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A P P U N T I

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10 GIUGNO 2008

RANKINE - HIRN

Esercizio 1 Ciclo Rankine - Hirn con un solo surriscaldamento

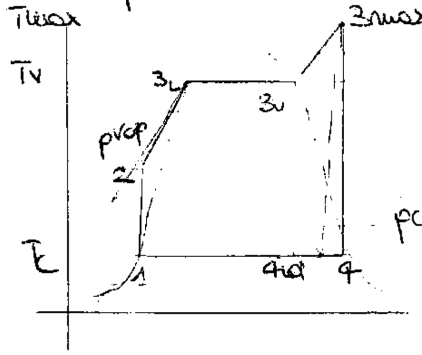
- condizioni stazionarie

→ $\dot{W}_t = 50MW$ (prodotta)

$p_c = 10kPa$ $p_v = 50$ Bar $T_{max}(vap) = 400°C$ $\eta_{is\,Turb} = 35\%$

Calcolare : $G_m(vap) = ?$ $x_4 = ?$ $\phi_{min} = ?$ $\eta_c = ?$

Ipotesi : Vapore condensato fino a liquido saturo!



da 3 a 4 espansione in Turbina con irreversibilità che produce $\dot{W}t$

Per calcolare la portata parto dalla Turbina

→ ricavo l_t e poi faccio $G_m = \frac{\dot{W}_t}{l_t}$

Applico I principio alla turbina:

$$\cancel{q} - l_t = \Delta h$$

$$l_t = -(h_4^{re} - h_{3max})$$

Stato 3max → uso Mollier a $T = 400°C$ e $p_v = 50$ Bar

$h_3 = 3200$ kJ/kg $s_3 = 6,65$ kJ/kgK

se ho η_{is} vuol dire che $s_4 \neq s_3^{re}$ ma $s_3^{re} = s_4^{id} = 6,65$ kJ/kg K

a $p_c = 10 \cdot 10^3 Pa = 0,1$ Bar ho ① $h_{1L} = h_1 = 191,83$ kJ/kg $s_{1L} = 0,6493$ kJ/kgK

④ $h_{4v} = h_{1v} = 2588,1$ kJ/kg $s_{1v} = 8,1511$ kJ/kgK

→ $s_4^{id} = (1 - x_{4id})\, s_l + x_{4id}\, s_v$

$s_4^{id} = s_l - x_4^{id} \cdot s_l + x_4^{id}\, s_v$ $x_4\,(s_v - s_l) = s_4^{id} - s_l$

$$x_4^{id} = \frac{s_4^{id} - s_l}{s_v - s_l} = 0,799 \cong 0,8$$

Calcolo $h_4^{id} = (1 - x_4)h_l + x_4 h_v \cong 2108,8$ kJ/kg

Esercizio 2 RIEMPIMENTO

Bombola $V = 50\ell$ contiene O_2 ($M = 32$ kg/kmol)

Ricaricata con rete a $p = 1500$ psi $T = 25°C$

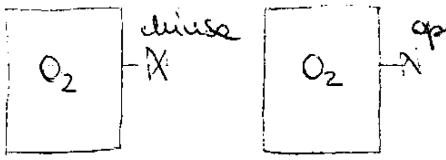
Riempimento finisce quando bombola in eq. barometrico con rete $p_2 =$

Ipotesi: • Bombola rigida: $V = \text{cost}$ e in. vuota

• gas ideale

• scambi di calore nulli ($Q = 0$)

Det: $m_{O_2} = ?$ $T_2 = ?$ Proc. rev = ?



RETE $p = 1500$ psi

$T = 25°C$

$m_1 = 0$ $m_{2_{O_2}} = ?$

$V = 50\ell$ $V = 50\ell$

$p_2 = 1500$ psi

$T_2 = ?$

Processo di riempimento

$$\cancel{\phi} - \cancel{W_x} = \frac{d}{dt}(U + \cancel{pot} + \cancel{E_c} + \cancel{E_p}) + \sum_{i=1}^{N} G_i (h + \cancel{e_c} + \cancel{e_p})$$

$$0 = \frac{dU}{dt} + \Sigma G_i h_i \qquad 0 = \frac{dU}{dt} - G_e h_e$$

con regole precitate

Th cons massa $\frac{dM}{dt} = \Sigma G_e - \cancel{\Sigma G_u}$ $m_2 - m_1 = G_e$

$$\frac{dU}{dt} + \cancel{\frac{dM}{dt}}^{(m_1 - m_2)} h_e = 0$$

bombola iniz. vuota

integro $m_2 u_2 - \cancel{m_1 u_1} + m_2 h_e - \cancel{m_1 h_u} = 0$

$u_2 = h_e$

$u_2 = c_v T_2$ $h_e = c_p \cdot T_r$

$\frac{J}{kmol \cdot K} : \frac{kmol}{kg}$

calcolo c_v e c_p sap che $R = \frac{\bar{R}}{M} = 258{,}81$ J/kg·K $\gamma = 1{,}$

$c_v = \frac{R}{\gamma - 1} = 649{,}53$ J/kg K $c_p = 908{,}34$ J/kg K

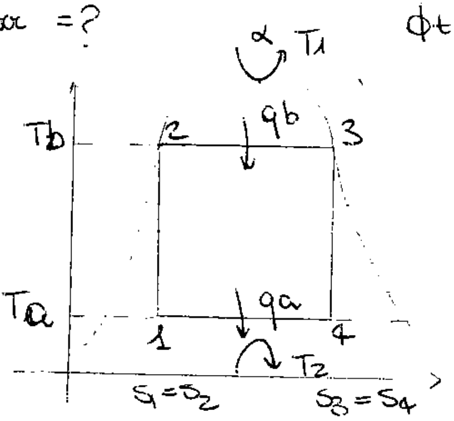
1. LUGLIO 2008

Esercizio 1 CICLO DIRETTO CARNOT + CONVEZIONE

$T_b = 388,2°C$ $T_a = 95,4°C$ $W_t = 1 kW$ Φ_t da sorg ad alta T

flusso scambio per convezione con $\alpha = 50 W/m^2 k$ $A = 1 m^2$

$S_{irr} = ?$ $\Phi_t = ?$ T_1 e T_2 temperature delle sorgenti



$\varphi_1 = \alpha(T_1 - T_b)$ $\varphi_2 = \alpha(T_a - T_2)$

$\Phi_b = ?$ $\Phi_b = S \cdot \varphi_1 = S \cdot \alpha (T_1 - T_b)$

Calcolo $\eta = 1 - \frac{T_a}{T_b} = 0,52$

$\eta = \frac{W_t}{\Phi_b}$ $\Phi_b = \frac{W_t}{\eta} = 1923,07 W$

Calcolo T_1 e T_2 sorgenti utili per calcolare flussi di entropia:

$\Phi_b = S \cdot \alpha (T_1 - T_b)$

$\Phi_b = S \cdot \alpha T_1 - S \alpha T_b$

$\Phi_b + S \alpha T_b = S \alpha T_1$ $T_1 = \frac{\Phi_b}{S \cdot \alpha} + T_b = 426,66°C = 699,81 k$

Calcolo T_2 come:

$T_2 = T_a - \frac{\Phi_a}{S \cdot \alpha} =$ $\eta = 1 - \frac{\Phi_a}{\Phi_b} \rightarrow \Phi_a = 923,04 W$

$= 299,94 k$

$$\boxed{\Sigma_{irr} = \frac{\Phi}{T} = \frac{\Phi_b}{T_1} - \frac{\Phi_a}{T_2}}$$

Esercizio 3

condotto orizzontale $l = 45\,m$ $\quad d_e = 10\,cm = 0{,}1\,m$

entra vapore saturo secco a $T = 140°C$

$T_{ec} = 20°C \quad T_{is} = 40°C$

Valutare $\alpha = ?$ su sez est condotto

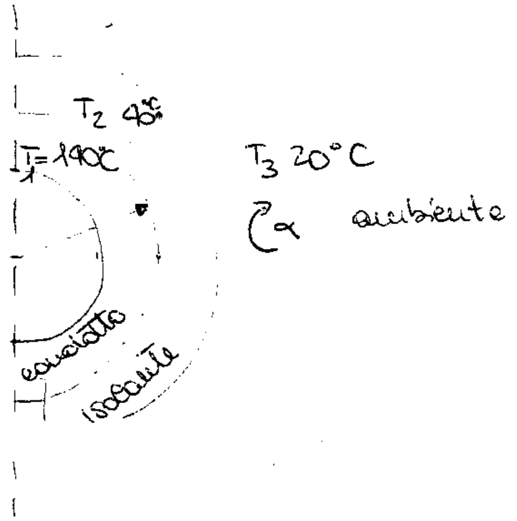
sap che: • $Nu = 0{,}53\, Ra^{0{,}25}$ (diametro = dim caratt)

• $\lambda = 0{,}0267\ W/m\cdot k \quad \nu = 16\ mm^2/s$

$Pr = 0{,}699$

Sapendo anche che $G_V = 180\ kg/h = 0{,}05\ kg/s$

determinare G fluido condensato fuori dal condotto = ?



calcolo $T_m = \frac{T_2 + T_3}{2} = 30°C \qquad \beta = \frac{1}{30} = 0{,}0\overline{33}\ 1/k$

$Gr = \frac{d_e^3}{\nu^2} g \beta (T_s - T_f) = 2529393{,}5$ come vengono calcoli?

$\frac{m^3 \cdot s^2}{m^4} \cdot \frac{m}{s^2} \cdot \frac{1}{k} \cdot k$

$Ra = Gr \cdot Pr = 1768046$

calcolo $Nu = 0{,}53 \cdot Ra^{0{,}25}$

$= 19{,}32$

$Nu = \frac{\alpha \cdot d_e}{\lambda} \qquad \alpha = 5{,}2\ W/m^2 k$

$\phi_{TOT} = \varphi_L \cdot L = \qquad \varphi_L = \frac{2\pi (T_2 - T_3)}{\frac{1}{r_e \cdot \alpha_e}} = 61{,}7\ W/m$

$= 2776{,}5$

$\phi = G_V \cdot (h_v - h_l)$ $\qquad$ a $T = \cancel{140°C}$ $h_l = 589{,}10\ kJ/kg$

↓ perché ho condensato $\qquad h_v = 2733{,}9\ kJ/kg$

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3 SETTEMBRE 2008

Esercizio 1

cilindro-pistone $m = 1kg$ di aria

1-2 $p_1 = 15 Bar$ $T = 20°C$ espansa fino a $p_2 = 1 Bar$ lungo politropica

$c = -239$ J/kg k

2-3 compressione isoterma $p_3 = p_1 = 15$ Bar

3-4 riscaldamento isobaro fino a $p_4 = p_1 = 15$ $T_4 = T_1 = 20°C$

$q = ?$ $l_{t} = ?$ $l_{te} = ?$

Aria → $c_p = 1004,5$ J/kg k $c_v = 717,5$ J/kg k

I principio trasf ~~1-2~~ POLITROPICA $q - l_i = \Delta u$

$$q = c(T_2 - T_1)$$

calcolo n → .. $n = \frac{c_p - c}{c_v - c} = 1,30$

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

$$T_2 = T_1 \left(\frac{p_1}{p_2}\right)^{\frac{1-n}{n}} = 0,53 \cdot T_1 \cong 156,9 \cong 157 k$$

calcolo $\boxed{q = c(T_2 - T_1) = 32,553 \ kJ/kg}$

calcolo l_i → $q - l_i = \Delta u$ $\boxed{l_i = q - \Delta u = q - c_v(T_2 - T_1) = 130 \ kJ/kg}$

~~2-3~~ compressione isoterma $T_2 = T_3 = T$

$$q - l_i = \cancel{\Delta u}_0$$

$$\boxed{q = l_i} \quad l_i = \int_2^3 p\,dv = \int_2^3 \frac{RT}{v}\,dv = RT \int_2^3 \frac{dv}{v} = RT \log \frac{v_3}{v_2} =$$

$$= -RT \log \left(\frac{\frac{RT}{p_3}}{\frac{RT}{p_2}}\right) = RT \log \frac{p_3}{p_2} = -122,2 \ kJ/kg$$

3-1 riscaldamento isobaro $p = 15$ Bar

$$q - l_i = \Delta u$$

$$l_i = \int p\,dv = (v_1 - v_3)p = \cancel{p}\left(\frac{RT_1}{\cancel{p_1}} - \frac{RT_3}{\cancel{p}}\right) = R(T_1 - T_3)$$

$$\boxed{q = c_v(T_3 - T_1) + R(T_1 - T_3) = 136,521 \ kJ/kg}$$

Esercizio 3:

$G_m = 7{,}2\ t/h = 2\ kg/s$ di H_2O a $T_i = 10°C$ $c_p = 4{,}2\ kJ/kg\,k$

$T_u = 40°C$ $\varepsilon = ?$ $p_c = ?$

$\alpha_{H_2O} = 2000\ kcal/h \cdot m^2 °C = 2326\ W/m^2 k$

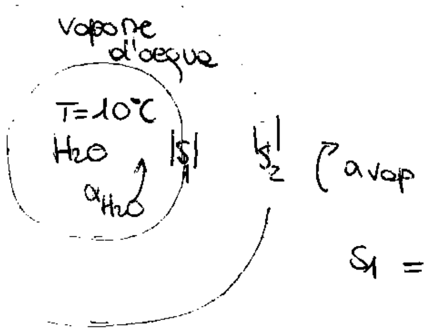
$\alpha_{vapore} = 1000\ kcal/h \cdot m^2 °C = 1163\ W/m^2 k$

Area esterna condotto interno $= 20m^2$

$\frac{S_e}{S_i} = \frac{6}{5}$

$\phi_{H_2O} = C_p f(T_{fu} - T_{fi})$

$\phi_{H_2O} = S_i \alpha \cdot \Delta T$



$S_1 = 20m^2$

$\frac{S_e}{S_i} = \frac{6}{5}$ $\quad S_e = 20\ m^2$ $\quad \pi r_i^2 = S_i$

$S_i = \frac{S_e \cdot 5}{6} = 16{,}67\ m^2$ $\quad r_i = \sqrt{\frac{S_i}{\pi}} = 2{,}30\ m$

$r_e = \sqrt{\frac{S_e}{\pi}} = 2{,}52\ m$

Se T aumenta (da 20 a 40) vuol dire che deve raffreddare qualcosa

acqua = fluido freddo $T_{fi} = 20°C$ $T_{fu} = 40°C$

$\alpha_i = 2000\ kcal/h m^2 °C = 2326\ kW/m^2 k$

$1W = 1{,}163\ kcal/h$

calcolo $C_f = G_{H_2O} \cdot c_p = 8400\ W/k$

riferito all'acqua $k_i = \left[\frac{1}{\alpha_i} + \frac{r_i}{r_e} \cdot \frac{1}{\alpha_e}\right]^{-1} = 823{,}247\ W/m^2 k$

$\frac{R_i}{r_e} = \frac{A_i}{S_e}$

$NTU = \frac{k_i A_i}{C_{min}} = 1{,}95$

se $\frac{C_{min}}{C_{max}} \to 0$ ~~$\varepsilon = 1 - e^{-NTU} = 1{,}827$~~

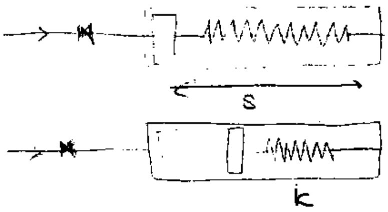
?

$\boxed{\text{Esercizio 2!}}$

Recipiente collegato a rete di adduzione a $p_e = 50$ bar $T_e = 300$ K

$p_0 = p_i$ $T_{f2} = ?$

- gas ideale biatomico $\gamma = 1{,}4$
- Recipiente adiabatico
- $k = 100$ kN/m
- $S = 20$ cm^2
- $\Delta x = 10$ cm
- Recipiente vuoto $(m_1 = 0)$



(1) $m_1 = 0$ $T = 300$ K

I principio sistemi aperti

$$\cancel{\Phi} - W_t = \frac{d}{dt}(U + p_0 V + \cancel{E_c} + \cancel{E_p}) + \sum G_j (h + \cancel{e_c} + \cancel{e_p})$$

$$-W_t = \frac{dU}{dt} + p_0 V \pm \frac{dM}{dt} h_u$$

integro $-L_t = m_2 u_2 - \cancel{m_1 u_1} + p_0 \Delta V - m_2 h_u + \cancel{m_1 h_u}$

$\Delta V = S \cdot \Delta x = 2 \cdot 10^{-4}\ m^2$

$L_t = \frac{k \Delta x^2}{2}$ $m_2 = \frac{p_2 V_2}{R T_2}$

$$-\frac{k \Delta x^2}{2} = m_2 (u_2 - h_u) + p_0 \Delta V$$

Bisogna calcolare c_v e c_p = ;

4 FEBBRAIO 2009

<u>Esercizio 1</u> (trasformazioni cicliche in pistone con gas)

cilindro-pistone $m = 1\,kg$ di Aria ($c_p = 1004,5$ $c_v = 717,5$)

4 trasformazioni reversibili

1-2 compressione adiabatica

2-3 fornitura di calore <u>isobara</u>

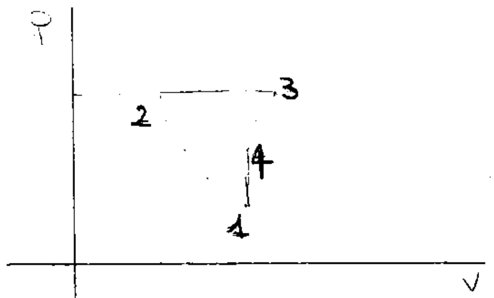
3-4 Espansione adiabatica

4-1 cessione calore isocora

Dati: $T_1 = 20°C = 293,15\,K$ $T_2 = 200°C = 473,15\,K$ $T_3 = 300°C = 573,15\,K$

$T_4 = 120°C = 393,15\,K$

$Q = ?$ $l_i = ?$



I principio trasf 1-2

$\cancel{q} - l_i = \Delta u$ ($q = 0$)

$\boxed{l_i = u_1 - u_2} = c_v(T_1 - T_2) = -129,150\ kJ/kg$

I principio trasf 2-3

fornitura calore isobara $q - l_i = \Delta u = c_v(T_3 - T_2)$

ma $\boxed{l_i = -\int p\,dv} = -p(v_3 - v_2) = -p\left(\frac{RT_3}{p} - \frac{RT_2}{p}\right) = -R(T_3 - T_2)$

$q + R(T_3 - T_2) = c_v(T_3 - T_2)$

$\boxed{q = (T_3 - T_2)(c_v + R)} = (T_3 - T_2)c_p = 100,45\ kJ/kg$

I principio 3-4

$\cancel{q} - l_i = \Delta u$ ($q = 0$) $\boxed{l_i = c_v(T_3 - T_4)} = 129,150\ kJ/kg$

I principio 4-1

$q - \cancel{l_i} = \Delta u$ ($l_i = 0$) $\boxed{q = c_v(T_4 - T_1)} = -71,750\ kJ/kg$

calcolo $v_{2l+v} = (1-x_2) v_l + x_2 v_v = 0{,}6951 \ m^3/kg$

$\rightarrow$ ~~$m_{TOT_2} = \frac{V_{TOT_2}}{v_{TOT_2}} = 0{,}001438 \ kg$~~

$x_2 = \frac{m_{2v}}{m_{TOT}}$ $\quad m_{2v} = 0{,}21 \ kg$

m_{TOT} → non cambia perchè il sistema è chiuso!

$\boxed{m_{2L} = m_{TOT_2} - m_{2v}} = 0{,}303 \ kg$

$-l_i = \Delta u = u_2 - u_1 \quad \rightarrow l_i = u_1 - u_2$

$u_1 = h_1 - p_1 v_1 = 1343{,}480 \ kJ/kg$

$u_2 = h_2 - p_2 v_2 = 1283{,}66 \ kJ/kg$

$l_i = u_1 - u_2 = 59{,}82 \ kJ/kg$

$\boxed{L_i = l_i \cdot m_{TOT} = 30{,}68 \ kJ}$

→ processo reversibile?

$\Delta s = \cancel{\frac{Q}{T}} + S_{irr}$

0 perchè termicamente isolato

$\boxed{S_{irr} = S_2 - S_1}$

calcolo $s_1 = (1-x_1) s_l + x_1 s_v = 3{,}2710 \ kJ/kg \, K$ (a 30 Bar)

$s_2 = (1-x_2) s_l + x_2 s_v = 3{,}7861 \ kJ/kg \cdot K$ (a 1 Bar)

$S_{irr} = 0{,}515 > 0 \quad \rightarrow$ processo irreversibile

$$H \cdot 2\pi r_i^2 \frac{1}{\lambda} \ln\frac{r_e}{r_i} + \frac{H \cdot 2\pi r_i^2}{r_e \alpha_e} = 2\pi T_f - 2\pi T_e - \frac{2\pi H \cdot r_i^2}{4\lambda}$$

$$H\, 2\pi r_i^2 \left[\frac{1}{\lambda} \ln\frac{r_e}{r_i} + \frac{1}{\alpha_e r_e} + \frac{1}{4\lambda}\right] = 2\pi (T_f - T_e)$$

$$H = \frac{2\pi (T_f - T_e)}{2\pi r_i^2 \left[\frac{1}{\lambda} \ln\frac{r_e}{r_i} + \frac{1}{\alpha_e r_e} + \frac{1}{4\lambda}\right]}$$

$r_e = 0{,}01$

$r_i = 0{,}005$

$$H \cdot \pi r_i^2 = \frac{2\pi \left[T_f - \frac{H}{4\lambda} r_i^2 - T_e\right]}{\frac{1}{\lambda} \ln\frac{r_e}{r_i} + \frac{1}{\alpha_e r_e}}$$

molt e div $\times 4\lambda$ 2° membro

$$\cancel{H} \cdot \pi r_i^2 \left[\frac{1}{\lambda} \ln\frac{r_e}{r_i} + \frac{1}{\alpha_e r_e}\right] = \frac{2\pi T_f \cdot 4\lambda - H r_i^2 \cdot 2\pi - 2\pi T_e 4\lambda}{4\lambda \cdot H}$$

$$4\lambda H + 2\pi \cdot H r_i^2 = \frac{2\pi T_f \cdot 4\lambda - 2\pi T_e \cdot 4\lambda}{\pi r_i^2 \left(\frac{1}{\lambda} \ln\frac{r_e}{r_i} + \frac{1}{\alpha_e r_e}\right)}$$

$$H (4\lambda + 2\pi r_i^2) = \frac{2\pi\, 4\lambda\, (T_f - T_e)}{\pi r_i^2 \left(\frac{1}{\lambda} \ln\frac{r_e}{r_i} + \frac{1}{\alpha_e r_e}\right)}$$

$$\boxed{H = \frac{2\pi\, 4\lambda\, (T_f - T_e)}{(4\lambda + 2\pi r_i^2) \cdot \pi r_i^2 \left[\frac{1}{\lambda} \ln\left(\frac{r_e}{r_i}\right) + \frac{1}{\alpha_e r_e}\right]}} = 102\ \mathrm{kW/m^3}$$

$Q = \Delta h = h_3 - h_2$

$h_3 = Q + h_2 = 2743,3\ kJ/kg$

$h_3 = h_{3v}$ cerco in tabella $\boxed{p_2 = p_3 \simeq 4,5\ Bar}$

calcolo $s_2 = (1-x_2)s_l + x_2 s_v = 5,34\ kJ/kgK$

$s_3 = 6,8597\ kJ/kg$

Flussi di entropia generati:

$$\cancel{\frac{dS}{dt}} + \sum_{j=1}^{n} G_j s_j = \frac{\Phi}{T} + \Sigma_{irr}$$

0 perché stazionario

1-2 trasf.

$$\sum_{j=1}^{n} G_j s_j = \cancel{\frac{\Phi}{T}} + \Sigma_{irr\,1-2}$$

$\boxed{\Sigma_{irr\,1-2} = G(s_2 - s_1)} \simeq 1,57\ kJ/kgK$ 1° proc. irreversibile

2-3

$\boxed{\Sigma_{irr\,2-3} = \Sigma G_j s_j - \frac{\Phi}{T_s}} = G(s_3 - s_2) - \frac{\Phi}{T_s}$ = viene < 0 perciò proc reversibile!

qual'è la T della sorg di calore?

$\frac{kJ}{kg} \cdot \frac{kg\,K}{kJ}$ $T_s = \frac{h_3 - h_2}{s_3 - s_2} = 420,9\ K \simeq 421\ K$

$V_{1A} = V_{1B} = 0{,}1\ m^3$

calcolo R del gas

$R = \frac{\bar{R}}{M_B} = 574{,}19$

$\frac{c_p}{c_v} = \gamma \qquad c_p - c_v = R \qquad c_v = \frac{R}{\gamma - 1} = 1435{,}48\ J/kg\,K$

$c_p = 2009{,}5\ J/kg\,K$

calcolo le masse:

$p_{1B} V_{1B} = M_{1B} \cdot R \cdot T_{1B} \qquad m_{1B} = \frac{p_{1B} V_{1B}}{R T_{1B}} = 0{,}058\ kg$

$p_{1A} = 1\ Bar \qquad p_{1B} = 1\ Bar$

$T_{1A} = T_{1B} = 300\ K \qquad m_{1A} = \frac{p_{1A} V_{1A}}{R T_{1A}} = 0{,}116\ kg$

aria

dopo riempimento $m_{2B} = 4 m_{1B} = 0{,}232\ kg$

$p_1 v_{1A} = R T_{1A} \qquad v_{1A} = \frac{R T_{1A}}{p_1} = 0{,}858\ m^3/kg$

1° prima in A $\qquad q = l_t \qquad l_t = R T_{1A} \cdot \ln \frac{v_{2A}}{v_{1A}}$

$T_{1A} = T_{1B}$ perché isotermo

$q = \frac{Q}{m_{1A}} = 86{,}2068\ kJ/kg$

$v_{1A} = \frac{V_{1A}}{m_{1A}} = 0{,}8620\ m^3/kg$

$Q - L_t = \Delta U$

$Q - L_t = 0 \qquad Q = L_t$

$Q = L_t = \int p\,dV = R T_A \ln \frac{v_{2A}}{v_{1A}}$

$Q = R T_A \ln \frac{V_{2A}}{V_{1A}}$

$e^{\frac{Q}{R T_A}} = \frac{V_{2A}}{V_{1A}}$

$0{,}89 \cdot V_{1A} = V_{2A} \qquad V_{2A} = 0{,}089\ m^3$

$V_{TOT\,1} = V_{TOT\,2} \quad \Rightarrow \quad V_{2B} = V_{TOT} - V_{2A} = 0{,}011\ m^3$

eq. gas $\quad p_{2B} V_{2B} = m_{2B} \cdot R \cdot T_{2B}$

faccio riempimento al sistema 2

$\underset{0}{\cancel{\Phi}}^{\text{adiabatico}} - \underset{0}{\cancel{W}}^{\text{rigido}} = \frac{dU}{dt} + \Sigma G_j h_j$

~~Esercizio 3~~ TRANSITORIO TERMICO

lastra quadrata $\ell = 10\,cm = 0{,}1\,m$ $m = 10g = 0{,}1\,kg$

sottoposta a transitorio termico

lastra : $c = 0{,}5\,kJ/kg\,K$

$\rho = 8\,kg/dm^3$

$a = 10\,mm^2/s$

diffusività

$T_1 = 10°C$ $T_f = 180°C$ $\phi_G = 10W$ $\alpha = ?$

affinché $T_{2L} = T_f = 180°C$ in $t = 2t_0$

$Bi = ?$

Equazione transitorio

$$\theta(t) = \theta_\infty\left(1 - e^{-\frac{t}{t_0}}\right) + \theta_0\, e^{-\frac{t}{t_0}}$$

θ_0 = eccesso temperatura $= T_i - T_f = 10 - 180 = -170°C$

$\theta_\infty = \dfrac{\phi_G}{\alpha \cdot S}$ 6,71 $S = \ell^2$

$t_0 = \dfrac{\rho c V}{\alpha S}$

temperatura e voglio avere 180 = 0

$\theta(t) = \theta(2t_0) = 180°C$ = temperatura che voglio che abbia la lastra

$$\cancel{180°C} = \frac{\phi_G}{\alpha \cdot \ell^2}\left(1 - e^{-2\cancel{t_0}/\cancel{t_0}}\right) + \theta_0\, e^{-2\cancel{t_0}/\cancel{t_0}}$$

0

$$0 = \frac{\phi_G}{\alpha \cdot \ell^2}\left(1 - e^{-2}\right) + \theta_0 e^{-2}$$

$$\theta_0 e^{-2} \cdot \alpha \cdot \ell^2 = \phi_G\left(1 - e^{-2}\right)$$

$$\boxed{\alpha = \frac{\phi_G\left(1 - e^{-2}\right)}{\theta_0 e^{-2} \cdot \ell^2} = 37{,}57\ W/m^2 K}$$

$\frac{V}{S} = \frac{\ell^2 s}{2\ell^2 + 4\ell s}$

se $s \ll 1$ $\frac{s}{2}$

$Bi = \dfrac{\alpha \cdot L}{\lambda}$ L = lungh. car = spessore della lastra

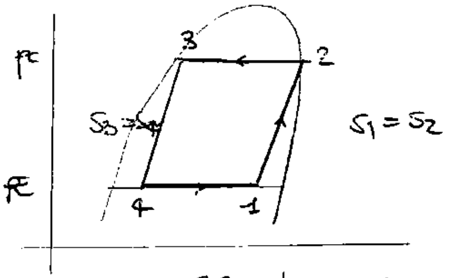
uso densità $\rho = 8\,\dfrac{kg}{dm^3}$ = kg/m³

ottengo volume in m^3 $V = \dfrac{\rho}{m} = 0{,}08\,m^3$

$V = \ell^2 \cdot s$ $s = \dfrac{V}{\ell^2} = \dfrac{0{,}08\ m^{\cancel{3}}}{(0{,}1)^2 \cancel{m^2}} = 8m$

$\boxed{Bi = \dfrac{\alpha \cdot s}{\lambda}}$ ma $a = \dfrac{\lambda}{\rho c}$ $\lambda = a \cdot \rho \cdot c$

ciclo inverso Carnot



COP = ?

$T_E = -60°C$ $\quad p_C = 10$ Bar

$s_2 = 1{,}72 \quad h_2 = 410$ kJ/kg $\quad h_1 = 342$ kJ/kg

$$COP = \frac{T_E}{T_C - T_E} = 2{,}13$$

Esercizio 2

1-2 compressione isoterma $\quad T_1 = 273{,}15$ K $\quad p_1 = 1$ Bar

$p_2 = 60$ Bar

2-3 fornitura calore isobara $p_2 = p_3$

3-1 Espansione adiabatica

$m = 1$ kg $\quad$ gas ideale $\quad \gamma = 1{,}67 \quad \bar{M} = 40$ kg/kmol $\quad \varepsilon = ?$

sistema chiuso

$R = 207{,}8575$ J/kg K

$$\varepsilon = \frac{\ell_n}{Q_{assorbito}} = 1 - \frac{Q_{ceduto}}{Q_{assorbito}}$$

PRIMO PRINCIPIO 1-2

$$q - \ell_i = \Delta u = 0 \qquad q = \ell_i$$

$$q - \int p\, dv = 0 \qquad q = \int_1^2 p\, dv = RT \int_1^2 \frac{dv}{v} = RT \ln \frac{v_2}{v_1} = RT \ln \frac{p_2}{p_1}$$

$$q_{ceduto} = -RT \ln \frac{p_2}{p_1} = -232{,}461 \text{ kJ/kg}$$

I PRINCIPIO 2-3

$$q - \ell_i = \Delta u \qquad \ell_i = p_2 (v_3 - v_2) = \cancel{p}\left(\frac{RT_3}{\cancel{p}} - \frac{RT_2}{\cancel{p}}\right)$$

$$q - R(T_3 - T_2) = c_v(T_3 - T_2) \qquad = R(T_3 - T_2)$$

$$= -236{,}686 \text{ kJ/kg}$$

calcolare T_3 con equaz. adiabatica

$$p_1^{\frac{1-\gamma}{\gamma}} T_1 = p_3^{\frac{1-\gamma}{\gamma}} \cdot T_3 \qquad p_3 = p_2$$

$$T_3 = \left(\frac{p_1}{p_3}\right)^{\frac{1-\gamma}{\gamma}} \cdot T_1 = 1411{,}85 \text{ K}$$

Cilindro pieno e infinito

$$\frac{d^2T}{dr^2} + \frac{1}{r}\frac{dT}{dr} + \frac{H}{\lambda} = 0$$

$$u = r\frac{dT}{dx} + \frac{d^2T}{dr^2}$$

come da appunti arrivo a $T = -\frac{r^2}{4}\frac{H}{\lambda} + C$

$$\cancel{-\lambda\frac{\partial T}{\partial x}\Big|_{r=r_e} = \alpha(T_{se} - T_e)} \quad \text{~~per~~ } r = r_e$$

sbagliato perché C se ne va

$$\cancel{\frac{1}{2} r \frac{H}{\lambda}\lambda + C\cdot\lambda \quad \alpha(T_{se} - T_e)}$$

per $x = r_e$ $\quad T = T_s$

$$T_s = -\frac{r_e^2}{4}\frac{H}{\lambda} + C \qquad C = T_s + \frac{r_e^2}{4}\cdot\frac{H}{\lambda}$$

$$T(r_e) = -\frac{r_e^2}{4}\frac{H}{\lambda} + \frac{H}{\lambda}\frac{r_e^2}{4} + T_s = \cancel{\frac{H}{\lambda}\frac{r^2}{4}(T_s - 1)}$$

$$T(x) = \frac{H}{4\lambda}(r_e^2 - x^2) + T_s$$ ← ho imposto una temperatura

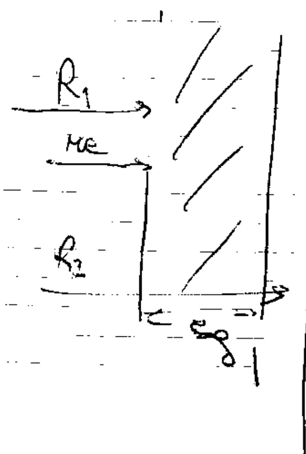
Voglio λ affinché T sia minima $\qquad \cancel{\frac{W}{mK}} \cdot \cancel{\frac{m^2K}{W}}$

$$\frac{\partial T}{\partial \lambda}\Big|_{x=r_e} = 0$$ verrebbe 0

$$\frac{H}{4}\left(-\frac{1}{\lambda^2}\right)(r_e^2 - r^2) = 0$$

Se impongo che $r = r_g$ ho scambio x convezione

$$-\lambda\frac{\partial T}{\partial r} = \alpha(T_s - T_e)$$



raggio critico

$$T_{1min} = R_2 = R_C = \frac{\lambda_G}{\alpha_e}$$

$$R_1 = \sqrt{\frac{A}{\pi}} = 252\,mm$$

$$\lambda_G = 2R_1\alpha_e = 0{,}1\ W/mK$$

$$\Phi_L = A\cdot H = \rho c\left(\frac{I}{A}\right)^2 A = 12{,}5$$

$$\Phi_C = \frac{2\pi(T_{1min} - T_e)}{\frac{1}{\lambda_G}\ln\frac{R_2}{R_1} + \frac{1}{\alpha_e R_2}}$$

$T_{1min} = 33{,}5°C$

$\frac{T_1+T_4}{T_2+T_3} = 0{,}8$ $\quad T_1+T_4 = 0{,}8(T_2+T_3)$ $\quad \boxed{T_4 = 0{,}8(T_2+T_3) - T_1} = 796{,}89\,K$

~~tura~~ $\eta = 1 - \frac{T_1}{T_2} = 1 - r_v^{\,1-\gamma}$

$\eta = 1 - \frac{T_1}{T_2} = 0{,}19$

$\eta = 1 - r_v^{\,1-\gamma}$ $\quad \boxed{\eta - 1 = r_v^{\,1-\gamma}}$ $\quad r_v = (\eta-1)^{1/1-\gamma} = 0{,}7$

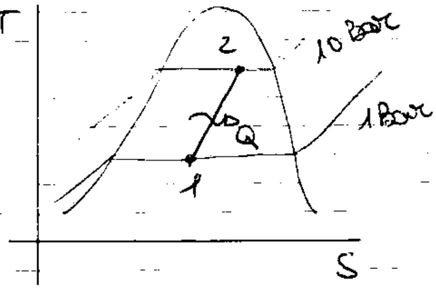
[redacted]

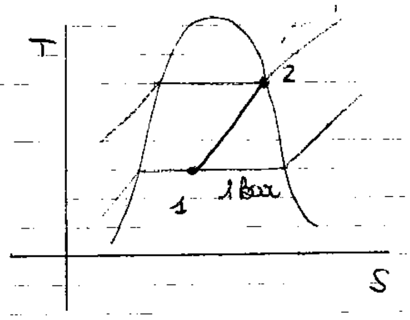
contenitore rigido $l+v$ $\quad p_1 = 1\,Bar$ $\quad x = 0{,}1$

Fornitura calore fino a $p_2 = 10\,Bar$ $\quad x_2 = ?$ $\quad Q = ?$

Se da 1 vado a 2 = VSS det $p_2 = ?$

Trasf. int. reversibile ?





I principio sist. chiusi

$q - \cancel{\ell}_0 = \Delta u$ rigido $\quad q = \Delta u = u_2 - u_1$

$u_2 = h_2 - p_2 v_2 \quad u_1 = h_1 - p_1 v_1$

Calcolo par. stato 1

$h_1 = (1-x_1)h_l + x_1 h_v = 643{,}299\ kJ/kg$

$v_{1_{l+v}} = (1-x_1)v_l + x_2 v_v = 0{,}17\ m^3/kg$

$s_1 = (1-x_1)s_l + x_1 s_v = 1{,}90841\ kJ/kg\,K$

Contenitore $\quad v_{1\,l+v} = v_{2\,l+v} = 0{,}17\ m^3/kg$

~~calcolo~~ $x_2 \rightarrow v_{2\,l+v} = (1-x_2)v_l + x_2 v_v$

$v_{2\,l+v} = v_l - x_2 v_l + x_2 v_v$

$x_2 (v_v - v_l) = v_{2\,l+v} - v_l$ $\quad \boxed{x_2 = \frac{v_{2\,l+v} - v_l}{v_v - v_l} = 0{,}87}$

flusso disperso dal ristoro = flusso scambiato x ~~....~~ convez

$$\phi = \varphi_{1-2} \cdot \cancel{S_1} = S_2 \cdot \alpha e (T_2 - Te) \qquad \frac{W}{m^2} \cdot \cancel{m^2} = \cancel{m^2} \cdot \frac{W}{m^2 \cancel{K}} \cdot \cancel{K}$$

$$\varphi_{1-2} S_1 = S_2 \alpha e T_2 - S_2 \alpha e Te$$

$$T_2 = \frac{\varphi_{1-2} S_1 + S_2 \alpha e Te}{S_2 \alpha e}$$

$$T_2 = \frac{\varphi_{1-2} S_1}{S_2} \cdot \frac{1}{\alpha e} + Te = 23°C$$

$$\varphi_{S_1} = \frac{\sigma(T_1^4 - T_2^4)}{\cancel{\frac{1-\varepsilon_1}{S_1 \varepsilon_1} S_1} + \frac{1}{\cancel{S_1} F_{1\to 2}} \cancel{S_1} + \frac{1-\varepsilon_2}{S_2 \varepsilon_2} \cdot S_1}$$

0 perché ε_1 per un corpo nero $\varepsilon = 1$

$$A = \left(\frac{S_1}{S_2} \frac{1-\varepsilon_2}{\varepsilon_2} + \frac{1}{F_{1\to 2}}\right) = 4,08$$

$$T_1^4 = T_2^4 + \frac{\varphi_{S_1} A}{\sigma} = 56°C$$

$$\varphi_{c-2} = \varphi_{2-c}$$

$$\phi = \frac{\sigma(T_1^4 - T_2^4)}{\cancel{\frac{1-\varepsilon_1}{\varepsilon_1}} \frac{\cancel{S_1}}{S_1} + \frac{1}{S_1 F_{1\to 2}} + \frac{1-\varepsilon_2}{\varepsilon_2} \cdot \frac{1}{S_2}}$$

0

$$\varphi_{c-2} \cdot S_2 = \frac{\sigma(T_1^4 - T_2^4)}{\frac{1}{S_1} \cdot \frac{1}{F_{1\to 2}} + \frac{1-\varepsilon_2}{\varepsilon} \frac{1}{S_2}}$$

so che $h_3 = h_4 = 2790$ kJ/kg lo cerco nelle tabelle $p_3 \approx 10$ Bar

$l_{tc} = v(p_2 - p_1)$

$h_2 = l_{tc} - h_1$

2-3 $q - l_t = \Delta u$

$l_t = -\int v\,dp = \cancel{-p(v_3 - v_2)}$ 0 isobara

$\boxed{q = h_3 - h_2}$ $\boxed{\Phi = G \cdot q}$

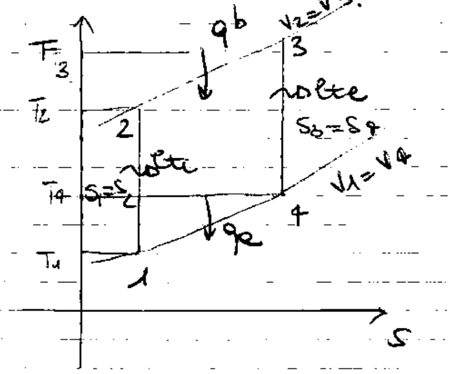
$\boxed{W_t = G \cdot l_{tc}}$

[redacted] ciclo Otto

① inizio compr. $p_1 = 1$ Bar $T_1 = 15°C$

③ inizio espans. $p_3 = 50$ Bar $T_3 = 1200°C$

$W_t = 1$ MW $\Phi = ?$ Aria standard tutte le trasf. rev.



Φ assorbito $= ?$

$\eta = \frac{W_t}{\Phi}$

$\eta = 1 - \frac{q_a}{q_b}$

① $p_1 = 1$ Bar $T_1 = 15°C$

I princ. 1-2 $\cancel{q} - l_{tc} = \Delta u$ $l_{tc} = c_v(T_1 - T_2)$

equaz. adiabatica $c_v = 717{,}5$ kJ/kg k

$T_2 p_2^{\frac{1-\gamma}{\gamma}} = T_1 p_1^{\frac{1-\gamma}{\gamma}}$ $c_p = 1004{,}5$ J/kg k

$T_3 p_3^{\frac{1-\gamma}{\gamma}} = T_4 p_4^{\frac{1-\gamma}{\gamma}}$

I princ 2-3 $q_b = c_v(T_3 - T_2)$

I princ 4-1 $q_a = c_v(T_1 - T_4)$

isocora $= v = cost$

$\frac{\cancel{R}T_2}{p_2} = \frac{\cancel{R}T_3}{p_3}$ $T_2 = \frac{p_2}{p_3} T_3$ $p_2 = \frac{T_2}{T_3} p_3$

$T_2 = \left(\frac{p_1}{p_2}\right)^{\frac{1-\gamma}{\gamma}} \cdot T_1$

[redacted]

Acciaio $\lambda_a = 40$ W/mK $\qquad T_f = 200°C$

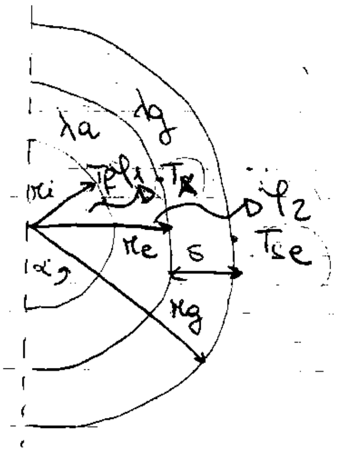
isolante $\lambda_{is} = 0{,}1$ W/mK

$d_i = 90$ mm $\qquad d_e = 100$ mm $\qquad \varphi_L = 100$ W/m $\qquad T_{se} = 40°C$

s isolamento = ? $\qquad \alpha_i = 500$ W/m²K

$r_i = 0{,}045$ m

$r_e = 0{,}05$ m



$\cancel{\varphi_L = 2\pi(T_{se} - T_x)}$

giusto?

$$\varphi_{1L} = \frac{2\pi(T_f - T_x)}{\frac{1}{r_i \alpha_i}}$$

$$\varphi_{2L} = \frac{2\pi(T_x - T_e)}{\frac{1}{\lambda_a}\ln\frac{r_e}{r_i} + \frac{1}{\lambda_g}\ln\frac{r_g}{r_e}}$$

da φ_{1L} calcolo T_x $\qquad \varphi_{1L} \cdot \frac{1}{r_i \alpha_i} = 2\pi T_f - 2\pi T_x$

$$2\pi T_x = 2\pi T_f - \frac{\varphi_{1L}}{r_i \alpha_i} \qquad T_x = \frac{2\pi T_f - \frac{\varphi_{1L}}{r_i \alpha_i}}{2\pi} = 199{,}29\,°C$$

posso anche calcolarla come

$$\varphi_1 = \frac{2\pi(T_f - T_x)}{\frac{1}{\lambda_a}\ln\frac{r_e}{r_i} + \frac{1}{\alpha_i r_i}} \quad 199{,}2$$

$$\varphi_{2L} = \frac{2\pi(T_x - T_e)}{\frac{1}{\lambda_a}\ln\frac{r_e}{r_i} + \frac{1}{\lambda_g}\ln\frac{r_g}{r_e}}$$

$$\varphi_{2L}\left(\frac{1}{\lambda_a}\ln\frac{r_e}{r_i} + \frac{1}{\lambda_g}\ln\frac{r_g}{r_e}\right) = 2\pi(T_x - T_e)$$

$$\varphi_{2L}\frac{1}{\lambda_a}\ln\frac{r_e}{r_i} + \frac{\varphi_{2L}}{\lambda_g}\ln\frac{r_g}{r_e} = 2\pi(T_x - T_e)$$

$$\ln\left(\frac{r_e}{r_i}\right)^{\frac{\varphi_{2L}}{\lambda_a}} + \ln\left(\frac{r_g}{r_e}\right)^{\frac{\varphi_{2L}}{\lambda_g}} = 2\pi(T_x - T_e)$$

$$\left(\frac{r_e}{r_i}\right)^{\frac{\varphi_{2L}}{\lambda_a} = x} \cdot \left(\frac{r_g}{r_e}\right)^{\frac{\varphi_{2L}}{\lambda_g} = y} = e^{2\pi(T_x - T_e)}$$

$$\left(\frac{r_e}{r_i}\right)^{x} \cdot \left(\frac{r_g}{r_e}\right)^{y} = e^{2\pi(T_x - T_e)}$$

$y = 1000$

$x = 2{,}5$

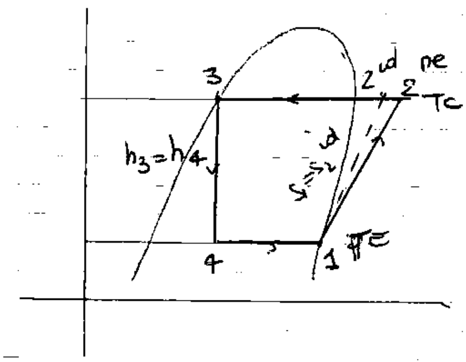
$$r_g^{\,y} = \frac{r_e^{\,y} \cdot e^{2\pi(T_x - T_e)}}{\left(\frac{r_e}{r_i}\right)^{x}}$$

3 FEBBRAIO 2010

Esercizio 1

Impianto frigorifero a semplice compressione HFC 134a

$T_E = -20°C$ $T_C = 40°C$ $COP = 2,5$



$$COP = \frac{h_1 - h_4}{h_2^{re} - h_1}$$

$$\eta_{is} = \frac{h_1 - h_2^{id}}{h_1 - h_2^{re}}$$

① $p_1 = 0,13$ MPa $= 1,3$ Bar

$h_1 = 390$ kJ/kg $s_1 = 1,75$ kJ/kg K

$s_1 = s_2^{id} = 1,75$ kJ/kg K

$h_2^{id} = 430$ kJ/kg $h_3 = 257$ kJ/kg K $= h_4$

dal COP calcolo h_2^{re}

$COP\,h_2^{re} - COP\,h_1 = h_1 - h_4$

$COP\,h_2^{re} = h_1(1 + COP) - h_4$ $h_2^{re} = \frac{h_1(1+COP) - h_4}{COP} = 443,2$ kJ/kg

$\eta_{is} = 0,75$

Esercizio 2

$V = 100$ l contiene O_2 $p_1 = 50$ Bar

svotamento a $p_2 = 2$ Bar $m_{erogata}$ $m_2 - m_1 = ?$

- contenitore rigido
- processo isotermo alla $T = 25°C$
- fluido ideale $\gamma = 1,4$ $M = 32$ kg/kmol

Processo reversibile?

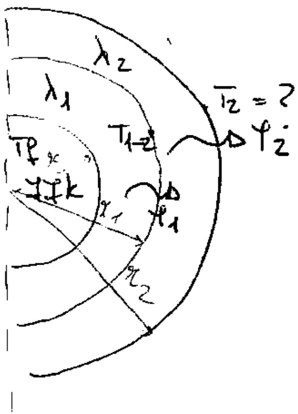
Esercizio 3

serbatoio a sfera $T_f = 77K$ $V_e = 2m^3$

1° strato isolante $\lambda_{1s} = 0{,}026\ W/mK$ $s_1 = 40\ mm$

2° strato isolante $\lambda_{2s} = 0{,}1\ W/mK$ $s_2 = 25\ mm$

$T_{1-2} = 215K$ $T_2 = ?$



$$V_{sfera} = \frac{4}{3}\pi r^3$$

$$3 \cdot V = 4\pi r^3$$

$$r = \sqrt[3]{\frac{3V}{4\pi}} = 0{,}78\ m$$

$$r_1 = r + s_1 = 0{,}82\ m$$

$$r_2 = r_1 + s_2 = 0{,}845\ m$$

$$\varphi_2 = \frac{4\pi(-T_{1-2} + T_2)}{\frac{1}{\lambda_2}\left(\frac{1}{r_2} - \frac{1}{r_1}\right)} \qquad \varphi_1 = \frac{4\pi(-T_f + T_{1-2})}{\frac{1}{\lambda_1}\left(\frac{1}{r_1} - \frac{1}{r}\right)}$$

$\varphi_1 = \varphi_2$ calcolo T_2

$$(4\pi T_2 - 4\pi T_{1-2})\frac{1}{\lambda_1}\left(\frac{1}{r_1} - \frac{1}{r}\right) = (4\pi T_{1-2} - 4\pi T_f)\left(\frac{1}{\lambda_2}\left(\frac{1}{r_2} - \frac{1}{r_1}\right)\right)$$

$$4\pi T_2 \cdot \frac{1}{\lambda_1}\left(\frac{1}{r_1} - \frac{1}{r}\right) = 4\pi(T_{1-2} - T_f)\left(\frac{1}{\lambda_2}\left(\frac{1}{r_2} - \frac{1}{r_1}\right)\right) + 4\pi T_{1-2}\frac{1}{\lambda_1}$$

$$T_2 = \frac{(4\pi T_{1-2} - 4\pi T_f)\left[\frac{1}{\lambda_2}\left(\frac{1}{r_2} - \frac{1}{r_1}\right)\right] + 4\pi T_{1-2}\frac{1}{\lambda_1}\left(\frac{1}{r_1} - \frac{1}{r}\right)}{\frac{4\pi}{\lambda_1}\left(\frac{1}{r_1} - \frac{1}{r}\right)} =$$

$=$

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calcolo $x_1 = \dfrac{s_1 - s_L}{s_V - s_L} = 0,272$

$\rightarrow$ $h_1 = (1-x_1)h_L + x_1 h_V = 917,2608 \text{ kJ/kg}$

calcolo $x_4 = \dfrac{s_4 - s_L}{s_V - s_L} = 0,75$

$h_4 = 2036,45 \text{ kJ/kg}$

$\boxed{l_{te} = -(h_4 - h_3) = 763,9 \text{ kJ/kg}}$ (lavoro scambiato)

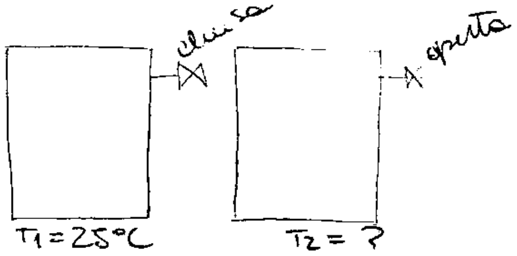
[redacted]

Bombola volume V collegata a serbatoio $T_c = 25°C$ $p = 1 \text{ Bar}$

$T_1 = 25°C$ $\underbrace{p_1 \quad p_2}_{\text{attraverso trafilazione}}$

- gas ideale monoatomico $\gamma = 1,67$
- p e T $\rightarrow$ costanti durante riempimento
- volume rigido bombola $(W_t = 0)$
- $E_c = E_p = 0$
- $T_1 = 25°C$
- processo adiabatico $(\phi = 0)$

$\dfrac{m_2}{m_1} = ?$ se $\dfrac{p_2}{p_1} = 40$



$T_1 = 25°C$ $T_2 = ?$

$V_1 = V_2$

p_1 p_2 $\dfrac{p_2}{p_1} = 40$

I Principio per sistemi aperti

$$\cancel{\phi} - \cancel{W_t} = \frac{dU}{dt} + \sum_{j=1}^{n} G_j h_j$$
$0 \quad\; 0$

$$\frac{dU}{dt} = +\frac{dM}{dt}$$

$$\frac{m_2}{m_1} = \frac{(c_v - c_p)\cancel{T_2}}{c_v \frac{T_2}{T_1} - c_p} \qquad \frac{T_2}{T_1} = \frac{p_2}{p_1} \cdot \frac{m_1}{m_2}$$

$$c_p - c_v = R \qquad c_p = \frac{\gamma}{\gamma - 1} R$$

$$\frac{\gamma}{\gamma-1} - \frac{1}{\gamma-1} = R \qquad R = \gamma - 1 \qquad c_v = \frac{1}{\gamma - 1} R$$

ma io ho $c_v - c_p \Rightarrow -R = 1 - \gamma$

$$\frac{m_2}{m_1} = \cancel{(1-\gamma)T_2}$$

$$\frac{m_2}{m_1} = \frac{-\cancel{R}}{\frac{\cancel{R}}{\gamma-1}\frac{T_2}{T_1} - \frac{\gamma}{\gamma-1}\cancel{R}T_1} = \frac{-1}{\frac{1}{\gamma-1}\frac{p_2}{p_1}\frac{m_1}{m_2} - \frac{\gamma T_1}{\gamma-1}}$$

$$\frac{1}{\gamma-1}\cdot\frac{p_2}{p_1} - \frac{m_2}{m_1}\frac{\gamma T_1}{\gamma-1} = -1$$

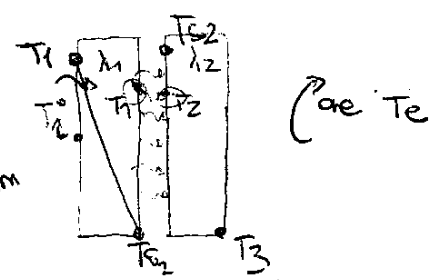
$$\frac{m_2}{m_1} = \frac{1 + \frac{1}{\gamma-1}\frac{p_2}{p_1}}{\frac{\gamma}{\gamma-1}T_1} = \frac{60{,}70}{793{,}15}$$

~~Esercizio 3~~

~~Riflettività $\neq \varepsilon$~~ k

2 strati piani con $\cancel{\lambda_1} = \cancel{\lambda_2} = 10\ W/m^2K$

$T_1 = 400°C \quad \alpha_e = 10\ W/m^2K \quad T_e = 20°C \quad \varphi_s = 200\ W/m^2$



per irraggiam

$$\varphi_{s1-2} = \frac{\sigma(T_1^4 - T_2^4)}{\frac{1-\varepsilon}{\varepsilon_1} + \frac{1}{F_{1\to2}}} \qquad \varphi_{s1-2} = \frac{\sigma(T_{S1}^4 - T_{S2}^4)}{\frac{1-\varepsilon}{\varepsilon} + \frac{1}{F_{1\to2}}}$$

1 per lastre sottilissim

$$\varphi_{s2-e} = (T_2 - T_e)\alpha_e$$

$$\varphi_{1-2} = k(T_1 - T_1)$$

Riflettività $= 1 - \varepsilon$

$$\varphi = k(T_1 - T_{S1})$$

$$\varphi = kT_1 - kT_{S1} \qquad T_{S1} = \frac{kT_1 - \varphi}{k} = T_1 - \frac{\varphi}{k}$$

$$\varphi = k(T_{S2} - T_3)$$

Devo avere T_3 $\qquad \varphi = \alpha(T_3 - T_e)$

T_{S2}

$$\downarrow\ T_3 = \frac{\varphi + \alpha T_e}{\alpha} = \frac{\varphi}{\alpha} + T_e$$

Stato ① entro a T = 25°C

$h_1 = 104,77$ kJ/kg $\quad V_1 = 0,0010029$ m³/kg $\quad p_{1L} = 0,03166$

Per 1a e 1b giorno pressione $\quad p = 1,5$ Bar

$h_{1a} = 466,9$ kJ/kg $\quad h_v = 2693,25$ kJ/kg

$p_1 = 1$ Bar $+ \frac{500 \cdot 9}{} \cong 1,5$ Bar

$h_1 = h_{1L} + v_{1L}(p_1 - p_{1L}) =$

$v_1 = 0,001053$ m³/kg

a $p = 1,5$ Bar $\quad h_{1L} = \cancel{466,9}$ kJ/kg $104,77$ kJ/kg a $T = 25°C$

$h_1 = h_{1L} + v_{1L}(p_1 - p_{1L}) = 104,917$ kJ/kg

$V_2 = S \cdot \Delta z = 0,0727$ m³ $= V_1$ $\quad$ però $v = a\ v_{1L+v}$

$p = 1,5$ Bar

$v_{1L} = 0,001053 \quad h_{1V} = 2693,25$

$v_{1v} = \cancel{0,6635}$ $1,1073 \quad h_{1L} = 466,9$ kJ/kg

$m_{1L} = \frac{V_1}{v_{1L}} = 69,04$ kg

$m_{1V} = \frac{V_1}{v_{1v}} = 0,065$

$m_{1TOT} = 69,15$ kg $\quad x_1 = \frac{m_V}{m_{TOT}} = 0,0009$

$v_{L+V} = 0,0020$ m³/kg $\quad h_{1L+V} = 490,71$ kJ/kg

① $T = 25°C \quad p_1 = 1,5$ Bar $\quad h_1^T = 104,77$ kJ/kg

$h_1 = h_{1L} + v_{1L}(p_1 - p_{1L}) = 104,924$ kJ/kg

①' h_L a $p = 1,5$ Bar

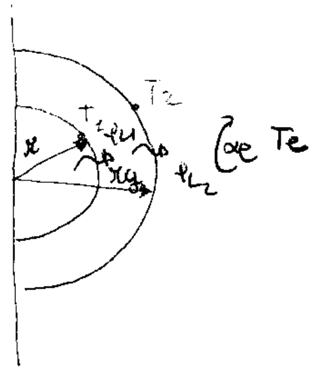
Esercizio 3

$\lambda_c = 15\ W/mK$ $\quad \rho_e = 0{,}946\ \mu\Omega m$ sez. circ $r = 2mm$ $\quad I = 12{,}5A$

$S_g = 4mm$ $\quad \lambda_G = 0{,}25\ W/mK$ $\quad \alpha = 8\ W/m^2K$ $\quad T_e = 25°C$

T_{sup} guaina = ?

viene generato calore



$$\varphi_L = \frac{H \cdot V}{L} = \frac{\frac{P}{V} \cdot V}{L} = \frac{R \cdot I^2}{L}$$

$$R = \rho \cdot \frac{L}{S} \qquad \varphi_L = \frac{\rho \cdot \frac{L}{S} \cdot I^2}{L} = \frac{\rho I^2}{\pi r^2} = 11{,}76\ W/m$$

$$r_g = r + S_g = (2+4) \cdot 10^{-3}\ m = 0{,}006\ m$$

Calcolare T_2 e T_1

Calcolo T_2 $\rightarrow$ $\varphi_{L2} = \dfrac{2\pi(T_2 - T_e)}{\frac{1}{r_g \alpha_e}}$

$$\varphi_{L2}\left(\frac{1}{r_g \alpha_e}\right) = 2\pi T_2 - 2\pi T_e \qquad \boxed{T_2 = \frac{\varphi_{L2}\left(\frac{1}{r_g \alpha_e}\right) + 2\pi T_e}{2\pi}} = 64{,}00°C$$

$$\varphi_{L1} = \varphi_{L2} = \frac{2\pi(T_1 - T_2)}{\frac{1}{\lambda_g} \ln \frac{r_g}{r}} \rightarrow \boxed{T_1 = \frac{\varphi_{L2}\left(\frac{1}{\lambda_g} \ln \frac{r_g}{r}\right) + 2\pi T_2}{2\pi}} = 72{,}22°C$$

provo a calcolarlo facendo il φ fino all'ambiente esterno

$$\varphi_{L2} = \frac{2\pi(T_1 - T_e)}{\frac{1}{\lambda_g} \ln\left(\frac{r_g}{r}\right) + \frac{1}{r_g \alpha_e}}$$

$$\varphi_{L2}\left[\left(\frac{1}{\lambda} \ln \frac{r_g}{r}\right) + \frac{1}{r_g \alpha_e}\right] = 2\pi T_1 - 2\pi T_e$$

$$T_1 = \frac{\varphi_L [\quad] + 2\pi T_e}{2\pi} = 72{,}21\ °C \quad \text{ok!}$$

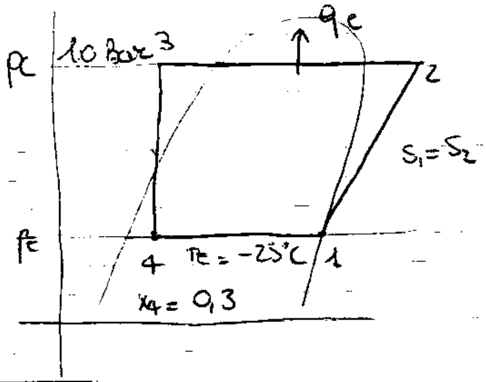
Luglio 2009

Esercizio 2

macchina frigorifera R134a a semplice compressione con sottoraffr.

$p_c = 10$ Bar $\quad T_E = -25°C \quad x_4 = 0{,}3 \quad COP = ?$

$q_c = ?$



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

Da Tabella $\quad h_1 = 330$ kJ/kg $\quad s_1 = 1{,}74$ kJ/kg K

$h_4 = 230$ kJ/kg $\quad h_2 = 430$ kJ/kg K

$COP \simeq 3$

potevo anche calcolarlo $h_4 = (1 - x_4) h_\ell + x_4 h_v$

$$\boxed{q_c = h_3 - h_2 \simeq -200 \text{ kJ/kg}}$$

[redacted] VRRAGG FILLE / NO

Due superfici grigie scambiano $\varphi = 40$ W/m²

$T_1 = 40°C \quad \varepsilon_1 = 0{,}5 \quad F_{1\to2} = ?$

$T_2 = 0°C \quad \varepsilon_2 = 0{,}3$

$$\varphi_{1\to2} = \frac{\sigma(T_1^4 - T_2^4)}{\frac{1-\varepsilon_1}{\varepsilon_1} + \frac{1}{F_{1\to2}} + \frac{1-\varepsilon_2}{\varepsilon_2}}$$

$$\varphi\left(\frac{1-\varepsilon_1}{\varepsilon_1}\right) + \varphi F_{1\to2} + \varphi\left(\frac{1-\varepsilon_2}{\varepsilon_2}\right) = \sigma(T_1^4 - T_2^4)$$

$$F_{1\to2} = \frac{\sigma(T_1^4 - T_2^4) - \varphi\left(\frac{1-\varepsilon_2}{\varepsilon_2}\right) - \varphi\left(\frac{1-\varepsilon_1}{\varepsilon_1}\right)}{\varphi}$$

ok!

$u_2 = h_2 - p_2 v_{2\,l+v}$ $\quad u_1 = h_1 - p_1 v_{1\,l+v}$ $\quad m_{2\,l+v} = 3{,}1198\ kg$

$v_{1\,l+v} = (1-x_1)\, v_l + x_1 v_v = 1{,}20\ m^3/kg$

$x_2 = \dfrac{m_{2v}}{m_{2\,l+v}} = 0{,}98$

$v_{2\,l+v} = 0{,}097\ m^3/kg$ $\qquad h_2 \neq h_e$

$h_1 = 3020{,}61\ kJ/kg$ $\qquad h_2 = 2759{,}42\ kJ/kg$

$u_2 = 2565420\ J/kg$

$u_1 = 1900610\ J/kg$ $\qquad$ segni giusti?

$u_2 - u_1 = 664{,}810\ kJ/kg$

$\rightarrow Q = m_2 u_2 - m_1 u_1 + m_2 h_e - m_1 h_e =$

$= (m_2 - m_1)(u_2 - u_1) + (m_2 - m_1)\, h_e =$

$= (m_2 - m_1)(u_2 - u_1 + h_e) = \cancel{15{,}889\ kJ/kg}$

$3462{,}01\ kJ/kg$

Volume irreversibilità: $\qquad s_e = s_1$ a $p = 20\ Bar$ $\quad s_e = 6{,}3367\ kJ/k$

$\dfrac{dS}{dt} + \Sigma G_j s_j = \dfrac{\phi}{T} + \Sigma_{irr}$

$m_2 s_2 - m_1 s_1 + m_2 s_e - m_1 s_e = \dfrac{Q}{T} + S_{irr}$

$(m_2 - m_1)(s_2 - s_1 + s_e) = \dfrac{Q}{T} + S_{irr}$

o devo considerare s_e?

$T = h$

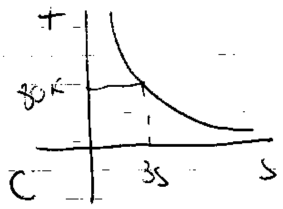
~~Esercizio~~ 3

da $T_1 = 20°C$ bisturi sottoposto a transitorio termico a contatto con il bisturi viene fatto esporre un fluido $cT = 80k$

$t = 3s$ $T_2 = 200°C$ → $T_2 = -180°C$ $RG \approx 0$

↓ temperatura a transitorio avvenuto

$t_0 = ?$ $\theta(t) = ?$



Fluido (Bisturi) a $T_1 = 20°C$

Investito da aria a $T = 80k = -193,15°C$

Fluido diminuisce di $200°C$ $T_2 = -180°C$

Equazione transitorio:

$$\theta(t) = \theta(\infty)\left(1 - \cancel{e^{-t/t_0}}\right) + \theta_0 e^{-t/t_0}$$

θ_0 = eccesso temperatura = $T_1 - T = 20 - (-193,15) = 213,15°C$ ok

$\theta_\infty = \cancel{\frac{\phi}{\alpha \cdot S}} = 0$ perché Resistenza termica interna trascurabile

$\theta(t) = \theta(3s) =$ T a cui voglio arrivare − T flusso che ea raffredda $= -180°C - (-193,15$

$= 13,15°C$

→ $\theta(t) = \theta_0 (e^{-t/t_0})$

213−200

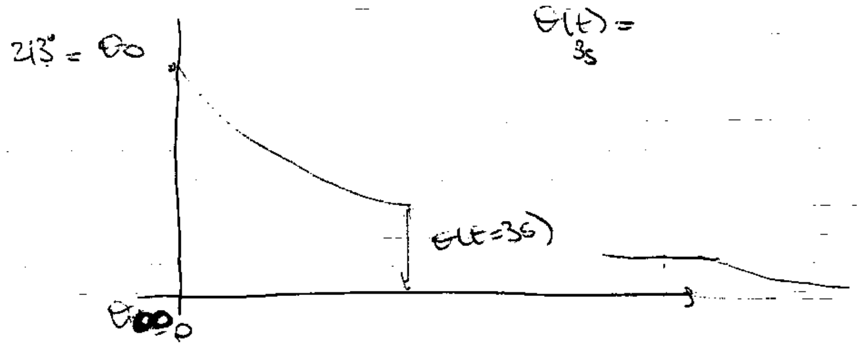
ricavo t_0

$$\frac{\theta(t)}{\theta_0} = e^{-t/t_0} \qquad \ln\left(\frac{\theta(t)}{\theta_0}\right) = -\frac{t}{t_0}$$

$$t_0 = \frac{-t}{\ln\left(\frac{\theta(t)}{\theta_0}\right)} = 1,076$$

$\theta(t) = 200°C$?

$\theta(t)$ = Tsistema − Tambiente esterno

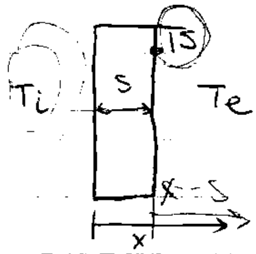


$$T(x) = \frac{H}{2\lambda}\left(s^2 - x^2\right) + T_e + \frac{\varphi}{\alpha}$$

Postulato Fourier $\varphi = -\lambda \frac{\partial T}{\partial x}$

sostituisco

$$T(x) = \frac{H}{2\lambda}\left(s^2 - x^2\right) + T_e - \lambda \frac{\partial T}{\partial x}$$



impongo $T = T_s$ per $x = s$

$\to T_s = -\frac{H}{2\lambda} s^2 + C$ $\qquad C = T_s + \frac{H}{2\lambda} s^2$

impongo una temperatura sulla superficie ~~esterna~~ interna

$T\big|_{x=0} = T_i \qquad T(x) = -\frac{H}{2\lambda} x^2 + C$

$T(x=0) = T_i \qquad T_i = -\frac{H}{2\lambda} \cancel{x^2} + C \quad (x=0) \qquad C = T_i + \cancel{\frac{H}{2\lambda} x^2}$

$$\boxed{T(x) = -\frac{H}{2\lambda} x^2 + T_i}$$ andamento di temperatura

il flusso su S ext $= \alpha \Delta T$ (scambio x conv in $x = s$)

$$-\lambda \frac{\partial T}{\partial x}\bigg|_{x=s} = \alpha\left(T_s - T_e\right)$$

$$-\frac{H}{\cancel{\lambda}} s \cdot (-\cancel{\lambda}) = \alpha\left(T_s - T_e\right)$$

$$H = -\frac{\alpha\left(T_s - T_e\right)}{s} \qquad 1^a \text{ equaz.}$$

impongo che $T\big|_{x=s} = T_s$

$$-\frac{H}{2\lambda} s^2 + T_i = T_s \qquad 2^a \text{ equaz.}$$

$$\begin{cases} H = -\frac{\alpha\left(T_s - T_e\right)}{s} \\ T_s = -\frac{H}{2\lambda} s^2 + T_i \end{cases}$$ risolvere . . .

Trasf veloce → adiabatiche

Trasf lente → isoterme

Esercizio 1

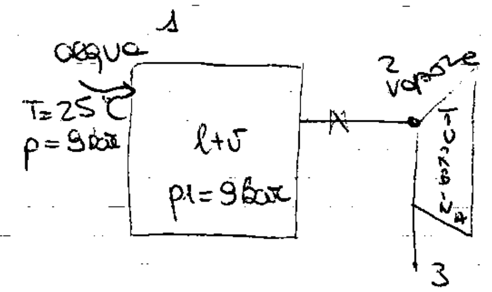
→ Serbatoio rigido l+v $p = 9$ Bar

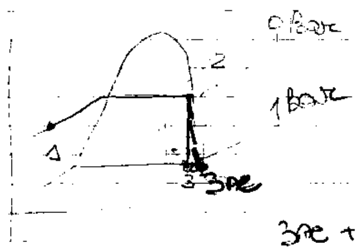
fornita G_{H_2O} a $p_1 = 9$ Bar e $T = 25°C$

→ esce vapore ed entra in turbina → espanso fino a $p_3 = 1$ Bar

$\eta_{is} = 80\%$ $\quad e_c = 0 \quad e_p = 0$

$G = ?$ $\quad \Phi = ?$ $\quad W_t = 64$ kW





3re + tendente al vapore x II principio

$$\eta_{is} = \frac{-h_3^{re} + h_2}{-h_3^{id} + h_2} \qquad \cancel{\Phi} - \ell_t = h_3^{re} - h_2$$

$$G = \frac{W_t}{\ell_t}$$

2 è vapore → calcolo h_2 da tab di saturazione a $p = 9$ Bar

$h_2 = 2772,1$ kJ/kg

Se l'espansione l'assumo adiab. reversibile $s_2 = s_3^{id} = 6,6192$ kJ/kg k

$p_3 = 1$ Bar $\quad s_l = 1,3027$ kJ/kg k $\quad s_v = 7,3598$ kJ/kg k

calcolo il titolo in 3

$$s_3 = (1 - x_3) s_l + x_3 s_v$$

$$s_3 = s_l - x_3 s_l + x_3 s_v$$

$$x_3^{id} = \frac{s_3^{id} - s_l}{s_v - s_l} = 0,87$$

calcolo $h_3^{id} = (1 - x_3) h_{l\,a\,1\,Bar} + x_3 h_v = 2381,87$ kJ/kg

Da η_{is} calcolo h_3^{re}

$$\eta_{is} h_3 \cancel{- \eta_{is} h_2^{id}} = h_3 \cancel{- h_2^{re}}$$

$$\cancel{h_2^{re}} = h_3 - \eta_{is} \cancel{(h_3 - h_2^{id})}$$

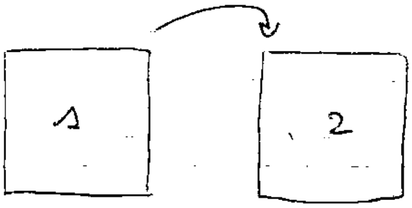
equilibrio termico con amb. esterno ↑

Esercizio 7

$V = 100\ l = 0{,}1\ m^3$ $\quad n = 20\ mol$ $\quad \gamma = 1{,}3$ $\quad T_1 = 15°C$

Poi il serbatoio è scambiato calore affinché $p_2 = 11\ Bar$ $\quad T_2 = ?$ $\quad Q = ?$

$Q = ?$



$kg \cdot \frac{m}{s^2} \cdot \frac{1}{m^2} \cdot m^3 = \frac{kJ}{kmol} \cdot \frac{J}{kg\,K} \cdot K$

$kg \cdot \frac{m^2}{s^2} = kg \cdot \frac{m}{s^2} \cdot m$

$V_1 = 0{,}1\ m^3 = V_2 = 0{,}1\ m^3 = V$

$p_1 = ?$ $\qquad T_2 = ?$

$T_1 = 288{,}15\ K$ $\qquad p_2 = 11\ Bar$

$n_1 = 20\ mol = n_2 = 20\ mol = n$

Equazione gas perfetti $\qquad \bar{R}$ = costante universale gas $= 8314{,}3\ J/kmol \cdot K$

$$pV = n\bar{R}T \qquad Pa = \frac{N}{m^2} = kg \cdot \frac{m}{s^2} \cdot \frac{1}{m^2}$$

$$kg \cdot \frac{m}{s^2} \cdot \frac{1}{m^2} \cdot m^3 = \cancel{kmol} \cdot \frac{J}{\cancel{kmol}\,\cancel{K}} \cdot \cancel{K}$$

$$kg \cdot \frac{m^2}{s^2} = F \cdot m = kg \cdot \frac{m}{s^2} \cdot m$$

analisi dimensionale

Calcolo $p_1 \to p_1V_1 = n\bar{R}T_1$ $\qquad$ pongo n in kmol $n = 0{,}02\ kmol$

$$p_1 = \frac{n\bar{R}T_1}{V_1} = 479\,153{,}109\ Pa \approx 5\ Bar$$

Calcolo $T_2 \to \boxed{p_2V = n\bar{R}T_2}$ $\quad T_2 = \frac{p_2V}{n\bar{R}} = \underline{661{,}51\ K}$

$$Q = c\,(T_2 - T_1) \cdot M$$

$\frac{J}{kg\,K} \cdot K = J/kg$ $\qquad$ ma lo voglio calcolato in kJ

$\to pV_1 = M \cdot R \cdot T$

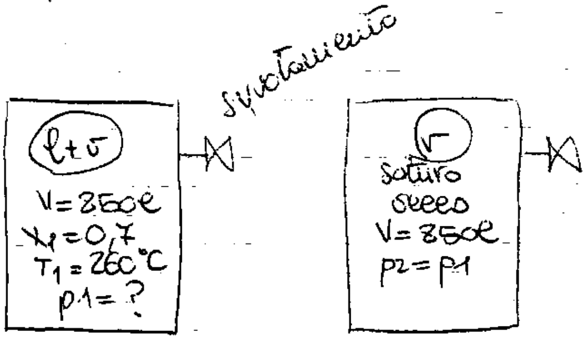
$p\cancel{V} =$

$$R = \frac{\bar{R}}{\bar{M}} = 8314{,}3\ \frac{J}{kmol\,K} \cdot \frac{kmol}{kg}$$

23 FEBBRAIO 2011

Esercizio 1

Serbatoio rigido $V = 350\,l$ contiene $l+v$ $x_1 = 0{,}7$ $T_1 = 260\,°C$
Viene spillato vapore e fornito calore $p_2 = p_1$ $Q = ?$ $\frac{m_{1v}}{m_{2v}} = ?$



① $T = 260\,°C$ $p_1 = 46{,}943\ Bar = p_2$

$v_{1l} = 0{,}0012756\ m^3/kg$ $v_{1v} = 0{,}04213\ m^3/kg$

$h_{l} = 1134{,}9\ kJ/kg$ $h_{v} = 2796{,}4\ kJ/kg$

$v_{1_{l+v}} = 0{,}0298\ m^3/kg$

$h_1 = (1-x)h_l + x h_v = 2297{,}95\ kJ/$

$m_{TOT\,l+v} = \frac{V_{TOT}}{v_{l+v}} = 28{,}52\ kg$

$x = \frac{m_{1v}}{m_{1\,l+v}}$ $m_{1v} = x_1 \cdot m_{TOT\,l+v} = 19{,}96\ kg$

② $p_2 = 46{,}943\ Bar$ $V_2 = 0{,}85\ m^3$

$v_v = 0{,}04404\ m^3/kg$ $h_v = 2797{,}7$ $(\sim 45\ Bar)$

$m_{2v} = \frac{V_{TOT}}{v_{2v}} = 19{,}30\ kg$

$\boxed{\frac{m_{2v}}{m_{1v}} = \frac{19{,}30}{19{,}96}} = \underline{0{,}9669}$

Svuotamento: $\phi - \cancel{W}_0 = \frac{dU}{dt} + \Sigma G_j s_j$ $-\frac{dM}{dt} = \Sigma G_q \cdot h_q$

$Q = m_2 u_2 - m_1 u_1 - m_2 h_u + m_1 h_u$ $h_u = h_2 = 2797{,}7\ kJ/kg$

$u_2 = h_2 - p_2 v_2 = 2600{,}639\ kJ/kg$

$u_1 = h_1 - p_1 v_1 = 2158{,}059\ kJ/kg$

$\boxed{Q = m_2 (u_2 - h_u) + m_1 (h_u - u_1)} = \underline{-3805{,}107} = 181\ldots\ kJ/\ldots = \underline{1{,}81\ldots}$

Esercizio 3

Scambiatore → controcorrente

$T_{if} = 30°C$ $T_{ic} = 110°C$ $\frac{C_{min}}{C_{max}} = 0{,}5$

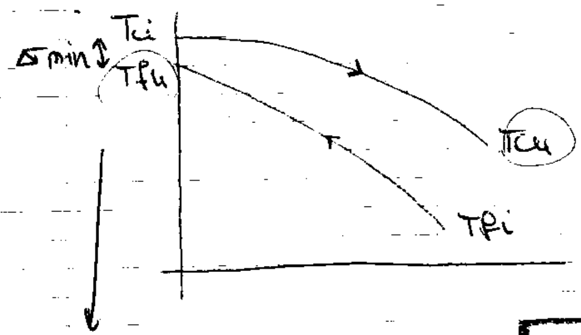
$\Delta T_{min} = 20°C$

$C_{max} = C_{caldo} = C_c$ ⇒ tracciare andamento qualitativo profili di temperatura

$T_{uf} = ?$ $T_{cu} = ?$ $\varepsilon = ?$ $NTU = ?$

$\frac{C_f}{C_c} = 0{,}5$ $C_{max} = C_c$ ⇒ $C_{min} = C_f$

se $C_{min} = C_f$ $\varepsilon = \frac{T_{fu} - T_{fi}}{T_{ci} - T_{fi}}$



dalla conf. vedo che $\boxed{\Delta T_{min} = T_{ci} - T_{fu}}$

allora calcolo $T_{fu} = T_{ci} - \Delta T_{min} = 110 - 20 = 90°C$

$\boxed{\varepsilon = \frac{T_{fu} - T_{fi}}{T_{ci} - T_{fi}}}$ $0{,}75 = 75\%$

$$\varepsilon = \frac{1 - e^{-\left(1 - \frac{C_{min}}{C_{max}}\right) NTU}}{1 - \frac{C_{min}}{C_{max}} e^{-\left(1 - \frac{C_{min}}{C_{max}}\right) NTU}}$$

pongo $1 - \frac{C_{min}}{C_{max}} = A$ $\frac{C_{min}}{C_{max}} = B$

$$\varepsilon = \frac{1 - e^{-A \cdot NTU}}{1 - B\, e^{-A\, NTU}}$$

25 GENNAIO 2010

(meccanici)

~~Esercizio 1~~

1. Serbatoio rigido $V = 5\,m^3$ contiene vapore SS a $p = 20$ bar
2. Per effetto delle dispersioni termiche, dopo un po', $p_2 = 16$ bar

Det $m_{cond} = ?$ $Q = ?$

se vuole la massa di liquido condensato vuol dire che una parte di vapore è diventata liquido

$$q - \cancel{l} = \Delta u = u_2 - u_1$$

$h_1 = 2797{,}2$ kJ/kg $\quad m_{TOT} = m_{vapore} = \frac{V}{v} = 50{,}23$ kg

$v_1 = 0{,}09954\ m^3/kg$

$$u_1 = h_1 - p_1 v_1 = 2598{,}120\ kJ/kg$$

In 2 so che $V_2 = 5\,m^3$ a $p = 16$ bar $\quad v_2 = v_1 = 0{,}09954$

a $p = 16$ bar

$v_{2L} = 0{,}0011586\ m^3/kg \quad v_{2V} = 0{,}1237\ m^3/kg$

$$v = (1 - x_2) v_l + x_2 v_v$$

$$x_2 = \frac{v - v_l}{v_v - v_l} = 0{,}80$$

$$x_2 = \frac{m_{2vapore}}{m_{2l+v} = m_{TOT}} \qquad m_{2vapore} = x_2 \cdot m_{TOT} = 40{,}184\ kg$$

$$m_L = m_{TOT} - m_{vapore} = 10{,}046\ kg$$

$$h_2 = (1 - x_2) h_l + x_2 h_v = 2405{,}072\ kJ/kg$$

$$u_2 = 2245802\ J/kg$$

$$q = u_2 - u_1 = -352{,}312\ kJ/kg$$

$$Q = q \cdot m_{TOT} = -17696{,}631\ kJ$$

Risultati

Baco alla ... !

$\boxed{m_2 \cong \text{kg}}$

Scrivo $p_2 V_2 = m_2 R T_2$

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

$$- p_2 \cdot \Delta V + g \Delta z^{m_p} = m_2 \left[c_v \cdot \frac{p_2 V_2}{m_2 R} + p_0 \Delta V + m_p \cdot g \cdot \Delta z - c_p T_e - g \Delta z \right]$$

$$-p_2 \Delta V + g \Delta z = c_v \frac{p_2 V_2}{R} + m_2 \left[p_2 \Delta V + m_p g \Delta z - c_p T_e - g \Delta z \right]$$

$$m_2 = \frac{m_p g \Delta z - p_e \Delta V - c_p \frac{p_2 V_2}{R}}{p_e \Delta V + \cancel{m_p g \Delta z} - c_p T_e \cancel{- g \Delta z}}$$

devo mettere 1 bar o 25 bar ?

Per irreversibilità:

$$\frac{dS}{dt} + \sum_{j=1}^{n} G_j s_j = \sum \cancel{\frac{\Phi}{T}} + S_{irr}$$

$$S_2 - \cancel{S_1} + (m_2 s_e - \cancel{m_1} s_e) = S_{irr}$$

$$m_2 s_2 - m_2 s_e = S_{irr}$$

$$m_2 (s_2 - s_e) = S_{irr}$$

$$s_2 - s_e = c_p \ln \frac{T_2}{T_e} - R \ln \frac{p_2}{p_e}$$

$p_e = 1$ bar $\quad p_2 = 25$ bar

Scambiatore controcorrente

$C_{min} = C_{max} \Rightarrow C_{min} - C_{max} = 0$

$T_{fi} = 60°C \quad T_{ci} = 120°C \quad NTU = 1{,}5 \quad \varepsilon = ? \quad T_{cu} = ? \quad T_{fu} = ?$

$$\varepsilon = \frac{1 - e^{-\left(1 - \frac{C_{min}}{C_{max}}\right) NTU}}{1 - \frac{C_{min}}{C_{max}} e^{-\left(1 - \frac{C_{min}}{C_{max}}\right) NTU}}$$

Verrebbe $\left[\frac{0}{0}\right]$ = forma indet. allora devo fare il limite

$$\lim_{\frac{C_{min}}{C_{max}} \to 1} \Rightarrow \varepsilon = \frac{NTU}{1 + NTU} = 0{,}6$$

posso usarla subito perché $C_{min} = C_{max}$

$$\varepsilon = \frac{T_{ci} - T_{cu}}{T_{ci} - T_{fi}} \Rightarrow 84°C = T_{cu} \qquad \varepsilon = \frac{T_{fu} - T_{fi}}{T_{ci} - T_{fi}} \Rightarrow 96°C = T_{fu}$$

Riempimento Bombola

$$\frac{dU}{dt} = \frac{dH}{dt} \, h_e$$

$$m_2 u_2 - m_1 u_1 = m_2 h_e - m_1 h_e$$

$$u_2 = u_1 = u$$

$$(m_2 - m_1) u = (m_2 - m_1) h_e$$

$u = c_v \cdot T_3 = 213922 \; J/kg$

calcolo h_e che ~~è h_2~~ => h uscita del compressore

$$h_e = u = 213922 \; J/kg$$

$$l_{te} = h'_1 - h_2 = h - h_e$$

I principio alla bombola

$$q - l_t = \Delta h$$

$$q = c \Delta T$$

$$c(T_{3_2} - T_{3_1}) - l_t = \Delta h = h_{3_2} - h_{3_1} = c_p (T_{3_2} - T_{3_1})$$

$$l_t = \int -V dp \qquad L_t = -\int V dp = -V (p_{3_2} - p_{3_1})$$

$$T_{3_1} \, p_{3_1}^{\frac{1-n}{n}} =$$

Calcolo p_2 con eq. politropica

$$p_1 v_1^n = p_2 v_2^n \qquad p_1 \left(\frac{V}{m_1}\right)^n = p_2 \left(\frac{V}{m_1/3}\right)^n$$

rapp compr.

$$\frac{p_2}{p_1} = \left(\frac{V}{m_1} \cdot \frac{m_2}{V}\right)^n = 5,4305$$

$$\frac{m_2}{m_1} = 3$$

Compressore => compressione adiabatica

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

$$T_2 = T_1 \left(\frac{p_1}{p_2}\right)^{\frac{1-\gamma}{\gamma}} = T_1 \left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}} \qquad \frac{T_2}{T_1} = \frac{p_2}{p_1}^{\frac{\gamma-1}{\gamma}} \Rightarrow \beta = \frac{p_2}{p_1}$$

$$l_e = c_p (T_2 - T_1)$$

$$l_e = c_p T_1 \left(\frac{T_2}{T_1} - 1\right) = \boxed{c_p T_1 \left(\beta^{\frac{\gamma-1}{\gamma}} - 1\right)} = -178,568 \; kJ/k$$

$\rightarrow q_a - \cancel{\ell_i}_0 = \Delta u$

perché volume costante

$\boxed{q_a = u_B - u_A = \cancel{1,763\ kJ/kg}}$ 1163,791

$u_B = h_B - p_B v_{2B} = 2073,225\ kJ/kg$

$u_A = h_A - p_A v_A = 909,434\ kJ/kg$

da B a C adiabatica rev → I PRINC:

$\cancel{q}_0 - \ell_i = \Delta u$

$\ell_i = u_B - u_C$

$u_C = h_C - p_C v_C$

$p_C = p_A = 2\ bar$ $\quad s_B = s_C = 5,4152\ kJ/kgK$

$\rightarrow x_C = \dfrac{s_C - s_\ell}{s_v - s_\ell} = 0,694$

$h_C = 2032,610\ kJ/kg$

$v_C = (1-x_C)v_\ell + x_C v_v = 0,6122548\ m^3/kg$

$u_C = 1910,359\ kJ/kg$

$\ell_i = u_B - u_C = 162,886\ kJ/kg$

da C a A isobara

$q - \ell_i = \Delta u$

$= -86,665$

$\ell_i = \int p\,dv = p\,(v_A - v_C)$ $\quad \Delta u = u_A - u_C$

$q_b = \Delta u + \ell_i = u_A - u_C + p(v_A - v_C) = -1000,925 + \quad =$

$= -1037,590\ kJ$

$\boxed{\eta = 1 - \dfrac{|q_b|}{q_a} = 0,065}$ $\quad \boxed{\dfrac{e_n}{q_a} = \dfrac{+\ell_{i\,AC} + \ell_{i\,AB}}{q_a}} = 0,065$

controllare risultato;

rendimento mi pare troppo basso

$$m_1\left(-R\ln\frac{p_2}{p_1}\right) = \frac{Q}{T} + S_{irr}$$

$$S_{irr} = m_1\left(-R\ln\frac{p_2}{p_1}\right) - \frac{Q}{T} =$$

$$T \cdot S_{in} = T(m_2(s_2 - s_1)) - Q$$

$$\dot{Q} = T m_2 (s_2 - s_1) - T S_{in}$$

→ conservazione portata

$$\phi - Wt = \frac{dU}{dt} + G_e h_e$$

$$0 = m_2 - m_1 + G_e \quad G_e = m_1 - m_2$$

$$\phi - Wt = m_2 u_2 - m_1 u_1 - m_2 h_e + m_1 h_e$$

oppure $\phi - Wt = \frac{dU}{dt} - G_e$

$$0 = m_2 - m_1 - G_e$$

$$G_e = m_2 - m_1$$

$$\phi - Wt = \frac{dU}{dt} - m_2 h_e + m_1 h_e$$

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