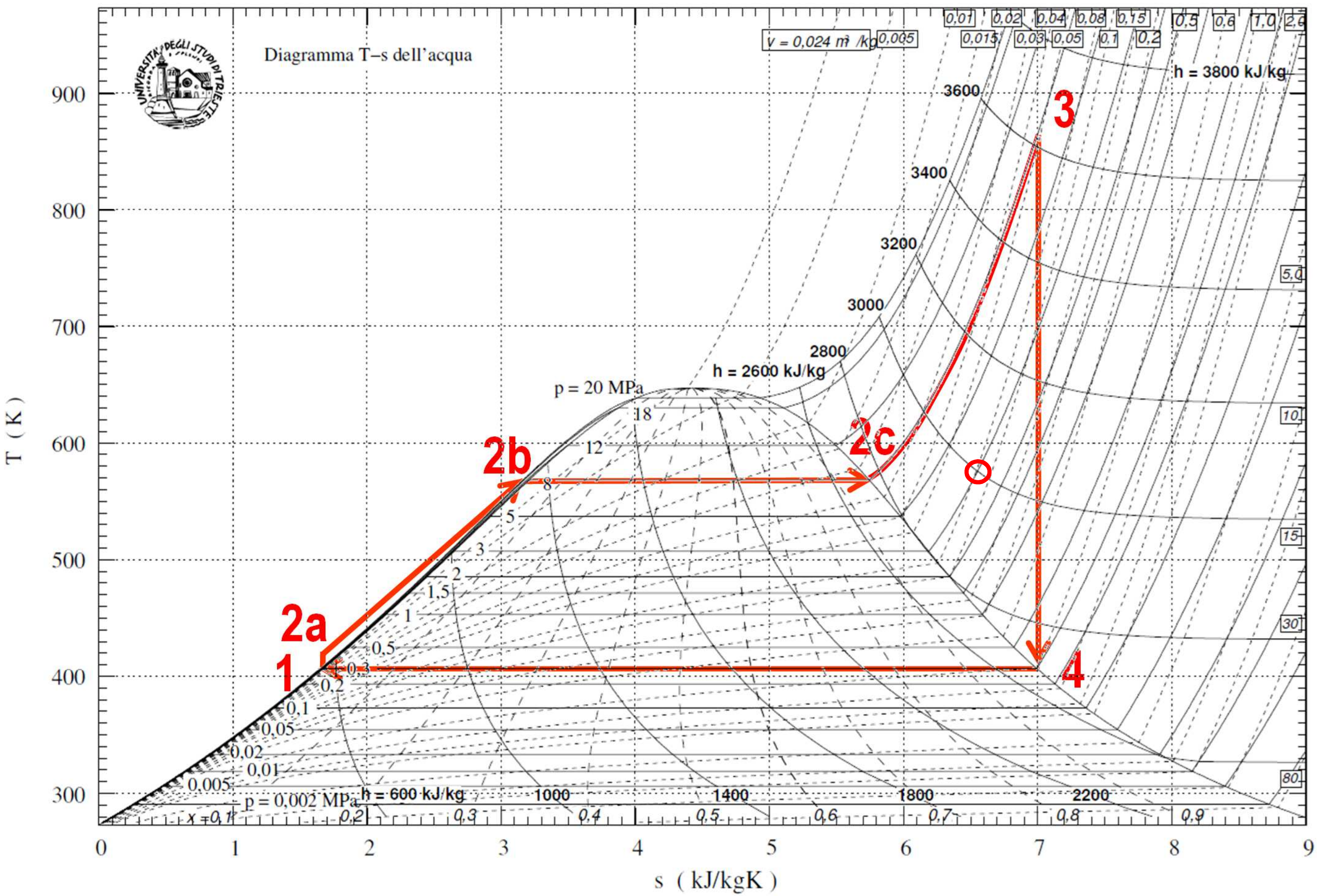
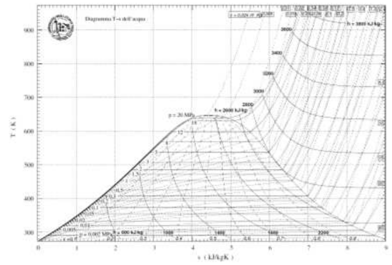
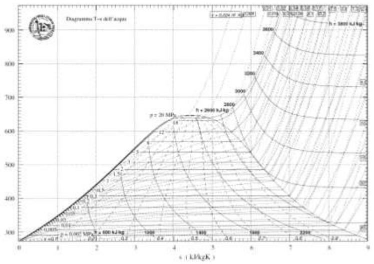


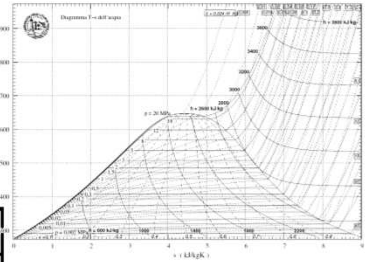
Diagramma T–s dell'acqua
T (K)
s (kJ/kgK)
p = 20 MPa
h = 2600 kJ/kg
h = 3800 kJ/kg
h = 600 kJ/kg
v = 0,024 m³/kg
p = 0,002 MPa
1
2a
2b
2c
3
4



t	p	volume	specifico	m³/kg	Entalpia		kJ/kg	Entropia		kJ/kg K	t
°C	bar	v_l	(v_v-v_l)	v_v	h_l	r	h_v	s_l	r/T	s_v	°C
0	0.006 017	0.001 000 2	206.298	206.299	-0.0	2501.6	2501.6	-0.0	9.1578	9.1578	0
0.01	0.006 112	0.001 000 2	206.162	206.163	+0.0	2501.6	2501.6	0	9.1575	9.1575	0.01
2	0.007 055	0.001 000 1	179.922	179.923	8.4	2496.8	2505.2	0.0306	9.0741	9.1047	2
4	0.008 129	0.001 000 0	157.271	157.272	16.8	2492.1	2508.9	0.0611	8.9915	9.0526	4
6	0.009 345	0.001 000 0	137.779	137.780	25.2	2487.4	2512.6	0.0913	8.9102	9.0015	6
8	0.010 720	0.001 000 1	120.965	120.966	33.6	2482.6	2516.2	0.1213	8.8300	8.9513	8
10	0.012 270	0.001 000 3	106.429	106.430	42.0	2477.9	2519.9	0.1510	8.7510	8.9020	10
12	0.014 014	0.001 000 4	93.834	93.835	50.4	2473.2	2523.6	0.1805	8.6731	8.8536	12
14	0.015 973	0.001 000 7	82.899	82.900	58.8	2468.5	2527.2	0.2098	8.5963	8.8060	14
15	0.017 139	0.001 000 8	77.977	77.978	62.9	2466.1	2529.1	0.2243	8.5582	8.7826	15
16	0.018 168	0.001 001 0	73.383	73.384	67.1	2463.8	2530.9	0.2388	8.5205	8.7593	16
18	0.020 624	0.001 001 3	65.086	65.087	75.5	2459.0	2534.5	0.2677	8.4458	8.7135	18
20	0.023 366	0.001 001 7	57.837	57.838	83.9	2454.3	2538.2	0.2963	8.3721	8.6684	20
25	0.031 660	0.001 002 9	43.401	43.402	104.8	2442.5	2547.3	0.3670	8.1922	8.5592	25
30	0.042 415	0.001 004 3	32.928	32.929	125.7	2430.7	2556.4	0.4365	8.0181	8.4546	30
35	0.056 216	0.001 006 0	25.244	25.245	146.6	2418.8	2565.4	0.5049	7.8495	8.3543	35
40	0.073 750	0.001 007 8	19.545	19.546	167.5	2406.9	2574.4	0.5721	7.6861	8.2583	40
45	0.095 820	0.001 009 9	15.275	15.276	188.4	2394.9	2583.3	0.6383	7.5277	8.1661	45
50	0.123 35	0.001 012 0	12.045	12.046	209.3	2382.9	2592.2	0.7035	7.3741	8.0776	50
55	0.157 41	0.001 014 5	9.577 9	9.578 9	230.2	2370.8	2601.0	0.7677	7.2248	7.9925	55
60	0.199 20	0.001 017 1	7.677 5	7.678 5	251.1	2358.6	2609.7	0.8310	7.0798	7.9108	60
65	0.250 09	0.001 019 9	6.201 3	6.202 3	272.0	2346.3	2618.4	0.8933	6.9388	7.8321	65
70	0.311 62	0.001 022 8	5.045 3	5.046 3	293.0	2334.0	2626.9	0.9548	6.8017	7.7565	70
75	0.385 49	0.001 025 9	4.133 1	4.134 1	313.9	2321.5	2635.4	1.0154	6.6681	7.6835	75
80	0.473 60	0.001 029 2	3.408 1	3.409 1	344.9	2308.8	2643.8	1.0753	6.5380	7.6133	80
85	0.578 03	0.001 032 6	2.827 8	2.828 8	355.9	2296.1	2652.0	1.1343	6.4111	7.5454	85
90	0.701 09	0.001 036 1	2.360 3	2.361 3	376.9	2283.2	2660.1	1.1925	6.2873	7.4798	90
95	0.845 26	0.001 039 9	1.981 2	1.982 2	398.0	2270.2	2668.1	1.2501	6.1665	7.4166	95
100	1.013 25	0.001 043 7	1.672 0	1.673 0	419.1	2256.9	2676.0	1.3069	6.0485	7.3554	100
105	1.208 0	0.001 047 7	1.418 3	1.419 3	440.2	2243.6	2683.7	1.3630	5.9331	7.2962	105
110	1.432 7	0.001 051 9	1.208 9	1.209 9	461.3	2230.0	2691.3	1.4185	5.8203	7.2388	110
350	165.35	0.001 741 1	0.007 06	0.008 799	1671.9	895.7	2567.7	3.7800	1.4376	5.2177	350
355	175.77	0.001 808 5	0.006 05	0.007 859	1716.6	813.8	2530.4	3.8489	1.2953	5.1442	355
360	186.75	0.001 895 9	0.005 04	0.006 939	1764.2	721.3	2485.4	3.9210	1.1390	5.060	360
365	198.33	0.002 016 0	0.003 99	0.006 011	1818.0	610.0	2428.0	4.0021	0.9558	4.9579	365
370	210.54	0.002 213 6	0.002 76	0.004 972	1890.2	452.6	2342.8	4.1108	0.7036	4.8144	370
374	220.81	0.002 842 7	0.000 63	0.003 465	2046.7	109.5	2156.2	4.3493	0.1692	4.5185	374
374.15	221.20	0.003 17	0	0.003 17	2107.4	0	2107.4	4.4429	0	4.4429	374.15

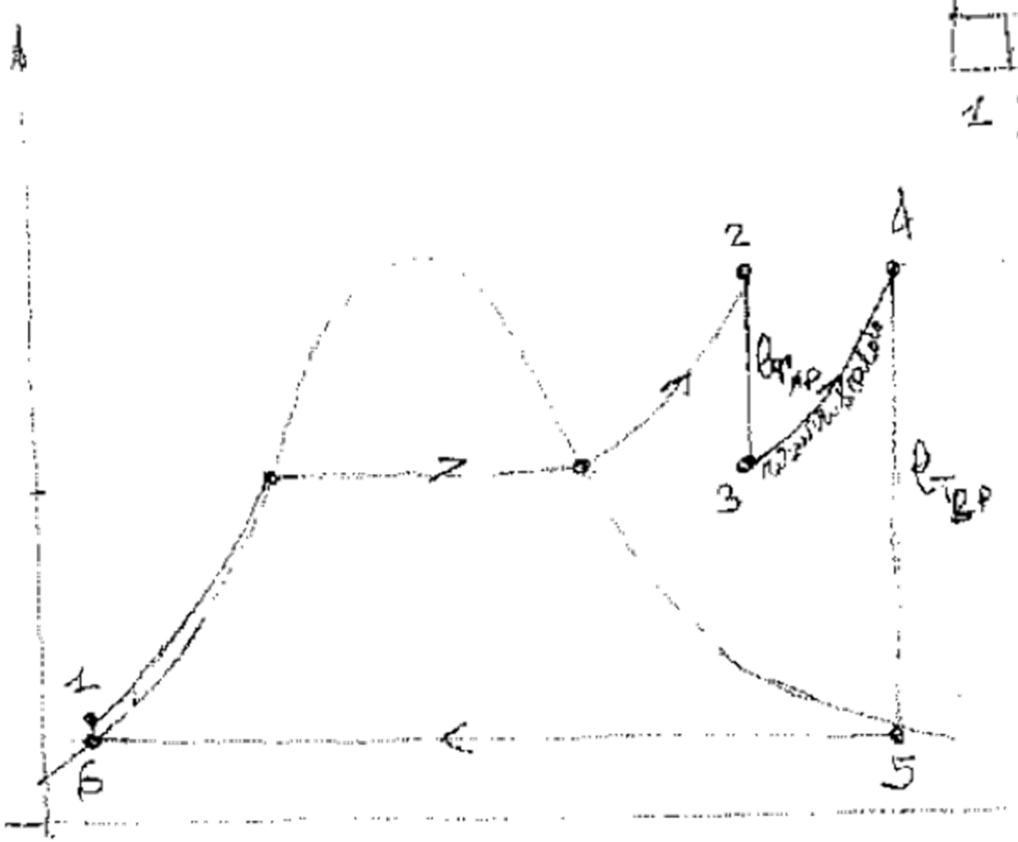


p	t	Volume specifico m^3/kg		Entalpia kJ/kg			Energia interna kJ/kg		Entropia kJ/kg K			p
bar	°C	v_l	v_v	h_l	r	h_v	u_l	u_v	s_l	r/T	s_v	bar
0.006 02	0	0.001 000 2	206.298 7	-0.0	2501.6	2501.6	-0.0	2375.6	-0.0	9.1578	9.1578	0.006 02
0.006 11	0.01	0.001 000 2	206.162 9	+0.0	2501.6	2501.6	0	2375.6	0	9.1575	9.1575	0.006 11
0.010	6.98	0.001 000 1	129.210 7	29.3	2485.0	2514.4	29.3	2385.2	0.1060	8.8706	8.9767	0.010
0.020	17.51	0.001 001 2	67.011 6	73.5	2460.2	2533.6	73.5	2399.6	0.2606	8.4640	8.7246	0.020
0.030	24.10	0.001 002 7	45.670 0	101.0	2444.6	2545.6	101.0	2408.6	0.3543	8.2242	8.5785	0.030
0.040	28.98	0.001 004 0	34.803 3	121.4	2433.1	2554.5	121.4	2415.3	0.4225	8.0530	8.4755	0.040
0.050	32.90	0.001 005 2	28.194 5	137.8	2423.8	2561.6	137.8	2420.6	0.4763	7.9197	8.3960	0.050
0.060	36.18	0.001 006 4	23.740 6	151.5	2416.0	2567.5	151.5	2425.1	0.5209	7.8103	8.3312	0.060
0.070	39.03	0.001 007 4	20.530 4	163.4	2409.2	2572.6	163.4	2428.9	0.5591	7.7176	8.2767	0.070
0.080	41.54	0.001 008 4	18.103 8	173.9	2403.2	2577.1	173.9	2432.3	0.5926	7.6370	8.2295	0.080
0.090	43.79	0.001 009 4	16.203 4	183.3	2397.9	2581.1	183.3	2435.3	0.6224	7.5657	8.1881	0.090
0.10	45.83	0.001 010 2	14.673 7	191.8	2392.9	2584.8	191.8	2438.1	0.6493	7.5018	8.1511	0.10
0.15	54.00	0.001 014 0	10.022 1	226.0	2373.2	2599.2	226.0	2448.9	0.7549	7.2544	8.0093	0.15
0.20	60.09	0.001 017 2	7.649 2	251.5	2358.4	2609.9	251.5	2456.9	0.8321	7.0773	7.9094	0.20
0.25	64.99	0.001 019 9	6.204 0	272.0	2346.4	2618.3	272.0	2463.2	0.8933	6.9390	7.8323	0.25
0.30	69.13	0.001 022 3	5.229 0	289.3	2336.1	2625.4	289.6	2468.2	0.9441	6.8254	7.7695	0.30
0.35	72.71	0.001 024 5	4.525 5	304.3	2327.2	2631.5	304.3	2473.1	0.9878	6.7288	7.7166	0.35
0.40	75.89	0.001 026 5	3.993 2	317.7	2319.2	2636.9	317.7	2477.2	1.0261	6.6448	7.6709	0.40
0.45	78.74	0.001 028 4	3.576 1	329.6	2312.0	2641.7	329.6	2480.8	1.0603	6.5703	7.6306	0.45
0.50	81.35	0.001 030 1	3.240 1	340.6	2305.4	2646.0	340.5	2484.0	1.0912	6.5035	7.5947	0.50
0.60	85.95	0.001 033 3	2.731 7	359.9	2293.6	2653.6	359.8	2489.7	1.1455	6.3872	7.5327	0.60
0.70	89.96	0.001 036 1	2.364 7	376.8	2283.3	2660.1	376.3	2494.6	1.1921	6.2883	7.4804	0.70
0.80	93.51	0.001 038 7	2.086 9	391.7	2274.0	2665.8	391.6	2498.8	1.2330	6.2022	7.4352	0.80
0.90	96.71	0.001 041 2	1.869 1	405.2	2265.6	2670.9	405.1	2502.7	1.2696	6.1258	7.3954	0.90
1.00	99.63	0.001 043 4	1.693 7	417.5	2257.9	2675.4	417.4	2506.0	1.3027	6.0571	7.3598	1.00
1.013 25	100.00	0.001 043 7	1.673 0	419.1	2256.9	2676.0	419.0	2506.5	1.3069	6.0485	7.3554	1.013 25
1.20	104.81	0.001 047 6	1.428 1	439.4	2244.1	2683.4	439.3	2512.0	1.3609	5.9375	7.2984	1.20
1.40	109.32	0.001 051 3	1.236 3	458.4	2231.9	2690.3	458.3	2517.2	1.4109	5.8356	7.2465	1.40
1.60	113.32	0.001 054 7	1.091 1	475.4	2220.9	2696.2	475.2	2521.6	1.4550	5.7467	7.2017	1.60
1.80	116.93	0.001 057 9	0.977 18	490.7	2210.8	2701.5	490.5	2525.6	1.4944	5.6677	7.1622	1.80
200.00	365.71	0.002 037 4	0.005 874 5	1826.6	591.6	2418.2	1785.9	2300.7	4.0151	0.9259	4.9410	200.00
210.00	369.79	0.002 201 8	0.005 022 5	1886.3	461.2	2347.5	1840.1	2242.0	4.1040	0.7172	4.8222	210.00
220.00	373.78	0.002 667 5	0.003 734 7	2010.3	186.3	2196.6	1951.6	2144.4	4.2934	0.2881	4.5814	220.00
221.20	374.15	0.003 170 0	0.003 170 0	2107.4	0	2107.4	2037.1	2037.3	4.4429	0	4.4429	221.20



Pressione bar (temp. sat. °C)		50	100	150	200	250	300	350	400	500	600	700	800
0.02 (17.5)	v	74.524	86.080	97.628	109.171	120.711	132.251	143.790	155.329	178.405	201.482	224.558	247.634
	h	2594.4	2688.5	2783.7	2880.0	2977.7	3076.8	3177.7	3279.7	3489.2	3705.6	3928.8	4158.7
	s	8.9226	9.1934	9.4327	9.6479	9.8441	10.0251	10.1934	10.3512	10.6413	10.9044	11.1464	11.3712
0.04 (29.0)	v	37.240	43.027	48.806	54.580	60.351	66.122	71.892	77.662	89.201	100.740	112.278	123.816
	h	2593.9	2688.3	2783.5	2879.9	2977.6	3076.8	3177.4	3279.7	3489.2	3705.6	3928.8	4158.7
	s	8.6016	8.8730	9.1125	9.3279	9.5241	9.7051	9.8735	10.0313	10.3214	10.5845	10.8265	11.0513
0.06 (36.2)	v	24.812	28.676	32.532	37.383	40.232	44.079	47.927	51.773	59.467	67.159	74.852	82.544
	h	2593.5	2688.0	2783.4	2879.8	2977.6	3076.7	3177.4	3279.6	3489.2	3705.6	3928.8	4158.7
	s	8.4135	8.6854	8.9251	9.1406	9.3369	9.5179	9.6863	9.8441	10.1342	10.3973	10.6394	10.8642
0.08 (41.5)	v	18.598	21.501	24.395	27.284	30.172	33.058	35.944	38.829	44.599	50.369	56.138	61.908
	h	2593.1	2687.8	2783.2	2879.7	2977.5	3076.7	3177.3	3279.6	3489.1	3705.5	3928.8	4158.7
	s	8.2797	8.5521	8.7921	9.0077	9.2041	9.3851	9.5535	9.7113	10.0014	10.2646	10.5066	10.7314
0.10 (45.8)	v	14.869	17.195	19.512	21.825	24.136	26.445	28.754	31.062	35.679	40.295	44.910	49.526
	h	2592.7	2687.5	2783.1	2879.6	2977.4	3076.6	3177.3	3279.6	3489.1	3705.5	3928.8	4158.7
	s	8.1757	8.4486	8.6888	8.9045	9.1010	9.2820	9.4504	9.6083	9.8984	10.1616	10.4036	10.6284
0.50 ((81.3)	v	0.001012	3.4181	3.8893	4.3560	4.8205	5.2839	5.7467	6.2091	7.1335	8.0574	8.9810	9.9044
	h	209.29	2682.6	2780.1	2877.7	2976.1	3075.7	3176.6	3279.0	3488.7	3705.2	3928.6	4158.5
	s	0.70349	7.6953	7.9406	8.1587	8.3564	8.5380	8.7068	8.8649	9.1552	9.4185	9.6606	9.8855
1.00 (99.6)	v	0.001012	1.6955	1.9363	2.1723	2.4061	2.6387	2.8708	3.1025	3.5653	4.0277	4.4898	4.9517
	h	209.33	2676.2	2776.1	2875.4	2974.5	3074.5	3175.6	3278.2	3488.1	3704.8	3928.2	4158.3
	s	0.70347	7.3618	7.6137	7.8349	8.0342	8.2166	8.3858	8.5442	8.8348	9.0982	9.3405	9.5654

20.00 (212.4)	h	210.97	420.49	633.09	852.55	2902.4	3025.0	3138.6	3248.7	3467.3	3689.2	3916.5	4149.4
	s	0.70258	1.30538	1.83994	2.32995	6.5454	6.7696	6.9596	7.1296	7.4323	7.7022	7.9485	8.1763
25.00 (223.9)	v	0.001011	0.001043	0.001089	0.001156	0.086 985	0.098 925	0.109 75	0.120 04	0.139 87	0.159 21	0.178 26	0.197 14
	h	211.4	420.86	633.4	852.76	2879.5	3010.4	3128.2	3240.7	3461.7	3685.1	3913.4	4147.0
	s	0.70235	1.30499	1.83939	2.32916	6.4077	6.6470	6.8442	7.0178	7.3240	7.5956	7.8431	8.0716
30.00 (233.8)	v	0.001011	0.001042	0.001089	0.001155	0.070 551	0.081 159	0.090 526	0.099 310	0.116 08	0.132 34	0.148 32	0.164 12
	h	211.83	421.24	633.71	852.96	2854.8	2995.1	3117.5	3232.5	3456.5	3681.0	3910.3	4144.7
	s	0.70212	1.3046	1.83883	2.32838	6.2857	6.5422	6.7471	6.9246	7.2345	7.5079	7.7564	7.9857
35.00 (242.5)	v	0.001011	0.001042	0.001089	0.001155	0.058 693	0.068 424	0.076 776	0.084 494	0.099 088	0.113 15	0.126 94	0.140 54
	h	212.26	421.62	634.03	853.17	2828.1	2979.0	3106.5	3224.2	3450.6	3676.9	3907.2	4142.4
	s	0.70188	1.30421	1.83828	2.32759	6.1732	6.4491	6.6626	6.8443	7.1580	7.4332	7.6828	7.9128
40.00 (250.3)	v	0.00101	0.001042	0.001088	0.001154	0.001251	0.058 833	0.066 446	0.073 376	0.086 341	0.098 763	0.110 90	0.122 85
	h	212.69	421.99	634.34	853.37	1085.78	2962.0	3095.1	3215.7	3445.0	3672.8	3904.1	4140.0
	s	0.70165	1.30382	1.83773	2.32681	2.79343	6.3642	6.5870	6.7733	7.0909	7.3680	7.6187	7.8495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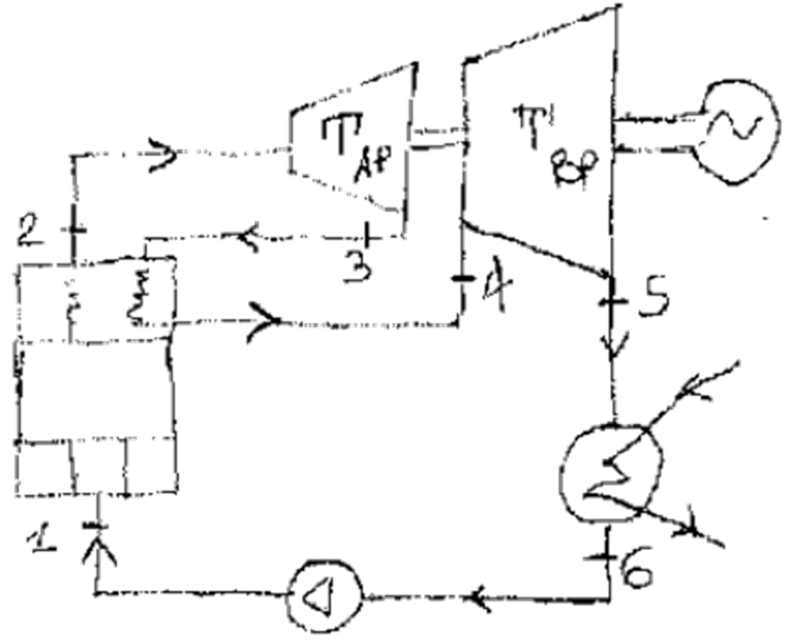
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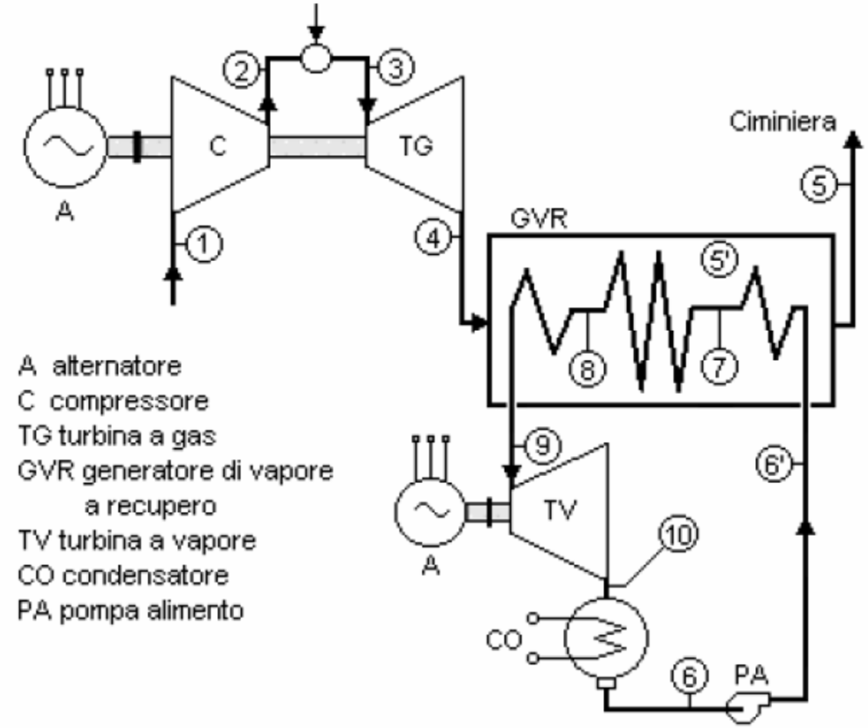
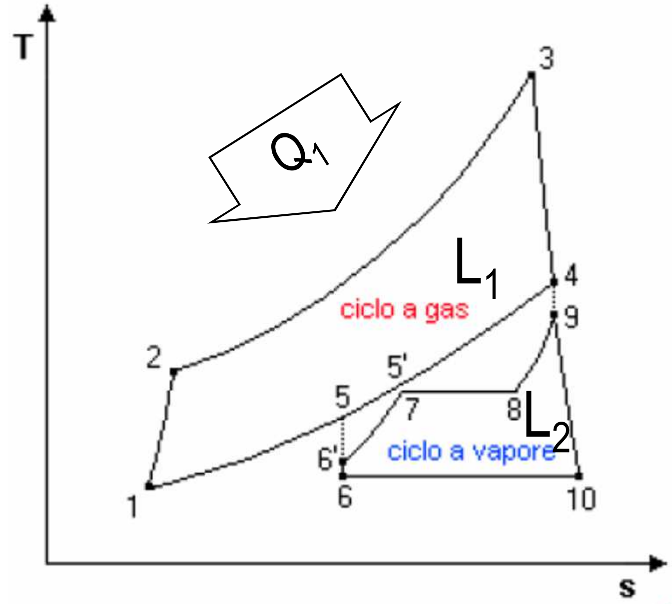
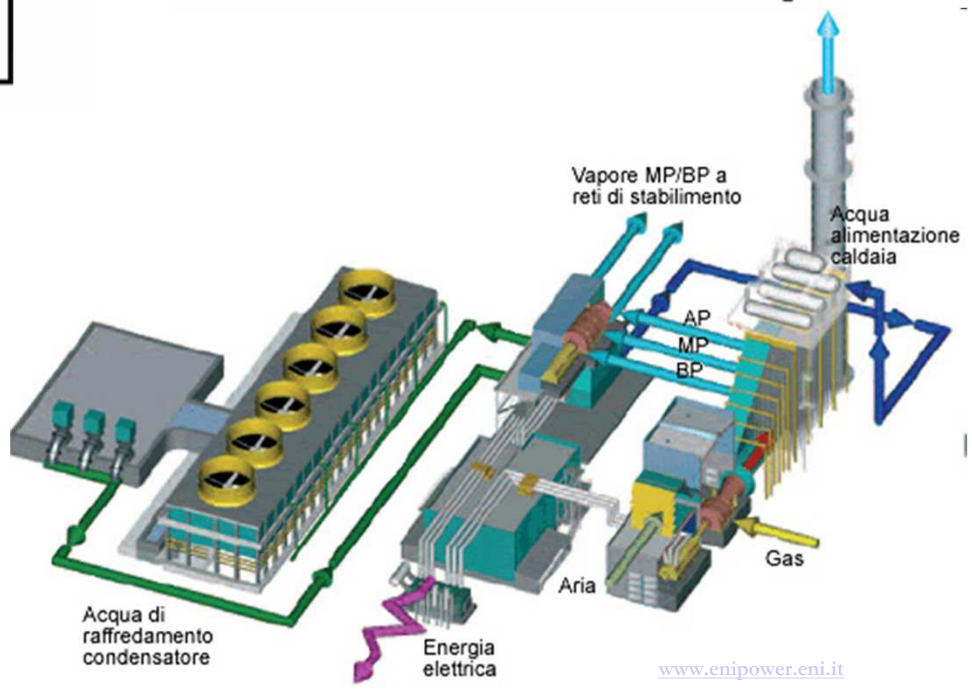


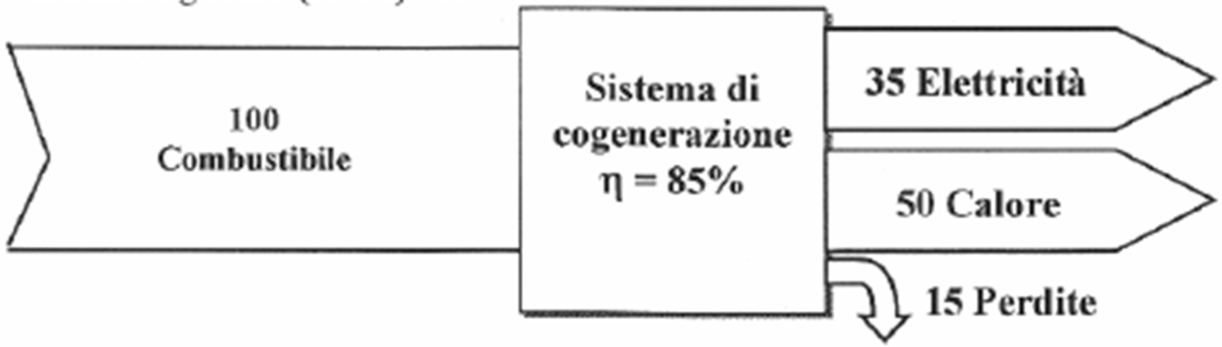


$$\eta_E = \frac{L_1 + L_2}{Q_1} > 0{,}50$$



SISTEMA DI COGENERAZIONE

Rendimento globale (35+50)/100 = 85%

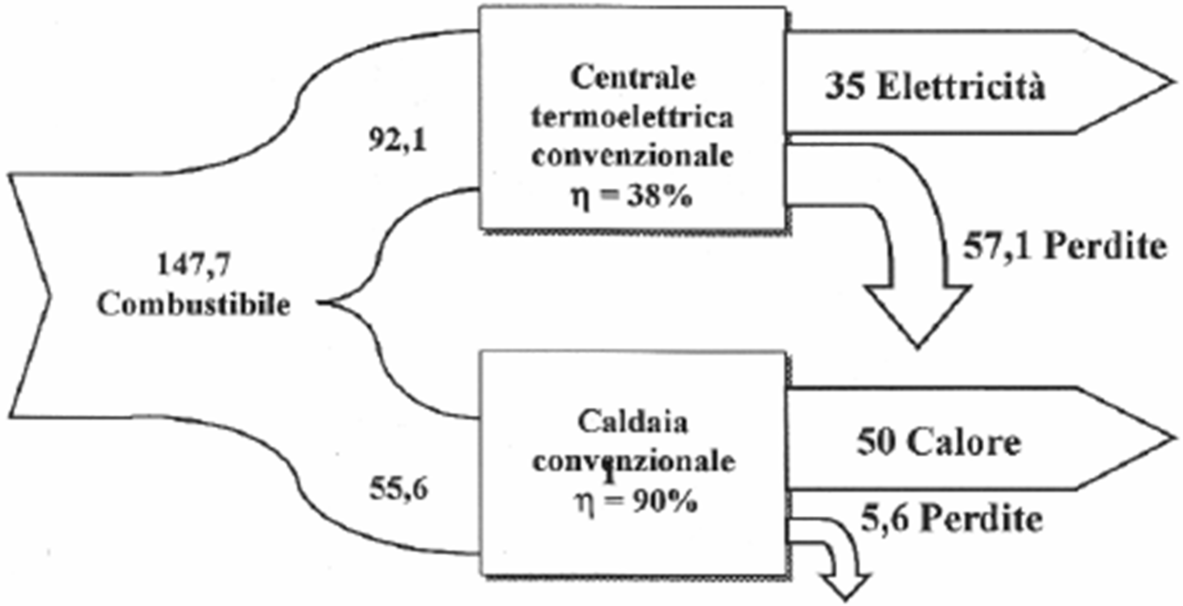


PRODUZIONE CONVENZIONALE SEPARATA

Rendimento elettrico netto medio centrale termoelettrica convenzionale 39%

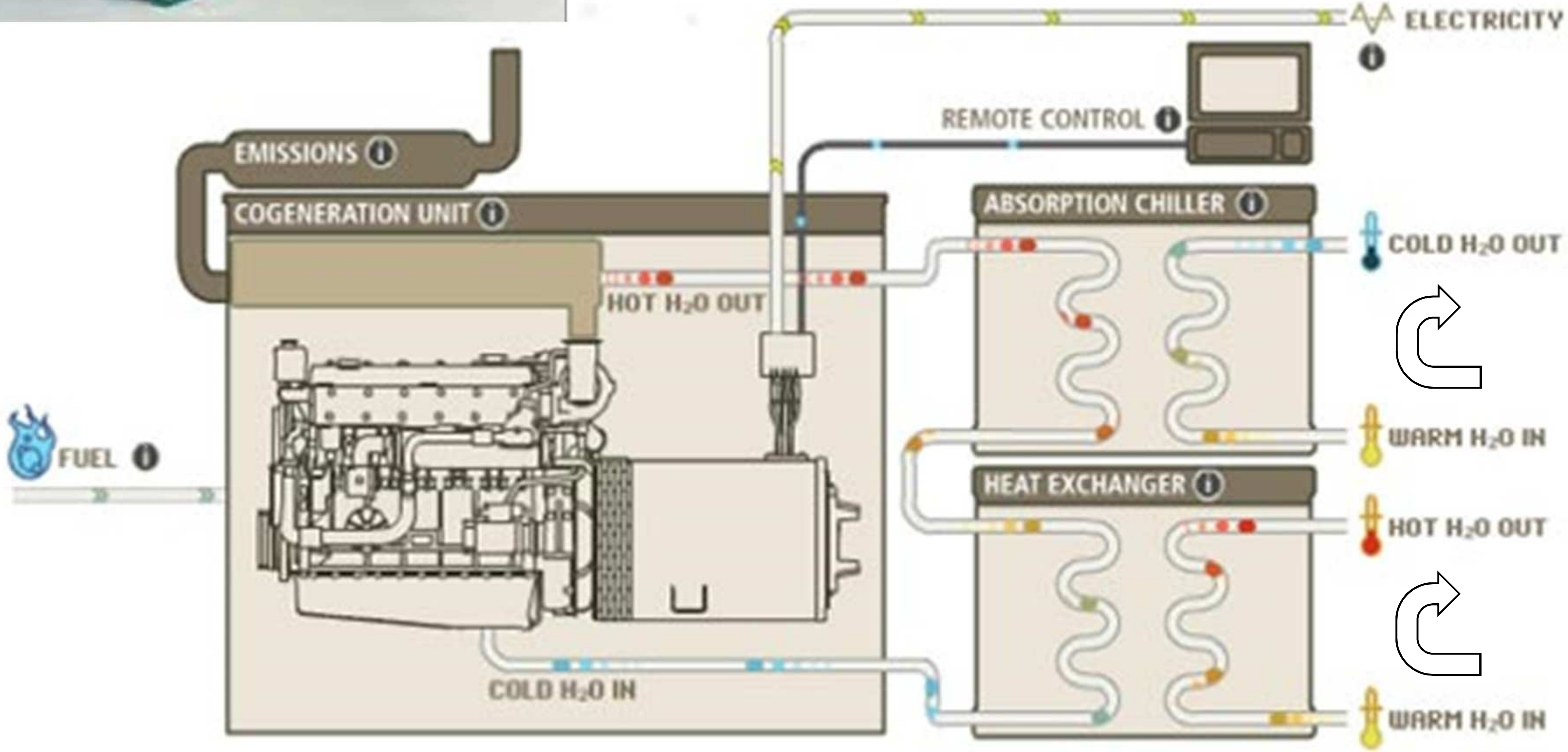
Rendimento termico caldaia 90%

Rendimento globale (35+50)/147,7 = 57,5%



	HONDA ECOWILL	SENERTEC DACHS
Cilindrata cc	163	579
Potenza elettrica kW	1.0	5.5
Potenza termica kW	3.25	12.5
Caldaia ausiliaria kW	14.0	30
Tmax acqua °C	80	95
Rendimento elettrico	20%	27%
Rendimento termico	65%	61%
Rendimento globale	85%	88%
Rumore dB	44	52
Ingombri mm	580*380*880	1060*720*1000
Peso kg	257	520

	DOMESTIC	SMALL COMMERCIAL
Electrical Output	240V 50Hz, 110V 60Hz	240V 50Hz, 110V 60Hz
Electrical Power, kWe	2.5	10
Heating Power, kW	11 (22 boost mode)	44
Overall Efficiency	90%	90%
Weight, kg	60	175
Dimensions, mm	870h x 600w x 400d	960h x 800w x 600d


ELECTRICITY
REMOTE CONTROL
EMISSIONS
COGENERATION UNIT
ABSORPTION CHILLER
COLD H2O OUT
HOT H2O OUT
WARM H2O IN
FUEL
HEAT EXCHANGER
HOT H2O OUT
COLD H2O IN
WARM H2O IN

30 Gemeinde Lajen - Lajen
Comune di Laion - Laion

Versorgungsgebiet: Lajen
Zona servita: Laion

Inbetriebnahme:
Messa in funzione: 10/2004

Wärmeerzeuger: 1 Biomasse-Heizkessel mit 1,3 MW, 1 Biodiesel-Heizkessel für Abdeckung der Lastspitzen mit 3,9 MW
Generatori di calore: 1 caldaia a biomassa con 1,3 MW, 1 caldaia a biodiesel per coprire le punte di carico con 3,9 MW

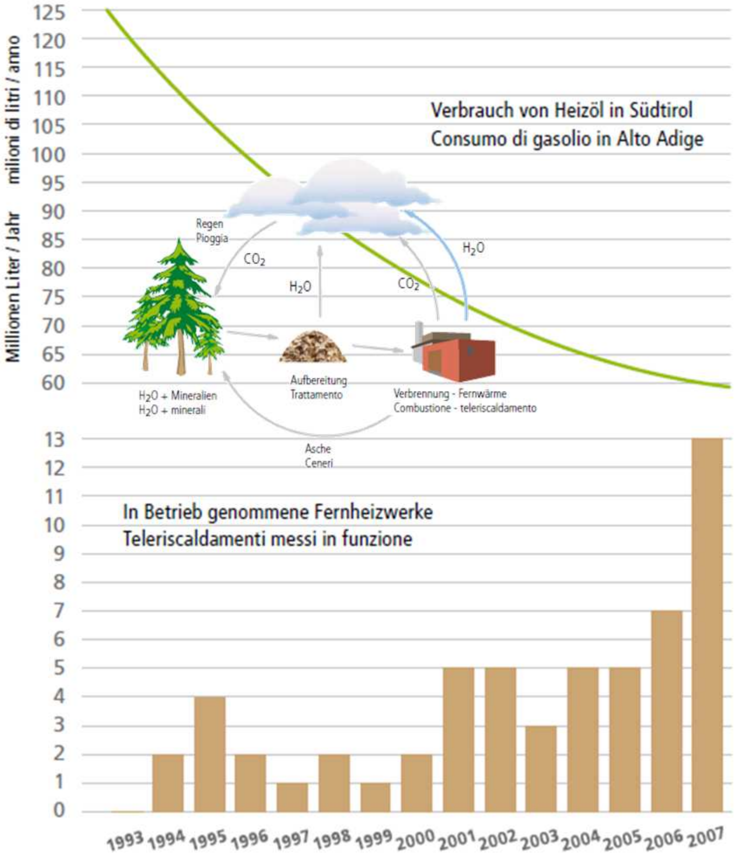
Angeschlossene Abnehmer:
Utenti allacciati: 110

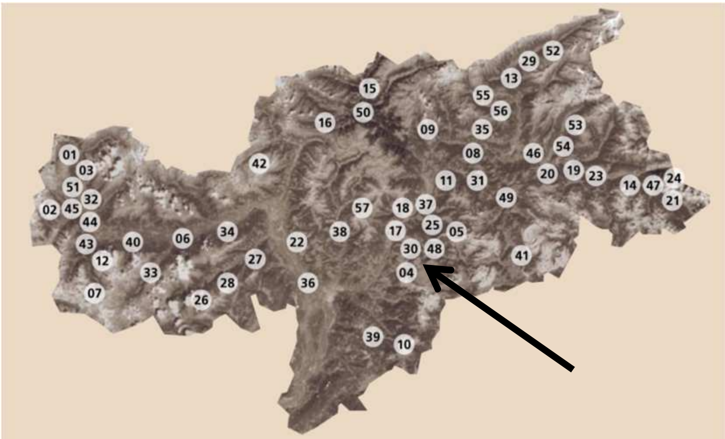
Anschlussleistung:
Potenza allacciata: 3.541 kW

Jährlich verkaufte Wärme:
Calore venduto per anno: 3.165.000 kWh

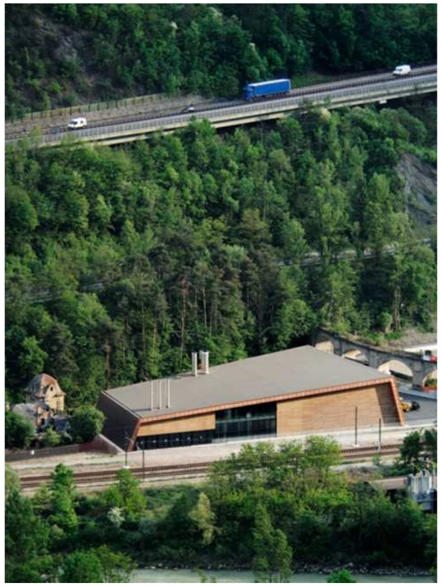
Jährliches Heizöläquivalent:
Equivalente di gasolio per anno: 395.625 l

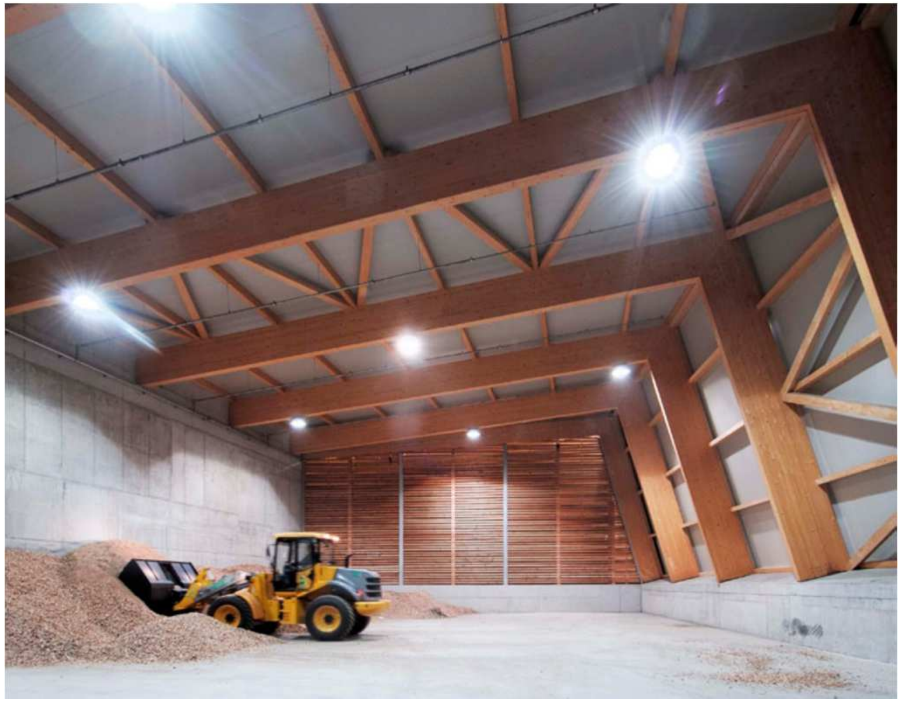
Jährliche CO_2 - Reduktion:
Riduzione di CO_2 per anno: 1.147 t





Progettista
Designer
Roland Baldi





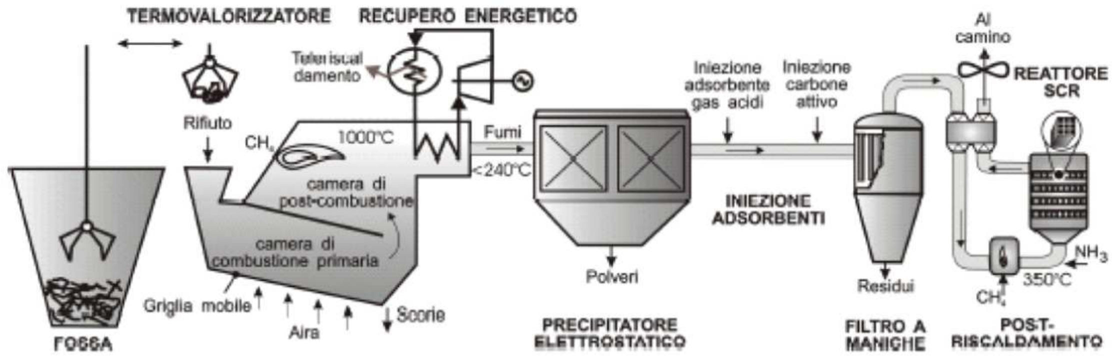
Università di Ferrara

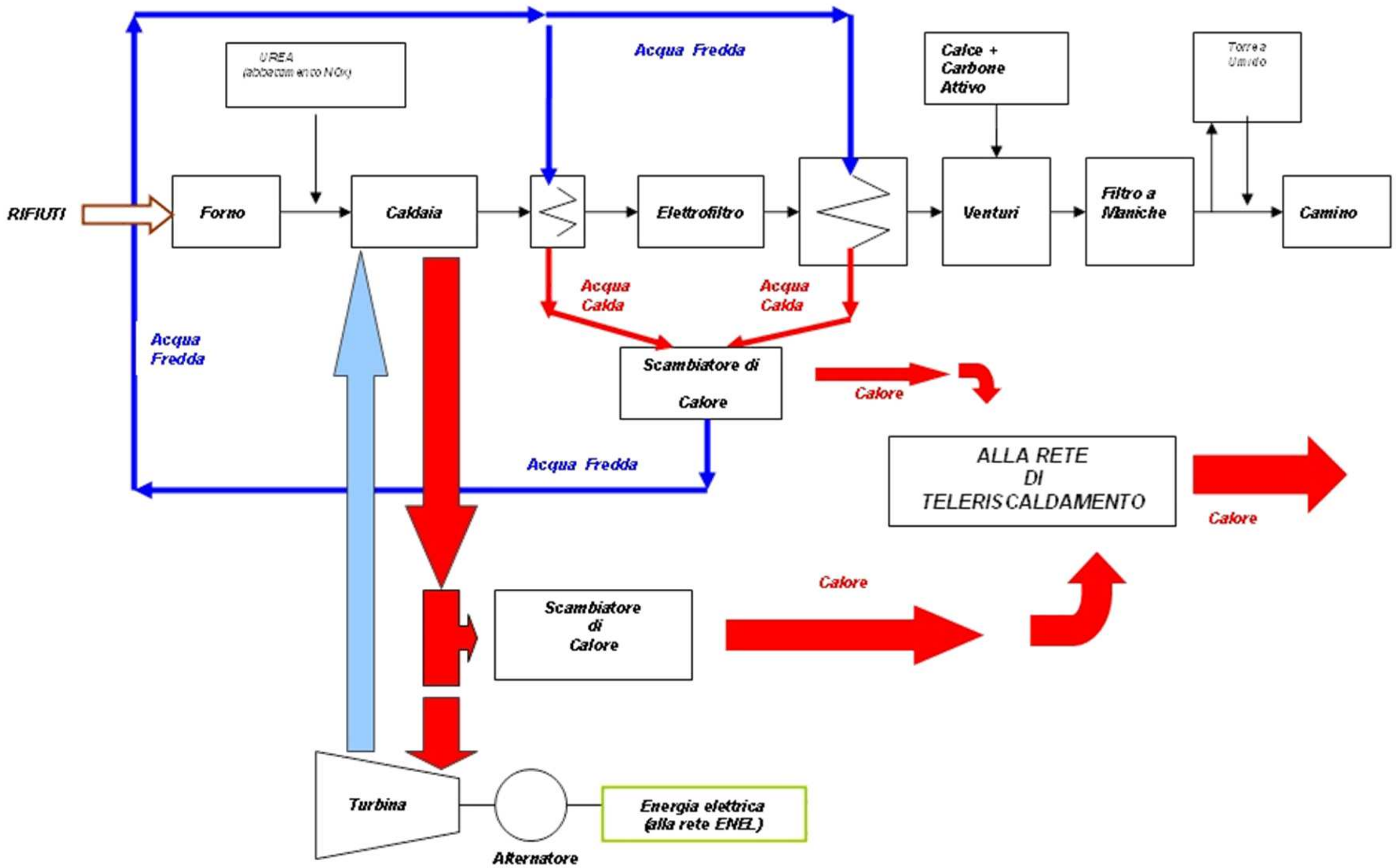
Facoltà di Architettura

Premio Internazionale Architettura Sostenibile Fassa Bortolo

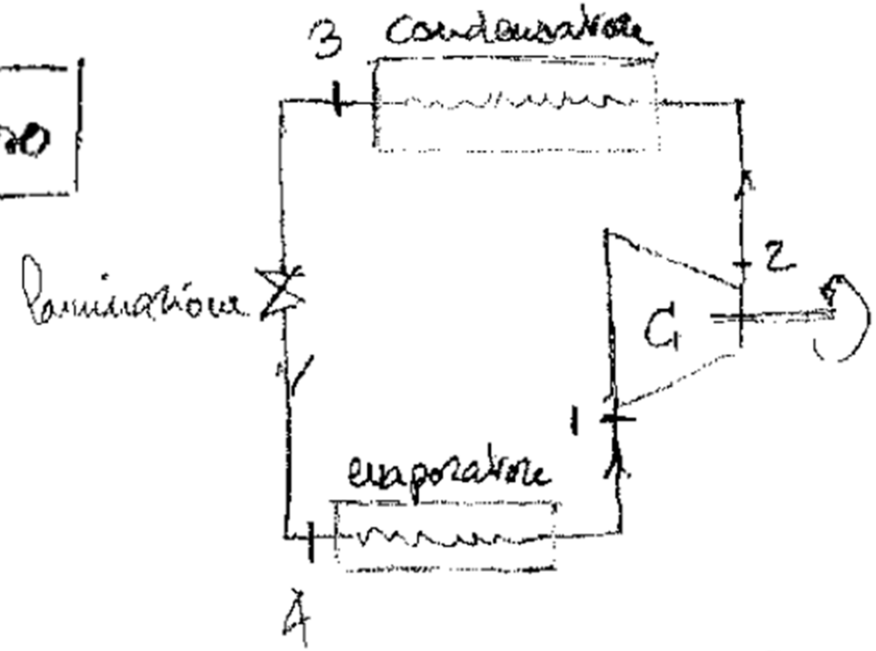
Fassa Bortolo qualità per l'edilizia

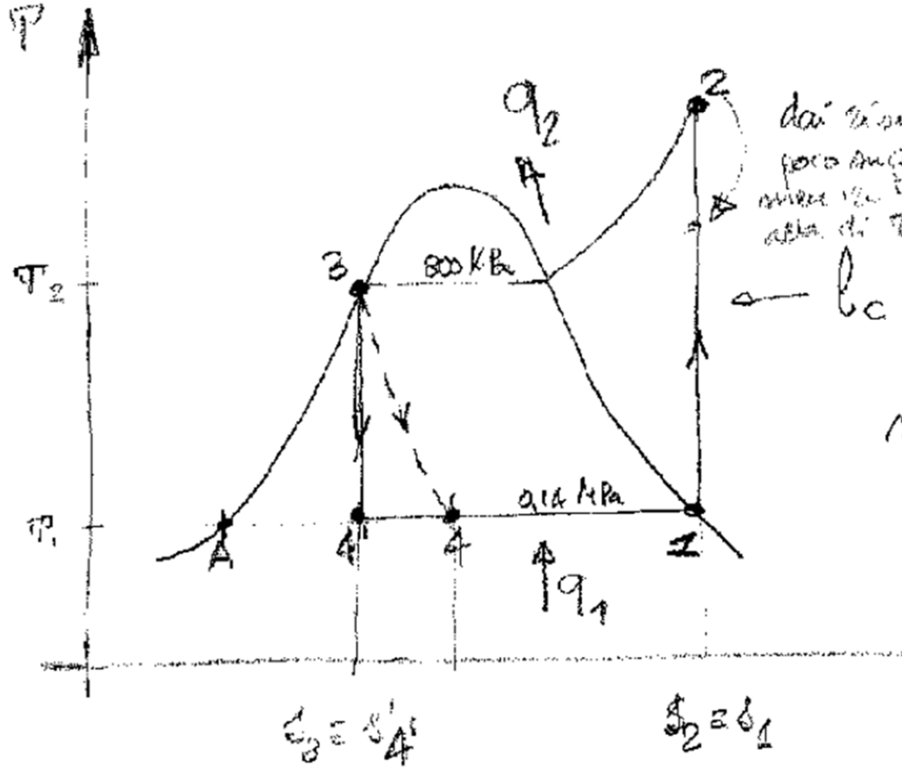
Premio Internazionale Architettura Sostenibile
sesta edizione 2009


TERMOVALORIZZATORE
RECUPERO ENERGETICO
Teleriscaldamento
Rifiuto
CH_4
1000°C
camera di post-combustione
camera di combustione primaria
Griglia mobile
Aria
Scorie
FOSSA
Fumi
<240°C
Polveri
PRECIPITATORE ELETTROSTATICO
Iniezione adsorbente gas acidi
Iniezione carbone attivo
INIEZIONE ADSORBENTI
Residui
FILTRO A MANICHE
Al camino
REATTORE SCR
NH_3
350°C
CH_4
POST-RISCALDAMENTO


RIFIUTI
Forno
UREA (abbattimento NOx)
Caldaia
Elettrofiltro
Calce + Carbone Attivo
Venturi
Filtro a Maniche
Torre a Umido
Camino
Acqua Fredda
Acqua Calda
Acqua Calda
Acqua Fredda
Acqua Fredda
Scambiatore di Calore
Calore
ALLA RETE DI TELERISCALDAMENTO
Calore
Calore
Scambiatore di Calore
Turbina
Alternatore
Energia elettrica (alla rete ENEL)

Ciclo a vapore inverso

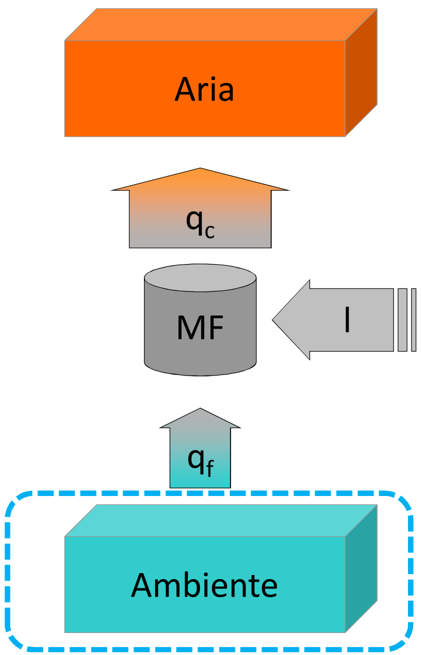




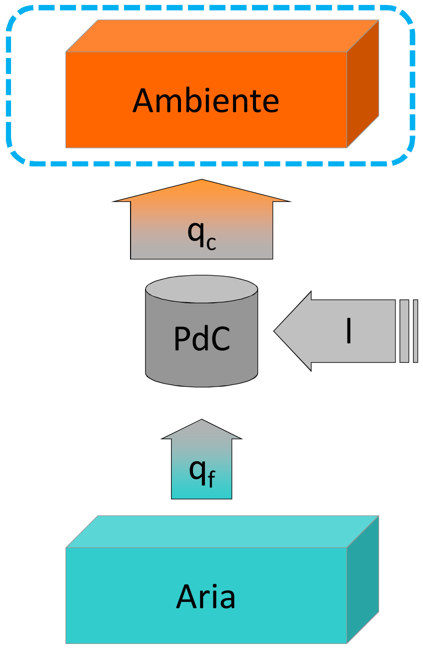
dai risultati T_2 è poco superiore a T_3 mentre T_3 è molto più alta di T_1

$\dot{m}_{R134a} = 0{,}05 \frac{k}{s}$

Caso estivo



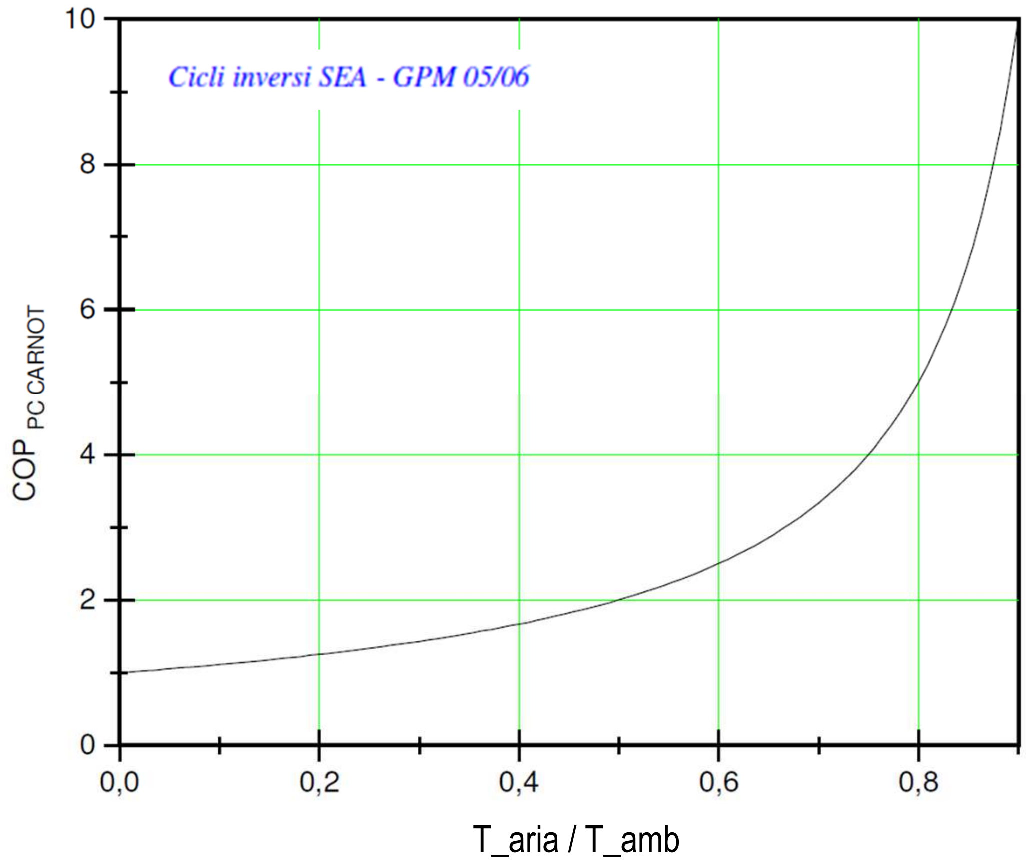
Caso invernale

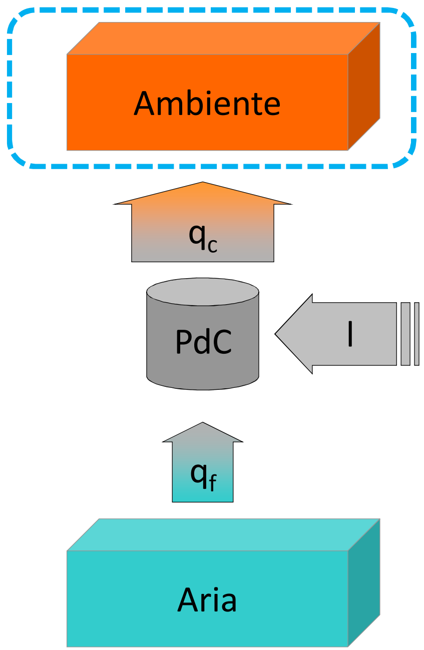


$$EER = \frac{q_f}{l} = \frac{q_f}{q_c - q_f}$$

$$COP = \frac{q_c}{l} = \frac{q_c}{q_c - q_f}$$

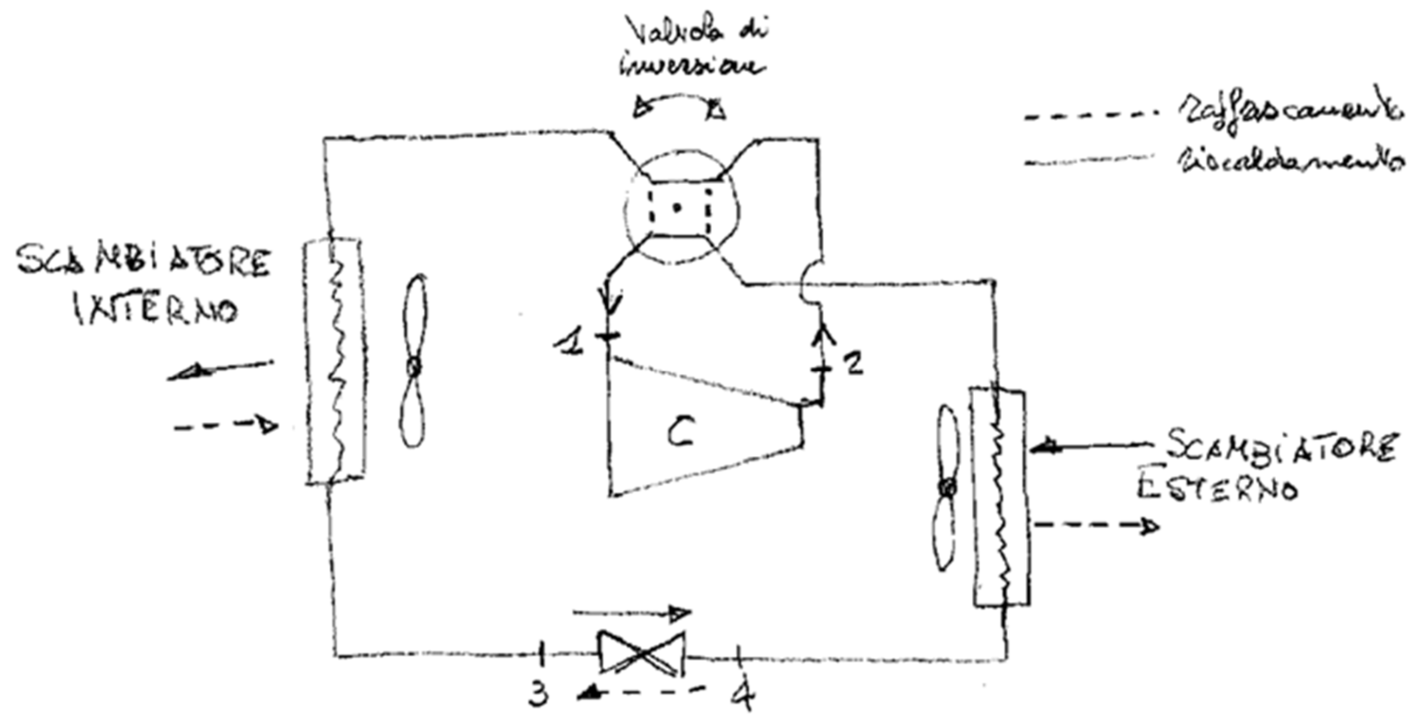
$$COP = EER + 1$$



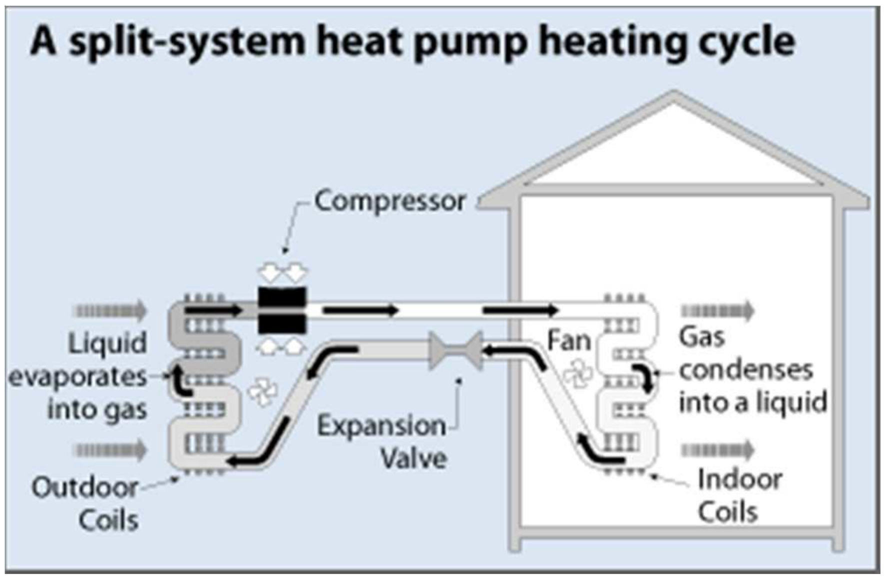


$$COP = \frac{q_c}{l} = \frac{q_c}{q_c - q_f} = \frac{T_c}{T_c - T_f} = \frac{T_{ambiente}}{T_{ambiente} - T_{aria}}$$

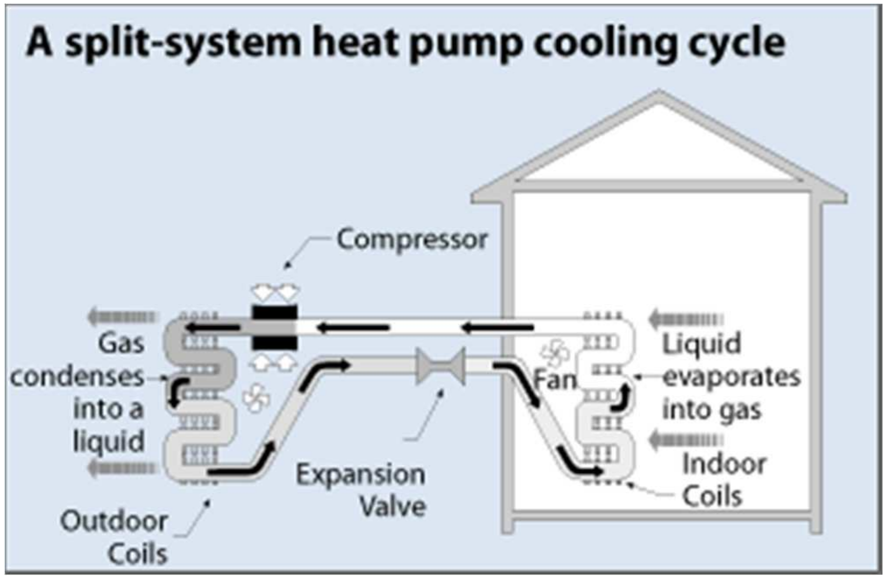
CARNOT



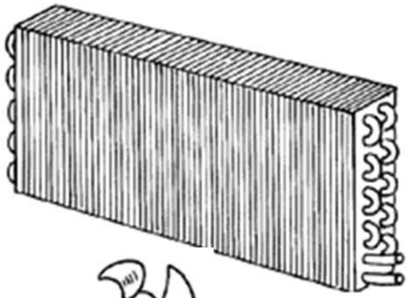
Valvola di inversione
Raffrescamento
Riscaldamento
SCAMBIATORE INTERNO
SCAMBIATORE ESTERNO
C
1
2
3
4



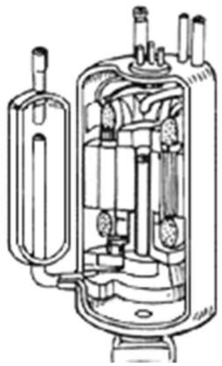
A split-system heat pump heating cycle
Compressor
Liquid evaporates into gas
Outdoor Coils
Expansion Valve
Fan
Gas condenses into a liquid
Indoor Coils

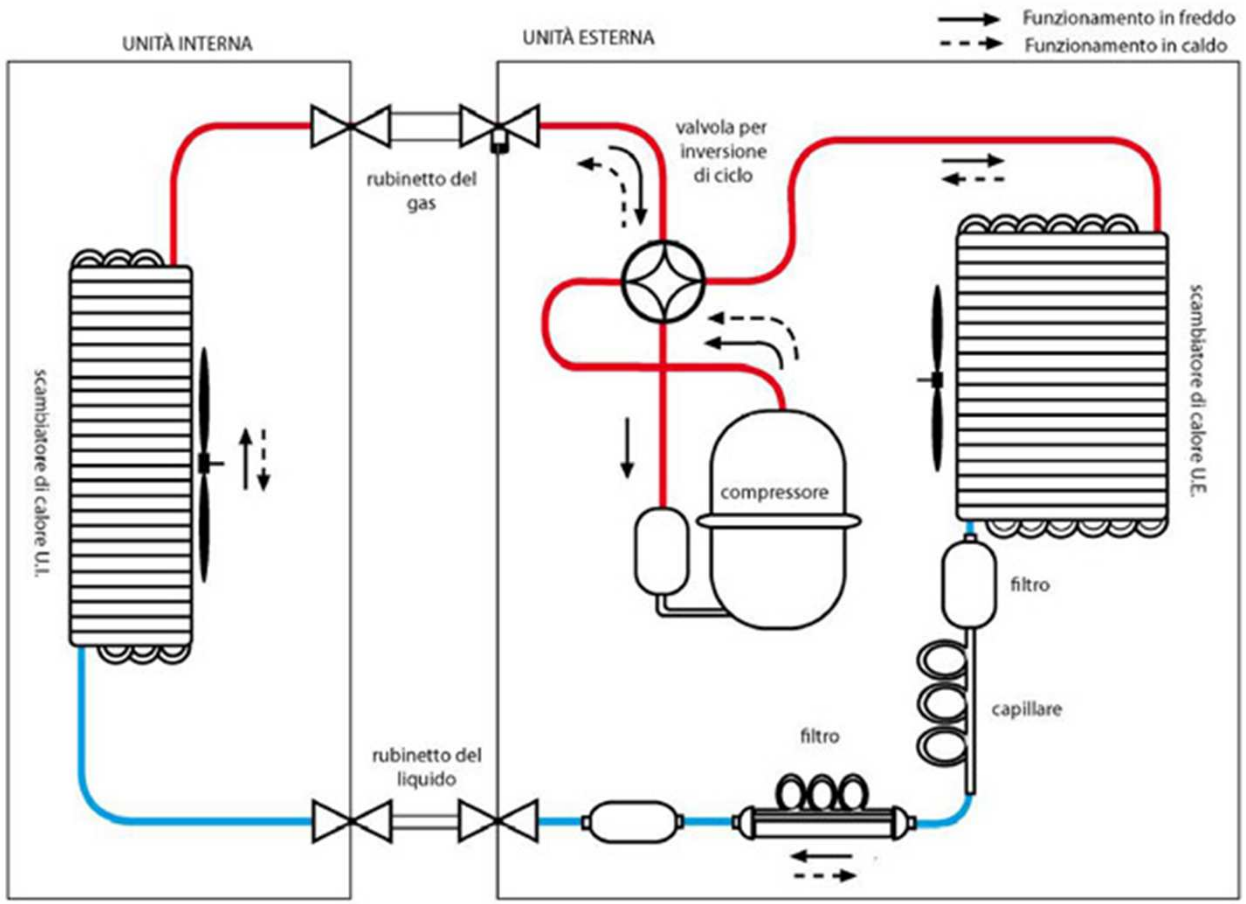


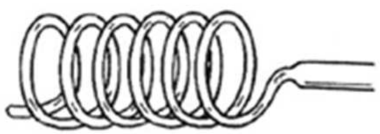
A split-system heat pump cooling cycle
Compressor
Gas condenses into a liquid
Outdoor Coils
Expansion Valve
Fan
Liquid evaporates into gas
Indoor Coils

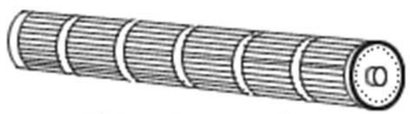


ventilatore
assiale





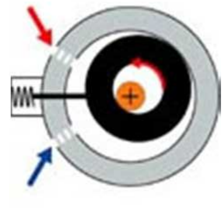


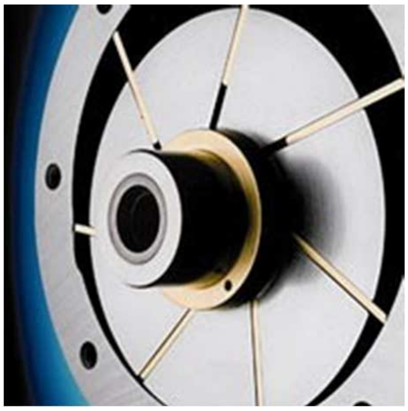


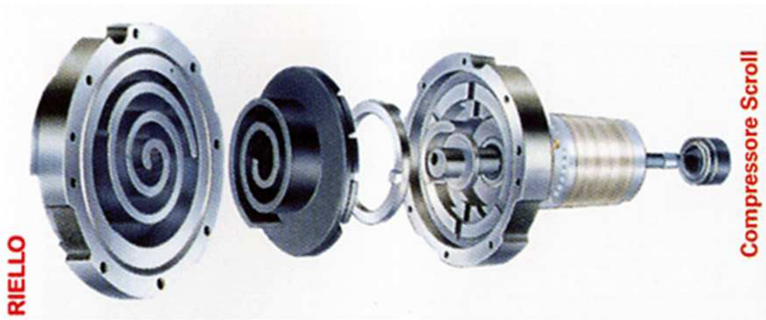
ventilatore tangenziale

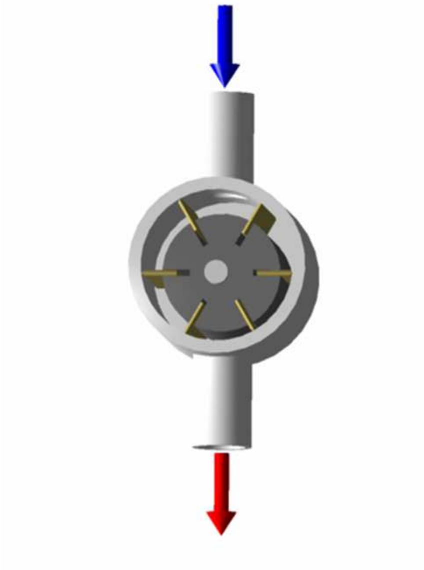
ventilatore
radiale

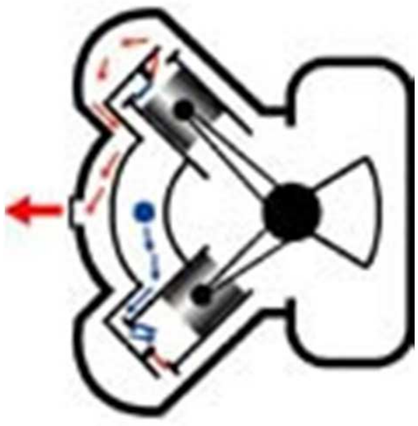

COMPRESSORE SCROLL
HITACHI CON INVERTER DC

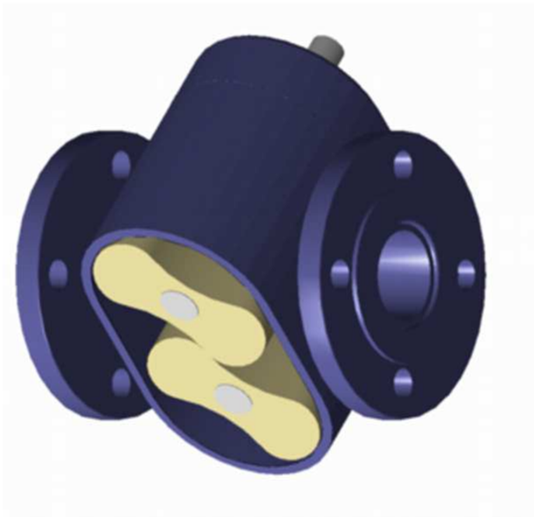




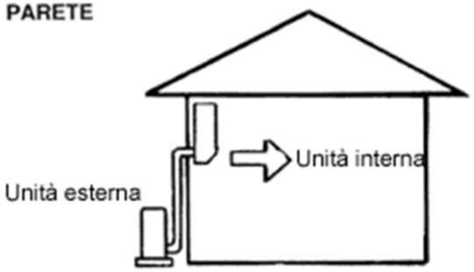

RIELLO
Compressore Scroll





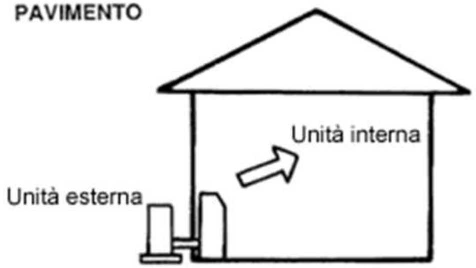


PARETE

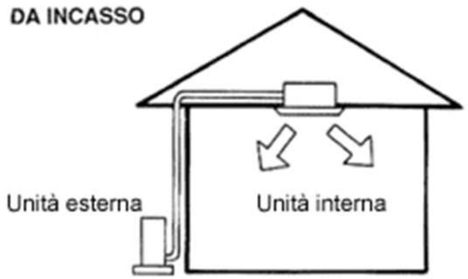


SOSPESO AL SOFFITTO

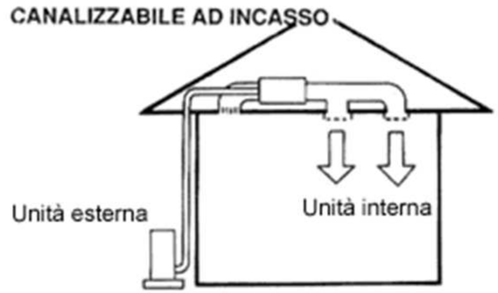
PAVIMENTO



DA INCASSO



CANALIZZABILE AD INCASSO



Una valvola di espansione termostatica è costituita da un elemento termostatico (1) che è separato dal corpo valvola mediante una membrana.

Un tubo capillare collega l'elemento con un bulbo (2), un corpo valvola con sede della valvola (3) e una molla (4).

Funzionamento della valvola di espansione termostatica:

Il funzionamento della valvola di espansione termostatica è determinato da 3 pressioni fondamentali:

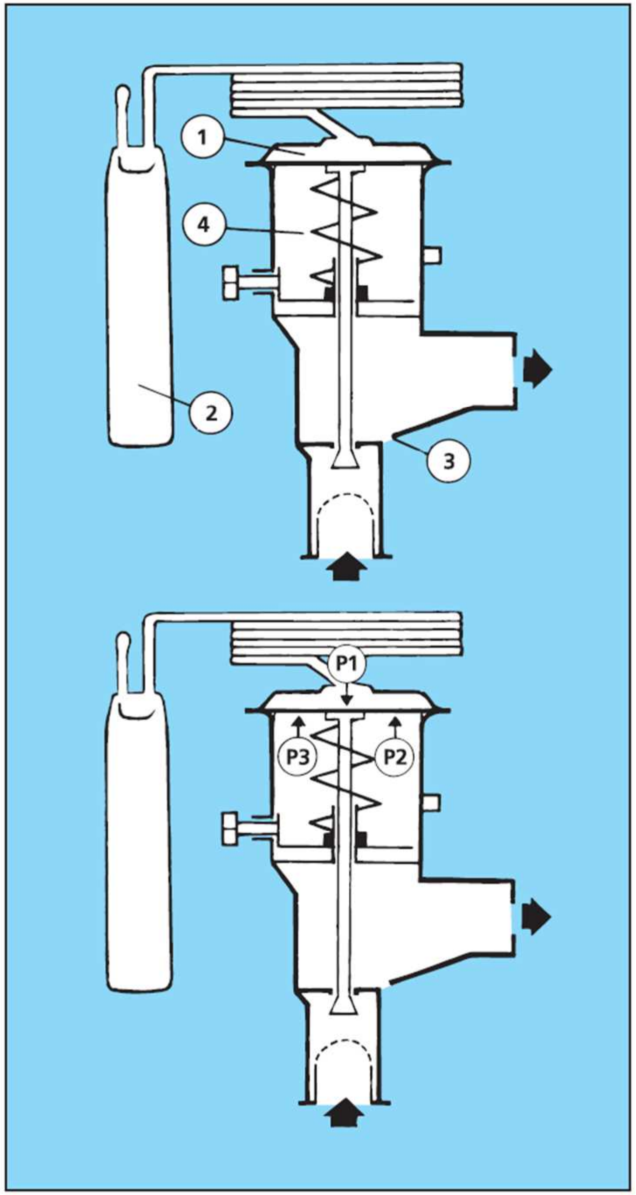
P1: Pressione del bulbo, che agisce sulla parte superiore della membrana e tende ad aprire la valvola.

P2: Pressione di evaporazione che agisce sulla parte inferiore della membrana e tende a chiudere la valvola.

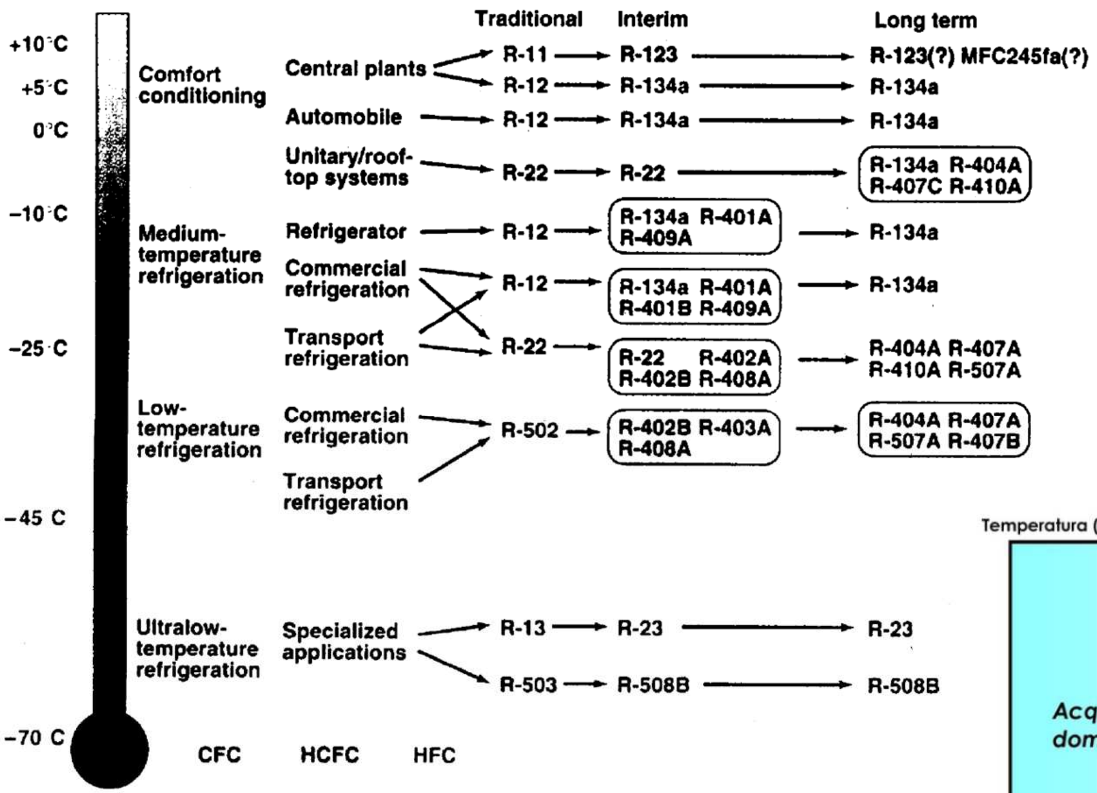
P3: Pressione della molla che agisce ugualmente sulla parte inferiore della membrana e tende a chiudere la valvola.

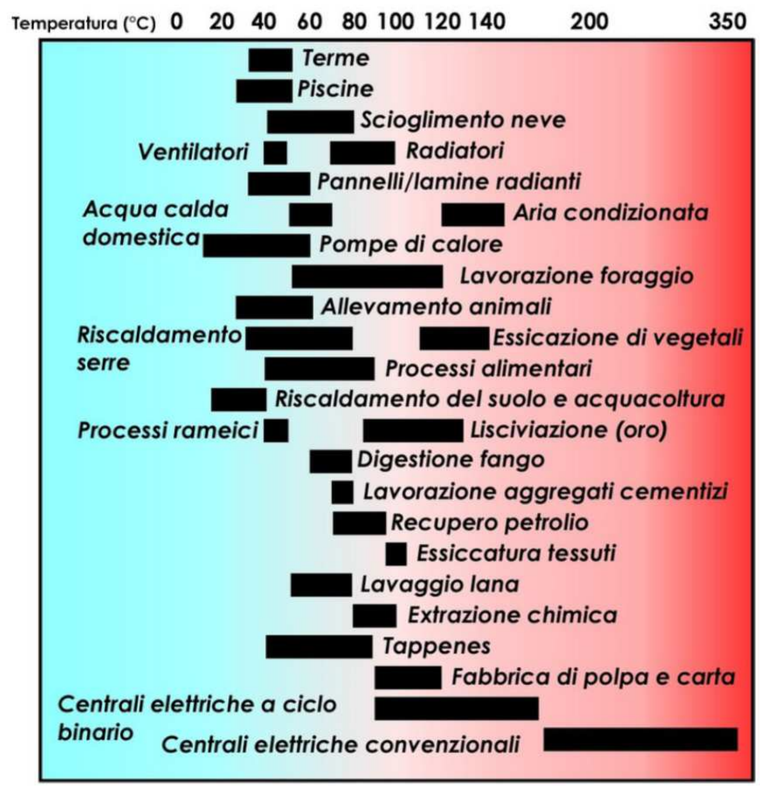
La regolazione della valvola di espansione termostatica è basata sull'equilibrio sulle 3 forze descritte.

La molla viene utilizzata per tarare il surriscaldamento.



Danfoss


Traditional
Interim
Long term
+10°C
+5°C
0°C
-10°C
-25°C
-45°C
-70°C
Comfort conditioning
Central plants
R-11
R-123
R-123(?) MFC245fa(?)
R-12
R-134a
R-134a
Automobile
R-12
R-134a
R-134a
Unitary/roof-top systems
R-22
R-22
R-134a R-404A
R-407C R-410A
Medium-temperature refrigeration
Refrigerator
R-12
R-134a R-401A
R-409A
R-134a
Commercial refrigeration
R-12
R-134a R-401A
R-401B R-409A
R-134a
Transport refrigeration
R-22
R-22 R-402A
R-402B R-408A
R-404A R-407A
R-410A R-507A
Low-temperature refrigeration
Commercial refrigeration
Transport refrigeration
R-502
R-402B R-403A
R-408A
R-404A R-407A
R-507A R-407B
Ultralow-temperature refrigeration
Specialized applications
R-13
R-23
R-23
R-503
R-508B
R-508B
CFC
HCFC
HFC


Temperatura (°C) 0 20 40 60 80 100 120 140 200 350
Terme
Piscine
Scioglimento neve
Ventilatori
Radiatori
Pannelli/lamine radianti
Acqua calda domestica
Aria condizionata
Pompe di calore
Lavorazione foraggio
Allevamento animali
Riscaldamento serre
Essicazione di vegetali
Processi alimentari
Riscaldamento del suolo e acquacoltura
Processi rameici
Lisciviazione (oro)
Digestione fango
Lavorazione aggregati cementizi
Recupero petrolio
Essiccatura tessuti
Lavaggio lana
Extrazione chimica
Tappenes
Fabbrica di polpa e carta
Centrali elettriche a ciclo binario
Centrali elettriche convenzionali

Compressione interrefrigerata

$$\Delta h_{A2E} = \ell_c^{A2} - q^{2E}$$

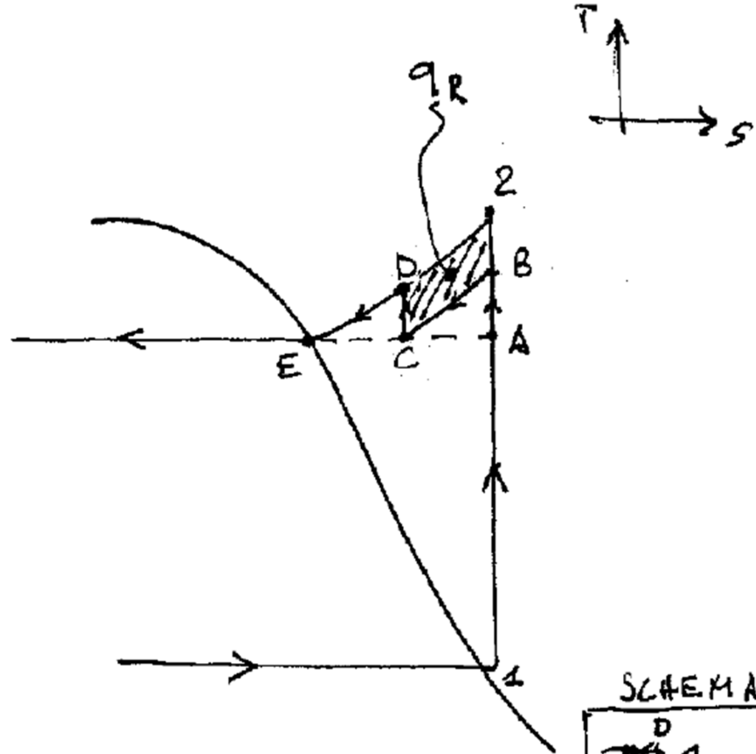
$$\Delta h_{ABCDE} = \ell_c^{AB} + \ell_c^{CD} - q^{BC} - q^{DE}$$

$$0 = \ell_c^{A2} - q^{2E} - \ell_c^{AB} - \ell_c^{CD} + q^{BC} + q^{DE}$$

$$-q_R$$

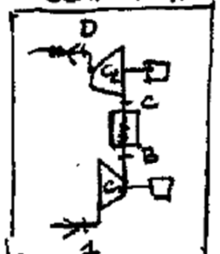
$$\Rightarrow \ell_c^{A2} = \ell_c^{AB} + \ell_c^{CD} + q_R$$

ovvero $\ell_c^{A2} > \ell_c^{AB} + \ell_c^{CD}$



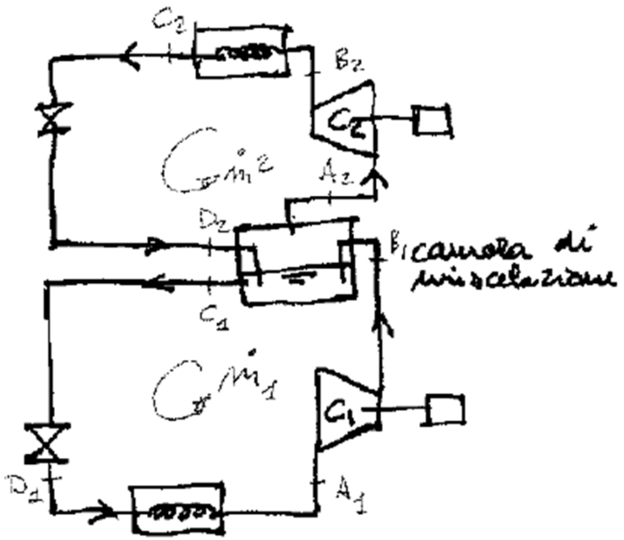
CICLO INVERSO

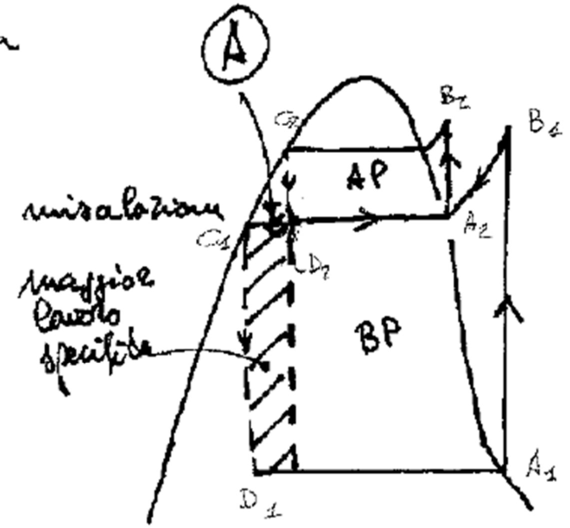
SCHEMA



Il frazionamento della compressione, con interposto uno scambiatore, mi permette di risparmiare lavoro di compressione, a parità di sorgenti. Lo svantaggio è legato alla necessità di un ulteriore compressore e dello scambiatore, che hanno rendimenti alti ma inferiori a 1. Tale opzione vale quindi per impianti non piccoli.

Doppia compressione con miscelazione intermedia

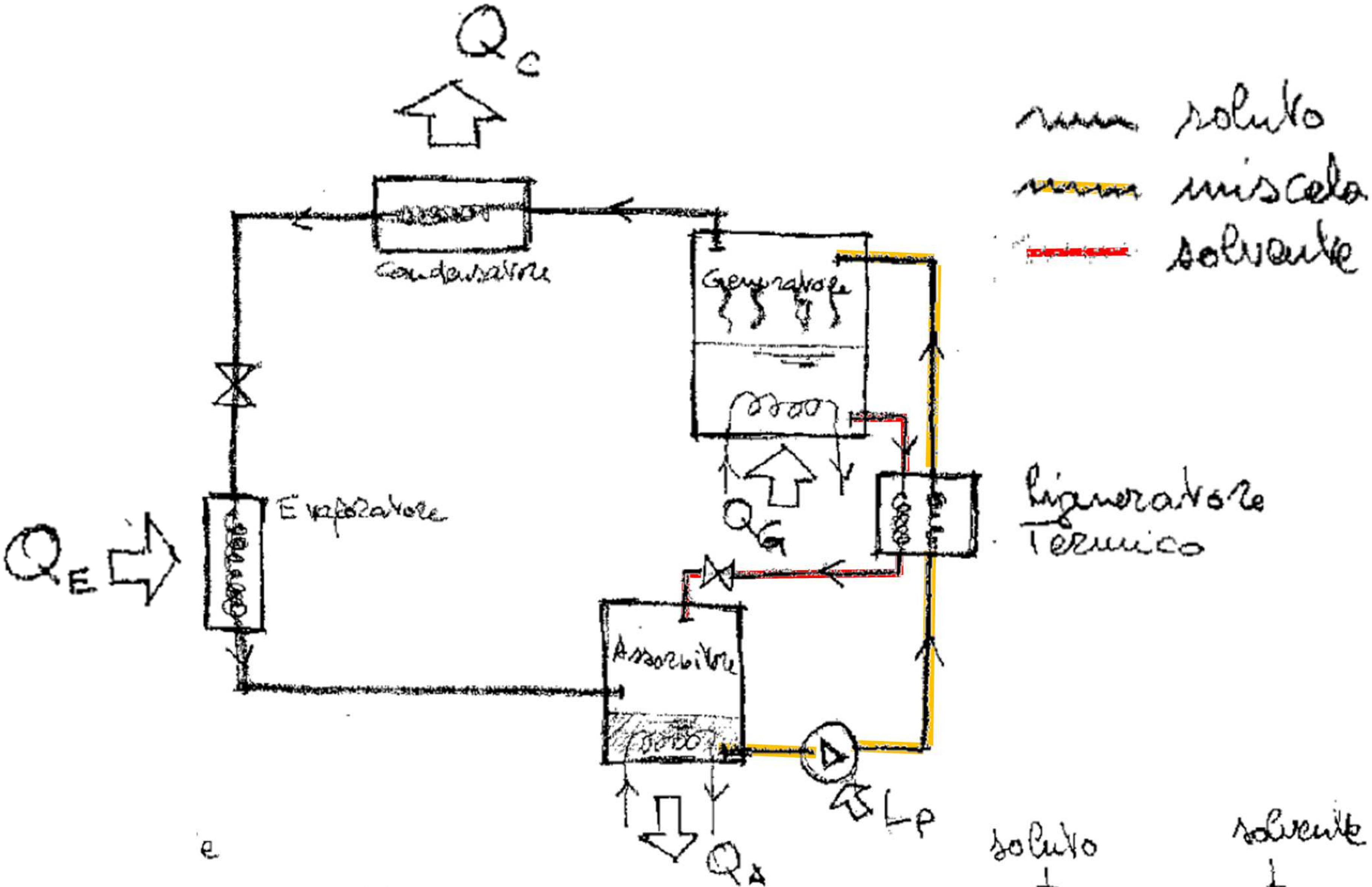




$$q_{B1 \to C1} \cdot \dot{m}_1 = q_{D2 \to A2} \cdot \dot{m}_2$$

i due cicli lavorano con frazioni di vapore

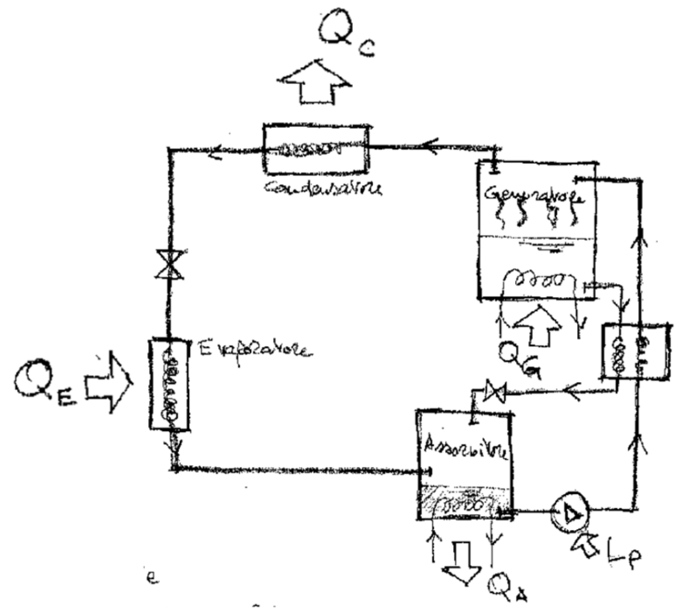
La differenza sta nella miscelazione al posto dello scambiatore tra i due circuiti. Questo separa in due cicli ad AP e BP, permettendo di avere un lavoro specifico complessivo maggiore attraverso (A).
Molto dipende dalla inclinazione delle curve limite. In ogni caso, l'aggiunta di due sistemi di laminazione non incide in modo significativo sui costi.



soluto ↓ , solvente ↓

Ammoniaca - Acqua

Acqua - Bromuro di Li



COP da intendere come EER

$$COP = \frac{Q_E}{Q_G + L_p} \cong \frac{Q_E}{Q_G}$$

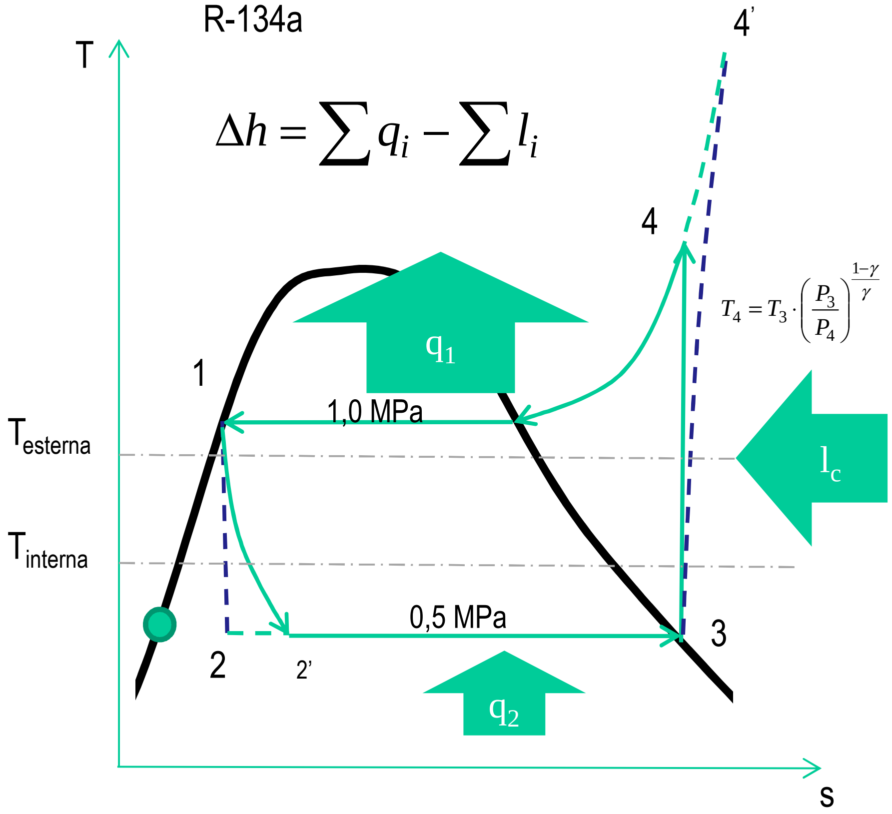
Supponendo l'intero ciclo come isoentropico :

$$\frac{Q_E}{T_E} + \frac{Q_G}{T_G} = \frac{Q_C + Q_A}{T_{amb}} \quad \text{ma} \quad Q_C + Q_A \overset{I^{\circ}\text{ principio}}{=} Q_G + Q_E$$

$$\Rightarrow \frac{1}{T_E}\frac{Q_E}{Q_G} + \frac{1}{T_G} = \frac{1}{T_{amb}} + \frac{Q_E}{Q_G} \cdot \frac{1}{T_{amb}}$$

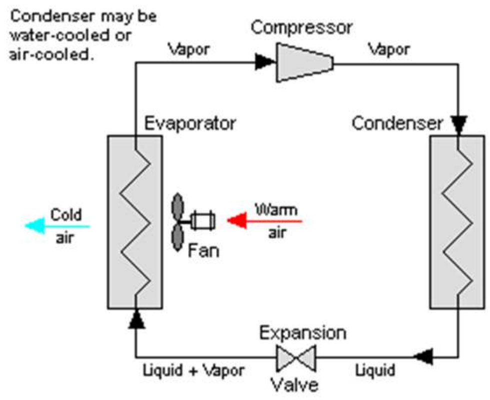
$$\text{quindi} \quad \frac{Q_E}{Q_G} = \boxed{\frac{\frac{1}{T_{amb}} - \frac{1}{T_G}}{\frac{1}{T_E} - \frac{1}{T_{amb}}} \cong COP}$$

$$\text{Se } T_G \to \infty, \quad COP = \frac{\frac{1}{T_{amb}}}{\frac{1}{T_E} - \frac{1}{T_{amb}}} = COP_{carnot} \text{ tra } T_{amb} \text{ e } T_E$$



$T_{terreno}$ = 17°C
$T_{ambiente}$ = 26°C
T_{aria} = 35°C

T_1 = 39,4°C
P_1 = 1,0 MPa
h_1 = 105,3 kJ/kg
h_{lv} = 162,7 kJ/kg



T_2 = 15,7°C
P_2 = 0,5 Mpa
h_2 = 71,3 kJ/kg
h_{lv} = 184,7 kJ/kg

Dalle tabelle del R-134a, h_4=270 kJ/kg

$$q_1 = h_4 - h_1 \cong 165 \frac{kJ}{kg}$$

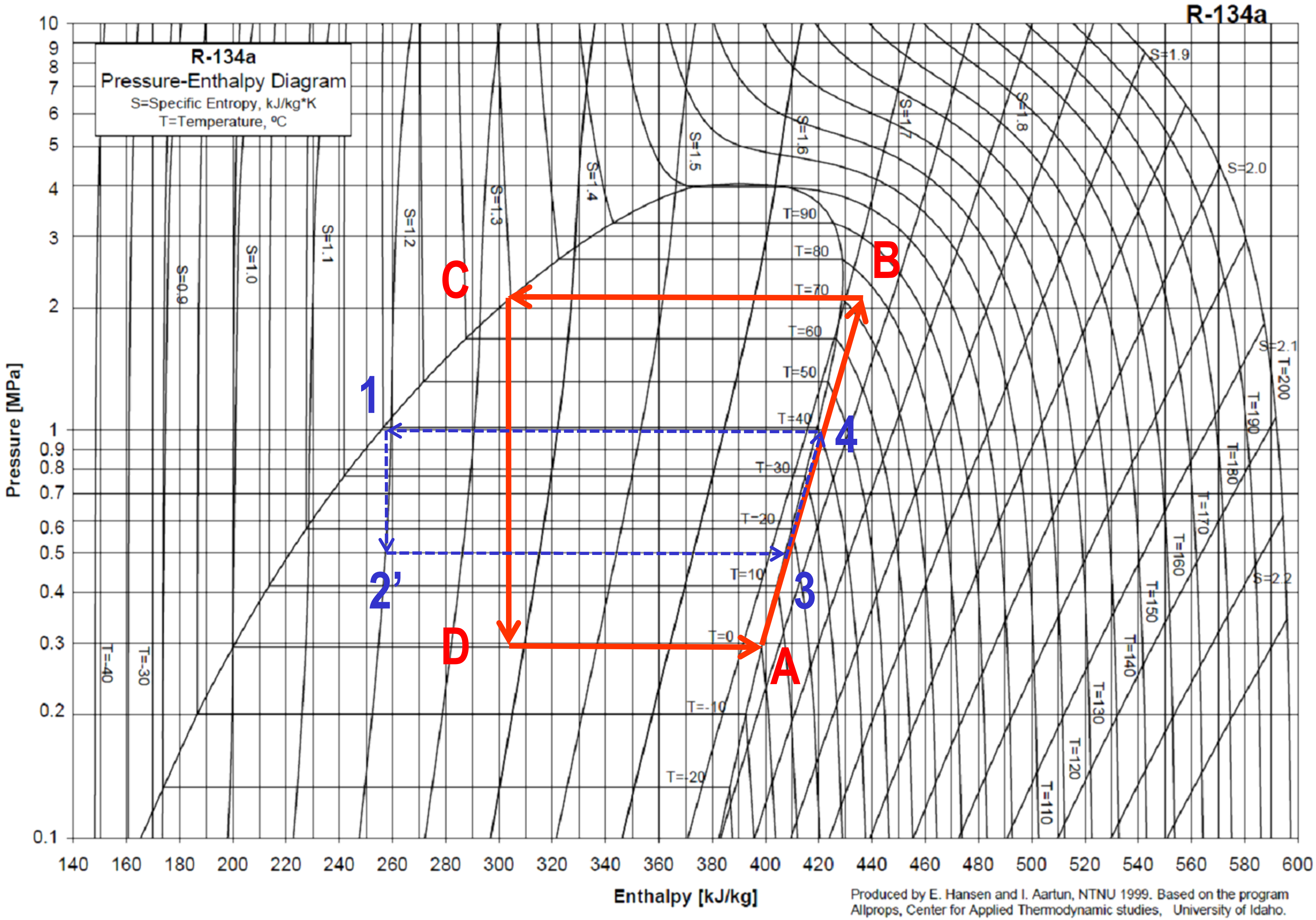
$$\dot{m} = \frac{P}{q_1} = \frac{10kW}{165\frac{kJ}{kg}} = 0{,}06 \frac{kg}{s}$$

$$\dot{V} = \frac{\dot{m}}{\rho} = 0{,}182 \frac{m^3}{ora}$$

$$c_p \approx 1{,}38 \frac{kJ}{kg \cdot K}$$

$$R = 0{,}08149 \frac{kJ}{kg \cdot K}$$

$$\rho \approx 1200 \frac{kg}{m^3}$$


R-134a
R-134a
Pressure-Enthalpy Diagram
S=Specific Entropy, kJ/kg*K
T=Temperature, ºC
Pressure [MPa]
Enthalpy [kJ/kg]
A
B
C
D
1
2'
3
4
Produced by E. Hansen and I. Aartun, NTNU 1999. Based on the program Allprops, Center for Applied Thermodynamic studies, University of Idaho.

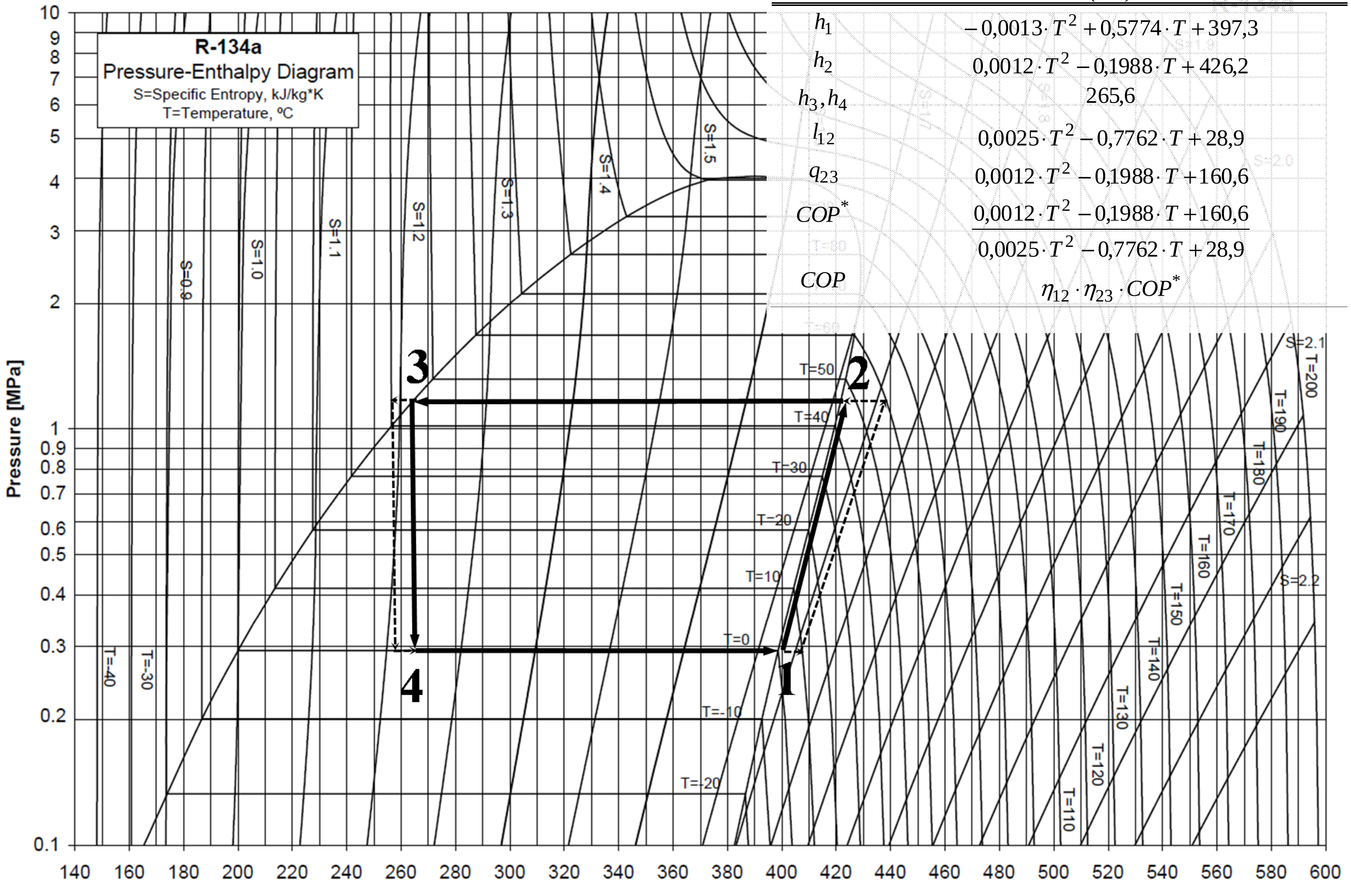
Tetrafluorethane - R134a - $C_2H_2F_4$

Temp. °C	Press. bar	Volume Specifico m³/kg liquido saturo $v_l \times 10^3$	vapore saturo v_v	Energia interna kJ/kg liquido saturo u_l	vapore saturo u_v	Entalpia kJ/kg liquido saturo h_l	vap. Δh_{lv}	vapore saturo h_v	Entropia kJ/kg K liquido saturo s_l	vapore saturo s_v	Temp. °C
-40	0.5164	0.7055	0.3569	49.94	254.43	49.98	222.88	272.86	0.8030	1.759	-40
-36	0.6332	0.7113	0.2947	54.66	256.71	54.71	220.67	275.38	0.8231	1.7536	-36
-32	0.7704	0.7172	0.2451	59.45	258.99	59.50	218.37	277.88	0.8431	1.7486	-32
-28	0.9305	0.7233	0.2052	64.29	261.27	64.35	216.01	280.36	0.8630	1.7441	-28
-26	1.0199	0.7265	0.1882	66.73	262.41	66.80	214.80	281.60	0.8729	1.7420	-26
-24	1.1160	0.7296	0.1728	69.19	263.55	69.27	213.57	282.83	0.8828	1.7400	-24
-22	1.2192	0.7328	0.1590	71.66	264.68	71.75	212.32	284.06	0.8927	1.7381	-22
-20	1.3299	0.7361	0.1464	74.15	265.82	74.24	211.05	285.29	0.9026	1.7362	-20
-18	1.4483	0.7395	0.1350	76.65	266.95	76.75	209.76	286.51	0.9124	1.7345	-18
-16	1.5748	0.7428	0.1247	79.16	268.08	79.28	208.45	287.72	0.9222	1.7328	-16
-12	1.8540	0.7498	0.1068	84.23	270.34	84.37	205.77	290.13	0.9418	1.7297	-12
-8	2.1704	0.7569	0.0919	89.36	272.58	89.52	203.00	292.52	0.9613	1.7269	-8
-4	2.5274	0.7644	0.0794	94.54	274.82	94.73	200.15	294.88	0.9807	1.7243	-4
0	2.9282	0.7210	0.0689	99.77	277.04	100.00	197.21	297.21	1.0000	1.7220	0
4	3.3765	0.7801	0.0600	105.06	279.25	105.33	194.19	299.51	1.0192	1.7199	4
8	3.8756	0.7884	0.0525	110.41	281.44	110.71	191.07	301.78	1.0384	1.7180	8
12	4.4294	0.7971	0.0460	115.81	283.61	116.16	187.85	304.01	1.0575	1.7162	12
16	5.0416	0.8062	0.0405	121.27	285.76	121.67	184.52	306.20	1.0765	1.7146	16
20	5.7160	0.8157	0.0358	126.78	287.89	127.24	181.09	308.34	1.0954	1.7132	20
24	6.4566	0.8257	0.0317	132.35	289.99	132.88	177.55	310.43	1.1143	1.7119	24
26	6.8530	0.8309	0.0298	135.16	291.03	135.73	175.73	311.46	1.1238	1.7112	26
28	7.2675	0.8362	0.0281	137.98	292.06	138.59	173.89	312.48	1.1332	1.7106	28
30	7.7006	0.8417	0.0265	140.82	293.08	141.47	172.00	313.48	1.1426	1.7100	30
32	8.1528	0.8473	0.0250	143.68	294.10	144.37	170.09	314.46	1.1520	1.7094	32
34	8.6247	0.8530	0.0236	146.56	295.10	147.29	168.14	315.43	1.1614	1.7088	34
36	9.1168	0.8590	0.0223	149.45	296.09	150.23	166.15	316.38	1.1708	1.7083	36
38	9.6298	0.8651	0.0210	152.36	297.07	153.19	164.12	317.31	1.1802	1.7077	38
40	10.164	0.8714	0.0199	155.28	298.04	156.17	162.05	318.22	1.1896	1.7071	40
42	10.720	0.8780	0.0188	158.23	299.00	159.17	159.94	319.12	1.1990	1.7065	42
44	11.299	0.8847	0.0177	161.20	299.94	162.20	157.79	319.99	1.2084	1.7060	44
48	12.526	0.8989	0.0159	167.20	301.77	168.33	153.33	321.66	1.2273	1.7047	48
52	13.851	0.9142	0.0142	173.29	303.53	174.56	148.66	323.22	1.2462	1.7034	52
56	15.278	0.9308	0.0127	179.49	305.21	180.91	143.75	324.66	1.2652	1.7020	56
60	16.813	0.9488	0.0114	185.80	306.79	187.40	138.57	325.97	1.2844	1.7003	60
70	21.162	1.0027	0.0086	206.20	310.13	204.32	124.08	328.41	1.3332	1.6948	70
80	26.324	1.0766	0.0064	219.86	312.12	222.69	106.41	329.10	1.3844	1.6857	80
90	32.435	1.1949	0.0046	239.8	311.32	243.67	82.63	326.30	1.4410	1.6685	90
100	39.742	1.5443	0.0027	268.58	298.47	274.72	34.40	309.11	1.5226	1.6147	100

Tetrafluorethane - R134a - $C_2H_2F_4$

Press.	Temp.	Volume Specifico m^3/kg		Energia interna kJ/kg		Entalpia kJ/kg			Entropia kJ/kg K		Press.
bar	°C	liquido saturo $v_l \times 10^3$	vapore saturo v_v	liquido saturo u_l	vapore saturo u_v	liquido saturo h_l	vap. Δh_{lv}	vapore saturo h_v	liquido saturo s_l	vapore saturo s_v	bar
0.6	-37.07	0.7097	0.3100	53.39	256.10	53.44	221.27	274.70	0.8177	1.755	0.6
0.8	-31.21	0.7184	0.2366	60.39	259.44	60.45	217.92	278.37	0.8470	1.7477	0.8
1.0	-26.43	0.7258	0.1917	66.20	262.16	66.27	215.06	281.33	0.8708	1.7425	1.0
1.2	-22.36	0.7323	0.1614	71.21	264.48	71.30	212.54	283.84	0.8909	1.7384	1.2
1.4	-18.80	0.7381	0.1395	75.64	266.50	75.75	210.27	286.02	0.9085	1.7352	1.4
1.6	-15.62	0.7435	0.1229	79.64	268.30	79.76	208.19	287.95	0.9241	1.7325	1.6
1.8	-12.73	0.7485	0.1098	83.29	269.92	83.43	206.26	289.69	0.9382	1.7303	1.8
2.0	-10.09	0.7532	0.0993	86.67	271.41	86.82	204.46	291.28	0.9511	1.7283	2.0
2.4	-5.37	0.7618	0.0834	92.75	274.05	92.93	201.14	294.07	0.9740	1.7252	2.4
2.8	-1.23	0.7697	0.0719	98.16	276.36	98.37	198.13	296.5	0.9941	1.7227	2.8
3.2	2.48	0.7770	0.0632	103.04	278.41	103.29	195.35	298.64	1.0119	1.7207	3.2
3.6	5.84	0.7839	0.0564	107.52	280.26	107.80	192.76	300.56	1.0281	1.7190	3.6
4.0	8.93	0.7904	0.0509	111.67	281.95	111.98	190.32	302.30	1.0429	1.7175	4.0
5.0	15.74	0.8056	0.0409	120.91	285.62	121.31	184.74	306.05	1.0753	1.7147	5.0
6.0	21.58	0.8196	0.0341	128.97	288.72	129.46	179.71	309.17	1.1029	1.7127	6.0
7.0	26.72	0.8328	0.0292	136.17	291.4	136.76	175.07	311.83	1.1272	1.7110	7.0
8.0	31.33	0.8454	0.0255	142.73	293.76	143.40	170.73	314.13	1.1489	1.7096	8.0
9.0	35.53	0.8576	0.0226	148.77	295.86	149.54	166.62	316.16	1.1686	1.7084	9.0
10.0	39.39	0.8695	0.0202	154.4	297.75	155.27	162.68	317.95	1.1868	1.7073	10.0
12.0	46.32	0.8928	0.0166	164.67	301.01	165.21	155.23	320.97	1.2194	1.7053	12.0
14.0	52.43	0.9159	0.0140	173.96	303.72	175.24	148.14	323.38	1.2483	1.7033	14.0
16.0	57.92	0.9392	0.0121	182.5	305.98	184.00	141.31	325.31	1.2744	1.7012	16.0
18.0	62.91	0.9631	0.0105	190.47	307.86	192.20	134.60	326.81	1.2984	1.6989	18.0
20.0	67.49	0.9878	0.0093	198	309.39	199.97	127.95	327.92	1.3208	1.6964	20.0
25.0	77.59	1.0562	0.0069	215.46	311.82	218.10	111.06	329.15	1.3717	1.6884	25.0
30.0	86.22	1.1416	0.0053	231.86	312.14	235.28	92.71	327.99	1.4186	1.6765	30.0

Quantity	Relationships in temperature at the evaporator (°C)
h_1	$-0{,}0013 \cdot T^2 + 0{,}5774 \cdot T + 397{,}3$
h_2	$0{,}0012 \cdot T^2 - 0{,}1988 \cdot T + 426{,}2$
h_3, h_4	265,6
l_{12}	$0{,}0025 \cdot T^2 - 0{,}7762 \cdot T + 28{,}9$
q_{23}	$0{,}0012 \cdot T^2 - 0{,}1988 \cdot T + 160{,}6$
COP^*	$\dfrac{0{,}0012 \cdot T^2 - 0{,}1988 \cdot T + 160{,}6}{0{,}0025 \cdot T^2 - 0{,}7762 \cdot T + 28{,}9}$
COP	$\eta_{12} \cdot \eta_{23} \cdot COP^*$



Produced by E. Hansen and I. Aartun, NTNU 1999. Based on the program Allprops, Center for Applied Thermodynamic studies, University of Idaho.