$$\Sigma dQ = \Sigma m_s \cdot (gdz + \frac{1}{2}dw^2 + du_i + du_c + ...) + \Sigma C_s dV + \Sigma dm_u \cdot (gz + \frac{1}{2}w^2 + h + u_c + ...)_u - \Sigma dm_e \cdot (gz + \frac{1}{2}w^2 + h + u_c + ...)_e + \Sigma dC_u V_u - \Sigma dC_e V_e + \Sigma dL' \qquad (\text{con } h = u_i + pv)$$

$$\Sigma Q_{12} = \Sigma m_s \cdot (g(z_2 - z_1) + \frac{1}{2}(w_2^2 - w_1^2) + (u_{i2} - u_{i1}) + ...) + \Sigma C_s (V_2 - V_1)_s + \Sigma \int_1^2 |\dot{m}| \left[g(z_u - z_e) + \frac{1}{2}(w_u^2 - w_e^2) + (h_u - h_e) + ... \right] d\tau + \Sigma \int_1^2 |I| \cdot (V_u - V_e)\, d\tau + \Sigma L'_{12}$$

$$\Sigma q = \Sigma m_s \cdot \left(g\frac{dz}{d\tau} + \frac{1}{2}\frac{dw^2}{d\tau} + \frac{du_i}{d\tau} + ... \right) + \Sigma C_s \frac{dV_s}{d\tau} + \Sigma |\dot{m}| \left[g(z_u - z_e) + \frac{1}{2}(w_u^2 - w_e^2) + (h_u - h_e) + ... \right] + |I| \cdot (V_u - V_e) + \Sigma P$$

$$\dot{m} = \rho \cdot A \cdot w \qquad dL = p \cdot v \cdot dm \qquad u_{g2} - u_{g1} = (-k_g \frac{1}{r_2^2}) - (-k_g \frac{1}{r_1^2})$$

$$0 = \dot{m} \int_1^2 v\, dp + \dot{m} g(z_2 - z_1) + \frac{1}{2}\dot{m}(w_2^2 - w_1^2) + \dot{m} R_{12} + P$$

$$R_{12} = -v \cdot (p_2 - p_1) = f_a \frac{L}{D}\frac{w^2}{2}$$

Trasformazione ciclica sist. chiuso o success. chiusa di sist. aperti

$$\frac{Q}{m} = \frac{L}{m} = \Sigma_{rev} \int p\, dv \qquad \frac{q}{\dot{m}} = \frac{P}{\dot{m}} = \Sigma_{rev} \left(-\int v\, dp \right)$$

Indicatori di efficienza mot. termici/macc. frigorifere/p. di calore

$$\eta = \frac{|L|}{|Q_1|} = 1 - \frac{|Q_2|}{|Q_1|} \qquad \varepsilon = \frac{|Q_2|}{|L|} \qquad \varepsilon' = \frac{|Q_1|}{|L|} = \frac{|Q_2|}{|L|} + 1 = \varepsilon + 1$$

Rendimento massimo per cicli bi-termici e tri-termici

$$\eta_{max} = 1 - \frac{\mathbf{T_2}}{\mathbf{T_1}} \qquad \varepsilon_{max(2)} = \frac{\mathbf{T_2}}{\mathbf{T_1} - \mathbf{T_2}} \qquad \varepsilon_{max(3)} = \frac{\mathbf{T_2}}{\mathbf{T_1} - \mathbf{T_2}} \left(1 - \frac{\mathbf{T_1}}{\mathbf{T_3}} \right)$$

$$\varepsilon'_{max} = \varepsilon_{max} + 1$$

Bilancio entropico sist. chiuso/sist. con deflusso

$$m_s(s_2 - s_1) = \frac{Q_{12}}{\mathbf{T_b}} + \Pi_{12} \qquad \Sigma |\dot{m}|(s_u - s_e) = \frac{q}{\mathbf{T_b}} + \dot{\Pi}$$

Titolo di vapore

$$x_V = \frac{m_V}{m} = \frac{\overline{v} - v_L}{v_V - v_L} \qquad \overline{v} = (1 - x_V)v_L + x_V v_V$$

Sostanze incomprimibili ($v = cost$)

$$u_{i2} - u_{i1} = \overline{c}\,(t_2 - t_1) \qquad h_2 - h_1 = \overline{c}\,(t_2 - t_1) + v\,(p_2 - p_1) \qquad s_2 - s_1 = \overline{c} \cdot \ln\left(\frac{\mathbf{T_2}}{\mathbf{T_1}}\right)$$

Gas ideali

$$p\,v = R\,\mathbf{T} \qquad u_{i2} - u_{i1} = c_v\,(T_2 - T_1) \qquad h_2 - h_1 = c_p\,(T_2 - T_1)$$

$$s_2 - s_1 = c_v \cdot \ln\left[\frac{\mathbf{T_2}}{\mathbf{T_1}}\left(\frac{v_2}{v_1}\right)^{k-1}\right] = c_p \cdot \ln\left[\frac{\mathbf{T_2}}{\mathbf{T_1}}\left(\frac{p_2}{p_1}\right)^{\frac{1-k}{k}}\right] = c_v \cdot \ln\left[\frac{p_2}{p_1}\left(\frac{v_2}{v_1}\right)^{k}\right]$$

$$\overline{R} = 8314.2 \text{ J/(kmol K)}$$

$$k = \frac{c_p}{c_v} \qquad c_v = \frac{1}{k-1}R \qquad c_p = \frac{k}{k-1}R \qquad R = \frac{\overline{R}}{M_m} \qquad k = \frac{\psi + 2}{\psi}$$

$$x_j = m_j/m \qquad X_j = V_j/V \qquad M = \Sigma X_j\, M_j \qquad c_v = \Sigma x_j c_{v_j} \qquad c_p = \Sigma x_j c_{p_j}$$

$$Q_{12} = \Sigma m_{\text{inerti}}\,(u_{i2} - u_{i1}) + ... + \Sigma m_r\,(u_{i0} - u_{i1}) - m_c \cdot U_0 + \Sigma m_p\,(u_{i2} - u_{i0}) + L_{12}$$

$$q = \Sigma \dot{m}_{\text{inerti}}\,(h_2 - h_1) + ... + \Sigma \dot{m}_r\,(h_0 - h_1) - \dot{m}_c \cdot H_0 + \Sigma \dot{m}_p\,(h_2 - h_0) + P$$

Conduzione e distr. temperatura cilindro combustibile pieno $t_c(r)$

$$|q| = \frac{|T_2 - T_1|}{R_t} \qquad R_p = \frac{s}{\lambda A} \qquad R_c = \frac{1}{2\pi L\lambda}\ln\frac{r_e}{r_i} \qquad t_c(r) = t_0 + \frac{H}{4\,\lambda_b}(r_0^2 - r^2)$$

Convezione

$$Nu = \frac{\alpha_c \cdot L^*}{\lambda^*} \qquad Re_{(F)} = \frac{\rho^* w^* L^*}{\mu^*} \qquad Gr_{(N)} = \frac{L^{*3}\rho^{*2}\, g\, \beta^* \Delta T^*}{\mu^{*2}} \qquad Pr = \frac{c_p^* \cdot \mu^*}{\lambda^*}$$

$$R_{conv} = \frac{1}{\alpha_c A}$$

Irraggiamento (attenzione alle **Temperature assolute**)

$$c = \lambda \cdot \nu \qquad \rho = q_r/q \qquad \tau = q_t/q \qquad \alpha = q_a/q = 1 - \rho - \tau \qquad A_1\, F_{12} = A_2\, F_{21}$$

Corpi neri

$$q_{12} = \sigma\, A_1\, F_{12}\,(\mathbf{T_1}^4 - \mathbf{T_2}^4) \qquad R_r = \frac{1}{\sigma\, A_1\, F_{12}\, 4\,\mathbf{T_m}^3} = \frac{1}{\alpha_r \cdot A_1} \qquad (\text{se } \Delta T < 100 \text{ K})$$

$$R_{S1} = \frac{1}{(\alpha_c + \alpha_r)\, A_1} = \left(\frac{1}{R_c} + \frac{1}{R_r}\right)^{-1} \qquad K = \frac{1}{R_{TOT} \cdot A} \qquad q = KA\,(T_1 - T_2)$$

Corpi grigi (le R non sono resistenze termiche!)

$$E = \varepsilon \cdot E_n \qquad R_j = \frac{1 - \varepsilon_j}{\varepsilon_j \cdot A_j} \qquad R_{jk} = \frac{1}{A_j \cdot F_{jk}} \qquad q_{jk} = \frac{\sigma\,(\mathbf{T_j}^4 - \mathbf{T_k}^4)}{R_j + R_{jk} + R_k}$$

Scambiatori di calore

$$|q| = KA \cdot \frac{\Delta' - \Delta''}{\ln\left(\frac{\Delta'}{\Delta''}\right)} F_t \qquad q_{max} = (\dot{m}c)_{min}(t_{1,in} - t_{2,in}) \qquad \varepsilon = \frac{q}{q_{max}}$$

$$r = \frac{(\dot{m}c)_{min}}{(\dot{m}c)_{max}} \qquad NTU = \frac{KA}{(\dot{m}c)_{min}} \qquad \varepsilon_{(r=1)} = \frac{NTU}{NTU + 1} \qquad \varepsilon_{(r=0)} = 1 - e^{-NTU}$$

Compressione ed espansione

$$\eta_{C,is} = \frac{L_{is}}{L} = \frac{m\,(u_{i1} - u_{i2,is})}{m\,(u_{i1} - u_{i2})} = \frac{\dot{m}\,(h_1 - h_{2,is})}{\dot{m}\,(h_1 - h_2)} = \frac{P_{is}}{P}$$

$$\eta_{E,is} = \frac{L}{L_{is}} = \frac{m\,(u_{i1} - u_{i2})}{m\,(u_{i1} - u_{i2,is})} = \frac{\dot{m}\,(h_1 - h_2)}{\dot{m}\,(h_1 - h_{2,is})} = \frac{P}{P_{is}}$$

$$\eta_I = \frac{|P_E| - |P_P|}{\dot{m}_c \cdot H_0}$$

Isoterme $\rightarrow p_2 = p_1\,(v_1/v_2)$

Isobare $\rightarrow v_2 = v_1\,(\mathbf{T_2}/\mathbf{T_1})$

Isocore $\rightarrow p_2 = p_1\,(\mathbf{T_2}/\mathbf{T_1})$