NUMERO: 2178A

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A P P U N T I

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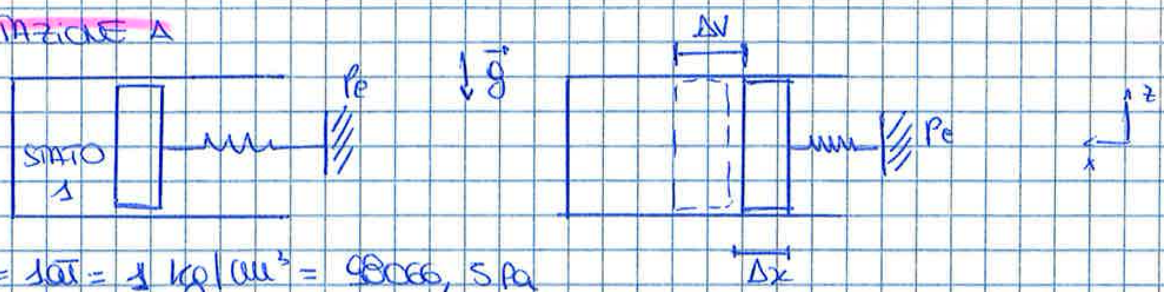
MATERIA: Termodinamica Applicata e Trasmissione del Calore - Esercizi e Temi Esame - Prof. Giaretto

ESERCITAZIONE A

A3



$p_e = 1at = 1\ kg/cm^3 = 98066,5\ Pa$

$A = 0,1\ m^2 \qquad k = 150\ kN/m$

$\Delta x = 10\ cm = 0,1\ m$

L_{iw}^{id}? L_a?

↳ se $\Delta x = 50\%$ da un processo reversibile

$L_i = L_t + L_o + \underbrace{\cancel{\Delta E_k}}_{\to 0} + \underbrace{\cancel{\Delta E_p}}_{\to 0}$

$L_i^{id} = L_t^{id} + L_o^{id} + \underbrace{\cancel{L_a}}_{\to 0} + \underbrace{\cancel{\Delta E_k}}_{\to 0} + \underbrace{\cancel{\Delta E_p}}_{\to 0}$

$L_o = p_e \Delta V = p_e (V_2 - V_1) = p_e(\cancel{V_1} + A \Delta x - \cancel{V_1}) = p_e A \Delta x = 980,67\ J$

$L_t = +\frac{1}{2} k \Delta x^2 = 750\ J$ (+ perché la molla "va con" la direzione x)

$L_i = 1730,67\ J \cong 1731\ J$

$L_a = L_i^{id} - L_i$ con $\Delta x' = 2\Delta x = 0,2\ m$

$L_i^{id} = L_t^{id} + L_o^{id}$

$L_t^{id} = +\frac{1}{2} k \Delta x'^2 = 3\ kJ$

$L_o^{id} = p_e A \Delta x' = 1961,33\ J$

$\Rightarrow L_i^{id} = 4961,33\ J$

$\Rightarrow L_a = 3230,33\ J \cong 3230\ J$

A2

k?

STATO ① $\underbrace{\cancel{L_i^{id}}}_{\to 0} = \underbrace{\cancel{L_t}}_{0} + \underbrace{\cancel{L_o}}_{0} + \underbrace{\cancel{\Delta E_k}}_{\to 0} + \Delta E_p + \underbrace{\cancel{L_a}}_{\to 0}$ $\qquad \Delta E_p = 0$

STATO ② $\underbrace{\cancel{L_i^{id}}}_{\to 0} = \Delta E_p + \underbrace{\cancel{L_o}}_{\to 0} + \underbrace{\cancel{L_a}}_{\to 0} + L_t$ $\qquad \Delta E_p = -L_t$

$L_t = -\frac{1}{2} k \underbrace{\Delta x^2}_{\to \Delta z} = -\frac{1}{2} k \Delta z^2$

$\Delta E_p = mg \Delta z$

$\to mg \cancel{\Delta z} = +\frac{1}{2} k \Delta z^{\cancel{2}} \Rightarrow k = \frac{2mg}{\Delta z}$

$W_t = G\ell_t$

$\ell_t = m \frac{R}{1-m} \Delta T = -255,251$ kW/kg

$\Rightarrow W_t = -35224,64$ W

B2

$G_{v_1} = 150$ m³/h $= 0,0412$ m³/s $N_2 = 28$ kg/kmol $\gamma = 7/5$

$p_1 = 1$ bar $= 100$ kPa

$T_1 = 20$°C $= 293,15$ K

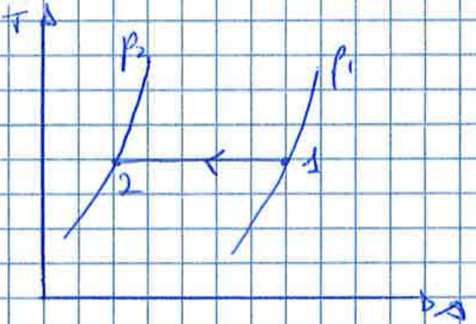
$p_2 = 30$ bar $= 3000$ kPa

gas ideale, trasf. reversibile

W_t? T_2? Φ?   isoterma, adiabatica, adiab. bistadio con interrefrigerazione

$R = \frac{\bar{R}}{M} = 297$ J/(kg·K)

- isoterma



$W_t = G\ell_t = -GRT\ln\left(\frac{p_2}{p_1}\right) = -14,036$ kW

$G = G_v \rho_1 = G_{v_1} \frac{1}{v_1}$

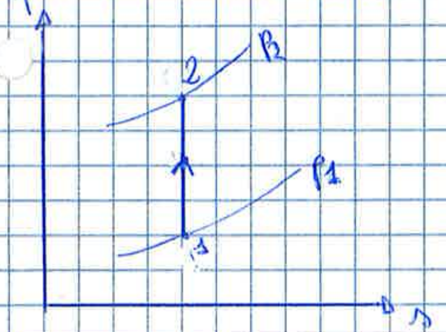
$p_1 v_1 = RT_1 \Rightarrow v_1 = \frac{RT_1}{p_1} = 0,87$ m³/kg

$\rho_1 = 1,15$ kg/m³

$G = 0,0474$ kg/s

$\Phi = Gq = G\ell_t = W_t$

- adiabatica reversibile! $\Rightarrow$ isentropica



$\Phi = 0$

$T_1 p_1^{\frac{1-\gamma}{\gamma}} = T_2 p_2^{\frac{1-\gamma}{\gamma}}$

$T_2 = T_1 \left(\frac{p_1}{p_2}\right)^{\frac{1-\gamma}{\gamma}} = 774,68$ K $= 501,53$ °C

$\cancel{\Phi}^{0} - W_t = \cancel{\frac{d}{dt}\left[U + E_k + E_p + p_0 V\right]_{vc}}^{0} + \sum \pm G_j \left(h + \cancel{e_k}^{0} + \cancel{e_p}^{0}\right)_j$

$-W_t = +G(h_u - h_e) = G(h_2 - h_1)$

$W_t = -G(h_2 - h_1) = -G\Delta h = -G c_p \Delta T =$

$= -G c_p (T_2 - T_1) = -23,726$ kW

$c_p = \frac{7}{2}R = 1039,5$ J/(kg·K)

$c_v = \frac{R}{\gamma - 1} = 717{,}5$ J/(kg·K)

$\Delta U = M c_v (T_2 - T_1)$

$p_2 = p_1 + p_{m} = p_1 + \frac{F_m}{S} = p_1 + \frac{k \Delta x}{S} = 298{,}067$ kPa

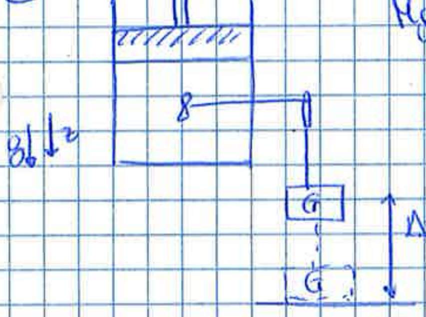
$p_2 V_2 = MRT_2 \Rightarrow T_2 = \frac{p_2 V_2}{MR} = 1074{,}37\ K = 801{,}22\ °C$

$\Delta U = 650{,}2$ J

con $c_v = \frac{R}{\gamma - 1} = 717{,}5$ J/(kg·K)

$Q = \Delta U + L_i = 650{,}2\ J + 39{,}61\ J = 689{,}81\ J$

84



$M_g = 0{,}1$ kg N_2 (28 kg/kmol, $\gamma = 1{,}4$)

$\Delta z = 1$ m

$R = \frac{\bar{R}}{M} = 297$ J/(kg·K)

$S_p = 1\ m^2$ $\qquad M_p = 500$ kg

$M_G = 12640$ kg

$p_0 = 1\ bar = 100\ kPa = p_1$

$T_0 = 25°C = 298{,}15\ K = T_1$

Q? $\quad V_2 = 5V_1$

$Q - L_i = \Delta U$

$L_i = L_t + L_0 + \Delta E_p + \cancel{\Delta E_k} \rightarrow 0$

$L_0 = p_0 \Delta V = p_0 (V_2 - V_1) = p_0 (5V_1 - V_1) = p_0 4V_1$

$L_t = L_{t_p} + L_{t_G} = L_{t_p} - |L_{t_G}| = M_p g \Delta x - M_G g \Delta z = M_p g \frac{\Delta V}{S_p} - M_G g \Delta z =$

(pistone verso l'alto e il grave verso il basso)

$= M_p g \frac{4V_1}{S_p} - M_G g \Delta z$

$p_1 V_1 = M_g R T_1 \Rightarrow V_1 = \frac{M_g R T_1}{p_1} = 88{,}5 \cdot 10^{-3}\ m^3$

$V_2 = 0{,}4425\ m^3$

$\Rightarrow L_t = M_p g \frac{4V_1}{S_p} - M_G g \Delta z = 1736{,}37\ J - 123998{,}4\ J = -122{,}262$ kJ

$L_0 = p_0 4V_1 = 35{,}4$ kJ

$\Delta E_p = M_g g \frac{\Delta V}{S_p} = 0{,}347$ J

$L_i = L_t + L_0 + \Delta E_p = -86{,}861$ kJ

$\Delta U = M_g c_v \Delta T = M_g c_v (T_2 - T_1)$

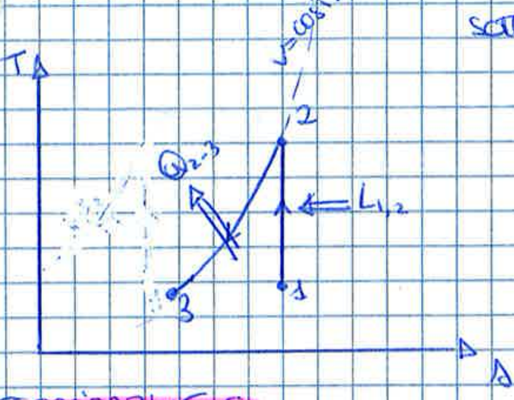
$c_v = \frac{R}{\gamma - 1} = 742{,}5$ J/(kg·K)

B6

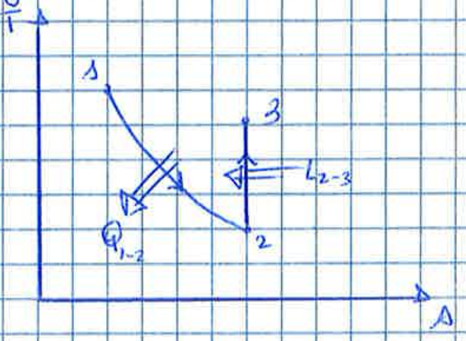
V, p_1, T_1

fornito $L_{1,2}$ trasf. adiabatica reversibile
(→ isoentropica)

sottratto $Q_{2,3}$ trasf isocora reversibile

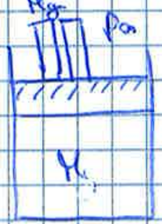


prima con l'isocora ⇝

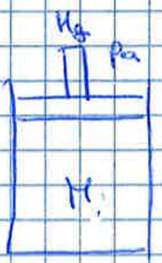


ESERCITAZIONE C

C-1



STATO ①



STATO ②

$M_p = 0$

$p_1 = 10 \text{ bar} = 1 \text{MPa}$

$M_i = 10 \text{ kg}$

$T_1 = 27°C \cong 300,15 K$

$p_a = 1 \text{ bar} = 100 \text{ kPa}$

$M_{g_1} = 2M_{g_2} \Rightarrow F_{1_G} = 2F_{2_G}$ $\qquad R = 287 \ J/(kg \cdot K)$

processo adiabatico

T_2 ? L_i ? Δs ? L_i^{id} ?

· stato 1

bilancio le forze per ottenere la pressione

$$\overset{F_1}{p_1 \cancel{S}} = \overset{F_a}{p_a \cancel{S}} \overset{+2F_G}{+ 2p\cancel{S}} \rightarrow p = \frac{p_1 - p_a}{2} = 4,5 \text{ bar} = 450 \text{ kPa}$$

· stato 2

$$p_2 \cancel{S} = p_a \cancel{S} + p\cancel{S} \Rightarrow p = p_2 - p_a \Rightarrow p_2 = p_a + p = 5,5 \text{ bar} = 550 \text{ kPa}$$

Sistema chiuso

1°P) $\underbrace{\cancel{Q}}_{\to 0} - L_i = \Delta U$

$L_i = -\Delta U$

$$L_i = \overset{0}{\cancel{L_r}} + L_0 + \Delta E_p + \overset{0}{\cancel{\Delta E_k}}$$

$$L_0 = p_a \Delta V = p_a (V_2 - V_1)$$

$$\Delta E_p = M_g g \Delta z = F \Delta z = pS\Delta z = p\Delta V$$

$$L_i = p_a \Delta V + p\Delta V = \Delta V (p_a + p) = p_2 \Delta V$$

$$V_1 = \frac{M R T_1}{p_1} = 0,861 \ m^3$$

$p_{A_1} V_{A_1} = M_{A_1} R T_{A_1} \Rightarrow M_{A_1} = \frac{p_{A_1} V_{A_1}}{R T_{A_1}} = 0,196 \text{ kg}$

1°P) $\underset{\to 0}{\cancel{Q}} - \underset{\to 0}{\cancel{L}} = \Delta U$ (chiuso se considero A+B)

$\Delta U = 0$

$U_2 = U_1$

$M c_v T = M_{1,A} c_v T_{1,A}$

$\downarrow$

$M_{2,A} c_v T_{2,A} + M_{2,B} c_v T_{2,B} = M_{1,A} c_v T_{1,A}$

$M_{2,A} \cancel{\frac{\gamma}{\gamma-1}} R T_{2,A} + M_{2,B} \cancel{\frac{\gamma}{\gamma-1}} R T_{2,B} = M_{1,A} \cancel{\frac{\gamma}{\gamma-1}} R T_{1,A}$

$M_{2,A} R T_{2,A} + M_{2,B} R T_{2,B} = M_{1,A} R T_{1,A}$

$p_2 V_{2,A} + p_2 V_{2,B} = p_{1,A} V_{1,A}$ $\qquad$ $V_{1,A} = V_{2,A}$ rigido!!!
$V_{2,B} = V_{1,B}$

$p_2 V_A + p_2 V_B = p_{1,A} V_A$

$p_2 (V_A + V_B) = p_{1,A} V_A$

$p_2 = \frac{p_1 V_A}{V_A + V_B} = 400 \text{ kPa}$

Essendo adiabatico

$T_{1,A} \, p_{1,A}^{\frac{1-\gamma}{\gamma}} = T_{2,A} \, p_2^{\frac{1-\gamma}{\gamma}}$

$\Rightarrow T_{2,A} = T_{1,A} \left(\frac{p_{1,A}}{p_2}\right)^{\frac{1-\gamma}{\gamma}} = 215,64 \text{ K} = -57,51 °C$

$p_2 V_{2,A} = M_{2,A} R T_{2,A} \Rightarrow M_{2,A} = \frac{p_2 V_{2,A}}{R T_{2,A}} = 0,0892 \text{ kg}$

$M_B = M_{1,A} - M_{2,A} = 0,1068 \text{ kg}$

$M_B = M_{2,B} \quad (M_{1,B} = 0)$

$p_2 V_{2,B} = M_{2,B} R T_{2,B} \Rightarrow T_{2,B} = \frac{p_2 V_{2,B}}{M_{2,B} R} = 360,37 \text{ K} = 87,22 °C$

$S_{irr} \to$ solo in B (adiabatica)

B → sistema aperto

$\frac{dS(t)}{dt} = \frac{\dot{Q}(t)}{T(t)} + \dot{S}_{irr}$

$\left[\frac{dS}{dt}\right]_{V_c} + \sum \pm \cancel{G_j s_j}^{\,0} = \cancel{\frac{\dot{Q}}{T}}^{\,0} + \dot{S}_{irr}$

7587,147 $\qquad$ 2,881 5168

$S_{irr} = M_B (s_{2,B} - s_{2,A}) = M_B \left[c_v \ln\left(\frac{T_{2,B}}{T_{2,A}}\right) + R \ln\left(\frac{V_{2,B}}{V_{2,A}}\right)\right] = \cancel{0,877} \frac{kJ}{K}$ 1118,05 J/K

$\ell_t = -c_p(T_4 - T_2) = 125{,}6 \text{ kJ}$

$W_t = G\ell_t = (M_2 - M_1)\,\ell_t$

$M_2 - M_1 = 0{,}000597 \text{ kg/s} \xrightarrow{\quad} \underset{(\times 3600)}{\text{in } 1h} \rightsquigarrow 2{,}15 \text{ kg}$

nella turbina entra una massa pari ad $(M_1 - M_2)$!

$\Rightarrow M_1 - M_2 = 2{,}15 \text{ kg}$

$\rightarrow Q = (M_1 - M_2)RT_2 = +180{,}879 \text{ kJ} \cong 180{,}9 \text{ kJ}$

$Q = M_1 R\underset{\hookrightarrow = T_1}{T_2} - M_2 RT_2 = M_1 RT_1 - M_2 RT_2 = p_1V_1 - p_2V_2$

se considero volume rigido $\Rightarrow V_2 = V_1$

$Q = (p_1 - p_2)V \Rightarrow V = \dfrac{Q}{p_1 - p_2} = 0{,}0136 \text{ m}^3$

Processo reversibile nella turbina $\Rightarrow \Sigma_{irr}$ solo nel recipiente

- $\dfrac{dS(t)}{dt} = \cancel{\dfrac{\dot{Q}(t)}{T_s(t)}} + \Sigma_{irr}$ $\hookrightarrow$ trascuro perché non ho T_s

$\left[\dfrac{dS}{dt}\right]_{vc} + G\,s_e = \Sigma_{irr}$ $\qquad s_e = s_2$

$G_u - \underset{=0}{\cancel{G_e}} = -\left(\dfrac{dM}{dt}\right)_{vc} \rightarrow G_u = -(M_2 - M_1)$

$M_2 s_2 - M_1 s_1 - (M_2 - M_1)s_2 = S_{irr}$

$S_{irr} = \cancel{M_2 s_2} - M_1 s_1 - \cancel{M_2 s_2} + M_1 s_2 = M_1(s_2 - s_1)$

$p_1V_1 = MRT_1 \Rightarrow M_1 = \dfrac{p_1V_1}{RT_1} = 2{,}263 \text{ kg}$

$(s_2 - s_1) = \underset{0}{\cancel{c_p \ln\left(\dfrac{T_2}{T_1}\right)}} - R\ln\left(\dfrac{p_2}{p_1}\right) = 859{,}77 \text{ J/(kg·K)}$

$\Sigma_{irr} = 1945{,}7 \text{ J/K}$

- se considero $T = T_1 = T_2$ (NEGUO!)

$S_{irr} = M_1\left[-R\ln\left(\dfrac{p_2}{p_1}\right)\right] - \dfrac{Q}{T} = 1328{,}6 \text{ J/K}$

CS

$V = 50\ell = 50\,dm^3 = 50 \cdot 10^{-3}\,m^3$ $O_2 \rightarrow \overline{M} = 32\ kg/kmol$ $\gamma = 1{,}4$

$p_2 = 12\ bar = 1{,}2\ MPa$

$T_e = 25\ °C = 298{,}15\ K$ $(= T_0)$

$p_e = 1\ bar = 100\ kPa$ $(= p_0)$

- serbatoio rigido e adiabatico ($\Delta V = 0$, $V_1 = V_2 = V$)
- gas ideale
- compressione stazionaria con η_p = cost. (ideale) ⟶ adiabatica rev.! (isoentropica)
- $M_1 = 0$ (M_1)

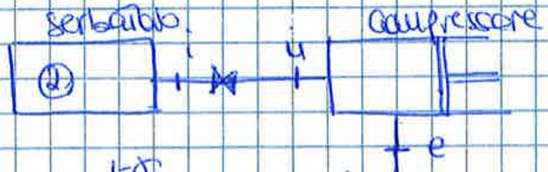
$\Delta e_k = 0$

$\Delta e_p = 0$

M_f ? (M_2) $L_{t,c}$? S_{irr} ?

laminazione ⇒ $h_i = h_u$, ~~[illegible]~~ gas ideale ⇒ $T_i \underset{\text{dopo la valvola}}{=} T_u$ $(= T_u)$

$p_2 = \overset{(1{,}2\ MPa)}{12\ bar} = p_i = p_u$ $p_e = 100\ kPa$



$$T_e\, p_e^{\frac{1-\gamma}{\gamma}} = T_u\, p_u^{\frac{1-\gamma}{\gamma}} \Rightarrow \underset{(=T_i)}{T_u} = T_e \left(\frac{p_e}{p_u}\right)^{\frac{1-\gamma}{\gamma}} = 606{,}42\ K = 333{,}27\ °C$$

1° P) sul serbatoio (sist. aperto)

$$\cancel{\Phi}^{0} - \cancel{W_t}^{0} = \frac{d}{dt}\left[U + \cancel{pV}^{0} + \cancel{E_k}^{0} + \cancel{E_p}^{0}\right]_{V_c} + \sum \pm G_j \left(h + \cancel{e_k}^{0} + \cancel{e_p}^{0}\right)_j$$

$$\left(\frac{dU}{dt}\right)_{V_c} - G_e h_i = 0 \qquad -G_e = -\left(\frac{dM}{dt}\right)_{V_c} \rightarrow G_e = \left(\frac{dM}{dt}\right)_{V_c}$$

$$M_2 u_2 - \cancel{M_1 u_1}^{0} - (M_2 - \cancel{M_1}^{0})h_i = 0$$

$$\cancel{M_2} u_2 - \cancel{M_2} h_i = 0$$

$$u_2 = h_i$$

$$c_v T_2 = c_p T_i \rightarrow T_2 = \frac{c_p T_i}{c_v} = 848{,}988\ K = 575{,}838\ °C$$

con $c_p = \frac{\gamma}{\gamma - 1} R = 910\ J/(kg \cdot K)$

$c_v = \frac{R}{\gamma - 1} = 650\ J/(kg \cdot K)$

$R = \frac{\overline{R}}{M} = 260\ J/(kg \cdot K)$

$$p_2 V_2 = M_2 R T_2 \Rightarrow M_2 = \frac{p_2 V_2}{R T_2} = 0{,}272\ kg = 272\ g$$

- ΔS_{est}

$$Q - l_i^{id} = \Delta u = 0$$

$$Q - l_i^{id} = 0$$

$$Q = l_i^{id} = p_0 \Delta V = p_0 (v_2 - v_1)$$

$v = \overline{V} \cdot m$

$$Q = p_0 m (\overline{V}_2 - \overline{V}_1) = p_0 m \left(\frac{\overline{R}\overset{T_2 = T_1}{T_2}}{p_2} - \frac{\overline{R}T_1}{p_1} \right) = p_0 \overset{1}{\cancel{m}} \overline{R}T \left(\frac{1}{p_2} - \frac{1}{p_1} \right) =$$

$$= p_0 \overline{R}T \left(\frac{1}{p_2} - \frac{1}{p_1} \right) = \underset{p_2}{\underset{\parallel}{p_0}} \overline{R}T \left(\frac{1}{p_2} - \frac{1}{2p_2} \right) = p_2 \overline{R}T \left(\frac{1}{p_2} - \frac{1}{2p_2} \right) =$$

$$= \cancel{p_2} \overline{R}T \frac{1}{\cancel{p_2}} \left(1 - \frac{1}{2} \right) = + \frac{1}{2} \overline{R}T$$

$|Q| = \frac{1}{2}\overline{R}T$ in realtà $|l_i^{id}| = \frac{1}{2}\overline{R}T$, ma $l_i^{id} = -\frac{1}{2}\overline{R}T$ perché subito dall'ambiente

$$\Delta S = \frac{Q}{T} + \cancel{S_{irr}}^{0} = \frac{-\frac{1}{2}\overline{R}\cancel{T}}{\cancel{T}} = -\frac{1}{2}\overline{R} \Rightarrow \Delta S = -\frac{1}{2}\overline{R}\cancel{M}$$

[vd. foglio!]

- ΔS_{TOT}

$$\Delta S_{TOT} = \Delta S_{est} + \Delta S_{gas} = -\frac{1}{2}\overline{R}M + \overline{R}\ln 2 = \overline{R}\left(\ln 2 - \frac{1}{2}M\right) =$$

$$L_i = L_i^{id} - L_a$$

SISTEMA RIGIDO ⟶ $L_i = 0$

$$\Rightarrow L_a = L_i^{id} = -\frac{1}{2}\overline{R}T\cancel{M} + \cancel{M}\overline{R}T\ln 2 = -\frac{1}{2}\overline{R}TM + \cancel{M}m\overline{R}T\ln 2 =$$

$$= +\frac{1}{2}\cancel{M}\overline{R}T + m\overline{R}T\ln 2 = -\frac{1}{2}\overline{M}m\overline{R}T + m\overline{R}T\ln 2 =$$

$$= -\frac{1}{2}\overline{M}\overline{R}T + \overline{R}T\ln 2 = \overline{R}T\left(-\frac{1}{2}\overline{M} + \ln 2\right)$$

ESERCITAZIONE D

D1 rigido $V_1 = V_2 = V = 0{,}15\ m^3$ $(= V_3)$

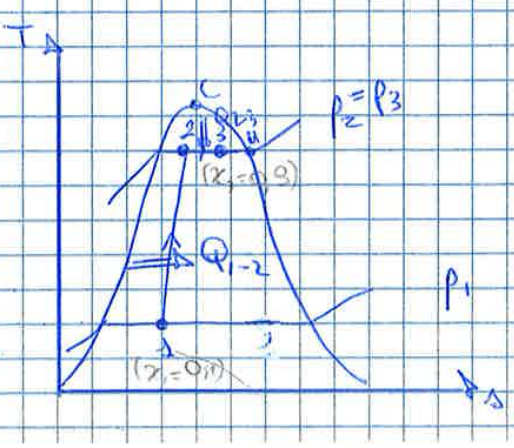
$x_1 = 1\% = 0{,}01$ $p_1 = 1\ bar = 100\ kPa$

$T_{est} = 260°C = 533{,}15\ K$

$p_2 = 21\ bar = 2{,}1\ MPa$

$x_3 = 90\% = 0{,}9$

ΔU? Q? S_{gen}?



$Q_{1-2} - L_i = \Delta U$

$L_i = 0$ perché sistema rigido (isocora)

$Q_{1-2} = \Delta U = M_1 (u_2 - u_1)$

$u_2 = h_2 - p_2 v_2 = 1220,622 \ kJ/kg$
$u_1 = h_1 - p_1 v_1 = 438,302 \ kJ/kg$

$\Rightarrow Q_{1-2} = 6,525 \ MJ$

Per trasf. 2-3

$\Phi - \cancel{W_t}^{0} = \frac{d}{dt} \left[U + \cancel{pV}^{0} + \cancel{E_k}^{0} + \cancel{E_p}^{0} \right]_t + \Sigma \pm G \left(h + \cancel{e_k}^{0} + \cancel{e_p}^{0} \right)_j$

$\Phi = \left(\frac{dU}{dt} \right)_{Vc} + G h_{3,v}$ $\qquad G = \left(\frac{dM}{dt} \right)_V = M_2 - M_3 = \Delta M$

↳ perché fuoriesce solo vapore (sarebbe ha punto estremo $\equiv h_{3,v} = h_{2,v}$)

$Q_{2-3} = M_3 u_3 - M_2 u_2 + \Delta M h_{3,v}$

$u_3 = h_3 - p_3 v_3 = 2432,12 \ kJ/kg$

$\Rightarrow Q_{2-3} = 11844 \ kJ$

$\Rightarrow Q_{tot} = Q_{1-2} + Q_{2-3} = 18,469 \ MJ$

• [1-2] ⇝ sistema chiuso

$\Delta S = \frac{Q_{1-2}}{T_S} + S_{irr}$ $\qquad T_S = T_{est} = 260°C$.

$S_{irr_{1-2}} = S_2 - S_1 - \frac{Q_{1-2}}{T_S} = M_1 (s_2 - s_1) - \frac{Q_{1-2}}{T_S} = 2774,25 \ J/K$

• [2-3] ⇝ sistema aperto (esce vapore)

2° p) $\frac{dS}{dt} = \frac{\Phi}{T_S} + \dot{S}_{irr}$

$\left[\frac{dS}{dt} \right]_{Vc} + \Sigma \pm G_j s_j = \frac{\Phi}{T_S} + \Sigma_{irr}$

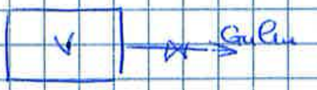
→ dovrebbero [illegible] stato finale cioè [illegible] [illegible]

$S_{irr_{2-3}} = - \frac{Q_{2-3}}{T_S} + M_3 s_3 - M_2 s_2 + \Delta M s_{3,v} = 3349,3 \ J/K$

$S_{irr_{tot}} = S_{irr_{1-2}} + S_{irr_{2-3}} = 6123,55 \ J/K = 6,124 \ kJ/K$

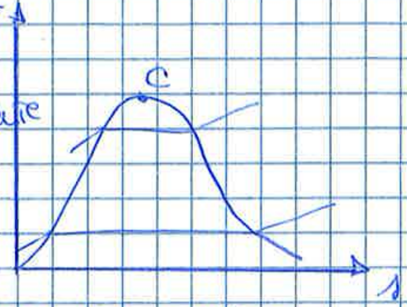
D4

$V = 1 m^3$
$T_1 = 400°C$
$p_1 = 50$ bar
spillamento



$p_1 = 50$ bar $\Rightarrow T_1' = 264°C \Rightarrow T_1' < T_1$ vapore surriscaldato

$x_2 = 100\% = 1$



$\Delta M = 76\% M_1 = 0{,}76 M_1$
trasf. rev. nel recipiente (è termicamente isolato $\Rightarrow$ adiabatico)
T_2? ρ_1?

Trattandosi di vapore surriscaldato $\Rightarrow$ diagramma di Mollier

$s_1 = 6{,}63$ kJ/(kg.K)
$h_1 = 3200$ kJ/kg

adiabatica e rev. $\Rightarrow$ isoentropica $s_1 = s_2$

in stato 2 $\rightarrow$ vapore saturo secco
$s_2 = s_{2,v}$
$h_2 = h_{2,v}$
$v_2 = v_{2,v}$

interpolazione con $s_{2,v}$

$$\frac{6{,}63 - 6{,}6254}{6{,}6662 - 6{,}6254} = \frac{T_2 - 175}{170 - 175} \Rightarrow T_2 = 174{,}44°C = 447{,}6\ K$$

$$\frac{6{,}63 - 6{,}6254}{6{,}6662 - 6{,}6254} = \frac{\overset{\overset{v_2}{\parallel}}{v_{2,v}} - 0{,}2168}{0{,}2428 - 0{,}2168} \Rightarrow v_2 = v_{2,v} = 0{,}2197\ m^3$$

$\rho_1 = \frac{1}{v_1}$

$v_1 = V/M_1$

$M_1 - M_2 = 0{,}76 M_1 \Rightarrow M_2 = 0{,}24 M_1$

$V = M_2 v_2 \Rightarrow M_2 = V/v_2 = 4{,}551$ kg

$M_1 = \frac{M_2}{0{,}24} = 18{,}96$ kg

$v_1 = 0{,}0527\ m^3/kg$

$\rho_1 = 18{,}98\ kg/m^3$

$y_{2,N_2} = \frac{m_{N_2}}{m_2} = 0,66 = \frac{V_{2,N_2}}{V_2} \rightarrow V_{2,N_2} = 0,66 V_2 = 5,28 \ m^3$

Non ho dati sufficienti ⇒ risolvo con le pressioni

$\Delta S = S_2 - S_1 = M_{O_2} R_{O_2} \left[\ln\left(\frac{p_{1,O_2}}{p_{2,O_2}}\right)\right] + M_{N_2} R_{N_2} \left[\ln\left(\frac{p_{1,N_2}}{p_{2,N_2}}\right)\right]$

$p_2 V_2 = m_2 \bar{R} T_2$

$\Rightarrow p_2 = \frac{m_2 \bar{R} T_2}{V_2} = 2494,29 \ Pa$

$y^2_{O_2} = \frac{p_{2,O_2}}{p_2} \Rightarrow p_{2,O_2} = p_2 y^2_{O_2} = 823,12 \ Pa$

$y^2_{N_2} = \frac{p_{2,N_2}}{p_2} \rightarrow p_{2,N_2} = p_2 \, y^2_{N_2} = 1671,17 \ Pa$

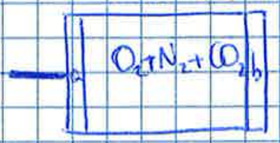
$p_{1,N_2} V_{1,N_2} = m_{1,N_2} \bar{R} T_1 \Rightarrow p_{1,N_2} = \frac{m_{1,N_2} \bar{R} T_1}{V_{1,N_2}} = 2660,576 \ Pa$

$p_{1,O_2} V_{1,O_2} = m_{1,O_2} \bar{R} T_1 \Rightarrow p_{1,O_2} = \frac{m_{1,O_2} \bar{R} T_1}{V_{1,O_2}} = 2217,15 \ Pa$

$\Rightarrow \Delta S = 31,75 \ J/K$

D7

STATO ①



STATO ②

$O_2 + N_2 \rightarrow a$
$CO_2 \rightarrow b$

$m_a = 0,9 \ kmol \qquad m_b = 0,1 \ kmol$

$V_1 = V_2 = V$

$\gamma_a = 1,4 \qquad \gamma_b = 1,33$

$T_0 = T_1 = 300K \qquad p_0 = p_1 = 1 \ bar$

$p_{a,2} = p_{b,2} = p_2$

miscela ideale
trasformazione isoterma $T_1 = T_2 = 300K$
L_i^{id}? (lavoro minimo)

Essendo $L_i^{id} \Rightarrow$ processo reversibile

2°p) $\Delta s = \frac{Q}{T} + \cancelto{0}{S_{irr}}$

1°p) $Q - L_i^{id} = \cancelto{0}{\Delta U}$

$Q = L_i^{id} = T \Delta s$

$$\frac{m_a}{V_1 - V_{2,b}} = \frac{m_b}{V_{2,b}}$$

$$m_a V_{2,b} = m_b (V_1 - V_{2,b})$$

$$m_a V_{2,b} = m_b V_1 - m_b V_{2,b}$$

$$V_{2,b} = \frac{m_b V_1}{m_a + m_b} = \frac{m_b V_1}{m} = 2{,}494\ m^3$$

$$V_{2,a} = V - V_{2,b} = 22{,}446\ m^3$$

$$p_{2,a} = \frac{m_a \bar{R} T}{V_{2,a}} = 100011{,}63\ Pa$$

$$p_{2,b} = \frac{m_b \bar{R} T}{V_{2,b}} = p_{2,a}$$

⇒ ~~ΔS/3~~ $p_2 = p_{2,b} = p_{2,a}$

$p_1 = 1 bar$ ⇒ $p_1 \simeq p_2$ ⇒ isobaro

Per mescolamento

$$\Delta S = S_2 - S_1 = -[M_a R_a \ln(y_a) + M_b R_b \ln(y_b)]$$

$$M_a R_a = m_a \cancel{M_a} \frac{\bar{R}}{\cancel{M_a}} = m_a \bar{R}$$

$$M_b R_b = m_b \bar{R}$$

$$y_a = \frac{m_a}{m} = 0{,}9 \qquad y_b = 0{,}1$$

$$\Rightarrow \Delta S = +[m_a \bar{R} \ln(y_a) + m_b \bar{R} \ln(y_b)] = -2702{,}84\ J/K$$

perché reversibile ⇒ devo avere risultato con ΔS < 0

$$\Rightarrow L^{id} = T\Delta S = -810{,}852\ kJ$$

D8

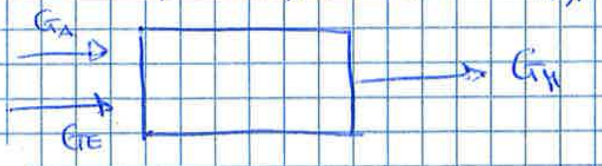
$G_A = 1{,}08\ kg/s \qquad T_A = 26\ °C = 299{,}15 K \qquad \varphi_A = 50\% = 0{,}5$

processo adiabatico ⇒ $\phi = 0$ (miscela)

$G_E = 0{,}12\ kg/s \qquad T_E = 34°C = 307{,}15 K \qquad \varphi_E = 70\% = 0{,}7$

trasf. isobara ⇒ $p_A = p_E = 1 atm = 101325 Pa$

T_M ? φ_M ? x_M ? $T_{R,M}$?



NON HO LE TABELLE

$\Delta s = 0$ essendo un ciclo

$$\cancel{\Delta s}^{\to 0} = \sum \frac{Q}{T} + s_{irr}$$

$$s_{irr} = -\sum \frac{Q}{T} = -\left[\frac{q_b}{T_s} - \frac{|q_a|}{T_{amb}}\right]$$

$q_b = 795,34$ kJ/kg

$q_a = c_v(T_1 - T_4)$

trasf. 3-4 adiabatica

$T_4 v_4^{\gamma-1} = T_3 v_3^{\gamma-1}$

$v_4 = v_1$
$v_3 = v_2$

$$\left(\frac{v_3}{v_4}\right)^{\gamma-1} = \frac{T_4}{T_3} \Rightarrow \frac{v_3}{v_4} = \frac{v_2}{v_1}$$

$$\Rightarrow T_4 = T_3\left(\frac{v_2}{v_1}\right)^{\gamma-1} = 864,06\ K = 590,91°C$$

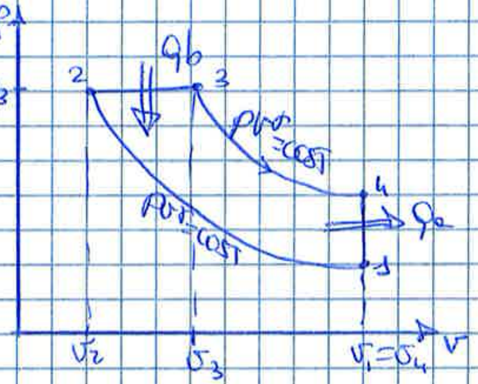
$q_a = c_v(T_1 - T_4) = -413,215$ kJ/kg

$$\Rightarrow s_{irr} = -\frac{q_b}{T_s} + \frac{|q_a|}{T_{amb}} \simeq 986\ J/(kg\cdot K) = 0,986\ kJ/(kg\cdot K)$$

(E2) Ciclo Diesel

$T_1 = 30°C = 303,15K$
$p_1 = 15\ psi = 6894,76\ Pa \cdot 15 =$
$= 103421,4\ Pa$
$T_2 = 400°C = 673,15K$
$T_3 = 1700°C = 1973,15K$

ciclo ideale → η?



trasf. 1-2 adiabatica

$$T_1 v_1^{\gamma-1} = T_2 v_2^{\gamma-1} \Rightarrow \frac{v_2}{v_1} = \sqrt[\gamma-1]{\frac{T_1}{T_2}} = 0,1361$$

~~trasf. 1-4 isocora~~

$$p_1 v_1 = RT_1 \Rightarrow v_1 = \frac{RT_1}{p_1} = 0,84\ m^3/kg$$

$\Rightarrow v_2 = v_1 0,1361 = 0,114$ m³/kg

$$p_2 v_2^\gamma = p_1 v_1^\gamma \Rightarrow p_2 = \frac{p_1 v_1^\gamma}{v_2^\gamma} = p_1\left(\frac{v_1}{v_2}\right)^\gamma = 1687,37\ kPa$$

$\Rightarrow l_{u_{TOT}}^{id} = l_{u_{1-2}}^{id} + l_{u_{3-4}}^{id} = 492,302$ kJ/kg

$T_4 = T_3 - \eta_{is,e}(T_3 - T_4^{id}) = 595,82$ °C

$T_2 = T_1 + \frac{T_2^{id} - T_1}{\eta_{is,c}} = 355,17$ °C

$\eta = 1 - \frac{T_1}{T_2}$ → solo caso ideale

$\eta = 1 - \frac{|q_a|}{q_b} = 1 - \frac{c_p(T_4 - T_1)}{c_p(T_3 - T_2)} = 1 - \frac{\cancel{c_p}|(T_1 - T_4)|}{\cancel{c_p}(T_3 - T_2)} = 0,388 \rightarrow 38,8\%$

- l_u

- trasf. 1-2

$l_{u_{1-2}} = -c_p(T_2 - T_1) = -329,647$ kJ/kg

- trasf. 3-4

$l_{u_{3-4}} = -c_p(T_4 - T_3) = 647,079$ kJ/kg

$\Rightarrow l_u = l_{u_{1-2}} + l_{u_{3-4}} = 317,432$ kJ/kg

- $l_{a,i}$

- trasf. 1-2 (compressione)

$\cancel{l_{a,c} = c_p(T_2 - T_2^{id})}$

$l_{ai,c} = c_c(T_2 - T_1)$

$c_c = c_v \frac{1 - m_c}{1 - m_c}$

$m_c = \frac{\ln(p_2/p_1)}{\ln(v_1/v_2)}$

$\begin{cases} p_2 v_2 = R T_2 \\ p_1 v_1 = R T_1 \end{cases}$ $\begin{cases} R = \frac{p_2 v_2}{T_2} \\ R = \frac{p_1 v_1}{T_1} \end{cases}$ $\Rightarrow \frac{p_2 v_2}{T_2} = \frac{p_1 v_1}{T_1} \rightarrow \frac{v_1}{v_2} = \overset{\overset{\beta_p}{\shortparallel}}{\frac{p_2}{p_1}} \cdot \frac{T_1}{T_2} =$

$= 5,255$

$m_c = 1,445$

$c_c = 72,56$ J/(kg·K)

$l_{ai,c} = 23,812$ kJ/kg

- trasformazione 1-2 (adiabatica&rev. → isoentropica)

$Q_{1-2}=0$

$L_{1-2} = -\Delta U = -Mc_v \Delta T = -Mc_v(T_2-T_1)$

$\Delta h = h_2 - h_1 = c_p(T_2-T_1) \Rightarrow T_2 = \frac{\Delta h}{c_p} + T_1 = 871,36\,K = 598,21°C$

$\Rightarrow L_{1-2} = -285,716\ kJ$

- trasformazione 2-3 (isoterma)

$\Delta U = 0 \Rightarrow L_{2-3} = Q_{2-3} = RT_2 \ln\left(\frac{v_3}{v_2}\right)$

$p_1 v_1 = RT_1 \Rightarrow v_1 = \frac{RT_1}{p_1} = 0,905\ m^3/kg$

$p_3 v_3 = RT_3 \rightarrow p_1 v_3 = RT_2 \Rightarrow v_3 = \frac{RT_2}{p_1} = 1,667\ m^3/kg$

$T_1 v_1^{\gamma-1} = T_2 v_2^{\gamma-1}$

$\Rightarrow v_2^{\gamma-1} = \frac{T_1}{T_2} v_1^{\gamma-1} \Rightarrow v_2 = v_1 \sqrt[\gamma-1]{\frac{T_1}{T_2}} = 0,1966\ m^3/kg$

$\Rightarrow L_{2-3} = Q_{2-3} = RT_2 \ln\left(\frac{v_3}{v_2}\right) = 534,574\ kJ$

- trasformazione 3-1 (isobara)

$Q - L_i = \Delta U$

$Q_{3-1} = Mc_p(T_1 - \underset{T_2 =}{T_3}) = -400\ kJ$

$\Delta U = +Mc_v(T_1 - T_3) = -285,716\ kJ$

$L_{i\,3-1} = Q - \Delta U = -114,284\ kJ$

$\eta = 1 - \frac{|\overset{<0}{Q_a}|}{\underset{>0}{Q_b}} = 1 - \frac{|Q_{3-1}|}{Q_{2-3}} = 0,252 \rightarrow 25,2\%$

h_p fluido incompressibile

$$\boxed{h_2} \simeq h_{1,L} + v_{1L}\,[p_v - p_c] = 180,625 \text{ kJ/kg}$$

$$\boxed{h_4} = h_3 - \eta_{is,e}\,(h_3 - h_4^{id}) = 2083,95 \text{ kJ/kg}$$

con h_4^{id} da ricavare tramite x_4^{id}

$$x_4^{id} = \frac{s_3 - s_1}{s_{4v} - s_1} = 0,716 \cong 0,72 \rightarrow 72\%$$

$$h_4^{id} = h_1(1 - x_4^{id}) + h_{4v}\,x_4^{id} = 1904,98 \text{ kJ/kg}$$

$$\Rightarrow \eta = 1 - \frac{h_4 - h_1}{h_3 - h_2} = 0,2717 \rightarrow 27,2\%$$

$$l_{t,c} = h_1 - h_2 = -4,165 \text{ kJ/kg} \longrightarrow \text{TRASCURABILE!}$$

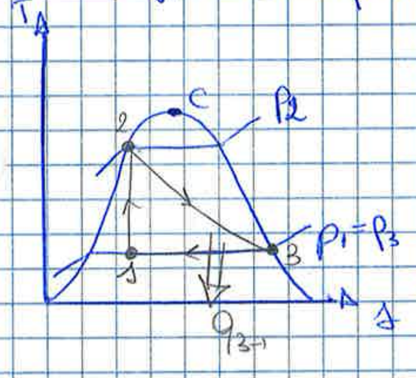
$$l_{t,e} = h_3 - h_4 = 715,9 \text{ kJ/kg}$$

F2

$M_{H_2O} = 1 \text{kg}$ $\quad$ $p_1 = 1 \text{bar} = 100 \text{kPa}$

$x_1 = 28,47\%$

trasf. 1-2 adiabatica (compressione)
stato 2 liquido saturo
stato 3 ($x_3 = 1$) vapore saturo secco $\quad p_3 = p_1$
trasf. 2-3 espansione



trasf. reversibili
$\Rightarrow$ 1-2 isoentropica

$q_{3-1} < 0$

$\Delta s_{2-3} \propto \Delta T_{2-3}$

$(s_3 - s_2) \propto (T_3 - T_2) \Rightarrow$ retta!

l_{1-2} ? l_{2-3} ? l_{3-1} ?

$$p_1 = 1 \text{ bar} \begin{cases} T_1 = 99,63\,°C \\ v_{1v} = 1,6943 \\ v_{1L} = 1,0431 \cdot 10^{-3} \end{cases} \!\!\!\!\!\!\!\! \begin{array}{l} \\ \left.\right\} \text{m}^3/\text{kg} \end{array}$$

$$\begin{cases} h_{1v} = 2675,1 \\ h_{1L} = 417,51 \\ s_{1v} = 7,3589 \\ s_{1L} = 1,3027 \end{cases} \begin{array}{l} \left.\right\} \text{kJ/kg} \\ \left.\right\} \text{kJ/(kg K)} \end{array}$$

- trasformazione 3-1 (isobara)

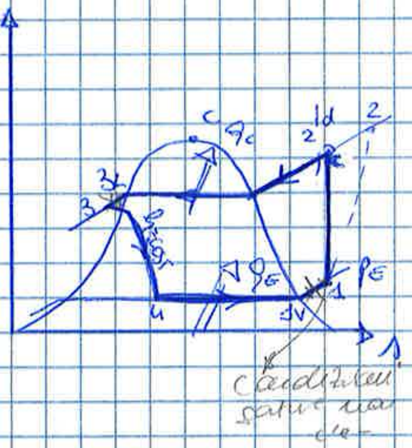
$q_{3-1} < 0$

$q_{3-1} - l_{3-1} = \Delta u$ → oppure $\Delta u = 0$ (isotermo) $\Rightarrow q_{31} = l_{31} = p(v_1 - v_3) =$
$= -121,3$ kJ/kg

$q_{3-1} = c_p \Delta T = \Delta h = h_1 - h_3 = -164,85$ kJ/kg

$l_{3-1} = q_{3-1} - \Delta u = q_{3-1} - (u_1 - u_3) = q_3 + u_3 - u_1 = -121,2$ kJ/kg

F3 Ciclo frigorifero a compressione di vapori R134a



$p_c = 8$ bar $= 800$ kPa
$p_E = 1$ bar $= 100$ kPa

compressione adiabatica rev ⇒ isoentropica

COP? fluido in condizioni sature

$$COP = \varepsilon_f = \frac{h_1 - h_4}{h_2 - h_1}$$

$h_4 = h_3 \cong h_{3,L}$
$h_1 \cong h_{1,v}$

Interpolazione

- $p_c = 8$ bar $= 800$ kPa

$$\frac{800000 - 770000}{815000 - 770000} \overset{0,67}{} = \frac{T - 30}{32 - 30}$$

$T = 31,34$ °C

$h_{3,v} = 0,67(415,78 - 414,82) + 414,82 = 415,46$ kJ/kg
$h_3 = h_{3,L} = 0,67(244,62 - 241,72) + 241,72 = 243,66$ kJ/kg

- $p_E = 1$ bar $= 100$ kPa

$h_1 = h_{1,v} = 0,78(382,82 - 381,57) + 381,57 = 382,55$ kJ/kg

$h_4 = h_3$

$s_1 = s_{1v} = s_2^{id} = 0,78(1,7471 - 1,7482) + 1,7482 = 1,747$ kJ/(kg·K)

Mollier per R134a???

$\Phi_c = \varphi_c \cdot S_p$

con $S_p = \underset{\swarrow}{0{,}6^2} + 4\,(0{,}6 \cdot 1{,}4) = 3{,}72 \text{ m}^2$

Non ·2 perché trascuro il pavimento dato che è perfettamente isolato

$(T_e > T_i)$

$$\varphi_c = \frac{T_e - T_i}{\frac{1}{\alpha_i} + \frac{s_I}{\lambda_I} + \underbrace{\cancel{\frac{s}{\lambda}}}_{\to 0\ (s \ll \text{ e } \lambda \gg)} + \frac{1}{\alpha_e}} = 19{,}43 \text{ W/m}^2$$

$\Rightarrow \Phi_c = 72{,}28 \text{ W}$

$\Phi_{TOT} = \Phi_v + \Phi_c = 94{,}08 \text{ W}$

$|W_t| = \dfrac{\Phi_{TOT}}{\varepsilon_p} = 10{,}55 \text{ W}$

$P_e = \dfrac{|W_t|}{\eta_{el}} = 11{,}53 \text{ W}$

Se $P_e' = 80\%\, P_e \longrightarrow \Phi_{TOT}' = 80\%\, \Phi_{TOT} = 75{,}264 \text{ W}$

Poiché modifico $s_I \Rightarrow$ cambia solo Φ_c

$\Phi_c' = \Phi_{TOT}' - \Phi_v = 53{,}464 \text{ W}$

$\varphi_c' = \dfrac{\Phi_c'}{S_p} = 14{,}37 \text{ W/m}^2$

$$\varphi_c' = \frac{T_e - T_i}{\frac{1}{\alpha_i} + \frac{1}{\alpha_e} + \frac{s_I'}{\lambda_I}} \longrightarrow \varphi_c' = \frac{T_e - T_i}{\frac{2}{\alpha} + \frac{s_I'}{\lambda_I}} \longrightarrow \frac{\varphi_c'}{T_e - T_i} = \frac{1}{\frac{2}{\alpha} + \frac{s_I'}{\lambda_I}} \longrightarrow$$

$$\longrightarrow \frac{\varphi_c'}{T_e - T_i} = \frac{1}{\frac{2\lambda_I + s_I'\alpha}{\alpha\lambda_I}} \longrightarrow \frac{\varphi_c'}{T_e - T_i} = \frac{\alpha\lambda_I}{2\lambda_I + s_I'\alpha} \longrightarrow \frac{\varphi_c'}{(T_e - T_i)\alpha\lambda_I} = \frac{1}{2\lambda_I + s_I'\alpha} \longrightarrow$$

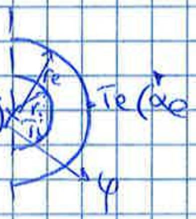
$$\longrightarrow \frac{(T_e - T_i)\alpha\lambda_I}{\varphi_c'} = 2\lambda_I + s_I'\alpha \longrightarrow s_I' = \left(\frac{(T_e - T_i)\alpha\lambda_I}{\varphi_c'} - 2\lambda_I\right)\Big/\alpha \cong 0{,}0846 \text{ m}$$

$\Delta s = s_I' - s_I \cong 0{,}0246 \text{ m} \cong 2{,}46 \text{ cm}$

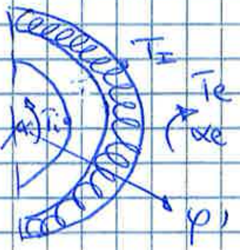
G4

$\lambda = 15 \ W/(m \cdot K)$

$d_i = 50 \ mm \rightarrow r_i = 25 \ mm$
$d_e = 54 \ mm \rightarrow r_e = 27 \ mm$
$T_i = 200°C$
$\alpha_i = 120 \ W/(m^2 \cdot K)$
$T_e = 15°C$
$\alpha_e = 12 \ W/(m^2 \cdot K)$



φ_L?



$T_I = 30°C$
$\varphi_L' = \varphi_L / 2$
stessi α

s_I ? λ_I ?

$$\varphi_L = \frac{2\pi (T_i - T_e)}{\frac{1}{r_i \alpha_i} + \frac{1}{r_e \alpha_e} + \frac{1}{\lambda} \ln\left(\frac{r_e}{r_i}\right)} = 339,4 \ W/m$$

$$\varphi_L' = \varphi_L / 2 = 169,7 \ W/m$$

$$\varphi_L' = \frac{2\pi (T_i - T_I)}{\frac{1}{r_i \alpha_i} + \frac{1}{r_e \alpha_e} + \frac{1}{\lambda} \ln\left(\frac{r_e}{r_i}\right) + \frac{1}{\lambda_I} \ln\left(\frac{r_I}{r_e}\right)}$$

$$r_I = r_e + s_I \longrightarrow s_I = r_I - r_e$$

$$\varphi_I = \alpha_e (T_I - T_e) = 180 \ W/m^2$$

$$\varphi_L' = 2\pi r_I \varphi_I \longrightarrow r_I = \frac{\varphi_L'}{2\pi \varphi_I} = 0,15 \ m$$

$$s_I = 0,123 \ m = 123 \ mm$$

$$1/\varphi_L' = \frac{\frac{1}{r_i \alpha_i} + \cancel{\frac{1}{r_e \alpha_e}} + \frac{1}{\lambda} \ln\left(\frac{r_e}{r_i}\right) + \frac{1}{\lambda_I} \ln\left(\frac{r_I}{r_e}\right)}{2\pi (T_i - T_I)}$$

$$\frac{2\pi (T_i - T_I)}{\varphi_L'} = \frac{1}{r_i \alpha_i} + \cancel{\frac{1}{r_e \alpha_e}} + \frac{1}{\lambda} \ln\left(\frac{r_e}{r_i}\right) + \frac{1}{\lambda_I} \ln\left(\frac{r_I}{r_e}\right)$$

$$\frac{1}{\lambda_I} \ln\left(\frac{r_I}{r_e}\right) = \frac{2\pi (T_i - T_I)}{\varphi_L'} - \frac{1}{r_i \alpha_i} - \cancel{\frac{1}{r_e \alpha_e}} - \frac{1}{\lambda} \ln\left(\frac{r_e}{r_i}\right)$$

$$\lambda_I = \frac{\ln\left(\frac{r_I}{r_e}\right)}{\frac{2\pi (T_i - T_I)}{\varphi_L'} - \frac{1}{r_i \alpha_i} - \cancel{\frac{1}{r_e \alpha_e}} - \frac{1}{\lambda} \ln\left(\frac{r_e}{r_i}\right)} \cong 0,29 \ W/(m \cdot K)$$

ESERCITAZIONE H

(H1) $I = 200A$

$[1\ ft = 10,16\ cm]$

$[1\ in = 2,562\ cm]$

$l = 3ft = 30,48\ cm = 0,3048\ m \rightarrow r = 0,1524\ m$

$d = 1\ in = 2,562\ cm = 0,02562\ m$

$\rho = 70\ \mu\Omega\ cm = 70 \cdot 10^{-6}\ \Omega \cdot 10^{-2}\ m = 70 \cdot 10^{-8}\ \Omega m$

TMAX ?

$T_e = 176,7°C$ $\lambda = 19,37\ kcal/(h \cdot m\ °C) = 22,52\ W/(m \cdot k)$

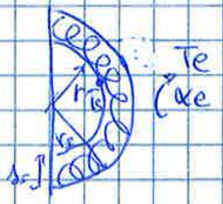
$H = \rho \cdot J^2 = \rho\left(\frac{I}{S}\right)^2 = \rho\left(\frac{I}{\pi\left(\frac{d}{2}\right)^2}\right)^2 = \frac{\rho I^2 4^2}{\pi d^4} \simeq 105356,6\ W/m^2$

$T_{MAX} = T_e + \frac{H}{4\lambda}(r^2) \cong 176,9°C$

(H2) I_{MAX} ?

$d = 2,59\ mm \rightarrow r = 1,295\ mm$

$\Delta_I = 1,27\ mm$



$r_I = r + \Delta_I = 2,565\ mm$

$T_e = 48,9°C$

$T_s = 93,3°C$

$\alpha_e = 19,52\ kcal/h\,m^2°C = 22,697\ W/(m^2 k)$

$\lambda_I = 0,119\ kcal/(h\,m\,k) = 0,138\ W/(m \cdot k)$

$\rho = 0,024\ \Omega\ mm^2/m = 0,024\ \Omega \cdot 10^{-6} m^2/m = 0,024 \cdot 10^{-6}\ \Omega m$

$H = \rho\left(\frac{I}{S}\right)^2$

$\varphi_L = \frac{H\pi r^2 \cancel{L}}{\cancel{L}} = H\pi r^2$

$\varphi_L = \frac{2\pi(T_s - T_e)}{\frac{1}{\lambda_I}\ln\left(\frac{r_I}{r}\right) + \frac{1}{r_I \alpha_e}} = 12,61\ W/m$

$\Rightarrow H = \frac{\varphi_L}{\pi r^2} = 2,393\ W/m^3$

$\Rightarrow I_{max} = \sqrt{\frac{H}{\rho} S^2} = 52,6\ A$

con $S = \pi r^2 = 5,27\ mm^2$

- $t = 590s$, aria

$\Theta_0 = T_{fin} - T_{aria} = 18,11 °C$

↳ T iniziale di questo 2° "processo"

$\Theta(t) = \Theta_0 e^{-t/t_{0,a}} = 12,9 °C$

$\Theta(t) = T'_{FIN} - T_{amb} \Rightarrow T'_{FIN} = \Theta(t) + T_{amb} = 32,9 °C$

- $t = 10s$, olio (dopo $600 s \Rightarrow 600s - 590s = 10s$ "di olio")

ciclo

$\Theta_0 = T'_{FIN} - T_{olio} = -47,1 °C$

$\Theta(t) = \Theta_0 e^{-t/t_{0,o}} = -32,88 °C$

$\Theta(t) = T''_{FIN} - T_{olio} \Rightarrow T''_{FIN} = \Theta(t) + T_{olio} = 47,12 °C$

- $t = 590 s$ (dopo altri 590s), aria

$\Theta_0 = T''_{FIN} - T_{aria} = 27,12 °C$

$\Theta(t) = \Theta_0 e^{-t/t_{0,a}} = 19,32 °C$

$\Theta(t) = T'''_{FIN} - T_{amb} \Rightarrow \underline{T'''_{FIN}} = \Theta(t) + T_{amb} = \underline{39,32 °C}$ (dopo 2 cicli)

(H4)

transitorio

$R_{INT} \ll R_{EST} \Rightarrow Bi \ll 0,1 \Rightarrow$ parametri concentrati

$T_i = T_{amb}$

$\Phi_G = 0,1 W$

$\Theta(t) = 50°C$ dopo $t = 3t_0$

$S = 1 cm^2 = 10^{-4} m^2$

α?

$$t_0 = \frac{\rho c V}{\alpha S} \Rightarrow \alpha = \frac{\rho c V}{t_0 S}$$

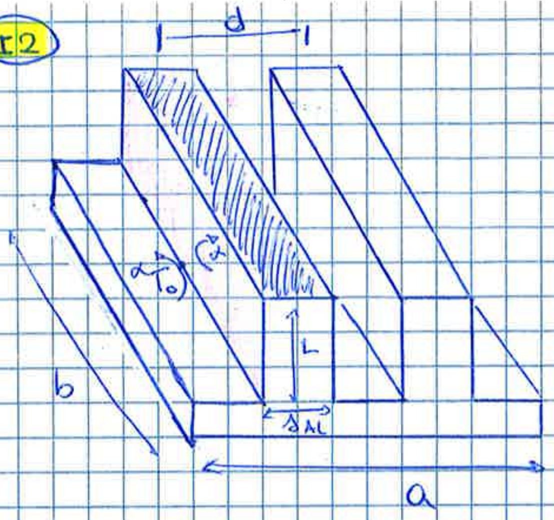
$$\Theta(t) = \Theta_\infty (1 - e^{-t/t_0}) + \cancel{\Theta_0 e^{-t/t_0}} \to 0$$ (perché $T_i = T_{amb} \to \Delta T = 0$ $\Rightarrow \Theta_0 = \Delta T = 0$)

$$\Theta_\infty = \frac{\Phi_G}{\alpha S} \Rightarrow \alpha = \frac{\Phi_G}{\Theta_\infty S}$$

$$\Theta_\infty = \frac{\Theta(t)}{1 - e^{-t/t_0}} = \frac{\Theta(t)}{1 - e^{-3\cancel{t_0}/\cancel{t_0}}} = \frac{\Theta(t)}{1 - e^{-3}} = 52,62 °C$$

$$\Rightarrow \alpha = \frac{\Phi_G}{\Theta_\infty S} = 19 \ W/(m^2 \cdot K)$$

I2



$a = 800$ mm $= 0{,}8$ m
$b = 1000$ mm $= 1$ m

40 alette / (N_{AL})

$T_e = 20°C$ (T_{amb})
$T_0 = 40°C$

$\Delta_{AL} = 3$ mm
$L = 30$ mm

$\lambda = 203$ W/(m K)
$\alpha = 7$ W/(m² °C)

θ_L ? ϕ_{TOT} ? $\eta_{al,TOT}$?

Ip punta adiabatica

$$\theta(x) = \theta_0 \frac{\cosh[\beta(L-x)]}{\cosh(\beta L)}$$

$$\Rightarrow \theta(L) = \theta_0 \frac{\cosh[\beta(L-L)]}{\cosh(\beta L)} = \theta_0 \frac{\cosh 0}{\cosh(\beta L)} = \frac{\theta_0 \cancel{\cosh 0}^{1}}{\cosh(\beta L)} =$$

$$= \frac{\theta_0}{\cosh(\beta L)}$$

$$\beta = \sqrt{\frac{\alpha P}{\lambda A}}$$

perimetro

$P = 2(b + \Delta_{AL}) = 2{,}006$ m
$A = b \cdot \Delta_{AL} = 0{,}003$ m²

$$\Rightarrow \beta = \sqrt{\frac{\alpha P}{\lambda A}} = 4{,}802 \ m^{-1}$$

$\theta_0 = T_0 - T_e = 20°C$

$$\rightarrow \theta_L = \frac{\theta_0}{\cosh(\beta L)} = 19{,}79\ °C \cong 19{,}8°C$$

$$\hookrightarrow \frac{e^{\beta L} + e^{-\beta L}}{2} = 1{,}0104$$

$S'_{TOT} = N_{AL}(S_{AL} + S_L)$

$S_{AL} = P \cdot L = 0{,}06018$ m²

$S_L = (d - \Delta_{AL})\,b = 0{,}017$ m²

con $d = \frac{a}{N_{AL}} = 0{,}02$ m

$S'_{TOT} = 3{,}0872$ m²

$S_{TOT} = S_{AL} + S_L = 0{,}07718$ m²

$$H = \rho J^2 = \rho\left(\frac{I}{S}\right)^2 = \rho\left(\frac{I}{\frac{\pi d^2}{4}}\right)^2 \Rightarrow I = \frac{\pi d^2}{4}\sqrt{\frac{H}{\rho}}$$

$\Rightarrow I_1 = 1{,}269$ A

$I_2 = 1{,}91$ A

I4

$\Phi = 5$ W

$T_{max} = 93°C$ (acciaio)

$T_e = 73°C$

S_{AL}? (sup. di scambio aletta)

$L = 10$ cm $- 0{,}1$ m

$Nu = 0{,}40\,(Gr\,Pr)^{0{,}25} = 0{,}40\,(Ra)^{0{,}25}$

$$\text{aria}\begin{cases}\lambda_f = 0{,}0307 \ W/(m\cdot K)\\ \nu = 2{,}19 \cdot 10^{-5} \ m^2/s\\ Pr = 0{,}706\end{cases}$$

$\Phi = \varphi \cdot \text{sup.} = \varphi \cdot S_{AL}$

$\varphi = \alpha\,(T_{max} - T_e)$

$$Gr = \frac{L^3 |\vec{g}|\, \beta\, (T_s - T_f)}{\nu^2} = \frac{L^3 |\vec{g}|\, \beta\, (T_{max} - T_e)}{\nu^2}$$

$$\overline{T}_f = \frac{T_A + T_e}{2} = 83°C$$

$$\beta = \frac{1}{\overline{T}} = 0{,}0028 \ K^{-1}$$

$\Rightarrow Gr = 1{,}145 \cdot 10^6$

$Gr\,Pr = Ra = 808{,}370 \ 10^3$

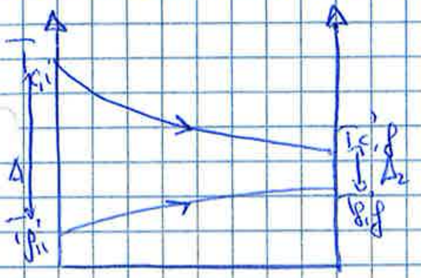
$Nu = 11{,}99$

$$Nu = \frac{\alpha L}{\lambda_f} \Rightarrow \alpha = \frac{Nu\,\lambda_f}{L} = 3{,}68 \ W/(m^2 K)$$

$\varphi = \alpha\,(T_{max} - T_e) = 73{,}6 \ W/m^2$

$$\Rightarrow S_{AL} = \frac{\Phi}{\varphi} = 0{,}0679 \ m^2$$

Passando (idealmente) in equicorrente, le uniche temperature che non cambiano sono $T_{c,i}$ e $T_{f,i}$ (le temp. iniziali dei fluidi) $\Rightarrow T'_{c,f}$ e $T'_{f,f}$



$\Delta_1 = T_{c,i} - T_{f,i} = 180°C$

$H = \frac{1}{C_c} + \frac{1}{C_f} = 0{,}001007584$ kg

$\Delta_2 = \Delta_1 e^{-kHS_{TOT}} = 9{,}34$ °C

$$\Phi = k S_{TOT} \left[\frac{\Delta_2 - \Delta_1}{\ln(\Delta_2/\Delta_1)}\right] = 89994{,}36 \text{ W}$$

Per ip. perfetta adiabaticità $|\Phi_c| = \Phi_f = \Phi$

$|\Phi_c| = C_c (T_{c,i} - T'_{c,f}) \Rightarrow T'_{c,f} = -\frac{|\Phi_c|}{C_c} + T_{c,i} = 70{,}28$ °C

$\Delta T_{ml} = \frac{\Delta_2 - \Delta_1}{\ln(\frac{\Delta_2}{\Delta_1})}$ → equicorrente $\Delta T'_{ml} = 38{,}24$
→ controcorrente $\Delta T_{ml} = 44{,}75$

$\Delta T'_{ml} < \Delta T_{ml} \Rightarrow$ controcorrente è più efficace

J2

Tubi concentrici $\Rightarrow S_{TOT} = S_{INT} = 2\pi r \cdot l$

$T_{f,i} = 15°C$ $G_f = 4000$ kg/h $= 1{,}11$ kg/s acqua
4,19 kJ/(kg·K)

$T_{f,u} = 30°C$ $T_{condensazione}$? $(T_{c,i})$

$\alpha_i = 5000$ kcal/(m²·h·°C) $= 5813{,}9$ W/(m²·K) (lato acqua)
$\alpha_e = 900$ kcal/(m² h °C) $= 1046{,}5$ W/(m²·K) (lato vapore)

$S_{TOT\ est.} = 1{,}5$ m² $\frac{S_{est}}{S_{int}} = 1{,}115$

Indifferente se nel caso equicorrente o controcorrente

Il cambiamento di fase (in questo caso condensazione) è a $T = cost \Rightarrow T_{c,i} = T_{c,u} = T_c$

cambiamento di fase $\Rightarrow C_{max} \to \infty$

$\Rightarrow \frac{C_{min}}{C_{max}} \to 0$

$\varepsilon = 1 - e^{NTU}$

$NTU = \frac{k_e S_{TOT}}{C_{min}}$

dato che il cambiamento di fase è la condensazione
$\Rightarrow$ interessa il fluido caldo $\Rightarrow C_{max} \equiv C_c$

$C_f = G_f c_{p,f} = 4650{,}9$ J/(K·s) $\equiv C_{min}$

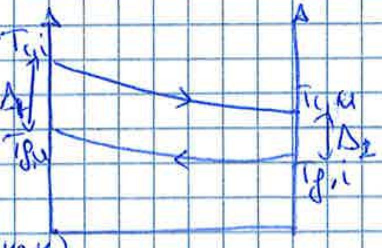
E4

$\ell = 1{,}7$ m

controcorrente

acqua

$c_{p,c} = c_{p,f} = 4{,}19$ kJ/(kg·K)



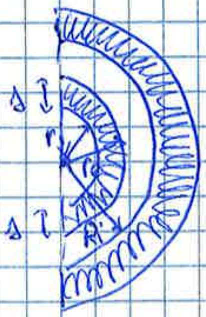
$\lambda = 45$ W/(m·K)

$d_i = 32$ mm

$s = 1{,}5$ mm $\Rightarrow d_e = d_i + 2s = 35$ mm

$\Rightarrow r_i = 16$ mm $\quad r_e = 17{,}5$ mm

D_{int} tubo esterno $= 48$ mm $\rightarrow R_i = 24$ mm



$G_c = 2130$ kg/h $= 0{,}592$ kg/s

$T_{c,i} = 95$ °C

$G_f = 3200$ kg/h $= 0{,}89$ kg/s

$T_{f,i} = 15$ °C $\quad T_{f,u} = 45$ °C

S? n? (numero sezioni necessarie)

$C_c = G_c c_{p,c} = 2480{,}5$ W/(K·S)

$C_f = G_f c_{p,f} = 3729{,}1$ W/(K·S)

$\Phi_c = -C_c (T_{c,u} - T_{c,i}) = (T_{c,i} - T_{c,u}) C_c$

$\Phi_f = C_f (T_{f,u} - T_{f,i}) \Rightarrow \Phi_c = \Phi_f = \Phi$ × ip. perfetta adiabaticità

$\rightarrow C_c (T_{c,i} - T_{c,u}) = C_f (T_{f,u} - T_{f,i})$

$T_{c,u} = -\frac{C_f}{C_c}(T_{f,u} - T_{f,i}) + T_{c,i} = 49{,}9$ °C

$H = \frac{1}{C_c} - \frac{1}{C_f} = 0{,}00035$ kg

$\Delta_2 = T_{c,u} - T_{f,i} = 34{,}9$ °C

$\Delta_1 = T_{c,i} - T_{f,u} = 50$ °C

$\frac{\Delta_2}{\Delta_1} = e^{-kHS_{TOT}}$

vd. quaderno

$T_{f,u} < T_{c,u} \Rightarrow$ scambiatore in controcorrente e anche in equicorrente

$T_{f,u} > T_{c,u} \Rightarrow$ solo in controcorrente

- $F_{I \to L} S_I = F_{L \to I} S_L$

$$\underbrace{\cancel{F_{I \to I}}}_{0} + F_{I \to L} + F_{I \to S} = 1 \Rightarrow \boxed{F_{I \to L}} = 1 - F_{I \to S} = 0{,}8$$

$$\boxed{F_{L \to I}} = \frac{F_{I \to L} S_I}{S_L} = \frac{F_{I \to L} \cancel{S_I}}{4 \cancel{S_I}} = 0{,}2$$

$F_{L \to I} = 0{,}2$

$F_{I \to L} = 0{,}8$

$F_{S \to L} = 0{,}8$

$F_{L \to S} = 0{,}2$

$F_{I \to S} = 0{,}2$

$F_{S \to I} = 0{,}2$

$F_{L \to L} \neq 0$!!!!

$$\Phi_{I \to S} = \frac{\overset{\to 5{,}67 \cdot 10^{-8}}{\sigma}(T_I^4 - T_S^4)}{\frac{1}{S_I F_{I \to S}}} = -5276{,}4 \text{ kW}$$

$$\Phi_{S \to L} = \frac{\sigma(T_S^4 - T_L^4)}{\frac{1}{S_S F_{S \to L}}} = 22680 \text{ kW}$$

$$\Phi_{I \to L} = \frac{\sigma(T_I^4 - T_L^4)}{\frac{1}{S_I F_{I \to L}}} = 1574{,}45 \text{ kW}$$

K2

corpo grigio | cavità grigia | SEMPRE T in [K] !

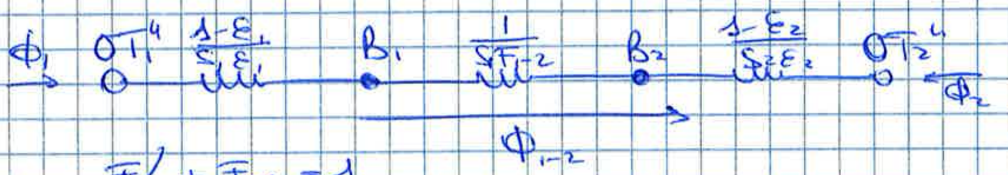
$T_1 = 600°C = 873{,}15 K$ | $S_2 = 5 m^2$

$S_{est,1} = 0{,}5 m^2$ | $T_2 = 27°C = 300{,}15 K$

$\varepsilon_1 = 35\% = 0{,}35$ | $\varepsilon_2 = 75\% = 0{,}75$

$F_{1-1} = 0$ | Φ_{1-2} ?

$F_{1-2} \neq 0$



$$\underbrace{\cancel{F_{1-1}}}_{0} + F_{1-2} = 1$$

$$F_{1-2} S_1 = F_{2-1} S_2 \Rightarrow F_{2-1} = \frac{S_1}{S_2} F_{1-2} = 0{,}1$$

$$\Phi_{1-2} = \frac{\sigma(T_1^4 - T_2^4)}{\frac{1-\varepsilon_1}{S_1 \varepsilon_1} + \frac{1}{S_1 F_{1-2}} + \frac{1-\varepsilon_2}{S_2 \varepsilon_2}} = 5{,}62 \text{ kW}$$

$$(\sigma T_1^4 - B_1)\left(\frac{1}{S_1 F_{1-2}}\right)\left(\frac{1}{S_1 F_{1-A}}\right) + (\sigma T_2^4 - B_1)\left(\frac{1-\varepsilon_1}{S_1\varepsilon_1}\right)\left(\frac{1}{S_1 F_{1-A}}\right) + (\sigma T_A^4 - B_1)\left(\frac{1-\varepsilon_1}{S_1\varepsilon_1}\right)\left(\frac{1}{S_1 F_{1-2}}\right)$$

$$\frac{\sigma T_1^4 - B_1}{S_1^2 F_{1-2} F_{1-A}} + \frac{\sigma T_2^4 - B_1}{S_1^2 F_{1-A}\varepsilon_1}(1-\varepsilon_1) + \frac{\sigma T_A^4 - B_1}{S_1^2 F_{1-2}\varepsilon_1}(1-\varepsilon_1) = 0$$

- $F_{1-2} + \underbrace{F_{1-1}}_{0} + F_{1-A} = 1$
- $S_1 F_{1-2} = S_2 F_{2-1}$

$\Rightarrow \boxed{F_{1-2}} = \frac{S_2 F_{2-1}}{S_1} = 0,915$

~~con $S_2 = \pi\left(\frac{d_2}{2}\right)^2 = 0,0316\ m^2$~~

~~$S_1 = \pi\left(\frac{d_1}{2}\right)^2 =$~~

con $S_1 = 2\pi\left(\frac{d_1}{2}\right)\cdot \ell = 0,126\ m^2$

$S_2 = 2\pi r_2 \cdot \ell = 2\pi\left(\frac{d_2}{2}\right)\cdot \ell = 0,314\ m^2$

} le superfici laterali sono sottoposte a scambi radiativi

$\Rightarrow \boxed{F_{1-A}} = 1 - F_{1-2} = 0,085$

dai grafici

$\gamma = \frac{r_2}{r_1} = \frac{d_2/2}{d_1/2} = \frac{d_2}{d_1} = 2,5$

$\beta = \ell / r_1 = \ell / d_{1/2} = \frac{2\ell}{d_1} = 12,5$

$\Rightarrow \boxed{F_{2-1}} = 0,367$

$\boxed{F_{2-2}} = 0,502$

$$\frac{\sigma T_1^4}{S_1^2 F_{1-2} F_{1-A}} - \frac{B_1}{S_1^2 F_{1-2} F_{1-A}} + \frac{\sigma T_2^4}{S_1^2 F_{1-A}\varepsilon_1}(1-\varepsilon_1) - \frac{B_1(1-\varepsilon_1)}{S_1^2 F_{1-A}\varepsilon_1} + \frac{\sigma T_A^4(1-\varepsilon_1)}{S_1^2 F_{1-2}\varepsilon_1} - \frac{B_1(1-\varepsilon_1)}{S_1^2 F_{1-2}\varepsilon_1} = 0$$

$$B_1 \underbrace{\left(\overset{809,87667}{\frac{1}{S_1^2 F_{1-2} F_{1-A}}} + \underset{481,02477}{\frac{1-\varepsilon_1}{S_1^2 F_{1-A}\varepsilon_1}} + \overset{45,8830}{\frac{1-\varepsilon_1}{S_1^2 F_{1-2}\varepsilon_1}}\right)}_{=1349,79} = \underbrace{\underbrace{\frac{\sigma T_1^4}{S_1^2 F_{1-2} F_{1-A}}}_{26680561,34} + \underbrace{\frac{\sigma T_2^4(1-\varepsilon_1)}{S_1^2 F_{1-A}\varepsilon_1}}_{3022768,078} + \underbrace{\frac{\sigma T_A^4(1-\varepsilon_1)}{S_1^2 F_{1-2}\varepsilon_1}}_{21118,46857}}_{=29734429,89}$$

$B_1 = 22029\ W/(m^2)$

$\Phi_1 = \frac{\sigma T_1^4 - B_1}{\frac{1-\varepsilon_1}{S_1\varepsilon_1}} = 2065,26\ W \Rightarrow \varphi_1 = \frac{\Phi_r}{S_1} \cong 16,4\ kW/m^2$

TABELLE di SATURAZIONE (T_c)

$h_{1,L} = 230,24$ kJ/kg $= h_{4,v}$

$h_{4,v} = 2600$ kJ/kg $= h_{1,v}$

$s_4 = s_3 \qquad s_2 = s_1$

$$x = \frac{s_4 - s_{4,L}}{s_{4,v} - s_{4,L}}$$

$s_{1,v} = s_{4,v} = 7,9896$ kJ/(kg.K)

$s_{1,L} = s_{4,L} = 0,7679$ kJ/(kg.K)

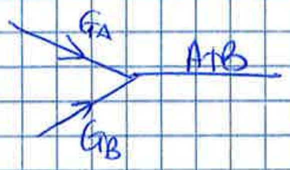
$s_{e_1} = s_3$

$\underset{(T_v)}{s_3} = s_{3v} = 0,32\,(6,2847 - 6,3208) + 6,3208 = 6,3092 \frac{kJ}{kg.K}$

$$\Rightarrow x = \frac{s_3 - s_{4,L}}{s_{4,v} - s_{4,L}} = 0,767 \rightarrow 76,7\ \%$$

ES 2

$G_A = 100$ kg/h



$\overline{M}_A = 4 + 15 = 19$ kg/kmol

$\gamma_A = 1,38$

$G_B \rightarrow \overline{M}_B = \frac{M_A}{2} = 9,5$ kg/kmol

$\gamma_B = \gamma_A = 1,38$

$V_B = 31\%\ V_{TOT}$

$V_A = 69\%\ V_{TOT}$

gas ideali, processo isotermo, isobaro ed adiabatico

G_B? proprietà miscela? ε_{IRR}?

$x_A = \frac{G_A}{\underbrace{G_A + G_B}_{G_{TOT}}} \qquad x_A = \frac{\overline{M}_A}{\overline{M}_{TOT}}\, y_A \qquad y_A = \frac{V_A}{V_{TOT}} = 69\% = 0,69$

$x_B = \frac{G_B}{G_A + G_B} \qquad x_B = \frac{\overline{M}_B}{\overline{M}_{TOT}}\, y_B \qquad y_B = \frac{V_B}{V_{TOT}} = 0,31$

ENTROPIA di MESCOLAMENTO

$$\Delta s = \underbrace{c_p \ln\left(\frac{T}{T_0}\right)}_{\to 0} - \underbrace{R \ln\left(\frac{p}{p_0}\right)}_{\to 0} = 0$$

$$\Delta S = 0 \Longrightarrow S_{irr} = -\frac{\delta Q}{T} \quad \text{chiuso}$$

$\delta Q \to 0$ (adiabatico)

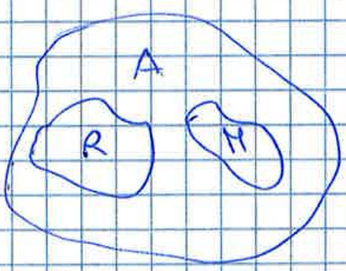
$$\Longrightarrow \Sigma_{irr} = \underbrace{\frac{dS}{dt}}_{\to 0} - \frac{\Phi}{T} = -\frac{\cancel{\Phi}}{T} = 0$$

⟹ processo internamente reversibile

ES. 3

$T_R = 150\ °C$ corpo nero $\varepsilon_R = 1$

$\varepsilon_M = 0,6$ $T_M = 40°C$



$S_A >> S_R$
$S_A >> S_M$

$S_A >> S_M > S_R$

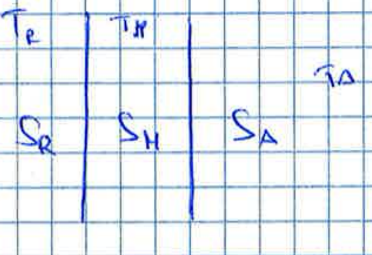
$T_A = 0°C$

$F_{R-M} = 54\ \%$ percentuale flusso emesso da R su M

$\frac{S_M}{S_R} = 0,53$

$\sigma = 5,67 \cdot 10^{-8}\ \frac{W}{m^2 K^4}$

φ_{R-M} ? φ_{R-A} ???



$$\varphi_{R-M} = \frac{\Phi_{R-M}}{S_R} = \left(\frac{\sigma(T_R^4 - T_M^4)}{\underbrace{\frac{1-\varepsilon_R}{\varepsilon_R S_R}}_{\to 0} + \frac{1}{S_R F_{R-M}} + \frac{1-\varepsilon_M}{\varepsilon_M S_M}}\right)\frac{1}{S_R}$$

$$= \frac{\sigma(T_R^4 - T_M^4)}{\left(\frac{1}{S_R F_{R-M}} + \frac{1-\varepsilon_M}{\varepsilon_M S_M}\right) S_R} = \frac{\sigma(T_R^4 - T_M^4)}{\frac{1}{F_{R-M}} + \frac{1-\varepsilon_M}{\varepsilon_M \frac{S_M}{S_R}}} = 9,18\ \frac{W}{m^2}$$

$$\varphi_{R-A} = \frac{\Phi_{R-A}}{S_R} = \left(\frac{\sigma(T_R^4 - T_A^4)}{\underbrace{\frac{1-\varepsilon_R}{\varepsilon_R S_R}}_{\to 0} + \frac{1}{S_R F_{R-A}} + \underbrace{\frac{1-\varepsilon_A}{\varepsilon_A S_A}}_{\to 0\ (S_A >>)}}\right) \cdot \frac{1}{S_R}$$

$$F_{R-A} + \underbrace{F_{R-R}}_{\to 0} + F_{R-M} = 1 \Longrightarrow F_{R-A} = 1 - F_{R-M} = 0,47$$

(sup. piana)

$$\varphi_{R-A} = \frac{\sigma(T_R^4 - T_A^4)}{\frac{1}{\cancel{S_R} F_{R-A}} \cancel{S_R}} = \sigma(T_R^4 - T_A^4) F_{R-A} = 13,49\ W/m^2$$

$q_a = h_2 - h_{1,a}$

- trovo h_2

tabelle di saturazione a $p_v = 45$ bar $\Rightarrow T_v'(p_v) = \frac{256,1+258,8}{2} = 257,45\ °C$

$T_v' < T_v \Rightarrow$ vapore surriscaldato $\Rightarrow$ Mollier

$h_2 = p_2 \cap T_2 = p_v \cap T_v = 3960$ kJ/kg

$s_2 = p_2 \cap T_2 = p_v \cap T_v = 7,6$ kJ/(kg.K)

$\Rightarrow q_a = h_2 - h_{1,a} = 3850,74$ kJ/kg

b) $l_{t,c} = -(h_2 - h_{1,b})$

- trovo $h_{1,b}$

vapore surriscaldato (sono fuori dalla curva, dal lato del vapore)

$h_{1,b} = p_1 \cap T_1 = p_0 \cap T_0 = 2500$ kJ/kg

~~[illegible]~~

$\Rightarrow \underset{(b)}{l_{t,c}} = -(h_2 - h_{1,b}) = -1460$ kJ/kg

$q_b = h_{1,b} - h_0 = 2395,15$ kJ/kg

a) s_{irr} ? sistema a deflusso

$$\frac{ds(t)}{dt} = \frac{\phi(t)}{T_s} + \Sigma_{irr}$$

$$\underbrace{\left[\frac{ds}{dt}\right]_{V_c}}_{\to 0} + \Sigma \pm G_j s_j = \frac{\phi}{T_s} + \Sigma_{irr}$$

(Hp. stazionario)

dentro
$$\begin{cases} G(s_2 - s_1) - \frac{\phi}{T_s} = \Sigma_{irr} \\ \cancel{G}(s_2 - s_1) - \cancel{G}\frac{q_a}{T_s} = \cancel{G} s_{irr} \end{cases}$$

$$s_{irr} = (s_2 - s_1) - \frac{q_a}{T_s} = 3,43 \text{ kJ/(kg.K)}$$

con $s_1 = s_0$ (compressione ideale)

b)

$$s_{irr} = (s_1 - s_0) - \frac{q_b}{T_s} = 4,87 \text{ kJ/(kg.K)}$$

con $s_1 = s_2$

· Trovo M_2

Applico 1° P (sistemi aperti) $\neq 0$! (il pistone si muove subisce luogo di deformazione)

$$\underset{0\ (\text{adiab.})}{\Phi} - \overset{0}{W_t} = \frac{d}{dt}\left[U + \cancel{E_k} + \cancel{E_p} + \boxed{p_0 V}\right]_{V_c} + \sum \pm G_j \left(h + \cancel{e_k} + \cancel{e_p}\right)_j$$

$$\cancel{\Phi} - \cancel{W_t} = \frac{dU}{dt} + \underbrace{\frac{d}{dt}(p_0 V)}_{} - G h_e$$

$$G h_e = U_2 - U_1 + \overset{\shortparallel}{L_0}$$

$$-G_e = -\left(\frac{dM}{dt}\right)_{V_c} \Rightarrow G_e = \left(\frac{dM}{dt}\right)_{V_c} = M_2 - M_1$$

$$(M_2 - M_1) h_e = M_2 u_2 - M_1 u_1 + L_0$$

$$M_2 h_e - M_1 h_e = M_2 (h_2 - p_2 v_2) - M_1 (h_1 - p_1 v_1) + (p_2 V_2 - p_1 V_1)$$

$$M_2 h_e - M_1 h_e = M_2 h_2 - \cancel{M_2 p_2 v_2} - M_1 h_1 + \cancel{M_1 p_1 v_1} + \cancel{M_2 v_2 p_2} - \cancel{M_1 p_1 v_1}$$

$$M_2 (h_e - h_2) = M_1 (h_e - h_1)$$

$$M_2 = \frac{M_1 (h_e - h_1)}{h_e - h_2}$$

a $p_1 = 1{,}9$ bar

$h_{1,L} = 497{,}94$ kJ/kg

$h_{1,V} = 2704{,}2$ kJ/kg

$h_1 = (1 - x_1) h_{1,L} + x_1 h_{1,V} = 1799{,}63$ kJ/kg

a $p_2 = p_1 = 1{,}9$ bar

$$h_2 = (1 - x_2) \underset{h_{2,L}}{\underset{\shortparallel}{h_{1,L}}} + x_2 \underset{h_{2,V}}{\underset{\shortparallel}{h_{1,V}}} = 2042{,}32 \text{ kJ/kg}$$

Vapore d'acqua in entrata a $p_s = 18$ bar

$h_e = h_{s,V} = 2796{,}4$ kJ/kg

$$\Rightarrow M_2 = \frac{M_1 (h_e - h_1)}{h_e - h_2} = 0{,}0022 \text{ kg}$$

Processo adiabatico

~~[illegible]~~

$$L_t = L_{t,2} - L_{t,1} = M_2 c_p \Delta T_2 - (-M_1 c_p \Delta T_1) = -M_2 h_2 + M_1 h_1 =$$

$$= M_1 h_1 - M_2 h_2 = -1433{,}73 \text{ J}$$

ES. 3

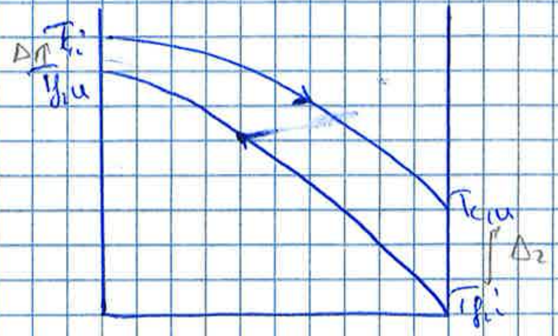
$T_{c,i} = 48°C = cost.$ (temp. condensazione)

$|\Phi| = 60\ kW$

$T_a = 15°C = T_{f,i}$

scambiatore a correnti //

$NTU = 1,5$



ε?

ΔT_{min}?

$\frac{1}{\alpha_e}$ → resistenza convettiva lato acqua di raffreddamento

$\frac{1}{\alpha_e} = 0,002\ (m^2 \cdot K)/W$

S?

$\varepsilon = 1 - e^{-NTU} = 0,78$

Dato che dobbiamo condensare un fluido → $C_{max} = C_{caldo} = C_c$

$\Rightarrow \varepsilon = \frac{T_{f,u} - T_{f,i}}{T_{c,i} - T_{f,i}} \Rightarrow T_{f,u} = \varepsilon (T_{c,i} - T_{f,i}) + T_{f,i} = 40,74\ °C$

$C_{min} = C_f$ e $C_c > C_f$

poiché $T_{c,i} = cost \Rightarrow T_{c,i} = T_{c,u} \Rightarrow$ controcorrente

$\Delta T_{min} = T_{c,i} - T_{f,u} = 7,26\ °C = 7,26\ K$ (è una differenza)

~~$\varepsilon = \frac{\Phi}{\Phi_{max}} \Rightarrow \Phi_{max} = \frac{\Phi}{\varepsilon} = 76923,1\ W$~~

~~$\Phi_{max} = C_f (T_{f,u} - T_{f,i}) = -C_c (T_{c,u} - T_{c,i}$~~

$\Phi = k S_{tot} \left(\frac{\Delta_2 - \Delta_1}{\ln \Delta_2 / \Delta_1} \right)$

$\Delta_2 = T_{c,u} - T_{f,i} = T_{c,i} - T_{f,i} = 33°C$

$\Delta_1 = T_{c,i} - T_{f,u} = 7,26\ °C$

$k = \left[\frac{1}{\alpha_i} + \cancel{\frac{\delta_{s,i}}{\lambda_{s,p}}} + \cancel{\frac{\delta}{\lambda_{s,e}}} + \cancel{\frac{1}{\alpha_e}} \right]^{-1} = \left[\frac{1}{\alpha_e} \right]^{-1} = 500\ \frac{W}{m^2 \cdot K}$

$S_{tot} = \frac{\Phi}{k \left(\frac{\Delta_2 - \Delta_1}{\ln \frac{\Delta_2}{\Delta_1}} \right)} = 7,1\ m^2$

Hp: reversibilità $\Rightarrow$ $s_{2,v} = s_3^{id} = s_{2,v}(p_1) = s_{1,v} = 6,7079 \frac{kJ}{kg \cdot K}$

$$x_3^{id} = \frac{s_3^{id} - s_{3,L}^{id}}{s_{3,v}^{id} - s_{3,L}^{id}} = 0,893$$

$$\Rightarrow h_3^{id} = (1 - x_3^{id}) h_{3,L}^{id} + x_3^{id} h_{3,v}^{id} = 2433,54 \text{ kJ/kg}$$

stato 2 → saturo vapore $\Rightarrow h_2 = h_{2,v}$

MA $h_{2,v} = h_{1,v}$

$\Rightarrow h_2 = h_{1,v} = 2763,3$ kJ/kg

$$\eta_{is,e} = \frac{h_2 - h_3}{h_2 - h_3^{id}} \Rightarrow h_3 = -\eta_{is,e}(h_2 - h_3^{id}) + h_2 = 2509,4 \text{ kJ/kg}$$

$$\Rightarrow \quad -W_t = G_v (h_3 - h_{2,v})$$

$$G_v = \frac{-W_t}{h_3 - h_{2,v}} = 0,205 \text{ kg/s}$$

$$G_v = G_L = 0,205 \text{ kg/s}$$

1° P) sistema aperto (sul recipiente)

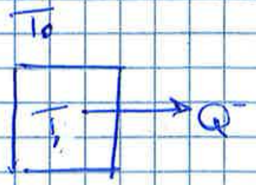
$$\phi - \cancel{W_t}^{0} = \cancel{\frac{d}{dt}}^{0}[U + E_k + E_p + pV]_{vc} + \sum^{\pm} G_j (h + \cancel{e_p}^{0} + \cancel{e_k}^{0})$$

$$\phi = + G_v (h_{2,v} - h_{1,L}) =$$

(esce vapore - entra liquido)

?

ES. 2



$V = 80\ L = 80\ dm^3 = 80 \cdot 10^{-3} m^3$

$n = 17$ moli $= 17 \cdot 10^{-3}$ kmol

gas triatomico $\Rightarrow$ $\gamma = 4/3 = 1,33$

$T_0 = T_i = 15° = 288,15 K$

$P_f = 5$ bar $= 500$ kPa

gas ideale T_f ? Q ? processo internamente rev. ?

$P_f V_f = n \bar{R} T_f \Rightarrow T_f = \frac{P_f V_f}{n \bar{R}} = 282,999 K = 9,85 °C$

$T_f < T_i \Rightarrow$ calore ceduto (Q^-)

Sistema chiuso

1°p) $Q - \underbrace{\cancel{L}}_{0} = \Delta U$

$Q = \Delta U = M(u_f - u_i) = M c_v (T_f - T_i)$

$M = \bar{M} \cdot n \Rightarrow M c_v = \bar{M} \cdot n \cdot c_v = n \underbrace{\bar{M} c_v}_{\bar{c}_v} = n \bar{c}_v$

$\bar{c}_v = \frac{1}{\gamma - 1} \bar{R} = 25194,85\ J/(K \cdot kmol)$

$\rightarrow Q = n \bar{c}_v (T_f - T_i) = -2,206\ kJ$

verificare se il processo è internamente reversibile

$\Delta S = \int \frac{\delta Q}{T} + S_{irr}$

è internamente rev. se $S_{irr} = 0$, cioè $\Delta S = \int \frac{\delta Q}{T}$

con $\int \frac{\delta Q}{T} = \frac{Q}{\bar{T}}$

$\bar{T} = \frac{\Delta U}{\Delta S}$ essendo isocora (V=cost.) ◄—

$\bar{T} = \frac{M c_v (T_f - T_i)}{M(s_f - s_i)}$

isocora $\rightarrow Q = M c_v (T_f - T_i)$

$\Delta S = \frac{Q}{\bar{T}} \rightarrow M(s_f - s_i) = \frac{\cancel{M c_v (T_f - T_i)}}{\frac{\cancel{M c_v (T_f - T_i)}}{M(s_f - s_i)}}$

$\rightarrow M(s_f - s_i) = M(s_f - s_i)$ ✓ (internamente reversibile

7 FEBBRAIO 2013

ES. 1

$CO_2 \rightarrow \overline{M}_{CO_2} = 44$ kg/kmol

$Ne \rightarrow \overline{M}_{Ne} = 20,2$ kg/kmol

$V_1 = 80\ L = 80 \cdot 10^{-3}\ m^3 = 0,08\ m^3$

$T_1 = T_0 = 25°C = 298,15\ K$

$p_1 = p_0 = 1\ bar = 100\ kPa$

$V_{1_{CO_2}} = 30\%$ $V_{1,Ne} = 70\%$

$V_{1_{CO_2}} = 30\%\ V_1 = 0,024\ m^3$ $V_{1_{Ne}} = 70\%\ V_1 = 0,056\ m^3$

3 fasi

a) $V_2 = V_1/3 = 0,0267\ m^3$

$T_2 = 420°C = 693,15\ K$

COMPRESSIONE
(trasf. adiabatica)

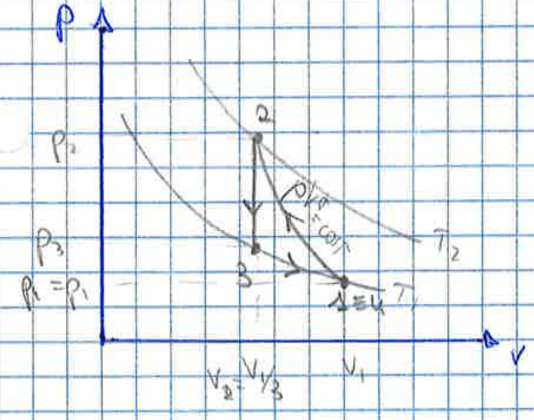
b) pistone fermo ⇒ isocora

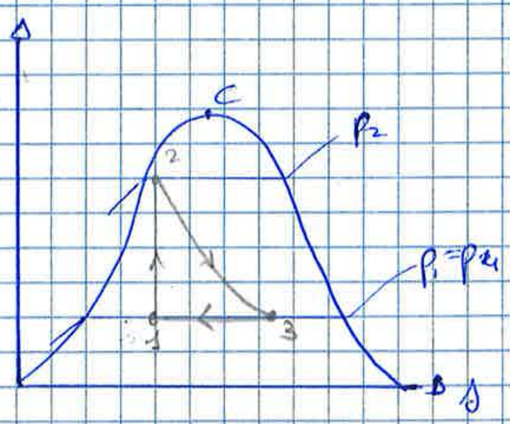
$T_3 = T_0 = T_1$

[illegible]

c) trasf. isoterma espansione

$p_4 = p_0 = p_1$





c'è attrito! ($L_a \neq 0$)

$L_{a_{fase\ a}}$? $L_{a_{fase\ c}}$? Q_{TOT} ?

$\Delta e_c = \Delta e_p = 0$ gas ideale

$L_a = L_i^{id} - L_i$

• trasf. 1-2 (adiabatica) $\underbrace{Q}_{=0} - L_i = \Delta U$

$L_i' = -M c_v (T_2 - T_1)$

$c_v = x_{CO_2} c_{v_{CO_2}} + x_{Ne} c_{v_{Ne}}$

$y_{CO_2} = \frac{V_{CO_2}}{V} = 0,3$ $y_{Ne} = \frac{V_{Ne}}{V} = 0,7$

$$\begin{cases} p_2 V_2 = M R T_2 \\ p_1 V_1 = M R T_1 \end{cases} \qquad \begin{cases} p_2 = \frac{M R T_2}{V_2} = 626,21 \text{ kPa} \\ R = \frac{p_1 V_1}{M T_1} = 301,48 \text{ J (kg·K)} \end{cases}$$

$$T_2^{id} = T_1 \left(\frac{p_1}{p_2}\right)^{\frac{1-\gamma}{\gamma}} = 554 \text{ K}$$

$$\Rightarrow L_i^{id} = -M c_v (T_2^{id} - T_1) = -13,53 \text{ kJ}$$

$$\Longrightarrow L_{a\,fase\,a} = L_i^{id} - L_i = 7,32 \text{ kJ}$$

- trasf. 3-4 (= 3-1)

$p_4 = p_1 = 100$ kPa

isoterma

$$L_i = M R T_1 \ln\left(\frac{v_1}{v_3}\right)$$

$$p_1 v_1 = R T_1 \Rightarrow v_1 = \frac{R T_1}{p_1} = 0,9 \text{ m}^3/\text{kg}$$

$$v_3 = \frac{R T_1}{p_3} = 0,3 \text{ m}^3/\text{kg}$$

con $p_3 V_3 = M R T_3 \rightarrow p_3 V_2 = M R T_1 \Rightarrow p_3 = \frac{M R T_1}{V_2} = 299,62$ kPa

$$\Rightarrow L_i = M R T_1 \ln\left(\frac{v_1}{v_3}\right) = 8,789 \text{ kJ}$$

$$L_i^{id} = M R T_1 \ln\left(\frac{v_1}{v_3^{id}}\right) = 9631,63 \text{ J}$$

con $v_3^{id} = v_2^{id} = \frac{R T_2^{id}}{p_2} = 0,27$ m^3

$$\Longrightarrow L_{a\,fase\,c} = L_i^{id} - L_i = 842,63 \text{ J}$$

$$Q_{TOT} = \underbrace{\cancel{Q_{1-2}}}_{\to 0 \text{ (adiabatica)}} + Q_{2-3} + \underbrace{Q_{3-4}}_{= Q_{3-1}}$$

$Q_{2-3} = M c_v (T_3 - T_2) = M c_v (T_1 - T_2) = -20,888$ kJ ISOCORA

$Q_{3-4} = L_{i\,3-4}$ ISOTERMA

$\Rightarrow Q_{TOT} = -12,1$ kJ

verifico $\Sigma Q = \Sigma L \Longrightarrow -12,1$ kJ $= -12,1$ kJ ✓

- trovo h_2

$h_2 = h_{2,v}$ a $p_1 = 1 bar$

$\boxed{h_2} = 2675,1$ kJ/kg

- trovo h_3^{id}

$$\eta_{is,c} = \frac{h_3^{id} - h_2}{h_3 - h_2}$$

$h_3^{id} = p_3 \cap s_3^{id} = 3555$ kJ/kg MOLLIER (VAPORE SURRISCALDATO)

con $s_3^{id} = s_2 = s_{2,v} = 7,3589$ kJ/(kg.K)

→ [illegible]

$$\Rightarrow \boxed{h_3} = \frac{h_3^{id} - h_2}{\eta_{isc}} + h_2 = 3885,5 \text{ kJ/kg}$$

→ $h_4 = h_3 - 0,9(h_2 - h_1) = 1572,3$ kJ/kg

$h_{4,L}(p_3) = 1008,3$ kJ/kg
$h_{4,v}(p_3) = 2803,3$ kJ/kg

$$\Rightarrow x_4 = \frac{h_4 - h_{4,L}}{h_{4,v} - h_{4,L}} = 0,31 \to 31\%$$

$s_4 = (1 - x_4) s_{4,L} + x_4 s_{4,v} = 3,74$ kJ/(kg.K)

$s_{4,L}(p_3) = 2,6454$
$s_{4,v}(p_3) = 6,1855$ } kJ/(kg.K)

Dimostrare reversibilità trasf. 1-2 e 3-4

- 1-2 ISOBARA (sist. aperto)

$$\frac{dS}{dt} = \frac{\Phi}{T} + \Sigma_{irr} \Rightarrow \Sigma_{irr} = 0 \Rightarrow \frac{dS}{dt} = \frac{\Phi}{T}$$

$$\frac{dS}{dt} = \cancel{\left(\frac{dS}{dt}\right)_{VC}} + \Sigma G_j s_j = G(s_2 - s_1)$$

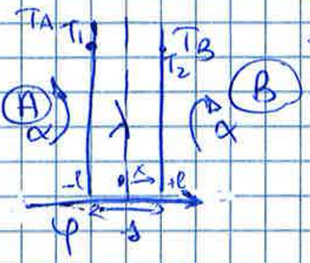
(1 solo entrata
1 solo uscita)

$\bar{T} = \frac{\Delta H}{\Delta S}$ essendo isobara ←

$$\bar{T} = \frac{G(h_2 - h_1)}{G(s_2 - s_1)}$$

$$\Phi = Gq = G c_p \Delta T = G \Delta h = G(h_2 - h_1)$$

ⓈES. 3



$T_2 \neq T_B$
$T_1 \neq T_A$ perché ho convezione

$s = 50\ \text{mm} = 0{,}05\ \text{m} = 2\ell$

$\lambda = 1\ \text{W}/(\text{m}\cdot\text{K})$

$T_A = 85\ °\text{C}$

$T_B = 25\ °\text{C}$

$\alpha = 55\ \text{W}/(\text{m}^2\text{K})$

$H = 18\ \text{kW}/\text{m}^3$

condizione stazionaria φ_A ? φ_B ???

$\varphi_G = \frac{HV}{S} = Hs = 900\ \text{W}/\text{m}^2$ per generazione interna di calore

$$\begin{cases} \varphi_A = \alpha(T_A - T_1) \\ \varphi_B = \alpha(T_2 - T_B) \\ \varphi_A = \frac{\lambda}{2\ell}(T_1 - T_2) - H\ell = \frac{\lambda}{s}(T_1 - T_2) - H\frac{s}{2} \\ \varphi_B = \frac{\lambda(T_1 - T_2)}{2\ell} + H\ell = \frac{\lambda(T_1 - T_2)}{s} + H\frac{s}{2} \end{cases}$$

$$\Rightarrow \alpha(T_A - T_1) = \lambda\frac{(T_1 - T_2)}{s} + H\frac{s}{2}$$

$$\alpha T_A - \alpha T_1 = \frac{\lambda}{s}T_1 - \frac{\lambda}{s}T_2 + H\frac{s}{2}$$

$$T_1\left(-\alpha - \frac{\lambda}{s}\right) = -\alpha T_A - \frac{\lambda}{s}T_2 + H\frac{s}{2}$$

$$T_1 = \frac{\alpha T_A + \frac{\lambda}{s}T_2 - H\frac{s}{2}}{\alpha + \frac{\lambda}{s}}$$

$$\Rightarrow \alpha(T_2 - T_B) = \frac{\lambda(T_1 - T_2)}{s} + H\frac{s}{2}$$

$$\alpha T_2 - \alpha T_B = \frac{\lambda}{s}T_1 - \frac{\lambda}{s}T_2 + H\frac{s}{2}$$

$$\alpha T_2 - \alpha T_B = \frac{\lambda}{s}\left(\frac{\alpha T_A + \frac{\lambda}{s}T_2 - H\frac{s}{2}}{\alpha + \frac{\lambda}{s}}\right) - \frac{\lambda}{s}T_2 + H\frac{s}{2}$$

$$\alpha T_2 + \frac{\lambda}{s}T_2 = \frac{\lambda}{s}\frac{1}{\alpha + \frac{\lambda}{s}}\alpha T_A + \frac{\lambda}{s}\frac{1}{\alpha + \frac{\lambda}{s}}\cdot\frac{\lambda}{s}T_2 - \frac{\lambda}{s}\frac{H\frac{s}{2}}{\alpha + \frac{\lambda}{s}} - \frac{\lambda}{s}T_2 + H\frac{s}{2}$$

$$\left(+\frac{\lambda}{s} + \alpha + \frac{\lambda}{s} - \frac{\lambda^2}{s^2}\frac{1}{\alpha + \frac{\lambda}{s}}\right)T_2 = \frac{\lambda}{s}\frac{1}{\alpha + \frac{\lambda}{s}}\alpha T_A - \frac{\lambda}{s}\frac{H\frac{s}{2}}{\alpha + \frac{\lambda}{s}} + H\frac{s}{2}$$

$$\begin{cases} p_2 V_2 = M_2 R T_2 \\ p_1 V_1 = M_1 R T_1 \end{cases} \quad \left[\begin{cases} \frac{p_2}{M_2 T_2} = \frac{R}{V_2} \\ \frac{p_1}{M_1 T_1} = \frac{R}{V_1} \end{cases}\right] = \quad \frac{p_2}{M_2 T_2} = \frac{p_1}{M_1 T_1} \Rightarrow \frac{M_2}{M_1} = \frac{p_2}{p_1} \frac{T_1}{T_2}$$

$$T_2 = \frac{(M_2 - M_1) c_p T_e + M_1 c_v T_1}{M_2 c_v} = \frac{M_2 c_p T_e - M_1 c_p T_e + M_1 c_v T_1}{M_2 c_v} =$$

$$= \frac{M_2 c_p T_e + M_1 (c_v T_1 - c_p T_e)}{M_2 c_v}$$

$$M_1 = \frac{M_2}{\frac{p_2}{p_1} \cdot \frac{T_1}{T_2}} = M_2 \frac{p_1 T_2}{p_2 T_1}$$

$$\Rightarrow T_2 = \frac{\cancel{M_2} c_p T_e + \cancel{M_2} \frac{p_1 T_2}{p_2 T_1} (c_v T_1 - c_p T_e)}{\cancel{M_2} c_v} = \frac{c_p T_e + \frac{p_1 T_2}{p_2 T_1}(c_v T_1 - c_p T_e)}{c_v}$$

$$T_2 c_v = c_p T_e + \frac{p_1 T_2 \cancel{T_1} c_v}{p_2 \cancel{T_1}} - \frac{p_1 T_2 c_p T_e}{p_2 T_1}$$

~~$T_2 c_v - \frac{p_1 T_2 c_v}{p_2} = c_p T_e \left(1 - \frac{p_1 T_2}{p_2 T_1}\right)$~~

$$T_2 \left(c_v - \frac{p_1 \cancel{T_2}}{p_2} + \frac{p_1 c_p T_e}{p_2 T_1}\right) = c_p T_e$$

$$T_2 = \frac{c_p T_e}{c_v - \frac{p_1 c_v}{p_2} + \frac{p_1 c_p T_e}{p_2 T_1}}$$

$$c_v = \frac{c_p}{\gamma}$$

$$\Rightarrow T_2 = \frac{\cancel{c_p} T_e}{\frac{\cancel{c_p}}{\gamma} - \frac{p_1 \cancel{c_p}}{\gamma p_2} + \frac{p_1 \cancel{c_p} T_e}{p_2 T_1}} = \frac{T_e}{\frac{1}{\gamma} - \frac{p_1}{\gamma p_2} + \frac{p_1 T_e}{p_2 T_1}} = 299,56\ K = = 26,41\ °C$$

$$\frac{M_2}{M_1} = \frac{p_2}{p_1} \frac{T_1}{T_2} = 6,72$$

~~pe~~ $\begin{cases} p_2 v_2 = RT_2 \\ p_3 v_3 = RT_3 \end{cases}$ $\begin{cases} \frac{v_2}{R} = \frac{T_2}{p_2} \\ \frac{v_3}{R} = \frac{T_3}{p_3} \end{cases}$ $v_2 = v_3 \Rightarrow \frac{T_2}{p_2} = \frac{T_3}{p_3}$

Gas ideale

$$\Delta s = c_p \ln\left(\frac{T}{T_0}\right) - R\ln\left(\frac{p}{p_0}\right) = c_v \ln\left(\frac{T}{T_0}\right) + R\ln\left(\frac{v}{v_0}\right)$$

Essendo 1-2 e 3-4 adiabatica rev. ⇒ isoentropiche
⇒ uso Δs per 2-3 e 4-1

- 2-3

$$\Delta s = c_v \ln\left(\frac{T_3}{T_2}\right) + \cancel{R\ln\left(\frac{v_3}{v_2}\right)} = c_v \ln\left(\frac{T_3}{T_2}\right)$$

$\frac{v_3}{v_2} \to 1$, $\ln \to 0$

$$\frac{\Delta s}{c_v} = \ln\left(\frac{T_3}{T_2}\right) \to e^{\frac{\Delta s}{c_v}} = \frac{T_3}{T_2} \Rightarrow T_3 = T_2 e^{\frac{\Delta s}{c_v}} = 1461,97\ k = 1188,82\ °C$$

$$p_3 = \frac{T_3 p_2}{T_2} = 35,1 \text{ bar}$$

$$p_1 v_1 = RT_1 \Rightarrow v_1 = \frac{RT_1}{p_1} = 0,773\ m^3/kg$$

$v_1 = v_4$

$$p_2 v_2 = RT_2 \Rightarrow v_2 = \frac{RT_2}{p_2} = 0,1195\ m^3/kg \qquad v_2 = v_3$$

- 3-4

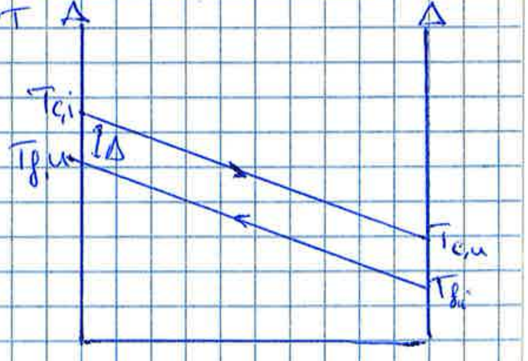
$$T_3 v_3^{\gamma-1} = T_4 v_4^{\gamma-1} \Rightarrow T_4 = T_3\left(\frac{v_3}{v_4}\right)^{\gamma-1} = 692,8\ k = 419,66\ °C$$

$$l_{34} = -c_v(T_4 - T_3) = 551,879\ kJ/kg$$

$$l_u = l_{12} + l_{3-4} = 316,1\ kJ/kg$$

ES.3

scambiatore a correnti // (controcorrente)



$T_{c,i} = 38\ °C = 311,15\ k$

$\Delta = 4\ k$

$\Delta = T_{c,i} - T_{f,u} \Rightarrow T_{f,u} = T_{c,i} - \Delta = 307,15\ k = 34\ °C$

$NTU = 1,1$

ε? $T_{f,i}$?

$C_c = C_f = C$

$$r = \frac{C_{min}}{C_{max}} = 1 \Rightarrow \varepsilon = \frac{NTU}{NTU+1} = 0,52$$

$$\varepsilon = \frac{\Phi}{\Phi_{max}} = \frac{-\cancel{C}(T_{c,u} - T_{c,i})}{\cancel{C}(T_{f,u} - T_{f,i})} = \frac{T_{c,i} - T_{c,u}}{T_{f,u} - T_{f,i}}$$

$p_1 V_1 = M_1 R T_1$

$R = \frac{\overline{R}}{M_{O_2}} = 259,8 \ J/(kg \cdot K)$

$\boxed{M_{1,O_2}} = \frac{p_1 V_1}{R T_1} = 0,065 \ kg$

1° P) sistemi ~~aperti~~ con deflusso

$$\phi - \underset{\to 0}{\cancel{W_t}} = \frac{d}{dt}\left[U + \overset{0}{\cancel{E_k}} + \overset{0}{\cancel{E_p}} + \overset{0}{\cancel{p_0 V}}\right]_{V_c} + \sum G_j \left(h + \overset{0}{\cancel{e_p}} + \overset{0}{\cancel{e_k}}\right)_j$$

$$\phi = \left(\frac{dU}{dt}\right)_{V_c} - G_e h_e$$

$$Q_{1O_2} = M_{2,O_2} u_2 - M_{1,O_2} u_1 - G_e h_e$$

$$-G_e = -\left(\frac{dM}{dt}\right)_{V_c} \Longrightarrow G_e = M_{2,O_2} - M_{1,O_2}$$

$$Q_{1O_2} = M_{2,O_2} u_2 - M_{1O_2} u_1 - \left(M_{2,O_2} - M_{1,O_2}\right) h_e$$

$$Q_{1,O_2} = Q_{1A}$$

per sist. aperti (1° P)

$$Q_A - \underset{\to 0}{\cancel{L_t^{id}}} = \Delta H \Longrightarrow Q_A = \Delta H = M_A (h_2 - h_1)$$

- trovo h_1

A $p_{1A} = 1,01$ bar (= 1 atm) ⟶ da tabelle di saturazione $T_1' = 99,63 \, °C$

$\Longrightarrow T_1' > T_1 \Longrightarrow$ liquido sottoraffreddato

liq. fluido incompressibile ($v = cost$)

$h_1(T_0; p_0) = h_L(T_0) + v_L(T_0)\left[p_0 - p_s(T_0)\right] =$

$h_L(T_0) = 104,75 \ kJ/kg$
$v_L(T_0) = 1\,0030 \cdot 10^{3} \ m^3/kg$
$p_s(T_0) = 0,0317 \ bar = 3170 \ Pa$
$p_0 = 1,01 \ bar = 101325 \ Pa$

$\Longrightarrow \boxed{h_1} = 104,848 \ kJ/kg$

~~$h_L(T_e; p_2) = h_{2,L}(T_e) + v_{2,L}(T_2)[p_2 - p]$~~

a $T_e = T_0 = 25 \, °C \longrightarrow p_e = p_{2,O_2} = 0,0317 \ bar = 3170 \ Pa$

$h_2(T_2; p_2) = h_L(T_2) + v_L(T_2)\left[p_2 - p_s(T_2)\right]$

$p_s(T_2) = \longrightarrow$ INTERPOLAZIONE

ES. 2

$\gamma = 1,4$

$O_2 \rightarrow \bar{M}_{O_2} = 32$ kg/kmol

$R = \frac{\bar{R}}{\bar{M}_{O_2}} = 259,87$ J/(kg K)

$p_f = 4300$ kPa → SEMPRE ADIABATICA!

compressione bi-stadio con interrefrigerazione

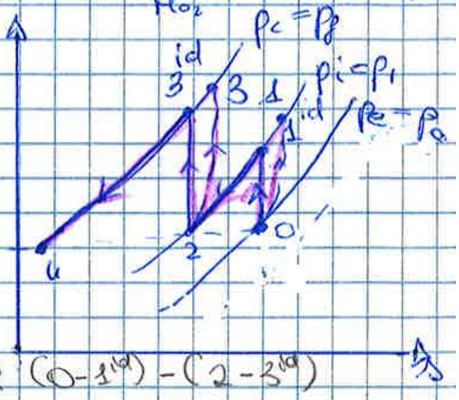
$p_e = p_0 = 1$ atm $= 101325$ Pa

$T_e = T_0 = 25°C = 298,15$ K

$\eta_{is,c} = 74\ \%$

scambi di calore isobari

$l_{t,c}$?



→ compressione / adiabatico rev. se caso ideale $(0-1^{id}) - (2-3^{id})$
\ " con $\eta_{is,c}$

$T_0 = T_2 = T_4$

$0 - 1^{id}$ → adiabatico rev. (isoentropico)
$1 - 2$ → isobaro
$2 - 3^{id}$ → adiabatico rev. (isoentropico)
$3 - 4$ → isobaro

2 stadi → $p_i = \sqrt[2]{\infty}$ 3 stadi → $p_i\ \sqrt[3]{\infty}$

$p_i = \sqrt{p_e \cdot p_f} = 660,074$ kPa $= p_1$

1° p) sistema ~~chiuso~~ aperto

• $0 - 1^{id}$ $\underset{\to 0}{\cancel{q}} - l_t^{id} = \Delta h$

$l_t^{id} = -\Delta h = -(h_1^{id} - h_0) = -c_p(T_1^{id} - T_0)$

• $0 - 1$ $\underset{\to 0}{\cancel{q}} - l_t = \Delta h$

$l_t = -c_p(T_1 - T_0)$

$$\eta_{is,c} = \frac{h_1^{id} - h_0}{h_1 - h_0} = \frac{T_1^{id} - T_0}{T_1 - T_0}$$

MA $\eta_{is,c} = \frac{T_3^{id} - T_2}{T_3 - T_2} = \frac{T_3^{id} - T_0}{T_3 - T_0}$

$T_0 p_0^{\frac{1-\gamma}{\gamma}} = T_1^{id} p_1^{\frac{1-\gamma}{\gamma}} \Rightarrow T_1^{id} = T_0 \left(\frac{p_0}{p_1}\right)^{\frac{1-\gamma}{\gamma}} = 508,3$ K $= 236,15$ °C

$\rightarrow T_1 = \frac{T_1^{id} - T_0}{\eta_{is,c}} + T_0 = 583,5$ K $= 310,34$ °C

$\Delta_1 = T_{g,i} - T_{a,i}$ $\Delta_2 = T_{a,u} - T_{g,u}$

$$\begin{cases} NTU = \dfrac{KS_{TOT}}{C_{min}} \\ \dfrac{\Delta_2}{\Delta_1} = e^{-KMS_{TOT}} \end{cases}$$

con $M = \dfrac{1}{C_c} + \dfrac{1}{C_f}$ per equicorrente

$$M = \frac{1}{C_{min}} + \frac{1}{C_{max}} = \frac{C_{max} + C_{min}}{C_{max}\,C_{min}} =$$

$$= \frac{1}{C_{min}}\left(1 + \underbrace{\cancel{\frac{C_{min}}{C_{max}}}}_{\to 0}\right) = \frac{1}{C_{min}}$$

$$\begin{cases} NTU = \dfrac{KS_{TOT}}{C_{min}} \\ \dfrac{\Delta_2}{\Delta_1} = e^{-\frac{KS_{TOT}}{C_{min}}} \end{cases} \qquad \begin{cases} \longrightarrow \\ -\ln\left(\dfrac{\Delta_2}{\Delta_1}\right) = \dfrac{KS_{TOT}}{C_{min}} \end{cases}$$

$$\Rightarrow NTU = -\ln\left(\frac{\Delta_2}{\Delta_1}\right) = -\ln\left(\frac{\cancel{\Delta_2}}{3{,}25\cancel{\Delta_2}}\right) = 1{,}18$$

$$\varepsilon = \frac{1 - e^{-\left(1 + \underbrace{\cancel{\frac{C_{min}}{C_{max}}}}_{\to 0}\right)NTU}}{1 + \underbrace{\cancel{\frac{C_{min}}{C_{max}}}}_{\to 0}} = 1 - e^{-NTU} = 0{,}693 \to 69{,}3\%$$

17 FEBBRAIO 2014

ES. 1 $V_1 = V_2 = V = 100\,L = 0{,}1\,m^3$

$V_{1,N_2} = 33\,L = 0{,}033\,m^3$

$V_{1,CO_2} = 32\,L = 0{,}032\,m^3$

$V_{1,He} = 35\,L = 0{,}035\,m^3$

$\bar{M}_{N_2} = 28\,kg/kmol$

$\gamma_{N_2} = 7/5 = 1{,}4$

$M_{CO_2} = 44\,kg/kmol$

$\gamma_{CO_2} = 1{,}33$

$M_{He} = 4\,kg/kmol$

$\gamma_{He} = 1{,}67$

miscela di gas ideali

$R_{CO_2} = \dfrac{\bar{R}}{M_{CO_2}} = 188{,}96\ J/(kg \cdot K)$

$R_{N_2} = 296{,}94\ J/(kg \cdot K)$

$R_{He} = 2078{,}6\ J/(kg \cdot K)$

R?

spostata massa $|\Delta M| = |M_2 - M_1|$?

processo isotermo $T_1 = T_2 = 17\ °C$

$Q = 55\ kJ$

$\Delta e_c = \Delta e_p = 0$ Δp ?

$$c_p = x_{CO_2} c_{p_{CO_2}} + x_{N_2} c_{p_{N_2}} + x_{He} c_{p_{He}} = 1108,8 \ J/(kg \cdot K)$$

$$c_v = x_{CO_2} c_{v_{CO_2}} + x_{N_2} c_{v_{N_2}} + x_{He} c_{_{He}} = 774,8 \ J/(kg \cdot K)$$

$$\Rightarrow Q = M_2 c_v \overset{\overset{T_1}{\parallel}}{T_2} - M_1 c_v T_1 + (M_1 - M_2) c_p T_1 = (M_2 - M_1) c_v T_1 + (M_1 - M_2) c_p T_1 =$$

$$= (M_2 - M_1) c_v T_1 - (M_2 - M_1) c_p T_1 = (M_2 - M_1) [c_v T_1 - c_p T_1]$$

$$\Rightarrow M_2 - M_1 = \frac{Q}{c_v T_1 - c_p T_1} = \frac{Q}{T_1 (c_v - c_p)} = -0,568 \ kg$$

$$\Rightarrow \Delta M = |M_2 - M_1| = 0,568 \ kg$$

~.~.~.

$$p_2 V_2 = M_2 R T_2$$

$$p_1 V_1 = M_1 R T_1$$

$$(p_2 - p_1) V_1 = M_2 R \overset{\overset{T_1}{\parallel}}{T_2} - M_1 R T_1$$

$$(p_2 - p_1) V_1 = R T_1 (M_2 - M_1)$$

$$\Delta p = p_2 - p_1 = \frac{R T_1 (M_2 - M_1)}{V_1} = 554,306 \ kPa = 5,54 \ bar$$

ES. 2

impianto frigorifero a semplice compressione

T_E = temp. di evaporazione

T_C = " " condensazione $\longrightarrow$ $h_c = 100 \ kJ/kg$

$r_E = 330 \ kJ/kg$ (a T_E) calore latente di vaporizzazione

$r_C = \frac{r_E}{2} = 165 \ kJ/kg$

Riempire!

Entalpie (kJ/kg)

	inferiore	superiore
T_C	$h_{3,l} = 100 \ kJ/kg$	$h_{2,v} = 265 \ kJ/kg$
T_E	$h_{4,l} = 0$	$h_{1,v} = 330 \ kJ/kg$

(coeff. di prestazione) COP = 2,2

$l_{t,c} = 65 \ kJ/kg$

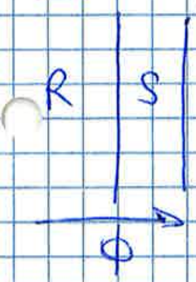
compressione adiabatica non rev.

$x_1 = 1$ $\Delta e_c = \Delta e_p = 0$ q? x_4?

↳ fine laminazione

fine condensazione $\Longrightarrow$ vapore saturo umido (SU)
liquido sottoraffreddato (SR)
liquido saturo (LS)

ES. 3



$S_S / S_R = 1{,}8$

$F_{R\to R} = 0$
$F_{S\to S} = 0$

$\varepsilon_R = 1$ CORPO NERO

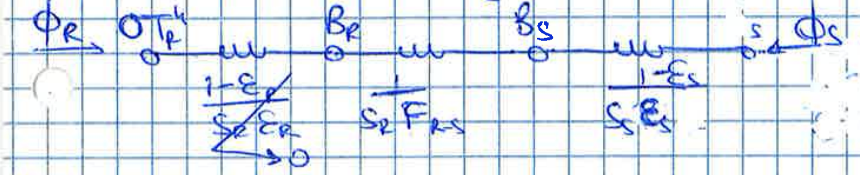
$T_R = 100°C = 373{,}15K$

$T_S = 40°C = 313{,}15K$

$r_S = 0{,}3$ coeff. di riflessione R NON scambia solo con S

$\varphi_{S-R} = -85\ W/m^2$ F_{R-S}? $\varphi_R = \frac{\phi_R}{S_R}$?

$r_S = 1 - \varepsilon \Rightarrow \varepsilon_S = 1 - r_S = 0{,}7$



$$\phi_{R-S} = \frac{\sigma (T_R^4 - T_S^4)}{\frac{1}{S_R F_{R-S}} + \frac{1-\varepsilon_S}{S_S \varepsilon_S}}$$

$$\phi_{S-R} = \frac{\sigma (T_S^4 - T_R^4)}{\frac{1}{S_S F_{S-R}} + \frac{1-\varepsilon_S}{S_S \varepsilon_S}} \Longrightarrow \varphi_{S-R} = \frac{\phi_{S-R}}{S_S} = \frac{\sigma (T_S^4 - T_R^4)}{\cancel{\frac{S_S}{S_S}}\left(\frac{1}{F_{S-R}} + \frac{1-\varepsilon_S}{\varepsilon_S}\right)}$$

$$\frac{\varphi_{S-R}}{\sigma (T_S^4 - T_R^4)} = \frac{1}{\frac{1}{F_{S-R}} + \frac{1-\varepsilon_S}{\varepsilon_S}}$$

$$\left(\frac{1}{F_{S-R}}\right) + \frac{1-\varepsilon_S}{\varepsilon_S} = \frac{\sigma (T_S^4 - T_R^4)}{\varphi_{S-R}}$$

$$\left(\frac{1}{F_{S-R}}\right) = \frac{\sigma (T_S^4 - T_R^4)}{\varphi_{S-R}} - \frac{1-\varepsilon_S}{\varepsilon_S}$$

$$\frac{1}{F_{S-R}} = \left(\overset{+6{,}518}{\frac{\sigma (T_S^4 - T_R^4)}{\varphi_{S-R}}} - \overset{0{,}4286}{\frac{1-\varepsilon_S}{\varepsilon_S}}\right) = +6{,}0894$$

$F_{S-R} = 0{,}16$

$F_{S-R} S_S = F_{R-S} S_R \Rightarrow F_{R-S} = F_{S-R} \frac{S_S}{S_R} = 0{,}288$

Da tabelle di saturazione a $p_1 = 8$ bar

$T_1 = 170,4\,°C = 443,55\,K$

$v_{1,L} = 1,1148 \cdot 10^{-3}$ $\}$ m^3/kg

$v_{1,V} = 0,2404$

$h_{1,L} = 721,23$ $\}$ kJ/kg

$h_{1,V} = 2768,9$

$s_{1,L} = 2,0464$ $\}$ $kJ/(kg \cdot K)$

$s_{1,V} = 6,6625$

Da $T_2 = 70,4\,°C = 343,55\,K$ → interpolazione

$p_2 = 0,31728\ bar = 31728\ Pa$

$v_{2,L} = 0,4(1,0234 \cdot 10^{-3} - 1,0228 \cdot 10^{-3}) + 1,0228 \cdot 10^{-3} = 1,02286 \cdot 10^{-3}$ $\}$ m^3/kg

$v_{2,V} = 0,4(4,8449 - 5,0447) + 5,0447 = 4,9648$

$h_{2,L} = 0,4(297,2 - 293,01) + 293,01 = 294,69$ $\}$ kJ/kg

$h_{2,V} = 0,4(2627,8 - 2626,1) + 2626,1 = 2626,8$

$s_{2,L} = 0,4(0,9671 - 0,9549) + 0,9549 = 0,9598$ $\}$ $kJ/(kg \cdot K)$

$s_{2,V} = 0,4(7,7392 - 7,7540) + 7,7540 = 7,7481$

$v_1 = (1 - x_1) v_{1,L} + x_1 v_{1,V} = 0,1973\ m^3/kg$

$h_1 = (1 - x_1) h_{1,L} + x_1 h_{1,V} = 2400,32\ kJ/kg$

$s_1 = (1 - x_1) s_{1,L} + x_1 s_{1,V} = 5,832\ kJ/(kg \cdot K)$

$$x_2 = \frac{v_2 - v_{2,L}}{v_{2,V} - v_{2,L}}$$

$$v_2 = \frac{V}{M_2}$$

$M_2 = M_1$ non cambia la massa

$M_1 = \frac{V}{v_1} = 0,253\ kg$

$\Rightarrow v_2 = 0,1976\ m^3/kg$

$x_2 = 0,039 \rightarrow 3,9\%$

$p_3 = p_1 \Rightarrow v_{1,L} = v_{3,L}$

$v_{1,V} = v_{3,V}$

$$v_3 = \frac{V}{M_3}$$

$M_3 = M_2 + \Delta M_{2-3} = 0,863\ kg$

$\Rightarrow v_3 = 0,058\ m^3/kg$

$x_3 = \frac{v_3 - v_{3,L}}{v_{3,V} - v_{3,L}} = 0,28 \rightarrow 28\%$

∘ 2-3 (aperto)

$$\frac{dS}{dt} = \frac{\Phi}{T} + S_{irr}$$

$$\frac{dS}{dt} = \left(\frac{dS}{dt}\right)_{vc} + G_e s_e = S_3 - S_2 - G_e s_e = M_3 s_3 - M_2 s_2 - G_e$$

$s_e = s_3(p_1) = s_{3,v}$ (curva vapore)

$$-/G_e = +\left(\frac{dM}{dt}\right) \Rightarrow G_e = M_3 - M_2$$

$$M_3 s_3 - M_2 s_2 - (M_3 - M_2)\, s_{3,v} = \frac{Q_{23}}{T_s} + S_{irr}$$

$T_s = \frac{\Delta U}{\Delta S}$ (e' indifferente se la considero come isobaro o isoc
SCELGO la T_s più alta!!!

$$T_s' = \frac{M_3 u_3 - M_2 u_2}{M_3 s_3 - M_2 s_2} = 381{,}54\ K$$

con $s_3 = (1 - x_3)\, s_{3,L} + x_3 s_{3,v} = 3{,}339$ kJ/(kg K)

$s_2 = (1 - x_2)\, s_{2,L} + x_2 s_{2,v} = 1{,}2265$ kJ/(kg K)

$$T_s'' = \frac{\Delta H}{\Delta S} = \frac{M_3 h_3 - M_2 h_2}{M_3 s_3 - M_2 s_2} = 396{,}5\ K$$

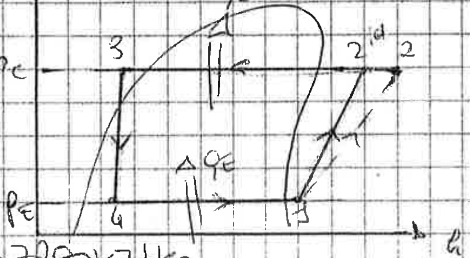
$\Rightarrow$ scelgo T_s''

$$\Rightarrow S_{irr} = M_3 s_3 - M_2 s_2 - (M_3 - M_2)\, s_3 V - \frac{Q_{23}}{T_s} = 292{,}8\ J/K$$

ES. 2

macchina frigorifera a semplice compressione di vapore

processo isobaro



$|h_2 - h_3| = 300$ kJ/kg

$\varepsilon = 2{,}4$

q_E ? $l_{t,c}$?

$q_E = h_1 - h_4$

~~$\varepsilon = \frac{h_1 - h_4}{h_2 - h_1} \Rightarrow h_1 - h_4 = \varepsilon (h_2 - h_1) = 720$ kJ/kg~~

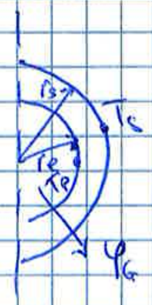
~~$\Rightarrow q_E = 720$ kJ/kg~~

ES. 3

$d_e = 1,3\ mm = 1,3 \cdot 10^{-3}\ m \longrightarrow r_e = 0,65 \cdot 10^{-3}\ m$

$\lambda = 1\ W/(m \cdot K)$

$\Delta_I = 1,2\ mm \qquad \lambda_I = 20\ W/(m \cdot K)$



funzionamento stazionario

$r_s = r_e + \Delta_I = \frac{d_e}{2} + \Delta_I = 1,85 \cdot 10^{-3}\ m$

$T_s = 105°C$

$\varphi_G = 7\ kW/m^2$

$\Phi_G ?\ T_{max} ?\ g ?$

↳ stessa sup. di separazione

g = rapporto gradienti di temp.

interno

stessa sp. interno

$\Phi_G = \varphi_G \cdot S = \varphi_G \cdot 4\pi r_e^2 = 37,17\ mW$

$T_p - T_i$

$T_{max} = T_p + \frac{H}{6\lambda}(r_e^2$ ~~[illegible]~~ $)$

$\Phi_G = H V$

$V = \frac{4}{3}\pi r_e^3 = 1 \cdot 10^{-9}\ m^3$

$\Rightarrow H = \frac{\Phi_G}{V} = 37170\ kW/m^3$

$$\Phi_G = \frac{4\pi (T_p - T_s)}{\frac{1}{\lambda_I}\left(\frac{1}{r_s} - \frac{1}{r_e}\right)} \Longrightarrow T_p = \frac{\Phi_G}{4\pi}\left[\frac{1}{\lambda_I}\left(\frac{1}{r_s} - \frac{1}{r_e}\right)\right] + T_s = 104,85°$$

$\Rightarrow T_{max} = 107,05\ °C$

Per trovare il rapporto dei gradienti io so che:

$\varphi_A = \varphi_B$

per il postulato di Fourier

$$-\lambda_A \frac{\partial T_A}{\partial n} = -\lambda_B \frac{\partial T_B}{\partial n}$$

$$\Rightarrow \frac{\partial T_A}{\partial n} \Big/ \frac{\partial T_B}{\partial n} = \frac{\lambda_B}{\lambda_A} = 20 = g$$