Es. 1

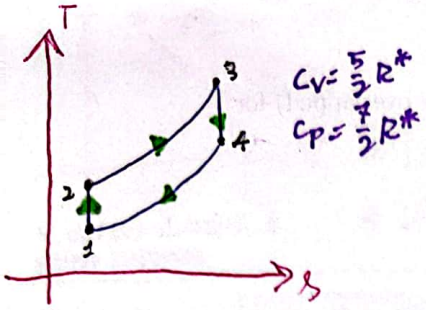
$\Delta V = 1800\,cc = \frac{1800 \cdot 10^{-6}\,m^3}{4} = V_1 - V_2 = 4{,}5 \cdot 10^{-4}\,m^3$

$r = \frac{V_1}{V_2} = 9$

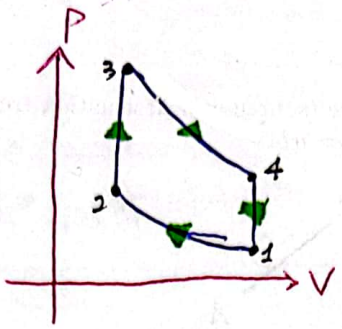
$\rightsquigarrow V_1 = 5{,}06 \cdot 10^{-4}\,m^3$

$V_2 = 5{,}63 \cdot 10^{-5}\,m^3$

$P_1 = 0{,}95 \cdot 10^5\,Pa \quad T_1 = 323{,}15\,°K \quad T_3 = 2773{,}15\,°K$



$C_V = \frac{5}{2}R^* \quad C_p = \frac{7}{2}R^*$



	P [Pa]	V [m³]	T [°K]
1	$0{,}95 \cdot 10^5$	$5{,}06 \cdot 10^{-4}$	323,15
2	$2{,}04 \cdot 10^6$	$5{,}63 \cdot 10^{-5}$	778,34
3	$7{,}25 \cdot 10^6$	$5{,}63 \cdot 10^{-5}$	2773,15
4	$3{,}35 \cdot 10^6$	$5{,}06 \cdot 10^{-4}$	1152,17

$R^* = \frac{R}{M_m = 28{,}8\,kg/kmol} = 288{,}7\,\frac{J}{kg\,°K}$

$PV = mR^*T \quad m = \frac{P_1 V_1}{R^* T_1} = 5{,}1 \cdot 10^{-4}\,kg$

1-2) $\Delta S = 0 = m\left(C_p \ln\left(T_2/T_1\right) + R^* \ln\left(V_2/V_1\right)\right) \rightarrow T_2 = 778{,}34\,°K \rightarrow P_2 = 2{,}04 \cdot 10^6\,Pa$

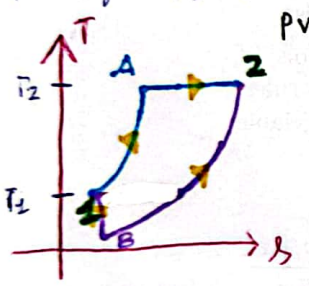
2-3) $\Delta V = 0 \quad V_3 = V_2 \rightarrow P_3 = 7{,}25 \cdot 10^6\,Pa$

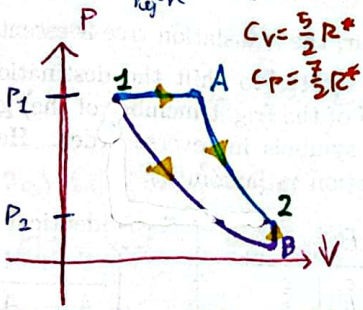
4-1) $\Delta V = 0 \quad V_4 = V_1$ 3-4) $\Delta S = 0 = m\left(C_V \ln\left(\frac{T_4}{T_3}\right) + R^* \ln\left(V_4/V_3\right)\right) \rightarrow T_4 = 1152{,}17\,°K \rightarrow P_4 = 3{,}35 \cdot 10^6\,Pa$

Es. 2

$m = 2\,kg \quad M_{N_2} = 28\,g/mol \rightarrow R^* = 296{,}95\,\frac{J}{kg\,°K} \quad P_1 = 6 \cdot 10^5\,Pa \quad T_1 = 293{,}15\,°K \quad P_2 = 2 \cdot 10^5\,Pa \quad T_2 = 343{,}15\,°K$

$PV = mR^*T$





$C_V = \frac{5}{2}R^* \quad C_p = \frac{7}{2}R^*$

	P [Pa]	V [m³]	T [°K]
I	$6 \cdot 10^5$	0,29	293,15
A	$6 \cdot 10^5$	0,34	343,15
B	$2{,}03 \cdot 10^5$	1,02	177,26
2	$2 \cdot 10^5$	1,02	343,15

$\Delta U = m C_V (T_2 - T_1) \quad \Delta H = m C_p (T_2 - T_1) \quad \Delta S = m\left(C_p \ln\left(T_2/T_1\right) - R^* \ln\left(P_2/P_1\right)\right) \quad \Delta V = V_2 - V_1$

$V_1 = 0{,}29\,m^3 \quad V_2 = 1{,}02\,m^3$

- $V_3 = 0{,}34\,m^3$ • $\Delta S = 0 = m\left(C_V \ln\left(T_B/T_3\right) + R^* \ln\left(V_B/V_1\right)\right) \rightarrow T_B = 177{,}26\,°K \quad P_B = 1{,}03 \cdot 10^5\,Pa$

- $Q_{1A} + Q_{A2} = P_2(V_2 - V_1) + mC_p(T_A - T_1) + mR^* T_2 \ln\left(V_2/V_1\right) = 363150\,J$

  $L_{1A} + L_{A2} = P_1(V_2 - V_1) + R^* T_2 \ln\left(V_2/V_1\right) = 253705$

- $Q_{1B} + Q_{B2} = 0 + mC_V(T_2 - T_B) = 363150\,J$

  $L_{1B} + L_{B2} = -mC_V(T_B - T_1) + 0 = 253570\,J$

Es. 3

$m = 0{,}3\,kg$ GAS BIATOMICO $T_1 = 89{,}15\,°K \quad P_1 = 10^5\,Pa \quad \beta = \frac{V_1}{V_4} = 1 \quad P_3 = 10^6\,Pa \quad M_{N_2} = 28 \cdot 10^{-3}\,\frac{kg}{mol}$

$P_3 T_3 = mR^* T_3 \quad R^* = 296{,}9\,\frac{J}{kg\,°K}$ $V_1 = 0{,}765\,m^3$ $V_2 = 0{,}066\,m^3 \rightarrow T_2 = 740\,°K$ $L = -\Delta U = -mC_V(T_3 - T_2) = -9{,}81 \cdot 10^4\,J$

$\Delta S = m\left(C_p \ln\left(\frac{T_2}{T_1}\right) - R^* \ln\left(\frac{P_2}{P_1}\right)\right) = 78{,}3\,\frac{J}{°K} > 0 \Rightarrow$ IRREV.

- $\Delta S_{1D} = 0 \quad m\left(C_p \ln\left(\frac{T_2}{T_1}\right) - R^* \ln\left(\frac{P_{2D}}{P_1}\right)\right) = 0 \rightarrow P_{2D} = 2{,}12 \cdot 10^6\,Pa$

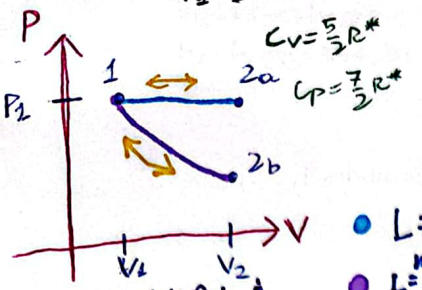
  $L_{1D} = L_R$

Es. 4

$T_1 = 293{,}15°K$ $P_1 = 58 \cdot 10^5 Pa$ $V_1 = 0{,}1\ m^3$ $V_2 = 0{,}3 m^3$ $R^* = 287 \frac{J}{kg°K}$ BIATOMICO

$P_1 V_1 = m R^* T_1 \rightarrow m = 6{,}89 kg$

$C_v = \frac{5}{2} R^*$ $C_p = \frac{7}{2} R^*$



	P [Pa]	V [m³]	T [°K]
1	$58 \cdot 10^5$	0,1	293,15
2a	$58 \cdot 10^5$	0,3	879,93
2b	$19{,}33 \cdot 10^5$	0,3	293,15

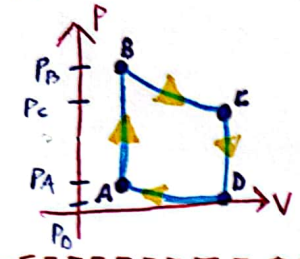
- $T_{2a} = \frac{P_{2a} V_{2a}}{m R^*} = 879{,}93°K$
- $P_{2b} = \frac{m R^* T_{2b}}{V_{2b}} = 19{,}3 \cdot 10^5 Pa$

- $L = P \cdot (V_{2a} - V_1) = 1{,}16 \cdot 10^6 J$ $\Delta U = m C_v (T_{2a} - T_1) = 2{,}9 \cdot 10^6 J$ $\Delta Q = \underset{=\Delta H}{m C_p (T_{2a} - T_1)} = 4{,}06 \cdot 10^6 J$
- $L = m R^* T \ln\left(\frac{V_{2b}}{V_1}\right) = 6{,}4 \cdot 10^5 J$ $\Delta U = 0$ $\Delta H = 0$ $Q = L = 6{,}4 \cdot 10^5 J$

SI NOTI CHE $\Delta U = Q - L$ È SEMPRE RISPETTATA

Es. 5

$n = 2 mol$ $PV = nRT$



	P [Pa]	V [m³]	T [°K]
A	$2 \cdot 10^5$	0,01	122
B	$8 \cdot 10^5$	0,01	488
C	$2{,}285 \cdot 10^5$	0,04	488
D	$0{,}571 \cdot 10^5$	0,04	122

$\Delta U_{TOT} = 0$

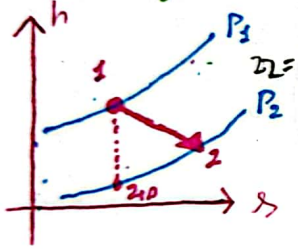
$\rightarrow Q_{TOT} = L_{TOT}$

$L_{TOT} = L_{AB} + L_{BC} + L_{CD} + L_{DA}$

$Q_{TOT} = 0 + nR T_B \ln(V_C/V_B) + 0 + nR T_D \ln(V_A/V_D) = 8{,}4 \cdot 10^3 J$

Es. 6

$l_R = 2000 \frac{kJ}{kg}$ $M_{He} = 4 \cdot 10^{-3} \frac{kg}{mol}$ MONOATOMICO $P_1 = 8 Bar = 8 \cdot 10^5 Pa$ $T_1 = 1073{,}15°K$ $P_2 = 2 \cdot 10^5 Pa$ η_2?



$l_{1D} = C_p (T_2 - T_{2iD})$

$C_p = \frac{5}{2} R^*$ $C_v = \frac{3}{2} R^*$ $R^* = \frac{R}{M_{He}} = 2078{,}62 \frac{J}{kg°K}$

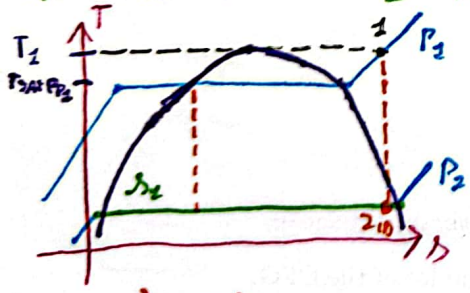
$\eta = \frac{l_R}{l_{1D}}$

1-2iD) $\Delta s = 0 = m\left(C_p \ln\left(\frac{T_{2iD}}{T_1}\right) - R^* \ln\left(\frac{P_2}{P_1}\right)\right)$ $\frac{5}{2} \ln\left(\frac{T_{2iD}}{T_1}\right) - \ln\left(\frac{P_2}{P_1}\right) = 0 \rightarrow T_{2iD} = 616{,}36°K$

$\Rightarrow \eta = \frac{l_R}{C_p (T_{2iD} - T_1)} = 84{,}3\%$

Es. 7

$P_1 = 20 MPa$ $T_1 = 500°C$ $P_2 = 0{,}7 MPa$ $l_R = 650 \frac{kJ}{kg}$



$\eta = \frac{l_R}{l_{1D}}$ $l_{1D} = h_1 - h_{2iD}$ $T_1 > T_{SAT} @ P_1 \rightarrow$ ACQUA SURRISCALDATA

$h_1 = h(20MPa, 500°C) = 3393{,}5 \frac{kJ}{kg}$

$s_1 = s_{2iD} = s(20MPa, 500°C) = 6{,}3348 \frac{kJ}{kg°K}$

$s_v @ P_2 = 6{,}7080 \frac{kJ}{kg°K}$ $s_1 @ P_2 = 1{,}9922 \frac{kJ}{kg°K}$ $s_1 < s_{2iD} < s_v$

$x = \frac{s_{1D} - s_1}{s_v - s_1} = 0{,}92$ $h_2 = (1-x) h_1 @ P_2 + x h_v @ P_2 = 2508{,}19 \frac{kJ}{kg} \rightarrow \eta_2 = 81{,}7\%$

Es. 8

$H = 100m$ $d = 100m$ $T_1 = 283{,}15°K$ $P_1 = 10^5 Pa$ $w_1 = 12 m/s$ $w_2 = 3 m/s$ $\eta_2 = 60\%$ $\dot{L}$?

BILANCIO DI ENERGIA $\dot{m}\left(h_2 - h_1 + g(z_2 - z_1) + \frac{w_2^2 - w_1^2}{2}\right) + \dot{Q} - \dot{L} = 0$

$h_2 - h_1 = c_p \Delta T$! $\Delta T \approx 0$ SUPPONIAMO ADIABATICA

$M_{ARIA} = 28{,}8 \frac{kg}{kmol}$

$\dot{L} = 60\% \cdot \left(\dot{m} \frac{w_2^2 - w_1^2}{2}\right)$

EQUAZIONE DI CONTINUITÀ $\dot{m} = \rho w \Omega = P_1 w_1 \left(\pi \frac{D^2}{4}\right)$ $\rho_1 = 1/v_1$

$P_1 v_1 = R^* T_1$ $v_1 = \frac{R/M \cdot T_1}{P_1} = 0{,}82 m^3/kg \rightarrow \dot{m} = 11{,}3 \cdot 10^{-4} kg/s$

$\dot{L} = 4{,}7 MW$

ES. 9 $= 0{,}27\ MPa$

$P = 2{,}7 \cdot 10^5\ Bar$ $M_1 = 4\ kg$ $x_1 = 0{,}2$ $M_2 = 2\ kg$ $x_2 = 1$ $T_2 = 353{,}15\ °K$ T_{eq} ?

$\Delta H = 0$ $M_{tot} h_{eq} = M_1 h_1 + M_2 h_2$ $M_{tot} = 6\ kg$

$h_1 = (1-x) h_l @P + x h_v @P = 0{,}2 \cdot 546{,}31 + 0{,}8 \cdot 2720{,}5 = 984{,}15\ \frac{kJ}{kg}$

$h_2 = h_v @T_2 = 334{,}91\ \frac{kJ}{kg}$ $h_{eq} = \frac{M_1 h_1 + M_2 h_2}{M_{tot}} = 765{,}74\ \frac{kJ}{kg}$

$h_{eq} > h_l \Rightarrow$ SISTEMA BIFASE $T_{eq} = T_{SAT}(0{,}27\ MPa) = 130°C$

ES. 10

CILINDRATA $= 0{,}0018\ m^3$ $\beta = \frac{V_1}{V_2} \Rightarrow T_3 = 273{,}15\ °K$ $P_1 = 0{,}95 \cdot 10^5\ Pa$ $T_1 = 323{,}15\ °K$ $M_m = 28{,}8 \cdot 10^{-3}\ \frac{kg}{mol}$ η?

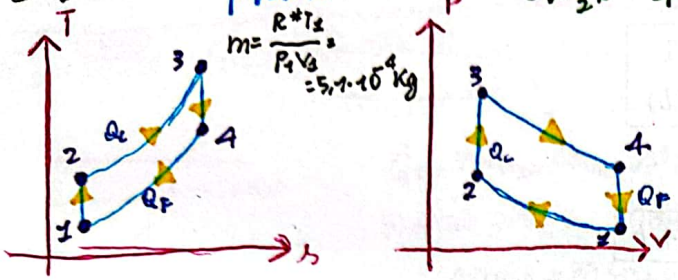
$\Delta V = V_1 - V_2 = \frac{CILINDRATA}{4} = 4{,}5 \cdot 10^{-4}\ m^3$

$\frac{V_1}{V_2} = 9$

$\rightarrow V_3 = 5{,}0625 \cdot 10^{-4}\ m^3$, $V_2 = 0{,}5625 \cdot 10^{-4}\ m^3$ $R^* = \frac{R}{M_m} = 288{,}7\ \frac{J}{kg\,°K}$

$PV = mR^*T$ $m = \frac{R^* T_1}{P_1 V_1} = 5{,}1 \cdot 10^{-4}\ kg$

$c_v = \frac{5}{2} R^*$ $c_p = \frac{7}{2} R^*$



	P [Pa]	V [m^3]	T [°K]
1	$0{,}95 \cdot 10^5$	$5{,}0625 \cdot 10^{-4}$	323,15
2	$2{,}04 \cdot 10^6$	$0{,}5625 \cdot 10^{-4}$	778,34
3	$7{,}25 \cdot 10^6$	$0{,}5625 \cdot 10^{-4}$	2773,15
4	$3{,}35 \cdot 10^6$	$5{,}0625 \cdot 10^{-4}$	1152,17

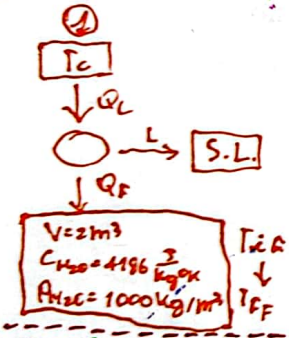
1-2) $\Delta S = 0 = m\left(c_v \ln(T_2/T_1) + R^* \ln(V_2/V_1)\right) \rightarrow T_2 = 778{,}34\ °K$ $P_2 = 2{,}04 \cdot 10^6\ Pa$

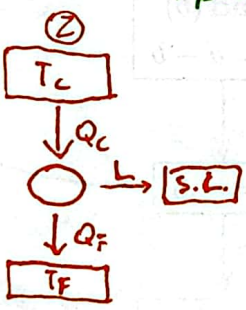
2-3) $V_3 = V_2 \rightarrow P_3 = 7{,}25 \cdot 10^6$ 4-1) $V_4 = V_1$ 3-4) $\Delta S = 0 = \frac{5}{2} \ln(T_4/T_3) + \ln(V_4/V_3) \rightarrow T_4 = 1152{,}17\ °K$ $P_4 = 3{,}35 \cdot 10^6\ Pa$

$\eta_2 = 1 - \frac{Q_F}{Q_C} = 1 - \frac{mc_p(T_4 - T_1)}{mc_p(T_3 - T_2)} = 58{,}4\%$

ES. 33 $\Sigma m = 0$

$T_C = 673{,}15\ °K$ ① $V_F = 2\ m^3$ $T_{ingr} = 288{,}15\ °K$ $T_{PF} = 318{,}15\ °K$ ② $T_F = 288{,}15\ °K$ η_{II}?





$\eta = 1 - \frac{Q_F}{Q_C}$

① $Q_C = m c_{H_2O} T_C \ln(T_{PF}/T_{ingr})$ $Q_F = m c_{H_2O}(T_{PF} - T_{ingr})$ $\rightarrow \eta_2 = 55\%$

② $\eta_2 = 1 - \frac{T_F}{T_C} = 57{,}2\%$

$\eta_{II} = \frac{\eta_1}{\eta_2} = 96{,}2\%$

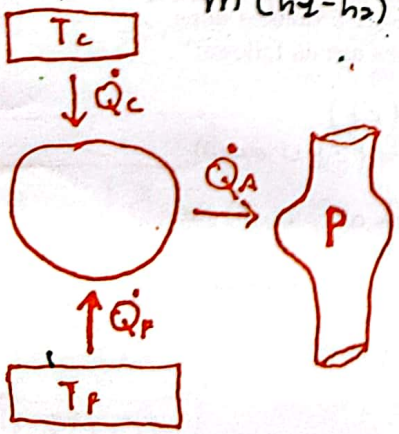
$\dot{V}_1 = 700\ m^3/h$ **ES. 0** $T_1 = 273{,}15\ °K$ $P_1 = 10^5\ Pa$ $T_2 = 313{,}15\ °K$ TDC $T_F = 273{,}15\ °K$ $T_C = 363{,}15\ °K$ $\dot{Q}_A$? $\dot{Q}_C$? $\dot{Q}_F$? ε?

$\dot{m}(h_1 - h_2) + \dot{Q}_A - \cancel{L} = 0$ ($\Sigma_{irr} = 0$) $\dot{m} = \frac{\dot{V}_1}{v_1}$ $PV_1 = R^* T_1$ $R^* = 288{,}7\ \frac{J}{kg\,°K}$

$\rightarrow \dot{m} = \frac{\dot{V}_1}{v_1} = 0{,}2468\ m^3/s \rightarrow \dot{m} = 0{,}2773\ kg/s$

$h_1 - h_2 = c_p(T_1 - T_2)$

$\dot{Q}_A = \dot{m} \cdot \frac{7}{2} R^* (T_2 - T_1) = 9{,}94 \cdot 10^3\ W$



BILANCIO ENERGIA $\dot{Q}_A = \dot{Q}_C + \dot{Q}_F$

BILANCIO ENTROPIA $\frac{\dot{Q}_C}{T_C} + \frac{\dot{Q}_F}{T_F} - \dot{m}\left(c_p \ln(T_2/T_1) - \cancel{R^* \ln(P_2/P_1)}\right) = 0$

$\rightarrow \dot{Q}_C = 2{,}67 \cdot 10^3\ W$

$\dot{Q}_F = 7{,}27 \cdot 10^3\ W$

$\varepsilon = \frac{\dot{Q}_A}{\dot{Q}_C} = 3{,}72$

ES.13

$\dot{m} = 1\,kg/s$ $T_1 = 473{,}15\,K$ $x_1 = 1$ $T_2 = 298{,}15\,K$ $P_2 = 0{,}1\,MPa$ $T_{amb} = 288{,}15\,K$ L?

SISTEMA APERTO A

$\dot{Q}_C$ → L S.L. → $\dot{Q}_F$ → T_{amb}

(A) $\dot{m}\left(h_1 - h_2 + g(z_1 - z_2) + \frac{w_1^2 - w_2^2}{2}\right) + \dot{Q}_C - L = 0$

$\rightarrow \dot{Q}_C = \dot{m}(h_1 - h_2)$

$h_1 = h_v(200°C) = 2793{,}15 \frac{kJ}{kg}$ $s_1 = s_v(200°C) = 6{,}4323 \frac{kJ}{kg\,K}$

$T_2 < T_{SAT}(0{,}1\,MPa)$ $h_2 = h_l(25°C) = 104{,}89 \frac{kJ}{kg}$ $s_2 = s_l(25°C) = 0{,}3671 \frac{kJ}{kg\,K}$

$\Rightarrow \dot{Q}_C = 2{,}7 \cdot 10^3\,kW$

BILANCIO ENTROPIA $\dot{m}(s_2 - s_1) + \frac{\dot{Q}_F}{T_{amb}} = 0 \rightarrow \dot{Q}_F = 1{,}75 \cdot 10^3\,kW$ $L = 9{,}5 \cdot 10^2\,kW$

ES.14

$\dot{Q}_C = 20\,kW$ $T_{1H_2O} = 306{,}15\,K$ $T_{2H_2O} = 310{,}15\,K$ $T_{1ARIA} = 278{,}15\,K$ $T_{2ARIA} = 275{,}15\,K$ $\dot{m}_{H_2O}, \dot{m}_{ARIA}, L, \varepsilon$?

$c_{P_{H_2O}} = 4186 \frac{J}{kg\,K}$ $c_{P_{ARIA}} = \frac{7}{2} \cdot \frac{R}{M_{MARIA}} = 1020{,}45 \frac{J}{kg\,K}$

T_{1H_2O} → T_{2H_2O} → $\dot{Q}_C$ → L → $\dot{Q}_F$ → T_{1ARIA} → T_{2ARIA}

$\dot{Q}_C = \dot{m}_{H_2O} c_{P_{H_2O}} \Delta T_{H_2O} \rightarrow \dot{m}_{H_2O} = 1{,}19\,kg/s$

BILANCIO ENTROPIA $\dot{m}_{H_2O} \Delta s_{H_2O} - \dot{m}_{ARIA} \Delta s_{ARIA} = 0$

$\Delta s_{H_2O} = m\, c_{P_{H_2O}} \ln\left(\frac{T_{2H_2O}}{T_{1H_2O}}\right)$ $\Delta s_{ARIA} = c_{P_{ARIA}} \ln\left(\frac{T_{2ARIA}}{T_{1ARIA}}\right)$ $\rightarrow \dot{m}_{ARIA} = 5{,}95\,kg/s$

$\dot{Q}_F = \dot{m}_{ARIA} c_{P_{ARIA}} \Delta T_{ARIA} = 17{,}95\,kW$

$L = \dot{Q}_F - \dot{Q}_C = 2{,}05\,kW$

$\varepsilon_{PDC} = \frac{\dot{Q}_C}{L} = 9{,}76$

ES.15

$T_C = 473{,}15\,K$ $\dot{Q}_C = 2000\,kW$ → L → LAVORO → $\dot{Q}_F$ → $T_F = 293{,}15\,K$

$\eta_{II} = 50\%$

L?

$\eta_I = \frac{L}{Q_C}$ $\eta_{II} = \frac{\eta_I}{\eta_{ID}}$

$\eta_{ID} = 1 - \frac{T_F}{T_C} = 80{,}1\%$ $\rightarrow \eta_I = 40\%$

$L = \dot{Q}_C \cdot \eta_I = 40\,kW$

ES.16

$T_F = 273{,}15\,K$ $T_{1A} = 473{,}15\,K$ $P_{1A} = 2\,MPa$ $T_{1B} = 473{,}15\,K$ VAPORE $T_2 = 293{,}15\,K$ $P_2 = 0{,}1\,MPa$ L? $\dot{Q}_{C_A} = \dot{Q}_{C_B}$

$\dot{Q}_C$ → L S.L. → $\dot{Q}_F$ → $T_F = 273{,}15\,K$

(A) $T_{1A} < T_{SAT}@2MPa \rightarrow h_1 = h_l@200°C = 852{,}45 \frac{kJ}{kg}$ $s_1 = s_l@200°C = 2{,}3309 \frac{kJ}{kg\,K}$

(B) $h_2 = h_v@2MPa, 200°C = 2793{,}2 \frac{kJ}{kg}$ $s_2 = s_v@200°C = 6{,}4323 \frac{kJ}{kg\,K}$

$h_F = h_l@20°C = 83{,}96 \frac{kJ}{kg}$ $s_F = s_l@20°C = 0{,}2966 \frac{kJ}{kg}$

SUPPONIAMO $= 1\,kg/s$

$L = \dot{Q}_C - \dot{Q}_F$ $Q_C = \dot{m}_A \Delta h_A = \dot{m}_B \Delta h_B$ $\dot{m}_A (h_F - h_1) = \dot{m}_B (h_F - h_2)$

$\rightarrow \dot{m}_A = 3{,}53\,kg/s$

$\dot{m}_A \Delta s_A + \frac{\dot{Q}_F}{T_F} = 0$ (o $\dot{m}_B \Delta s_B$)

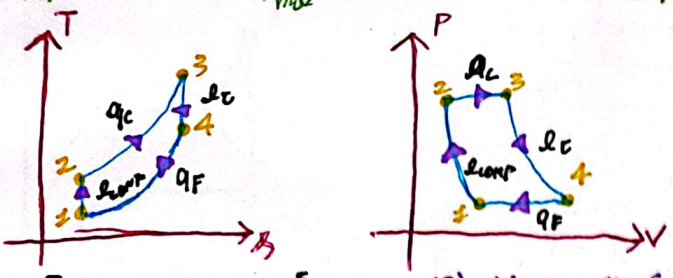
$\rightarrow \dot{Q}_C = 2{,}71 \cdot 10^3\,kW$

$\dot{Q}_F = 1{,}96 \cdot 10^3\,kW$

$L = 0{,}75 \cdot 10^3\,kW$

ES. 17

$M_m = 28{,}8 \cdot 10^{-3}\ kg/mol$ $r = 20$ q_c? T_4? η? $L = 250 MW = 250 \cdot 10^6 W$ $\dot{m}$? $v_3 = 100 m/s$ Ω_3?



	P [Pa]	T [°K]
1	10^5	300,15
2	$20 \cdot 10^5$	706,42
3	$20 \cdot 10^5$	1700,15
4	10^5	722,38

$R^* = 288{,}69 \frac{J}{mol\,°K}$

$c_v = \frac{5}{2} R^*$ $c_p = \frac{7}{2} R^*$

$r = P_2/P_1 \rightarrow P_2 = 20 \cdot 10^5 Pa$

12) $\Delta s = 0 = m c_p \ln(T_2/T_1) - R^* \ln(P_2/P_1) \rightarrow T_2 = 706{,}42 °K$

23) $\Delta P = 0$ 41) $\Delta P = 0$ 34) $\Delta s = 0 = c_p \ln(T_4/T_3) - R^* \ln(P_4/P_1) \rightarrow T_4 = 722{,}38 °K$

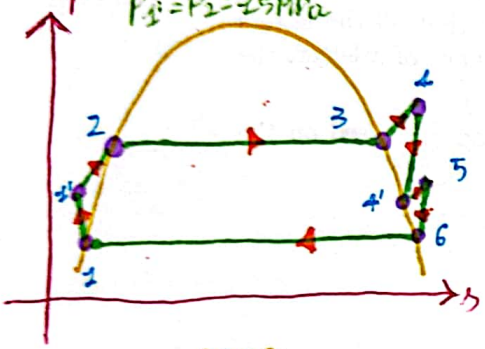
$q_c = c_p (T_3 - T_2) = 1004{,}08 \cdot 20^3 \frac{KJ}{Kg}$ $q_F = c_p (T_4 - T_1) = 426{,}63 \cdot 10^3 \frac{KJ}{Kg}$ $\eta = 1 - \frac{q_F}{q_c} = 57{,}58\%$

$L = \dot{m} (l_{TURBINA} - l_{COMPRESSORE}) = \dot{m} c_v ((T_3 - T_4) - (T_2 - T_1)) \rightarrow \dot{m} = \frac{L}{c_v ((T_3 - T_4) - (T_2 - T_1))} = 283{,}58 \frac{Kg}{s}$

EQUAZIONE DI CONTINUITÀ $\boxed{\dot{m} = \rho w \Omega}$ $\rho_3 = \frac{1}{v_3}$ $Pv = R^* T \rightarrow v_3 = \frac{R^* T_3}{P_3} = 4{,}91 m^3/Kg$ $\Omega_3 = 13{,}92 m^2$

$Q_c = \dot{m} q_c = 284{,}7 MW$ $Q_F = \dot{m} q_F = 120{,}98 MW$

$\dot{Q}_{cR} = 90\% \cdot Q_{F\,TB}$ $T_1 = 33°C$ TURBINA ALTA 4 = 600°C 15MPa 4' = 1MPa TURBINA BASSA 600°C, 1MPa $\eta_{RANKINE}$, L, $\eta_{CICLO\,COMBINATO}$?



	h [KJ/Kg]	s [KJ/Kg °K]
1	137,82	
1'	152,82	
2		
3		
4	3582,3	6,6776
4'	2806,98	6,6776
5	3697,9	8,0290
6	2440,32	8,0290

} NON RILEVANTI

32,88°C $\rightarrow$ DA TABELLA INP

① $h_1 = h_1 @ 33°C \simeq 137{,}82 \frac{KJ}{Kg}$

①' $h_{1'} - h_1 = v (P_{1'} - P_1)$ ASSUMIAMO $v = 0{,}001 m^3/Kg$ $P_1 = P @ 32{,}88°C = 5 KPa \rightarrow h_{1'} = 152{,}82 \frac{KJ}{Kg}$

②

③

④ $h_4 = h_6 (600°C, 15 MPa) = 3582{,}3 \frac{KJ}{Kg}$ $s_4 = s @ (600°C, 15 MPa) = 6{,}6776 \frac{KJ}{Kg\,°K}$

④' $s_{4'} = s_4$ DA VALUTARE SU 1MPa PESO $= \frac{s_4 - s_{@SAT}}{s_{@200°C} - s_{@SAT}} = \frac{0{,}85}{84{,}7}$ $h_{4'} = (1 - PESO) h_{@SAT} + PESO \cdot h_{@200°C} = 2806{,}98 \frac{KJ}{Kg}$

⑤ $h_5 = h @ (600°C, 1 MPa) = 3697{,}9 \frac{KJ}{Kg}$ $s_5 = s @ (600°C, 1 MPa) = 8{,}0290 \frac{KJ}{Kg\,°K}$

⑥ $s_6 = s_5$ DA VALUTARE SU $P_2 = 5 KPa$ $s_{@5KPa} = 8{,}3951 \frac{KJ}{Kg\,°K}$ $x = \frac{s_6 - s_{f@5KPa}}{s_{fg@5KPa}} = 0{,}95 \rightarrow h_6 = (1 - x) h_{f@5KPa} + x h_{g@5KPa} = 2440{,}32 \frac{KJ}{Kg}$

$\dot{m}_R = \frac{\dot{Q}_{cR}}{q_{cR}}$ $q_{cR} = (h_4 - h_1) + (h_5 - h_{4'}) = 4335{,}4 \frac{KJ}{Kg}$ $\dot{m}_R = 25{,}11 Kg/s$

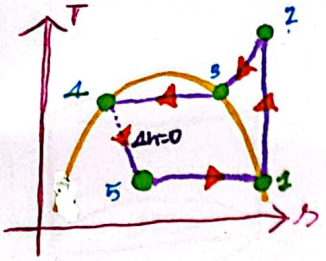
$L_R = \dot{m}_R (l_{TURBINA_1} + l_{TURBINA_2} - l_{POMPA}) = \dot{m} ((h_4 - h_{4'}) + (h_5 - h_6) - (h_{1'} - h_1)) = 50669{,}47 KW$

$\eta_R = \frac{L_R}{\dot{Q}_{cR}} = 46{,}54\%$

$\eta_{CICLO\,COMBINATO} = \frac{L_{TB} + L_R}{\dot{Q}_{cR}} = 100\%$

Es.18 (R134a)

$T_5 = T_1 = -28°C$ $P_2 = 0{,}8 MPa$ $\dot{Q}_F = 200 \cdot 10^3 W$ ε_F? $\dot{m}$? $\dot{Q}_c$? $\Delta \dot{S}_{4-5}$?



	$h\ [\frac{kJ}{kg}]$
1	230,38
2	274,84
3	NON RILEVANTE
4	93,42
5	93,42

$h_1 = h_{v@-28°C} = 239{,}38 \frac{kJ}{kg}$ $s_1 = s_{v@-28°C} = 0{,}9411 \frac{kJ}{kg°K}$

$s_2 = s_1$

$h_2 = h@(s_2, P_2)$

$PESO = \frac{s_2 - s_{@40°C}}{s_{@50°C} - s_{@40°C}} = 0{,}11$

$h_2 = (1-PESO)\, h_{@40°C} + PESO\, h_{@50°C} = 274{,}84 \frac{kJ}{kg}$

$h_4 = h_{v@0,8MPa} = 93{,}42 \frac{kJ}{kg}$ $s_4 = s_{v@0,8MPa} = 0{,}3439 \frac{kJ}{kg°K}$

$h_5 = h_4$

$\dot{L} = \dot{m}(h_2 - h_1)$

$h_5 = (1-x) h_{l@-28°C} + x \cdot h_{v@-28°C} \rightarrow x_5 = 0{,}137$

$\rightarrow s_5 = (1-x) s_{l@-28°C} + x\, s_{v@-28°C} = 0{,}382 \frac{kJ}{kg°K}$

$\varepsilon_F = \frac{Q_F}{L}$

$\dot{Q}_c = \dot{m}(h_2 - h_4)$

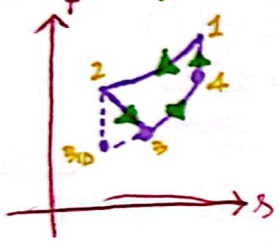
$\dot{Q}_F = \dot{m}(h_2 - h_5)$

$\Delta \dot{S}_{4-5} = \dot{m}(s_5 - s_4)$

$\dot{Q}_F = \dot{m} = \frac{\dot{Q}_F}{h_2 - h_5} = 1{,}46 kg/s$ $\dot{L} = 64{,}91 kW$ $\varepsilon_F = 3{,}08$ $\dot{Q}_c = 264{,}87 kW$ $\Delta \dot{S}_{4-5} = 0{,}053 \frac{kJ}{kg°K}$

Es.19 $\eta_C = 0{,}85$

$\dot{m} = 0{,}7 kg/s$ $\dot{Q}_c$? $\dot{Q}_F$? L_T? ε? (ARIA) $M_m = 28{,}8 \cdot 10^{-3} \frac{kg}{mol}$ BIATOMICO $\rightarrow c_p = \frac{7}{2} R^*$ $c_v = \frac{5}{2} R^*$



	T [°K]	P [Pa]
1	370	$3 \cdot 10^5$
2	310	$3 \cdot 10^5$
3	211,75	10^5
3ID	226,49	10^5
4	270	10^5

12) $\Delta P = 0$

34) $\Delta P = 0$

23ID) $\Delta s = 0 = m c_p \ln(\frac{T_2}{T_{3ID}}) - R^* \ln(\frac{P_2}{P_3})$

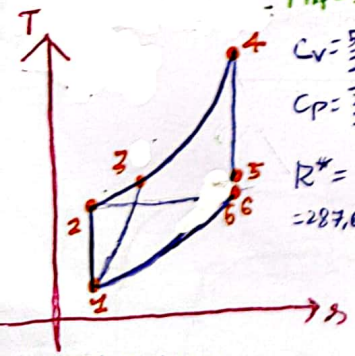
$\rightarrow T_{3ID} = 226{,}49°K$

$\eta_C = \frac{T_{3ID} - T_2}{T_3 - T_2} \rightarrow T_3 = 211{,}75°K$

$\dot{Q}_c = \dot{m} c_p (T_1 - T_2) = 4{,}24 \cdot 10^4 W$ $\dot{Q}_F = \dot{m} c_p (T_4 - T_3) = 4{,}12 \cdot 10^4 W$ $\dot{L}_C = 6{,}195 \cdot 10^4 W$ $\varepsilon = \frac{\dot{Q}_c}{\dot{Q}_F - \dot{Q}_c} = 6{,}24$

Es.20

$M_A = 28{,}9 \cdot 10^{-3} \frac{kg}{mol}$ $r = \frac{P_2}{P_1} = 6$ $W_{TV_2} = 150 \cdot 10^3 W$ P_5? $\dot{L}$? $\dot{m}$? T_3? η_T?



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

$c_p = \frac{7}{2} R^*$

$R^* = 287{,}69 \frac{J}{kg°K}$

	P [Pa]	T [°K]
1	$100 \cdot 10^3$	300
2	$600 \cdot 10^3$	500,55
3	$600 \cdot 10^3$	958,94
4	$600 \cdot 10^3$	1600
5	$375,48 \cdot 10^3$	1399,45
6	$100 \cdot 10^3$	958,94

$P_2 = 6 \cdot P_1 = 600 kPa$ 2-3-4 ISOBARA 6-1 ISOCORA

1-2) $\Delta s = 0 = c_p \ln(T_2/T_1) - R^* \ln(P_2/P_1) \rightarrow T_2 = 500{,}55°K$

$\dot{Q}_{COMPRESSORE} < \dot{L}_{TURBINA-1}$

$c_p(T_2 - T_3) = c_p(T_4 - T_5) \rightarrow T_5 = 1399{,}45°K$

4-5) $\Delta s = 0 = \frac{7}{2} \ln(T_4/T_5) - \ln(P_4/P_5) \rightarrow P_5 = 375{,}48 kPa$

5-6) $\Delta s = 0 = \frac{7}{2} \ln(T_5/T_6) - \ln(P_5/P_6) \rightarrow T_6 = 958{,}94°K$

COMPONENTI IDEALI $\rightarrow \eta_T = 1 = \frac{T_3 - T_2}{T_6 - T_2} \rightarrow T_3 = T_6$

TUTTO IN COMPRESSORE

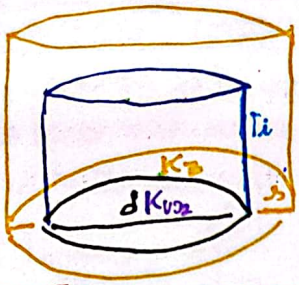
$\dot{L} = \dot{L}_{TV_1} + \dot{L}_{TV_2} = c_p(T_5 - T_6) = 445{,}11 \frac{kJ}{kg}$

$W_{TV_2} = \dot{L}_{TV_2} \cdot \dot{m} \rightarrow \dot{m} = \frac{W_{TV_2}}{\dot{L}_{TV_2}} = 0{,}34 kg/s$

$\eta_{TUR} = \frac{\dot{L}}{\dot{Q}_C} = \frac{\dot{L}}{c_p(T_4 - T_3)} = \frac{T_5 - T_6}{T_4 - T_3} = 68{,}72\%$

ES.21

$d = 0{,}012\,m$ $s = 0{,}001\,m$ $\alpha = 2 \cdot 10^8\ W/m^3$ $T_3 = 830{,}15\,°K$ $K_{UO_2} = 2\ \frac{W}{m°K}$ $K_2 = 25\ \frac{W}{m°K}$ T_{MAX}?



$$T_{UO_2} = \frac{\alpha}{4K_{UO_2}}\left(\frac{d}{2} - r\right)^2 + T_i$$

$\dot{Q}$ COSTANTE $\quad \dot{Q}_{UO_2} = \dot{Q}_2$

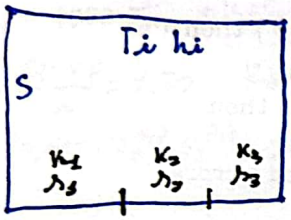
$$\pi\left[\left(\frac{d}{2}\right)^2 \frac{\alpha}{2}\right] = \frac{K_{s2}}{s} \cdot \frac{2\pi L}{\ln\left(\frac{d/2+s}{d/2}\right)} (T_2 - T_3) \rightarrow T_i = 852\,°K$$

$T_{UO_2(MAX)} = T_{UO_2(r=0)} = 1752\,°K$

ES.22

$S = 0{,}5\,m^2$ $s_1 = 0{,}08\,m$ $K_1 = 3\ \frac{W}{m°K}$ $s_2 = 0{,}03\,m$ $K_2 = 0{,}1\ \frac{W}{m°K}$ $s_3 = 0{,}005\,m$ $K_3 = 20\ \frac{W}{m°K}$

$T_i = 850°C = 1123{,}15\,°K$ $T_e = 0°C = 273{,}15\,°K$ $h_i = 100\ \frac{W}{m^2°K}$ $h_e = 30\ \frac{W}{m^2°K}$ R_{TOT}? T_1? T_2? T_3? $\dot{Q}$?



$$R_{TOT} = R_{CONV_i} + R_{COND_1} + R_{COND_2} + R_{COND_3} + R_{CONV_e}$$

$$R_{CONV_i} = \frac{1}{h_i S} \quad R_{COND_1} = \frac{s_1}{K_1 S} \quad R_{COND_2} = \frac{s_2}{K_2 S} \quad R_{COND_3} = \frac{s_3}{K_3 S} \quad R_{CONV_e} = \frac{1}{h_e S}$$

$R_{TOT} = 0{,}740\,°K/W$ $\quad \dot{Q} = \frac{\Delta T_{TOT}}{R_{TOT}} = \frac{T_i - T_e}{R_{TOT}} = 1148{,}6\,W$ $\quad \dot{Q}$ COSTANTE

$$\dot{Q} = \frac{T_i - T_1}{R_{CONV_i}} \rightarrow T_1 = 827{,}03°C$$

$$\dot{Q} = \frac{T_1 - T_2}{R_{COND_1}} \rightarrow T_2 = 765{,}77\,°C \qquad \dot{Q} = \frac{T_2 - T_3}{R_{COND_2}} \rightarrow T_3 = 76{,}61°C$$

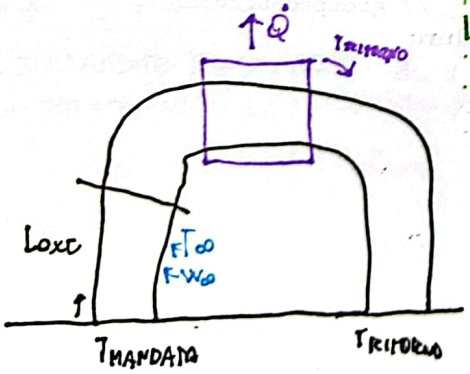
ES.23

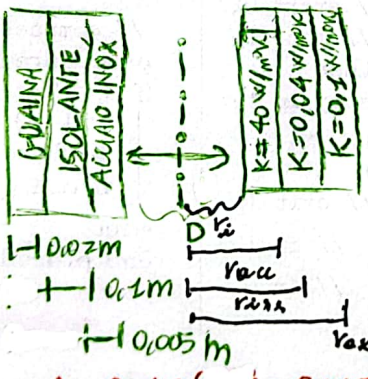
$L = 1200\,m$ $L_{EXC} = 100\,m$ $T_\infty = 0°C = 273{,}15\,°K$ $w_\infty = 10\,m/s$ $\dot{Q} = 20774\ \frac{K}{W}$ $T_{MANDATA} = 100°C = 373{,}15\,°K$

$T_{RITORNO} = 57°C = 330{,}15\,°K$

IPOTESI: $\dot{w}_{H_2O} = 2\,m/s$

- POTENZA DISPERSA NEL TRATTO ESTERNO TRASCURABILE





D?

P (POTENZA DI POMPAGGIO)?

$$\dot{m} = \rho w A = \rho w \pi \left(\frac{D}{2}\right)^2 \rightarrow D = \sqrt{\frac{2\dot{m}}{\rho w \pi}}$$

$$\dot{Q} = \dot{m} c_p \Delta T_{H_2O} \qquad \dot{m} = \frac{\dot{Q}}{c_p \Delta T_{H_2O}}$$

$$c_p = \frac{c_{p@330°K} + c_{p@373°K}}{2} = 4{,}2\ \frac{kJ}{kg\,°K} \qquad \dot{m} = 115\,kg/s$$

$$\rho = \frac{\rho_{@330°K} + \rho_{@373°K}}{2} = 971\,kg/m^3 \qquad D = \sqrt{\frac{4\dot{m}}{\pi w \rho}} = 0{,}27\,m$$

NEL MONDO REALE SI AVRÀ $D = 0{,}3\,m$ → RICALCOLO $w \Rightarrow w_{H_2O} = 4{,}67\,m/s$ ACCETTABILE

- $r_{ii} = 0{,}15\,m$
- $r_{acc} = 0{,}155\,m$
- $r_{ins} = 0{,}255\,m$
- $r_{exc} = 0{,}275\,m$

PERDITA DI CARICO $\Delta P = f \frac{L}{2D} \rho \frac{w^2}{2}$ → $P = f \frac{L w^2}{2D}$ (f = COEFFICIENTE DI ATTRITO)

SI CERCANO PARAMETRI TERMOFISICI INTERMEDI A QUELLI DATI, QUINDI 350°K CIRCA

$P = 0{,}184\, Re^{-0{,}2}$ (MOTO TURBOLENTO) $\quad Re = \frac{wD}{\nu} \quad \nu = \frac{\nu_{@340°K} + \nu_{@360°K}}{2} = 0{,}38 \cdot 10^{-6}\ m^2/s$

$Re = 1{,}32 \cdot 10^6 \gg Re_{critico} = 2300$ (CONFERMA DI MOTO TURBOLENTO) $\Rightarrow f = 0{,}011 \quad P = 7056\ W$

PER FINIRE, VERIFICARE L'IPOTESI CHE SIA TRASCURABILE RISPETTO A $Q \simeq 21\ MW$

! VALUTO TRA INGRESSO ED USCITA DEI 100m

$\dot{Q}_{DISPERSA\ 100m} = \frac{\Delta T}{R_{TOT}}$

$R_{TOT} = \frac{1}{h_i A_i} + \frac{\ln(\frac{r_{acc}}{r_i})}{2\pi L K_{acc}} + \frac{\ln(\frac{r_{isol}}{r_{ins}})}{2\pi L K_{isol}} + \frac{\ln(\frac{r_e}{r_{isol}})}{2\pi L K_g} + \frac{1}{h_o A_e}$

p = f * (Lw2) / (2D)

P = vp = (1/)*f*((Lw2) / (2D))
-> P = f * (L*w2) / (2D)

ACQUA FLUSSO INTERNO AI TUBI

PARAMETRI TERMOFISICI A $100°C = 373{,}15°K$

- $C_p = 4220\ \frac{J}{Kg°K}$
- $K = 0{,}681\ \frac{W}{M°K}$
- $\nu = 0{,}29 \cdot 10^{-6}\ m^2/s$
- $\rho = 958\ Kg/m^3$

$Pr = \frac{C_p \nu \rho}{K} = 1{,}72 \quad Re = \frac{wD}{\nu} = 1{,}73 \cdot 10^6 \gg Re_{critico}$ → MOTO TURBOLENTO

$Nu = 0{,}023 \cdot Re^{0{,}8} \cdot Pr^{0{,}3} = 2692 \quad Nu = \frac{hD}{K} \rightarrow h_i = 6111\ \frac{W}{m^2 °K}$

ARIA FLUSSO ESTERNO. AL CILINDRO

IPOTESI: PARAMETRI TERMOFISICI CALCOLATI ALLA TEMPERATURA DI FILM DI 280°K (7 °C)

- $K = 0{,}0246\ \frac{W}{m°K} \quad Pr = 0{,}717 \quad \nu = 1{,}4 \cdot 10^{-5}\ \frac{m^2}{s}$

$Re = \frac{w_\infty D_{ext}}{\nu} \quad D_{ext} = D + 2r_i + 2r_{acc} + 2r_{isol} + 2r_{ext} = 0{,}55m \rightarrow Re = 3{,}9 \cdot 10^5 > Re_{critico}$ → MOTO TURBOLENTO

$Nu = C \cdot Re^m \cdot Pr^{1/3}$ per $40.000 < Re < 400.000 \Rightarrow C = 0{,}027;\ m = 0{,}805$

→ $Nu = 765{,}6 \rightarrow h_e = \frac{Nu\,K}{D_{ext}} = 34{,}24\ \frac{W}{m^2 °K}$

$\Rightarrow R_{TOT} = 211 \cdot 10^{-4}\ \frac{°K}{W} \qquad \Delta T = 100°K = T_{MANDATA} - T_\infty$

→ $\dot{Q} = 4739\ W$

DECISAMENTE TRASCURABILE

ULTIMO STEP: VALUTO LA TEMPERATURA ESTERNA DISPERSA (ESTR SUPERFICIE)

$\dot{Q}_{DISPERSA\ 100m} = h_e A_e (T_s - T_\infty) \rightarrow T_s = T_\infty + \frac{\dot{Q}}{h_e \pi D_{ext} L} = 0{,}8°C \neq 7°C$ IPOTIZZATO

CIN PRATICA, A QUESTO PUNTO RICALCOLARE I PARAMETRI DELL'ARIA A 7°C)