FORMULA SHEET: THERMODYNAMICS (MECH.) 4
AND THERMODYNAMICS FOR ENERGY SYSTEMS (MSc)

Using standard notation as in the lectures.

General

Conservation of mass:

$$\dot{m}_{CV} = \sum_i \dot{m}_i - \sum_e \dot{m}_e$$

Conservation of energy:

$$\dot{W}_{ac} = \sum_j \dot{Q}_j + \sum_i \dot{m}_i h_i - \sum_e \dot{m}_e h_e - \dot{E}_{CV}$$

Entropy balance:

$$\dot{S}_{CV} = \sum_j \frac{\dot{Q}_j}{T_j} + \sum_i \dot{m}_i s_i - \sum_e \dot{m}_e s_e + \dot{S}_{gen,ac}$$

$$s_2 - s_1 = s_2^0 - s_1^0 - R \ln\left(\frac{P_2}{P_1}\right)$$

$$s_2 - s_1 = \int_1^2 \frac{C_{p0}}{T} dT - R \ln\left(\frac{P_2}{P_1}\right)$$

$$s_2 - s_1 = \int_1^2 \frac{C_{v0}}{T} dT + R \ln\left(\frac{v_2}{v_1}\right)$$

Carnot efficiency: $\eta_{Carnot} = 1 - \frac{T_L}{T_H}$

Universal gas constant: R_u = 8.314 kJ kmol^{-1} K^{-1}

Exergy

Irreversibility: $I = T_0 S_{gen}$

Stored specific exergy: $$\phi = (e - e_0) + P(v - v_0) - T_0(s - s_0)$$

Exergy flow rate due to heat transfers: $$\dot{\Phi}_q = \sum_j \dot{Q}_j \left(1 - \frac{T_0}{T_j}\right)$$

Specific exergy transfer by flow: $$\phi = \psi_1 - \psi_2 = (h_{tot,i} - h_{tot,e}) - T_0(s_i - s_e)$$

Exergy balance:

$$\dot{\Phi}_{CV} = +\sum_j \dot{Q}_j \left(1 - \frac{T_0}{T_j}\right) - \dot{W}_{CV} + P_0 \dot{V} + \sum_i \dot{m}_i \psi_i - \sum_e \dot{m}_e \psi_e - T_0 \dot{S}_{gen}$$

Gas mixtures & psychrometry

Mass fraction: $f_i = \frac{m_i}{m_{tot}}$

Mole fraction: $y_i = \frac{n_i}{n_{tot}}$

Conversions:

$$f_i = \frac{y_i M_i}{\sum_j y_j M_j}$$

$$y_i = \frac{f_i / M_i}{\sum_j f_j / M_j}$$

Adiabatic saturator result:

$$\omega_1 (h_{v,1} - h_l) = C_p (T_2 - T_1) + \omega_2 (h_{v,2} - h_l)$$

Humidity ratio:

$$\omega = \frac{\left({}^{M_v}/_{M_{air}} \right) P_v}{P_{mix} - P_v}$$

Vapour pressure:

$$P_v = \varphi P_g$$

Power cycles

Isentropic efficiency for turbines and compressors:

$$Turbine\ isentropic\ efficiency = \frac{Actual\ turbine\ work}{Isentropic\ turbine\ work}$$

$$Compressor\ isentropic\ efficiency = \frac{Isentropic\ compressor\ work}{Actual\ compressor\ work}$$

Approximate pump work:

$$w_{\ pump} = \frac{v_{\ 1} \cdot \left(P_{\ 2} - P_{\ 1} \right)}{\eta_{\ pump}}$$

Regenerator effectiveness:

$$\varepsilon_{regen} = \frac{q_{regen,\ act}}{q_{regen,\ \max}}$$

See also Thermodynamics 2 formula sheet (next page)

2^{nd} Year Thermodynamics Formula-Sheet

$Pv = RT$ $W_b = \int_1^2 PdV$ $h = u + Pv$ $x = \frac{m_g}{m_f + m_g}$

$y = y_f + xy_{fg}$ $PV^n = constant$ $E = U + KE + PE$

$E_{in} - E_{out} = \Delta E_{system}$ $Q_{net} - W_{net} = \Delta E_{system}$ $C_P = C_V + R$

$du = C_v dT$

$dh = C_P dT$ $\dot{m} = \rho V_{av} A = \frac{V_{av} A}{v}$ $k = \frac{C_P}{C_V}$

$$\dot{Q}_{in} + \dot{W}_{in} + \sum \dot{m}_i \left(h_i + \frac{\vec{V}_i^2}{2} + gz_i \right) = \dot{Q}_{out} + \dot{W}_{out} + \sum \dot{m}_e \left(h_e + \frac{\vec{V}_e^2}{2} + gz_e \right)$$

$$\dot{Q}_{net} - \dot{W}_{net} = \sum \dot{m}_e \left(h_e + \frac{\vec{V}_e^2}{2} + gz_e \right) - \sum \dot{m}_i \left(h_i + \frac{\vec{V}_i^2}{2} + gz_i \right)$$

$\eta_{th} = \frac{W_{net,out}}{Q_{in}}$ $\eta_{th} = 1 - \frac{Q_L}{Q_H}$ $COP_R = \frac{Q_L}{W_{net,in}}$ $COP_{HP} = \frac{Q_H}{W_{net,in}} = \frac{Q_H}{Q_H - Q_L}$

$\frac{Q_L}{Q_H} = \frac{T_L}{T_H}$ $\oint \frac{\delta Q_{net}}{T} \leq 0$ $dS \geq \frac{\delta Q_{net}}{T}$ $s_2 - s_1 = C_{av} ln \frac{T_2}{T_1}$

$s_2 - s_1 = C_v ln \frac{T_2}{T_1} + R ln \frac{v_2}{v_1}$ $s_2 - s_1 = C_p ln \frac{T_2}{T_1} - R ln \frac{P_2}{P_1}$

$s(T_2, P_2) - s(T_1, P_1) = s^0(T_2) - s^0(T_1) - R ln \frac{P_2}{P_1}$

$\left(\frac{T_2}{T_1}\right)_{s=const.} = \left(\frac{v_1}{v_2}\right)^{k-1}$ $\left(\frac{T_2}{T_1}\right)_{s=const.} = \left(\frac{P_2}{P_1}\right)^{(k-1)/k}$ $\left(\frac{P_2}{P_1}\right)_{s=const.} = \left(\frac{v_1}{v_2}\right)^k$

$S_{in} - S_{out} + S_{gen} = \Delta S_{system}$ $\Delta S_{isolated} \geq 0$ $Q_{net} = \int_1^2 TdS$

$r = \frac{V_{max}}{V_{min}} = \frac{V_{BDC}}{V_{TDC}}$ $MEP = \frac{W_{net}}{V_{max} - V_{min}} = \frac{w_{net}}{v_{max} - v_{min}}$ $\frac{V_3}{V_2} = r_c$