Politecnico di Milano

CS-L Ingegneria Energetica

Soluzione del compito di Fisica Tecnica del 15 febbraio 2013

ATTENZIONE: la presente soluzione è puramente indicativa e non si escludono errori e/o omissioni.

PROBLEMA # 1

① $\exists\, PM_{12} \Leftrightarrow V_2 \neq V_1$ & $(S_2 - S_1) \geq 0$

$$V_2 \overset{(GP)}{=} \frac{nR^*T_2}{p_2} = \frac{p_1V_1}{\cancel{R^*}T_1}\cdot\frac{\cancel{R^*}T_2}{p_2} = \frac{p_1}{p_2}\frac{T_2}{T_1}V_1 = \frac{1}{10}\,\frac{373}{293}\,10\cdot10^{-3} = 1{,}27\cdot10^{-3}\,kg$$

$$(S_2-S_1)^A \overset{(GP)}{=} Mc_p\left[\ln\frac{T_2}{T_1} - \frac{R}{c_p}\ln\frac{p_2}{p_1}\right] =$$

$$= 1{,}27\cdot10^{-3}\times1003{,}5\left[\ln\frac{373}{293} - \frac{2}{7}\ln\frac{10}{1}\right]$$

$$(S_2-S_1)^A = -4{,}975\,\frac{J}{K} < 0 \Rightarrow \nexists\, PM_{12}$$

$M = \frac{p_1V_1}{R^*T_1} = \frac{10^5\times0{,}010}{286{,}7\times293} = 11{,}9\cdot10^{-3}\,kg$

$R^* = \frac{8314{,}5}{29} = 286{,}7\,\frac{J}{kgK}$

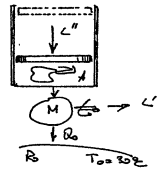
$c_p = \frac{7}{2}R^* = 1003{,}5$ "

$c_v = \frac{5}{2}R^* = 716{,}8$ "

② C = AUM

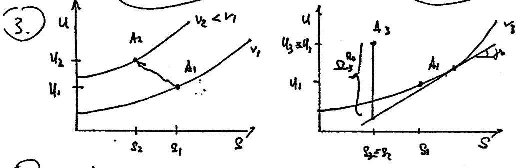
$$\begin{cases}(U_2-U_1)^C = Q^{C\leftarrow} - L^{C\rightarrow}\\ (S_2-S_1)^C = S_Q^{C\leftarrow} + \cancel{S_{gen}^C}\xrightarrow{PR}0\end{cases}\quad\begin{cases}(U_2-U_1)^A + \cancel{(U_2-U_1)^M}\to0 = Q^{C\leftarrow} - L^{C\rightarrow} & Q^{C\leftarrow}\equiv Q_0^{C\leftarrow}\\ (S_2-S_1)^A + \cancel{(S_2-S_1)^M}\to0 = S_Q^{C\leftarrow} \overset{(eq.bc)}{\equiv} \frac{Q_0^{C\leftarrow}}{T_0}\end{cases}$$

$$\begin{cases}L^{C\rightarrow} = Q_0^{C\leftarrow} - (U_2-U_1)^A = Q_0^{C\leftarrow} - Mc_v(T_2-T_1)\\ Q_0^{C\leftarrow} = T_0(S_2-S_1)^A \overset{(GP)}{=} T_0Mc_p\left[\ln\frac{T_2}{T_1} - \frac{R}{c_p}\ln\frac{p_2}{p_1}\right] = 303{,}15\times(-4{,}975) = -1507{,}8\,J\end{cases}$$



$Q_0^{C\rightarrow} = \boxed{1507{,}8\,J}$ & $L^{C\rightarrow} = L' + L'' = \boxed{-2190\,J}$

③



$tg\,\gamma_0 = 313 > 293 = tg\,\alpha_1$

④ C = AUPUM

$$L'^{C\rightarrow} = Q_0'^{C\leftarrow} - \left[(U_2-U_1)^A + (U_2-U_1)^P\right] = Q_0'^{C} - \left[(U_2-U_1)^A + \overset{(M.I.)}{Mc(T_2-T_1)}\right]$$

$$Q_0'^{C\leftarrow} = T_0\left[(S_2-S_1)^A + (S_2-S_1)^P\right] = -1507{,}8 + McT_0\ln(T_2/T_1) =$$

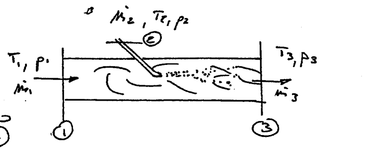
$$= -1507{,}8 + \underbrace{0{,}002\times700\times313\ln(313/293)}_{107{,}41}$$

$$L'^{C\rightarrow} = -1405{,}4 - 682{,}2 - 112 = -2199{,}6\,J$$

$$Q_0'^{C\leftarrow} = -1405{,}4 \longrightarrow 1 - \frac{Q_0}{Q_0'} = 1 - \frac{1507{,}8}{1405{,}4} = -0{,}073 = -7{,}3\%,\ ok!$$

PROBLEMA # 2

①
$$\begin{cases}\frac{dM}{dt} = \dot m_1^{\leftarrow} + \dot m_2^{\leftarrow} - \dot m_3^{\rightarrow} = 0 & (SS)\\ \frac{dE}{dt} = \dot m_1^{\leftarrow}h_1 + \dot m_2^{\leftarrow}h_2 - \dot m_3h_3 - \cancel{\dot Q}\xrightarrow{Ad}0 = 0 & (S.S)\end{cases}$$



$$\begin{cases}\dot m_3 = \dot m_1 + \dot m_2\\ \dot m_1h_1 + \dot m_2h_2 - (\dot m_1 + \dot m_2)h_3 = 0\end{cases}$$

$$\dot m_2 = \frac{h_1 - h_3}{h_3 - h_2}\,\dot m_1$$

$$\dot m_2 = \frac{3064{,}2 - 2748{,}7}{2748{,}7 - 167{,}66}\times1 = 0{,}122\,\frac{kg}{s}$$

h_1 @ 5 bar, 300°C = 3064,2 $\frac{kJ}{kg}$

$h_3 = h_{vs}$ @ 5 bar = 2748,7 "

h_2 @ 10 bar, 40°C = $h_{ls}(40°C) + v\Delta p$

$= 167{,}56 + \frac{0{,}001(10^6 - 7500)}{1000} = 167{,}66$

②
$$\frac{dS}{dt} = \dot m_1s_1 + \dot m_2s_2 - \dot m_3s_3 - \cancel{\frac{\dot Q}{T}}\xrightarrow{Ad.}0 + \dot S_{gen} = 0\quad(S.S.)$$

$$\dot S_{gen} = \dot m_3s_3 - \dot m_1s_1 - \dot m_2s_2$$

$$\dot S_{gen} = 1{,}122\times6{,}8213 - 1\times7{,}4599 + - 0{,}122\times0{,}5725 = 0{,}124\,\frac{kW}{K}$$

$s_1 = 7{,}4599\,\frac{kJ}{kgK}$

$s_3 = 6{,}8213$ "

$s_2 \cong s_{ls}(40°C) = 0{,}5725\,\frac{kJ}{kgK}$

↪ IRREVERSIBILE !

③ $\dot L_{dis} = T_0\dot S_{gen} = 293\times0{,}124 = \boxed{36{,}2\,kW}$

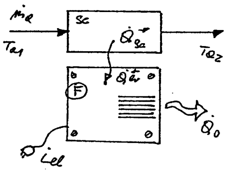
PROBLEMA # 3

①
$$\begin{cases}\frac{dM^{sc}}{dt} = \dot m_{a1}^{\leftarrow} - \dot m_{a2}^{\rightarrow} = 0 & (S.S)\\ \frac{dE^{sc}}{dt} = \dot m_{a1}^{\leftarrow}h_{a1} - \dot m_{a2}h_{a2} - \dot Q_{sc}^{\rightarrow} = 0 & (S.S)\end{cases}$$

$$\dot m_{a2}^{\rightarrow} = \dot m_{a1}^{\leftarrow} = \dot m_a$$

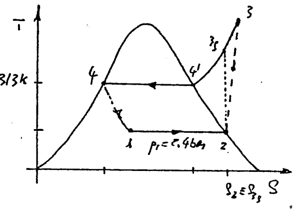
$$\dot Q_{sc}^{\rightarrow} = \dot m_a(h_{a1} - h_{a2}) \overset{(L,I)}{=} \dot m_a c\,(T_{a1} - T_{a2}) =$$

$$= \frac{700}{3600}\,4{,}1\,\frac{kJ}{kgK}\,(25 - 7) = \boxed{14{,}35\,kW}$$



②
$$\begin{cases}\frac{dM^{EV}}{dt} = \dot m_1 - \dot m_2 = 0\\ \frac{dE^{EV}}{dt} = \dot m_1h_1 - m_2h_2 + \dot Q_{ev}^{\leftarrow} = 0 & (RS)\end{cases}$$

$$\begin{cases}\dot m_2 = \dot m_1\\ m_1(h_1 - h_2) + \dot Q_{ev}^{\leftarrow} = 0 \rightarrow \dot m_1 = \frac{\dot Q_{ev}^{\leftarrow}}{h_2 - h_1}\end{cases}$$



$$\longrightarrow \dot m_1 = \frac{\dot Q_{sc}^{\rightarrow}}{h_2 - h_4} = \frac{14{,}35}{244{,}1 - 106{,}2} = \boxed{0{,}104\,\frac{kg}{s}} = 374{,}6\,kg/h$$

VALVOLA

$$\begin{cases}\frac{dM^V}{dt} = \dot m_4 - \dot m_1 = 0 & (RS)\\ \frac{dE^V}{dt} = \dot m_4h_4 - \dot m_1h_1 - \cancel{\dot Q}\to0 - \cancel{\dot L}=0\\ \hookrightarrow h_1 = h_4 = \tilde h_{ls}(4) & (RS)\\ T_4 = 313\,K = 40°C \rightarrow h_4 = 106{,}2\,\frac{kJ}{kg}\\ h_2 = \tilde h_{vs}(p_1) = 244{,}1\,\frac{kJ}{kg}\end{cases}$$

③ $\dot L^{C\leftarrow} = \frac{\dot L_{id}^C}{\eta_c}$ (PROBL. REV. ASSOC.)

$$\begin{cases}\frac{dM^C}{dt} = \dot m_2 - \dot m_3 = 0 & (R.S.)\\ \frac{dE^C}{dt} = \dot m_2h_2 - \dot m_3h_{3s} - \cancel{\dot Q}\to0 + \dot L_{id}^{C\leftarrow} = 0\\ \frac{dS^C}{dt} = \dot m_2s_2 - \dot m_3s_{3s} - \cancel{\dot S_{Q}} + \cancel{\dot S_{gen}} = 0 & (R.S.)\end{cases}$$

$$\begin{cases}\dot m_3 = \dot m_2\\ \dot L_{id}^{C\leftarrow} = \dot m_2(h_{3s} - h_2)\\ s_{3s} = s_2 \equiv \tilde s_{vs}(p_2) = 0{,}9222\,\frac{kJ}{kgK}\end{cases}$$

$$\begin{cases}h_{3s} = \tilde h(p_3, s_2)\\ p_3 = p_{4'} \equiv \tilde p_s(T_4) = 10{,}16\,bar\end{cases}$$

$$h_{3s} \simeq \tilde h(1\,MPa, 0{,}9222) = 273{,}6\,\frac{kJ}{kg}$$

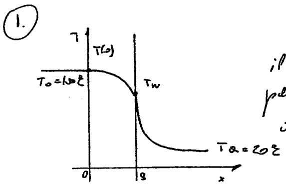
$$\dot L_{id} = 0{,}104(273{,}6 - 244{,}1) = 3{,}07\,kW$$

$$\dot L^{C\leftarrow} = \frac{3{,}07}{0{,}7} = \boxed{4{,}39\,kW}$$

④ $\varepsilon_R \doteq \frac{\dot Q_{ev}^{\leftarrow}}{\dot L_c^{\leftarrow}} = \frac{14{,}35}{4{,}39} = \boxed{3{,}27}$

PROBLEMA # 4

①



Dovendo essere adiabatica la sup. interna, il flusso termico in x=0 è nullo, la temp è pari a quella interna e la tangente è orizzontale, cioè ho:

$$\begin{cases}q(0) = 0\\ T(0) = T_0\end{cases}$$

②
$$\frac{d^2T}{dx^2} = -\frac{\sigma}{k},\quad \frac{dT}{dx} = -\frac{\sigma}{k}x + C_1$$

$$T = -\frac{\sigma}{2k}x^2 + \cancel{C_1x} + C_2 \quad \&\quad q(x) = -k\frac{dT}{dx} = \sigma x - \cancel{C_1k}$$

$$\left.\begin{array}{l}q(0) = 0 \rightarrow \sigma\cdot0 - C_1k = 0 \rightarrow C_1 = 0\\ T(0) = C_2 = T_0 = 100°C\end{array}\right\}\quad \begin{array}{l}T = T_0 - \frac{\sigma}{2k}x^2\\ q = \sigma x\end{array}$$

$$q(s) = h\left[T(s) - T_a\right] \longrightarrow \sigma s = h\left[T_0 - \frac{\sigma s^2}{2k} - T_a\right] = h(T_0 - T_a) - \frac{h\sigma s^2}{2k}$$

$$\sigma = \frac{h(T_0 - T_a)}{s + hs^2/2k} = \frac{5(100 - 20)}{0{,}005 + 5(0.005)^2/2\cdot0{,}2} = \boxed{75\cdot294{,}12\,W/m^3}$$

③ $T(s) = T_0 - \frac{\sigma s^2}{2k} = 100 - \frac{75\cdot294{,}12\times(0.005)^2}{2\times0{,}2} = \boxed{95{,}3\,°C}$

④ $q(s) = \sigma s = 75\cdot294{,}12\times0.005 = 376{,}47\,W/m^2$

$q_{rad} \leq 0{,}1\,q = 36{,}647\,W/m^2$

$$q_{rad} = \frac{\sigma(T_w^4 - T_a^4)}{\frac{1-\varepsilon_1}{\varepsilon_1} + \underset{=1}{\frac{1}{F_{12}}} + \underset{\to0}{\frac{(1-\varepsilon_2)A_1}{\varepsilon_2A_2}}} = \sigma\varepsilon_1(T_w^4 - T_a^4)$$

$$\varepsilon_1 = \frac{q_{rad}}{\sigma(T_w^4 - T_a^4)} = \frac{36.647}{5.67(3{,}6845^4 - 2{,}9315^4)} = 0{,}06 \rightarrow \rho \overset{(opaco)}{=} 1 - \alpha \overset{(kirchhoff)}{=} 1 - \varepsilon = 0{,}9$$

⑤ $T_f = \frac{95{,}3 + 20}{2} = 57{,}65\,°C = 330{,}8\,K \rightarrow \alpha_p \overset{(GP)}{=} 0{,}00302$

$$Gr = \frac{\rho^2g\alpha_p(T - T_a)H^3}{\mu^2} = \frac{(1{,}1181)^2\,9{,}81\times0{,}003\,(95.3 - 20)\times(0.3)^3}{(19.05\cdot10^{-6})^2} = 2.077\cdot10^8$$

$$Pr = \frac{\mu c_p}{k} = \frac{19.05\cdot10^{-6}\times1007{,}4}{0{,}0273} = 0{,}7,\quad Ra = Gr\cdot Pr = 1{,}454\cdot10^8$$

$$Nu = 0.59\,Ra^{0.25} = 64{,}85 \longrightarrow h = \frac{Nu\,k}{H} = \frac{64{,}85\times0.0273}{0{,}3} = \boxed{5.9\,\frac{W}{m^2K}}$$