Politecnico di Milano — CS-L Ingegneria Energetica

Soluzione del compito di Fisica Tecnica del 15 febbraio 2013

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

PROBLEMA # 1

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

$V_2 = \frac{m R^* T_2}{p_2} = \frac{p_1 V_1}{R^* T_1} \cdot \frac{R^* T_2}{p_2} = \frac{p_1}{p_2}\frac{T_2}{T_1} V_1 = \frac{1}{10}\,\frac{373}{293}\,10\cdot 10^{-3} = 1{,}27\cdot 10^{-3}\ \mathrm{m^3}$

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

$M = \frac{p_1 V_1}{R^* T_1} = \frac{10^5 \times 0{,}010}{286{,}7 \times 293} = 11{,}9\cdot 10^{-3}\ \mathrm{kg}$

$R^* = \frac{8314{,}5}{29} = 286{,}7\ \frac{J}{kg\,K}$, $c_p = \frac{7}{2}R^* = 1003{,}5$, $c_v = \frac{5}{2}R^* = 716{,}8$

$= 1{,}27\cdot 10^{-3}\times 1003{,}5\left[\ln\frac{373}{293} - \frac{2}{7}\ln\frac{10}{1}\right]$

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

2. $C = AUM$

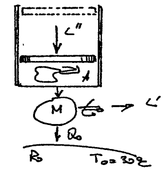
$(U_2 - U_1)^C = Q^{C\leftarrow} - L^{C\rightarrow}$; $\{(U_2-U_1)^A + (U_2-U_1)^M = Q^{C\leftarrow} - L^{C\rightarrow}$

$(S_2 - S_1)^C = S_Q^{C\leftarrow} + S_{irr}$; $\{(S_2-S_1)^A + (S_2-S_1)^M + S_Q^{C\leftarrow} = \frac{Q_0^{C\leftarrow}}{T_0}$ (rev)

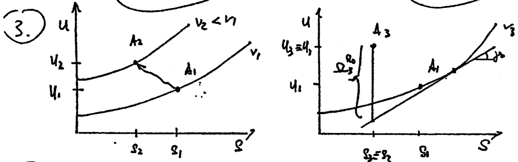
$L^{C\rightarrow} = Q_0^{C\leftarrow} - (U_2 - U_1)^A = Q_0^{C\leftarrow} - M c_v (T_2 - T_1)$

$Q_0^{C\leftarrow} = T_0 (S_2 - S_1)^A = T_0 M c_p\left[\ln\frac{T_2}{T_1} - \frac{R}{c_p}\ln\frac{p_2}{p_1}\right] = 303{,}15\times(-4{,}975) = -1507{,}8\ J$

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



3.



$tg\,\alpha_0 = 313 > 293 = tg\,\alpha_1$

4. $C = AUPUM$

$L^{C\rightarrow} = Q_0^{C\leftarrow} - [(U_2 - U_1)^A + (U_2 - U_1)^P] = Q_0^{C\leftarrow} - [(U_2-U_1)^A + mc(T_2 - T_1)]$

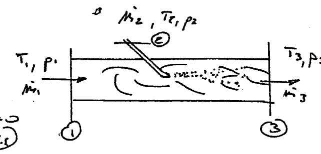
$Q_0^{C\leftarrow} = T_0[(S_2 - S_1)^A + (S_2 - S_1)^P] = -1507{,}8 + Mc T_0 \ln(T_2/T_1) =$

$= -1507{,}8 + \underbrace{0{,}002\times 700\times 313\ln(313/293)}_{101{,}41}$

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

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

PROBLEMA # 2



1. $\begin{cases} \frac{dM}{dt} = \dot m_1^{\leftarrow} + \dot m_2^{\leftarrow} - \dot m_3^{\rightarrow} = 0 \\ \frac{dE}{dt} = \dot m_1 h_1 + \dot m_2 h_2 - \dot m_3 h_3 - \cancel{\dot Q} = 0 \end{cases}$ (RP) (Ad)

$\begin{cases} \dot m_3 = \dot m_1 + \dot m_2 \\ \dot m_1 h_1 + \dot m_2 h_2 - (\dot m_1 + \dot m_2) h_3 = 0 \end{cases}$

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

$\dot m_2 = \frac{3064{,}2 - 2748{,}7}{2748{,}7 - 167{,}66}\times 1 = 0{,}122\ \frac{kg}{s}$

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

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

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

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

2. $\frac{dS}{dt} = \dot m_1 s_1 + \dot m_2 s_2 - \dot m_3 s_3 - \cancel{\frac{\dot Q}{T}} + \dot S_{gen} = 0$ (Ad.) (RP)

$\dot S_{gen} = \dot m_3 s_3 - \dot m_1 s_1 - \dot m_2 s_2$

$\dot S_{gen} = 1{,}122\times 6{,}8213 - 1\times 7{,}4599 +$

$- 0{,}122\times 0{,}5725 = 0{,}124\ \frac{kW}{K}$

$s_1 = 7{,}4599\ \frac{kJ}{kg\,K}$

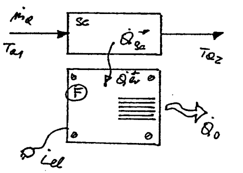
$s_3 = 6{,}8213$ "

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

$\hookrightarrow$ IRREVERSIBILE!

3. $\dot L_{dis} = T_0 \dot S_{gen} = 293\times 0{,}124 = 36{,}2\ kW$

PROBLEMA # 3



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

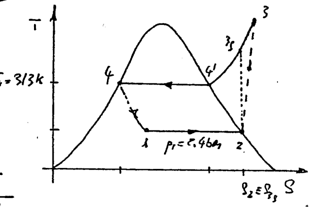
$\dot m_{a2}^{\rightarrow} = \dot m_{a1}^{\leftarrow} = \dot m_a$

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

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

2. $\begin{cases} \frac{dM^{ev}}{dt} = \dot m_1 - \dot m_2 = 0 \\ \frac{dE^{ev}}{dt} = \dot m_1 h_1 - \dot m_2 h_2 + \dot Q_{ev}^{\leftarrow} = 0 \end{cases}$ (RP)

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



$\rightarrow \dot m_1 = \frac{\dot Q_{ev}}{h_2 - h_4} = \frac{14{,}35}{244{,}1 - 106{,}2} = 0{,}104\ \frac{kg}{s}$

$= 374{,}6\ kg/h$

VALVOLA

$\begin{cases} \frac{dM^v}{dt} = \dot m_4 - \dot m_1 = 0 \\ \frac{dE^v}{dt} = \dot m_4 h_4 - \dot m_1 h_1 - \cancel{\dot Q} - \cancel{\dot L} = 0 \end{cases}$ (RP)

$\hookrightarrow h_1 = h_4 = \tilde h_{ls}(4)$

$T_4 = 313\,K = 40°C \rightarrow h_4 = 106{,}2\ \frac{kJ}{kg}$

$h_2 = h_{vs}(p_1) = 244{,}1\ \frac{kJ}{kg}$

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

$\begin{cases} \frac{dM^c}{dt} = \dot m_2 - \dot m_3 = 0 \\ \frac{dE^c}{dt} = \dot m_2 h_2 - \dot m_3 h_{3s} - \cancel{\dot Q} + \dot L_{id}^{C\leftarrow} = 0 \\ \frac{dS^c}{dt} = \dot m_2 s_2 - \dot m_3 s_{3s} - \cancel{\frac{\dot Q}{T}} + \cancel{\dot S_{gen}} = 0 \end{cases}$ (RP) (R.I.)

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

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

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

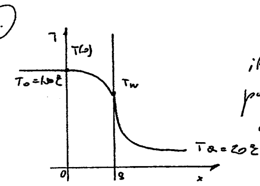
$\dot L_{id} = 0{,}104(273{,}6 - 244{,}1) = 3{,}07\ kW$

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

4. $\varepsilon_F = \frac{\dot Q_{ev}^{\leftarrow}}{\dot L^{C\leftarrow}} = \frac{14{,}35}{4{,}39} = 3{,}27$

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:

$q(0) = 0$

$T(0) = T_0$

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

$T = -\frac{\sigma}{2k}x^2 + \cancel{C_1 x} + C_2$ & $q(x) = -k\frac{dT}{dx} = \sigma x - \cancel{C_1 k}$

$q(0) = 0 \rightarrow \sigma\cdot 0 - C_1 k = 0 \rightarrow C_1 = 0$

$T(0) = C_2 = T_0 = 100°C$

$\begin{cases} T = T_0 - \frac{\sigma}{2k}x^2 \\ q = \sigma x \end{cases}$

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

$\sigma = \frac{h(T_0 - T_a)}{s + h s^2/2k} = \frac{5(100 - 20)}{0{,}005 + 5(0{,}005)^2/2\cdot 0{,}2} = 75\,294{,}12\ W/m^3$

3. $T(s) = T_0 - \frac{\sigma s^2}{2k} = 100 - \frac{75\,294{,}12\times(0{,}005)^2}{2\times 0{,}2} = 95{,}3\ °C$

4. $q(s) = \sigma s = 75\,294{,}12\times 0{,}005 = 376{,}47\ W/m^2$

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

$q_{rad} = \frac{\sigma(T_w^4 - T_a^4)}{\frac{1-\varepsilon_1}{\varepsilon_1} + \frac{1}{F_{12}} + \frac{(1-\varepsilon_2)A_1}{\varepsilon_2 A_2}} = \sigma\varepsilon_1(T_w^4 - T_a^4)$

$F_{12} = 1$, $A_2 \to \infty$

$\varepsilon_1 = \frac{q_{rad}}{\sigma(T_w^4 - T_a^4)} = \frac{36{,}647}{5{,}67\,[3{,}6845^4 - 2{,}9315^4]} = 0{,}06 \rightarrow \rho = 1 - \alpha = 1 - \varepsilon = 0{,}94$ (opaco) (Kirchhoff)

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

$G_r = \frac{\rho^2 g\,\alpha_p (T_w - T_a) H^3}{\mu^2} = \frac{(1{,}1181)^2\, 9{,}81\times 0{,}003\,(95{,}3 - 20)\times(0{,}3)^3}{(19{,}05\cdot 10^{-6})^2} = 2{,}077\cdot 10^8$

$P_r = \frac{\mu c_p}{k} = \frac{19{,}05\cdot 10^{-6}\times 1007{,}4}{0{,}0273} = 0{,}7$, $R_a = G_r \cdot P_r = 1{,}454\cdot 10^8$

$N_u = 0{,}59\,R_a^{0{,}25} = 64{,}85 \longrightarrow h = \frac{N_u k}{H} = \frac{64{,}85\times 0{,}0273}{0{,}3} = 5{,}9\ \frac{W}{m^2 K}$