Soluzione del compito di Fisica Tecnica del 9 settembre 2015

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

La valutazione della prova scritta si basa in modo paritario sullo svolgimento formale e su quello numerico.
Per essere ammessi all'orale è necessario riportare una votazione dello scritto di almeno 16/30,
non ci sono penalità per chi riporta una votazione non inferiore a 10/30

PROBLEMA #1

1) $\exists\, PM_2 \iff (S_2-S_1)^C \geq 0$

$(S_2-S_1)^C = (S_2-S_1)^A + (S_2-S_1)^P =$

$= m_A c_p \left(\ln \frac{T_2^A}{T_1^A} - \frac{R}{c_p} \ln \frac{p_2}{p_1} \right) + m_P c \ln \frac{T_2^P}{T_1^P} =$

$A: T_2 = T_1,\ p_2 = ...$

$= 11{,}9 \cdot 10^{-3} \times 1003{,}5 \left(\ln \frac{373}{293} - \frac{2}{7} \ln \frac{10}{1} \right) + 0{,}002 \times 700 \ln \frac{373}{293} =$

$= -4{,}975 + 0{,}338 = -4{,}637\ \frac{J}{K} < 0 \rightarrow \nexists\, PM_2!$

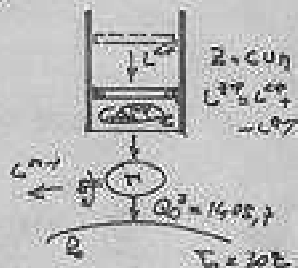
$m_A = \frac{p_1 V_1}{R^* T_1} = \frac{10^5 \times 0{,}010}{286{,}7 \times 293} = 11{,}9 \cdot 10^{-3}\ kg$

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

$c_p = \frac{7}{2} R^* = 1003{,}5\ J/kg\,K$

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

2) $\begin{cases} (U_2-U_1)^Z = -Q_0^{2\to} + L^{2\leftarrow} \\ (S_2-S_1)^Z = -S_{Q_0}^{2\to} + S_{irr}^Z \end{cases}$ $\quad \begin{cases} (U_2-U_1)^C + (U_2-U_1)^R = -Q_0^{2\to} + L^{2\leftarrow} \\ (S_2-S_1)^C + (S_2-S_1)^R = -Q_0^{2\to}/T_0 \end{cases}$ (q.l.r.)



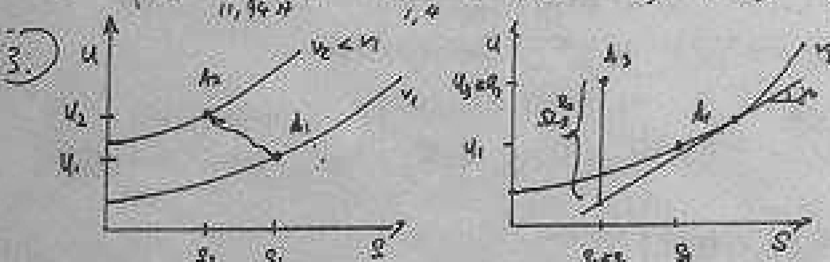
$\begin{cases} L^{2\leftarrow} = (U_2-U_1)^C + Q_0^{2\to} = (U_2-U_1)^A + (U_2-U_1)^P + Q_0^{2\to} \\ Q_0^{2\to} = -T_0 (S_2-S_1)^C = +4{,}637 \times 303{,}15 = 1405{,}7\ J \end{cases}$

$L^{2\leftarrow} = m_A c_v (T_2 - T_1) + m_P c (T_2 - T_1) + Q_0^{2\to} = (m_A c_v + m_P c)(T_2 - T_1) + Q_0^{2\to}$

$L^{2\leftarrow} = (11{,}9 \cdot 10^{-3} \times 1003{,}5 + 0{,}002 \times 700)(100-20) + 1405{,}7 = 2473\ J = L^{C\leftarrow} - L^{R\to}$

(11,947; 1,4)

3.



4) $\begin{cases} (U_2-U_1)^Z = -Q^{1 2\to} + L^{1 2\leftarrow} \\ (S_2-S_1)^Z = -S_{Q}^{1 2\to} + S_{irr}^Z \end{cases}$ $\quad \begin{cases} (U_2-U_1)^A + (U_2-U_1)^P = -Q_0^{1 2\to} + L^{1 2\leftarrow} \\ (S_2-S_1)^A + (S_2-S_1)^P = -Q_0^{1 2\to}/T_0 \end{cases}$ $\quad (U_2-U_1)^P = 0,\ (S_2-S_1)^P = 0$

$\begin{cases} L^{1 2\leftarrow} = (U_2-U_1)^A + Q_0^{1 2\to} = (956{,}3 + 1508{,}2)\ J = 2463{,}5\ J \\ Q_0^{1 2\to} = -T_0 (S_2-S_1)^A = +4{,}975 \times 303{,}15 = 1508{,}2\ J \end{cases}$

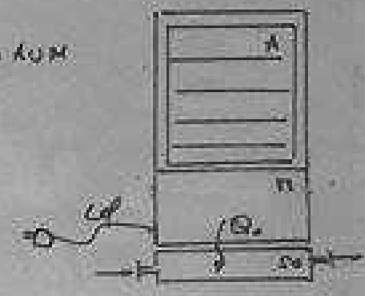
$\varepsilon_Q = \left| 1 - \frac{Q_0'}{Q_0} \right| = \left| 1 - \frac{1508{,}2}{1405{,}7} \right| = 7{,}29\% < 10\%$ ok!

$\varepsilon_L = \left| 1 - \frac{L'}{L} \right| = \left| 1 - \frac{2463{,}5}{2473} \right| = 0{,}38\% < 10\%$ ok!

PROBLEMA #2

(1-2) $\tau = 1\,h$

$\begin{cases} (U_2-U_1)^Z = L_{el}^{2\leftarrow} + Q_0^{2\leftarrow} \\ (S_2-S_1)^Z = S_Q^{2\leftarrow} + S_{irr}^Z \end{cases}$



$(U_2-U_1)^Z = (U_2-U_1)^A + (U_2-U_1)^R = Mc\,(T_2-T_1)^A$ (L.I.)

$(S_2-S_1)^Z = (S_2-S_1)^A + (S_2-S_1)^R = Mc \ln \frac{T_2}{T_1}$ (L.I.)

$S_Q^{2\leftarrow} = \frac{Q_0^{2\leftarrow}}{T_0}$ (q.l.r.)

$\begin{cases} Q_0^{2\leftarrow} = (U_2-U_1)^Z - L_{el}^{2\leftarrow} = Mc(T_2-T_1) - L_{el} \\ S_{irr} = (S_2-S_1)^Z - S_Q^{2\leftarrow} = Mc \ln \frac{T_2}{T_1} - \frac{Q_0^{2\leftarrow}}{T_0} \end{cases}$ $\quad M = 50 \times 0{,}5 = 25\ kg$

$\begin{cases} Q_0^{\leftarrow} = 25 \times 4186 (5-20) - 0{,}2 \times 3{,}6 \cdot 10^6 = -2'289'750\ J \quad (-1'569'750) \\ S_{irr} = 25 \times 4186 \ln \frac{278{,}15}{293{,}15} + \frac{2'289'750}{323{,}15} = 1589{,}1\ \frac{J}{K} \quad (-5496{,}6 + 7085{,}7) \end{cases}$

FUNZIONA? DA a' IRREV.!

(3.)

$\begin{cases} U_2 - U_1 = L'_{el} + Q_0'^{2\leftarrow} \\ S_2 - S_1 = S'_{Q_0} + S'_{irr} = \frac{Q_0'}{T_0} \end{cases}$ $\quad \begin{cases} L'_{el} = (U_2-U_1) - T_0 (S_2-S_1) \\ Q_0' = T_0 (S_2-S_1) \end{cases}$

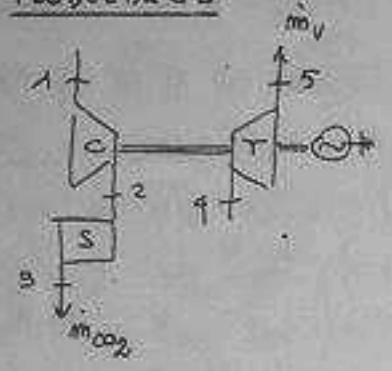
(L.I.)

$L'_{el} = Mc\,(T_2-T_1) - M c T_0 \ln \frac{T_2}{T_1} =$

$= -1'569'750 + 323{,}15 \times 5495{,}6 = 205'484\ J = 0{,}057\ kWh$

$1'776'234$

Problema 3



④ VAP. SURR.:

$p = 35$ MPa

T (°C)	h (kJ/kg)	s (kJ/kgK)
350	3104,0	6,6579
400	3 222,3	6,8405

$h_4 = 3104 + 0,4(3222,3 - 3104,0) =$
$\simeq 3151,3$ kJ/kg

$s_4 = 6,6579 + 0,4(6,8405 - 6,6579) =$
$\simeq 6,7309$ kJ/kg

⑤ VAP. UMIDO: $h_5 = (1-x_5)h_{5,LS} + x_5 h_{5,VS} = 0,15 \cdot 251,40 + 0,85 \cdot 2609,7 =$
$p_5 = 20$ kPa $\simeq 2256,0$ kJ/kg

$s_5 = (1-x_5)s_{5,LS} + x_5 s_{5,VS} = 0,15\,0,8320 + 0,85\,7,3086 =$
$= 6,8471$ kJ/kg $> s_4 \rightarrow$ ESP. ADIAB. IRREV.

$L_{t,T} = \dot{m}_v (h_4 - h_5) = \frac{100}{3600}(3151,3 - 2256,0) = 24,9$ kW

$L_{GE} = L_{t,T} - L_{t,C} = 24,9 - 4 = 20,9$ kW

$x_{5s} = \frac{s_4 - s_{5,LS}}{s_{5,VS} - s_{5,LS}} = \frac{6,7309 - 0,8320}{7,0766} = 0,834 < x_5$ (ok)

$h_{5s} = (1-x_{5s})h_{5,LS} + x_{5s} h_{5,VS} = 0,166\,251,40 + 0,834 \cdot 2609,7 =$
$\simeq 2218,2$ kJ/kg

$\eta_{s,T} = \frac{h_4 - h_5}{h_4 - h_{5s}} = \frac{3151,3 - 2256,0}{3151,3 - 2218,2} = 0,96$

$c_{p,CO_2} = \frac{\gamma}{2}\frac{R_u}{M_m} = \frac{\gamma}{2}\frac{8314}{44} = 661,3 \frac{J}{kgK}$ $(\delta = c = 0)$

$L_{t,C} = \dot{m}_{CO_2} c_{p,CO_2}(T_2 - T_1) \rightarrow T_2 = T_1 + \frac{L_{t,C}}{\dot{m}_{CO_2} c_{p,CO_2}} =$

$= 15 + \frac{4000 \cdot 3600}{25 \cdot 661,3} = 886,01$ °C

$\dot{Q}_s = \dot{m}_{CO_2} c_{p,CO_2}(T_3 - T_2) = \frac{25}{3600} \cdot 661,3 \cdot (10 - 886,01) = -3809,3$ W

$T_{2s} = T_1 \left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}} = 288,15 \cdot 100^{0,1/1,4} = 1074,11$ K $= 800,96$ °C $< T_2$

$\eta_{t,C} = \frac{T_{2s} - T_1}{T_2 - T_1} = \frac{800,96 - 15}{886,01 - 15} = 0,90$

Problema 4

① $\dot{Q}_{conv} = h \pi D_3 L (T_3 - T_a)$

$h = \frac{Nu\,k}{D_3}$

$Ra = Gr \cdot Pr = 3,784 \cdot 10^7 \times 7 = 2,652 \cdot 10^7$

$Gr = \frac{\beta^2 \rho g (T_3 - T_a) D_3^3}{\mu^2} = \frac{(1,1181)^2 3,21 \times 0,003 (34-15)(0,26)^3}{(19,04 \cdot 10^{-6})^2} = 3,784 \cdot 10^7$

$Pr = \frac{\mu c_p}{k} = \frac{19,04 \cdot 10^{-6} \times 1003,2}{0,0273} = 0,7$

$Nu = \left\{ 1 + \frac{0,387 (2,652 \cdot 10^7)^{1/6}}{\left[1 + (0,559/0,7)^{9/16}\right]^{8/27}} \right\}^2 = 42,5$

$\hookrightarrow h = \frac{42,5 \times 0,0273}{0,26} = 4,46$ W/m²K

$\hookrightarrow \dot{Q}_{conv} = 4,46 (\pi \, 0,26 \times 10)(34 - 15) = 692,9$ W

$\varepsilon = \alpha = 1 - \rho = 0,1$

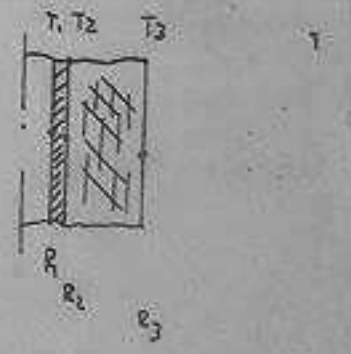
$\dot{Q}_{rad} = \sigma \varepsilon \pi D_3 L \left(T_3^4 - T_w^4\right) = 5,67 \cdot 10^{-8} \times 915 \times 2,165 \left(307,15^4 - 288,15^4\right) =$
$= 92,9$ W

$\dot{Q}_{dis} = 692,9 + 92,9 = 785,8$ W

② $R_1 = \frac{D_1}{2} - s_1 = \frac{6}{2} - 0,5 = 2,5$ cm

$h = 0,05$ m

$R_3 = \frac{D_e}{2} + s_{is} = \frac{5}{2} + 10 = 13$ cm, $D_3 = 0,26$ m



$T_1 = T_3 + \dot{Q}_{dis}\left(R_{k,t} + R_{k,is}\right) = T_3 + \dot{Q}_{dis}\left(\frac{\ln(R_2/R_1)}{2\pi k_t L} + \frac{\ln(R_3/R_2)}{2\pi k_{is} L}\right)$
$\quad 9000 \cdot 195 \qquad 9965 \cdot 750$

$= 34 + 785,8\left[\frac{\ln(6/5)}{\pi \cdot 20 \cdot 10} + \frac{\ln(26/6)}{2\pi \, 0,05 \times 12}\right] = 400$ °C $= 673,2$ K

$0,466\,895$