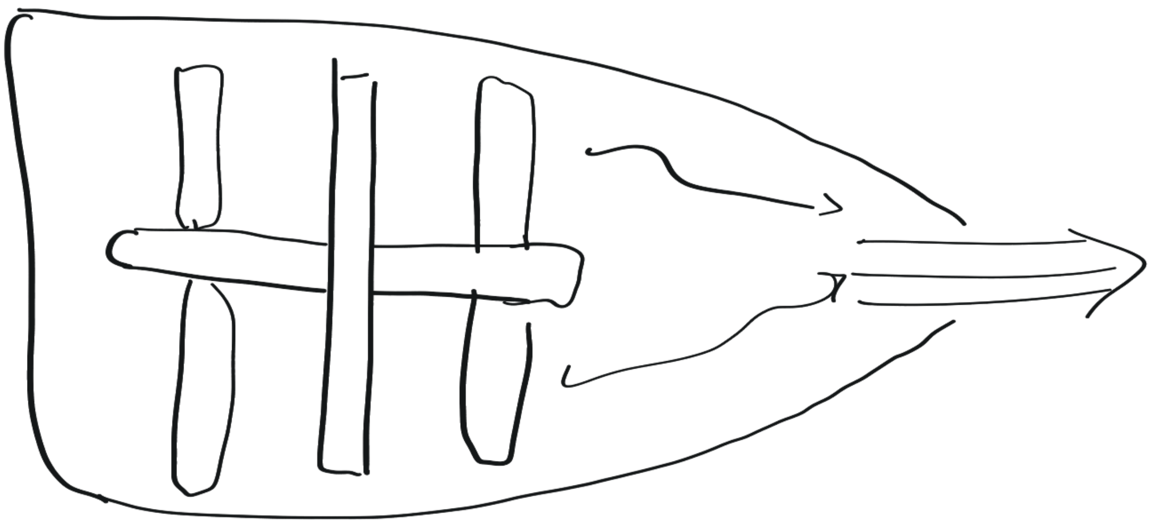
MOTO STAZIONARIO DEI FLUIDI IN CONDOTTI ADIABATICI

ugelli ↙ ↳ diffusori

- UGELLI: ENTALPIA (PRESSIONE) → EN CINETICA
- DIFFUSORI: EN. CINETICA → ENTALPIA (PRESSIONE)



BILANCIO DI MASSA

$$\rho \bar{w} A = \text{cost} \quad (1)$$

$$d\rho \bar{w} A + \rho \, d\bar{w} A + \rho \bar{w} \, dA = 0 \quad (2)$$

Equazione di continuità locale

$$\frac{(2)}{(1)} \rightarrow \boxed{\frac{d\rho}{\rho} + \frac{d\bar{w}}{\bar{w}} + \frac{dA}{A} = 0} \quad (A)$$

BILANCIO DI ENERGIA

$$\dot{m}\left(h^* + \frac{1}{2}\bar{w}^2 + \cancel{gz}\right)_1 + \cancel{\dot{Q}}^{\,0 \text{ adiabatico}} - \cancel{\dot{L}}^{\,0} = \dot{m}\left(h^* + \frac{1}{2}\bar{w}^2 + \cancel{gz}\right)_2$$

condotti statici
↳ nessuna macchina, solo per forma di condotto

$$h^* = \frac{1}{2}\bar{w}^2 = \text{cost} \qquad dh^* + \frac{1}{2}\cdot 2\cdot \bar{w}\, d\bar{w} = 0$$

$$\boxed{dh^* + \bar{w}\, d\bar{w} = 0} = \underline{dh^* = -w\, dw}$$

Bilancio Entropico

$$S_2^* = S_1^* + \cancel{S_{irr}}^{\,0 \text{ adiabatica e quasistatica}}$$

$$S_2^* = S_1^* \rightarrow \boxed{dS^* = 0}$$

$$dh^* = T\cancel{dS^*}^{\,0} + v^* dP = v^* dP = \frac{dP}{\rho}$$

$$\boxed{\frac{dP}{\rho} = -\bar{w}\, d\bar{w}} \cdot \frac{1}{\bar{w}^2} \rightarrow \frac{dP}{\bar{w}^2 \rho} = -\frac{d\bar{w}}{\bar{w}}$$

$$\boxed{\frac{d\bar{w}}{\bar{w}} = -\frac{1}{\bar{w}^2}\frac{dP}{\rho}}$$ (M)

$$\frac{d\rho}{\rho} - \frac{1}{\bar{w}^2}\frac{dP}{\rho} + \frac{dA}{A} = 0$$

$$\frac{dA}{A} = \frac{1}{\bar{w}^2}\frac{dP}{\rho} - \frac{d\rho}{\rho} = \frac{dP}{\rho}\left[\frac{1}{\bar{w}^2} - \frac{d\rho}{dP}\right]$$

Analizziamo:

$$\left(\frac{dP}{d\rho}\right)_s \rightarrow \left[\frac{N}{m^2} \cdot \frac{m^3}{kg}\right] = \left[\cancel{kg}\frac{m}{s^2} \cdot \frac{m}{\cancel{kg}}\right]$$

$$\hookrightarrow \left[\frac{m^2}{s^2}\right] \rightarrow$$ velocità del suono → velocità a cui si propagano le piccole perturbazioni

$$\left(\frac{dP}{d\rho}\right)_s = c^2 \text{ (velocità del suono}^2\text{)}$$

$$\frac{dA}{A} = \frac{dP}{\rho}\left[\frac{1}{\bar{w}^2} - \frac{1}{c^2}\right] = \frac{dP}{\bar{w}^2\rho}\left[1 - \frac{\bar{w}^2}{c^2}\right]$$

$$\frac{dP}{\bar{w}^2\rho} = -\frac{d\bar{w}}{\bar{w}}$$

numero di Mach

$$M = \frac{w}{c}$$

se $M > 1$ → moto supersonico

se $M < 1$ → moto subsonico

$$\frac{dA}{A} = \frac{dP}{w^2\rho}\left[1 - M^2\right] = -\frac{d\bar{w}}{\bar{w}}\left[1 - M^2\right]$$

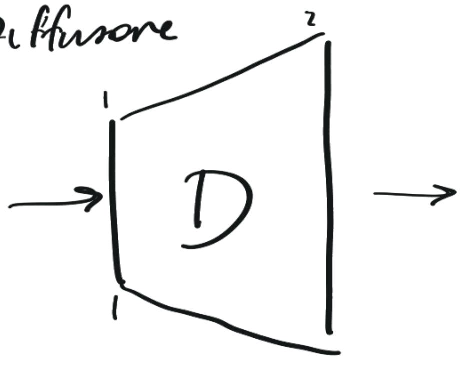
<u>se $M < 1$</u> moto subsonico

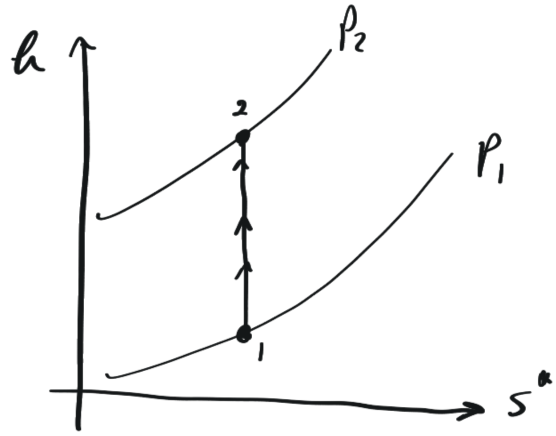
$$dA \propto dP \propto -d\bar{w}$$

se A aumenta → divergente → aumenta P e diminuisce $\bar{w}$

se A diminuisce → convergente → diminuisce P e aumenta $\bar{w}$

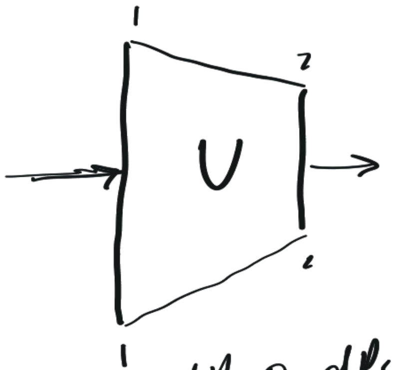
Diffusore

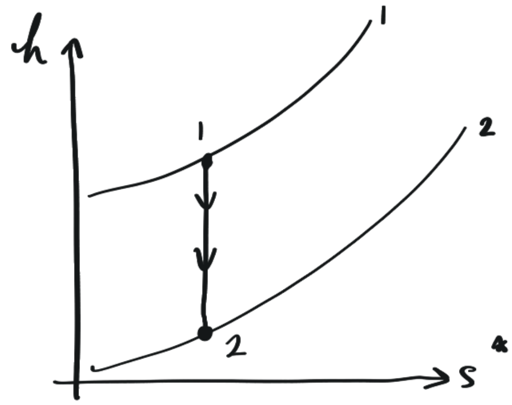




$dA>0,\ dP>0,\ d\bar{w}<0$

Ugello





$dA<0,\ dP<0,\ d\bar{w}>0$

se $M>1$

$dA \propto -dP \propto d\bar{w}$

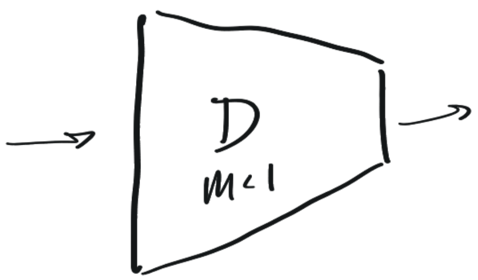
se A aumenta, P diminuisce e $\bar{w}$ aumenta

→ divergente → ugello

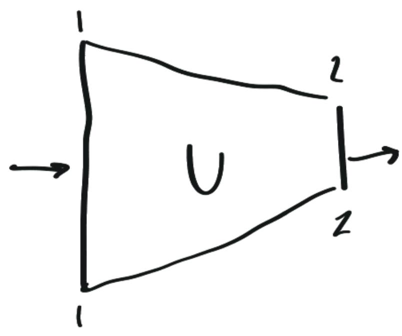
se A diminuisce, P aumenta e $\bar{w}$ diminuisce

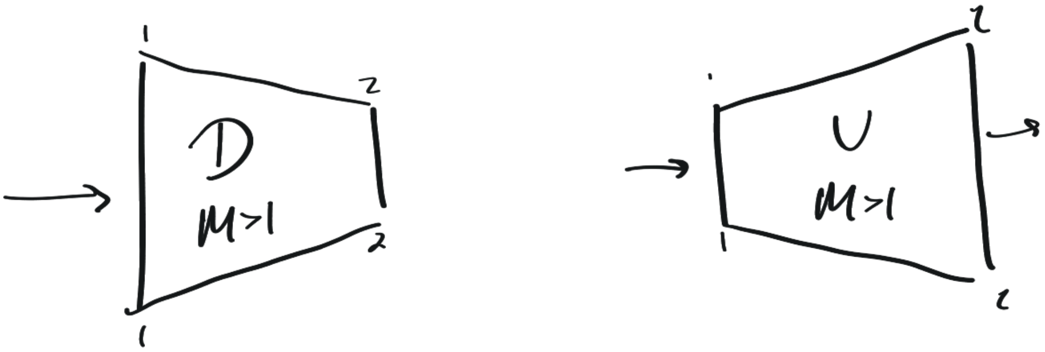
→ convergente → diffusore

Diffusore



Ugello





Grafici uguali

Per fluidi incomprimibili

$$c=\sqrt{\left(\frac{dP}{d\rho}\right)_s} \to \infty \quad \times \text{ fluido incomprimibile}$$

c per aria come gas ideale

ARIA → GAS IDEALE BIATOMICO con $M_m = 28,96 \frac{kg}{kmol}$

$$ds^* = c_v^* \frac{dP}{P} + c_p^* \frac{dv^*}{v^*} = 0 \qquad \rho = \frac{1}{v^*} \qquad \gamma = \frac{c_p^*}{c_v^*} = 1,4 \times \text{ARIA}$$

$$c_v^* \frac{dP}{P} = -c_p^* \frac{dv^*}{v^*} \to \frac{dP}{P} = -\gamma \rho \, d\rho^{-1} = \gamma \rho \frac{1}{\rho^2} d\rho$$

$$\to \frac{dP}{P} = \gamma \frac{d\rho}{\rho} \to \boxed{\frac{dP}{d\rho} = \gamma \frac{P}{\rho}}$$

$$c = \sqrt{\left(\frac{dP}{d\rho}\right)_s} = \sqrt{\gamma \frac{P}{\rho}} \qquad \frac{P}{\rho} = R^* T \qquad c = \sqrt{\gamma R^* T}$$

c funzione di solo γ e T

per aria a 25°C = 298,15 K

$$c = \sqrt{1{,}4 \cdot \frac{8314{,}5}{28{,}96} \cdot 298{,}15} \simeq 346{,}18 \ \frac{m}{s} \cdot 3{,}6 = 1246 \ \frac{km}{h}$$

Fine sistemi Aperti

Macchine Termodinamiche

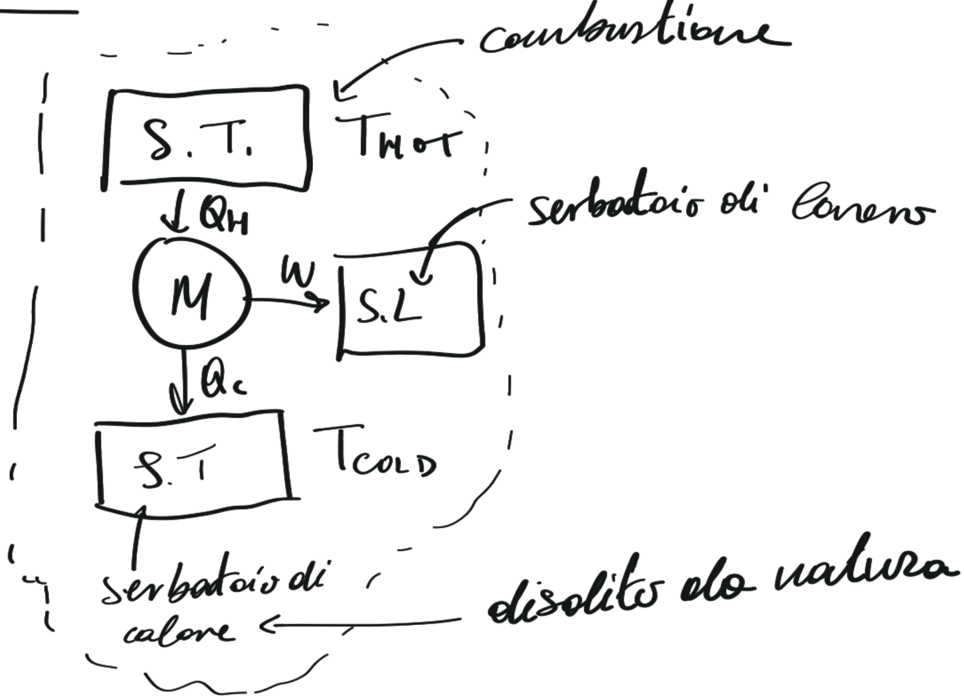
↳ modello per tutti i sistemi che convertono Q in L

Tipi

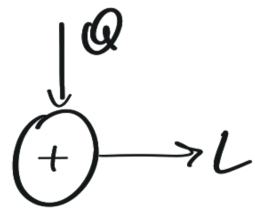
- Macchine Termodinamiche Motrici (MTM)
  ↳ modello per rappresentare sistemi che convertono con continuità calore in lavoro
  (centrali termoelettriche, motori a combustione elettrica)
- MACCHINE TERMODINACHE OPERATRICI (MTO)
  ↳ FRIGORIFERI
  ↳ POMPE DI CALORE

  } TRASFERIMENTO DI CALORE DA SERBATOIO A BASSA T verso SERBATOIO AD ALTA T

MTM



Bilancio Energetico per M $\quad \Delta U_M = Q - L$



Funzione di stato

$$\Delta U_M = Q_H - Q_C - W = 0 \rightarrow W = Q_H - Q_C$$

Composto isolato → perchè l'unico che sappiamo fare

$$\Delta S_{TOT} = \Delta S_H + \Delta S_C + \cancel{\Delta S_M}^{\,0} + \Delta S_{SL} = S_{IRR} \geq 0$$

Funzione di stato

$$= -\frac{Q_H}{T_H} + \frac{Q_C}{T_C} + 0 + 0 = S_{IRR} \geq 0$$

≠0 se irreversibile

$Q_{C\ AGGIUNTIVO}$

$$-\frac{Q_H}{T_H} + \frac{Q_C}{T_C} = S_{IRR} \rightarrow Q_C = \underbrace{\boxed{Q_H \frac{T_C}{T_H}}}_{Q_{C\,MIN}} + \boxed{T_C S_{IRR}}$$

$$W = Q_H - Q_C = Q_H - Q_H \frac{T_C}{T_H} - T_C S_{IRR} = \underbrace{\boxed{Q_H \Big(\underbrace{1 - \frac{T_C}{T_H}}_{\eta_C}\Big)}}_{W_{MAX}} - \overbrace{T_C S_{IRR}}^{W_{perso}}$$

rendimento di carnot

$$W = W_{MAX} - W_{perso} = \eta_C \, Q_H - T_C S_{IRR}$$

se processo reversibile:

$$S_{irr}=0 \Rightarrow W = W_{MAX} = Q_H \cdot \eta_c \rightarrow Q_c = Q_{C\,MIN} = Q_H \cdot \frac{T_c}{T_H}$$

RIESCO A CONVERTIRE Q_H INTERAMENTE IN W?

DEVE ESSER $\eta_c = 1 - \frac{T_c}{T_H} = 1$ $\begin{cases} T_c \rightarrow 0 \\ T_H \rightarrow \infty \end{cases}$

T_H limitato dal processo di combustione e resistenza meccanica dei materiali

T_c limitata dalla natura (T_{ATM}, T_{FIUME}, ...)

η_c sarà sempre <1

RENDIMENTO DI PRIMO PRINCIPIO

$$\eta_I = \frac{\text{EFFETTO UTILE}}{\text{SPESA}} = \frac{W}{Q_H} = \frac{Q_H\left(1-\frac{T_c}{T_H}\right) - T_c S_{irr}}{Q_H}$$

$$= \left(1-\frac{T_c}{T_H}\right) - \frac{T_c S_{irr}}{Q_H} = \eta_c - \frac{T_c S_{irr}}{Q_H}$$

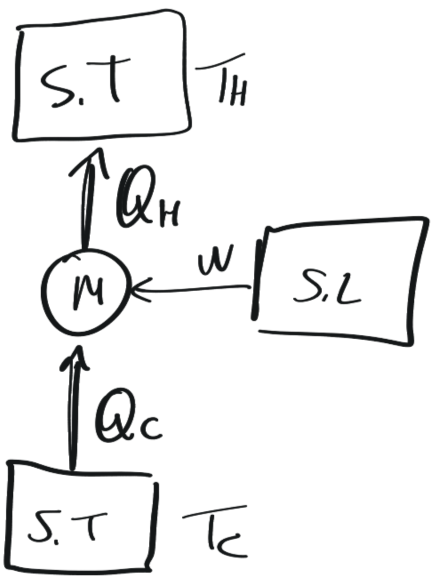
$\eta_I = \eta_{MAX}$ quando $S_{irr}=0$ $\boxed{\eta_I = \eta_c = 1 - \frac{T_c}{T_H} < 1}$

RENDIMENTO DI SECONDO PRINCIPIO

$$\eta_{II} = \frac{\eta_{I\,reale}}{\eta_{I\,IDEALE}} = \frac{\dfrac{W_{reale}}{\cancel{Q_H}}}{\dfrac{W_{IDEALE}}{\cancel{Q_H}}} = \frac{W_R}{W_{ID}} \le 1$$

$= 1$ se $\eta_I = \eta_c$ cioè se $S_{IRR} = 0$

MTO FRIGORIFERI E POMPI DI CALORE



Freccie cambiate

Frigoriferi

Q_c calore utile

Pompa di Calore

Q_H calore utile

$$\Delta U_M = Q_C - Q_H + W = 0 \rightarrow W = Q_H - Q_C$$

0 stessi motori

$$\Delta S_{TOT} = \Delta S_H + \Delta S_C + \cancel{\Delta S_M}^{\,0} + \cancel{\Delta S_L}^{\,0} = S_{IRR} \ge 0$$

$$= \frac{Q_H}{T_H} - \frac{Q_C}{T_C} = S_{IRR} \ge 0 \rightarrow \boxed{Q_C = Q_H \frac{T_C}{T_H} - T_C S_{IRR}}$$

$$W = Q_H - Q_H \frac{T_C}{T_H} + T_C S_{IRR}$$

$$W = \boxed{Q_H \left(1 - \frac{T_C}{T_H}\right)} + \boxed{T_C S_{IRR}}$$

W_{MINIMO} se lavoro reversibilmente

↳ W AGGIUNTIVO DOVUTO ALLE IRREVERSIBILITÀ

$$W = Q_H \cdot \eta_c + T_c S_{IRR}$$

$$= W_{MIN} + W_{AGG}$$

non rendimento perchè può andare sopra a 1

EFFICENZA FRIGORIFERA

$$\varepsilon_{F_I} = \frac{\text{Efficenza Utile}}{\text{Spesa}} = \frac{Q_c}{W} = \frac{\left[Q_H \cdot \frac{T_c}{T_H} - T_c S_{IRR}\right] \cdot \frac{T_H}{Q_H}}{\left[Q_H\left(1 - \frac{T_c}{T_H}\right) + T_c S_{IRR}\right] \cdot \frac{T_H}{Q_H}}$$

$$= \frac{T_c - \frac{T_c T_H S_{IRR}}{Q_H}}{T_H - T_c + \frac{T_c T_H S_{IRR}}{Q_H}}$$

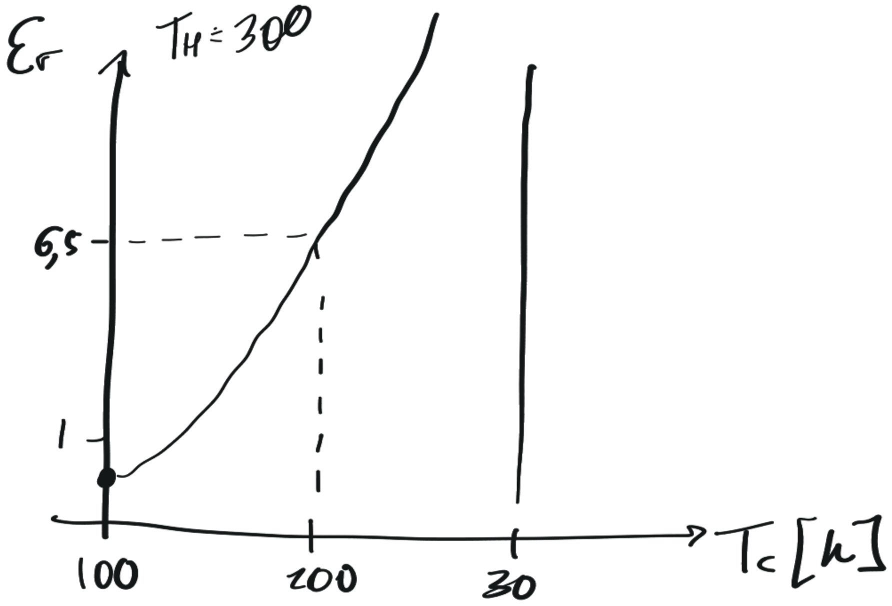
se $S_{IRR} = 0$ $\boxed{\varepsilon_{FI} = \frac{T_c}{T_H - T_c}}$

Fisso $T_H = 300\,K$ Temperatura Ambiente

se $T_c = 300\,K \rightarrow \varepsilon_{F_I} \rightarrow \infty$

se $T_c = 260\,K \rightarrow \varepsilon_{F_I} = \frac{260}{300-260} = \frac{26\cancel{0}}{4\cancel{0}} = 6{,}5$

se $T_c = 100\,K \rightarrow \varepsilon_{F_I} = \frac{100}{300-100} = \frac{100}{200} = 0{,}5$



$\varepsilon_{F\,I} \to \infty$ per $T_C \to T_H$ per frigorifero ideale

POMPA DI CALORE (PdC) $\varepsilon_{F\,I}$ = Coefficient of Performance (COP)

$$\varepsilon_{PdC} = \frac{Q_H}{W} = \frac{Q_H \cdot \frac{1}{Q_H}}{\left[Q_H\left(1-\frac{T_C}{T_H}\right) + T_C \cdot S_{irr}\right] \cdot \frac{1}{Q_H}} = \frac{1}{\frac{T_H - T_C}{T_H} - \frac{T_C S_{irr}}{Q_H}}$$

se $S_{irr} = 0$

$$\varepsilon_{PdC\,I} = \frac{T_H}{T_H - T_C}$$

se $T_H = T_C \to \varepsilon_{PdC} \to \infty$

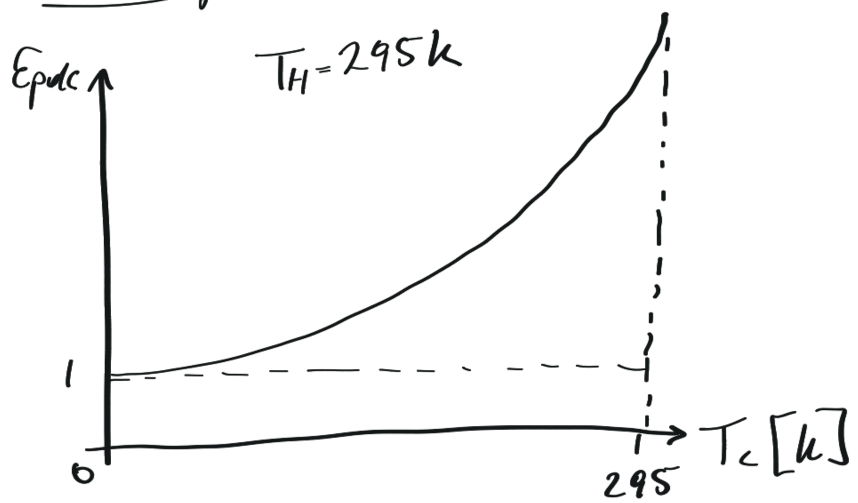
FISSO $T_H = 295\,K$ (T_{amb} DA RISCALDARE)

SE $T_C = 288$ $\varepsilon_{pdc} = \frac{295}{295-288} = \frac{295}{7} = 42, \ldots$

se $T_C = 100$ $\varepsilon_{pdc} = \frac{295}{295-100} = \frac{295}{195} = 1,51$

Limite per Tc che scende

ε



EFFICIENZE DI SECONDO PRINCIPIO

$$\varepsilon_{F\,II} = \frac{\varepsilon_{IR}}{\varepsilon_{ID}} = \frac{\frac{Q_C}{W}}{\frac{Q_C}{W_{ID}}} = \frac{W_{ID}}{W} \leq 1$$

$$\varepsilon_{PdC\,II} = \frac{\varepsilon_{IR}}{\varepsilon_{ID}} = \frac{\frac{Q_H}{W}}{\frac{Q_H}{W_{ID}}} = \frac{W_{ID}}{W} \leq 1$$