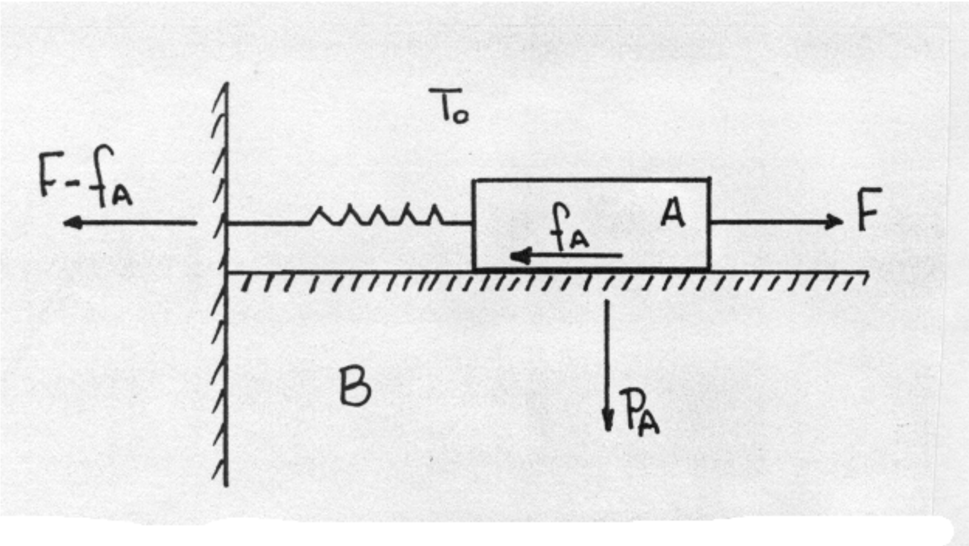
ENTROPY GENERATION ELEMENTARY PROCESSES

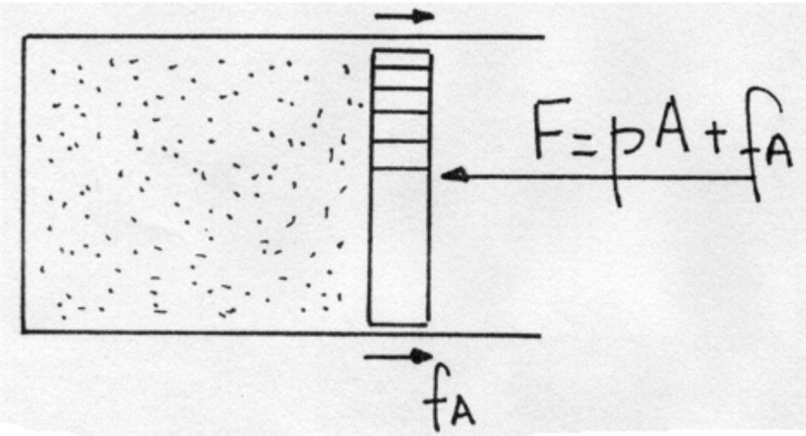
1. MECHANICAL FRICTION



$$f_A = \mu'_{AB} P_A \qquad (1)$$

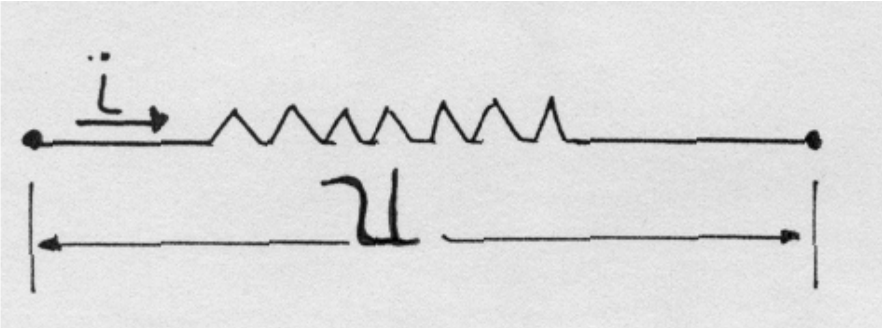
$$W_{friction} = f_A . \Delta \ell \ \ (converted - to - heat) \qquad (2)$$

$$S_{gen} = \frac{W_{friction}}{T_o} = \frac{f_A . \Delta\ell}{T_o} \qquad (3)$$



$$S_{gen} = \sum \frac{\partial q_i}{T_i} \qquad (4)$$

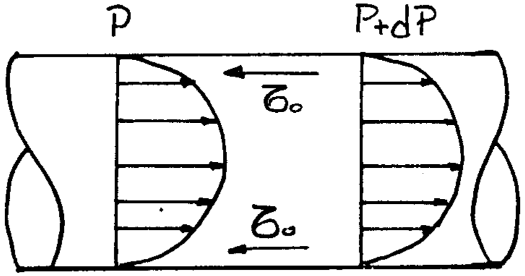
2. ELECTRICAL HEATING (Joule Effect)

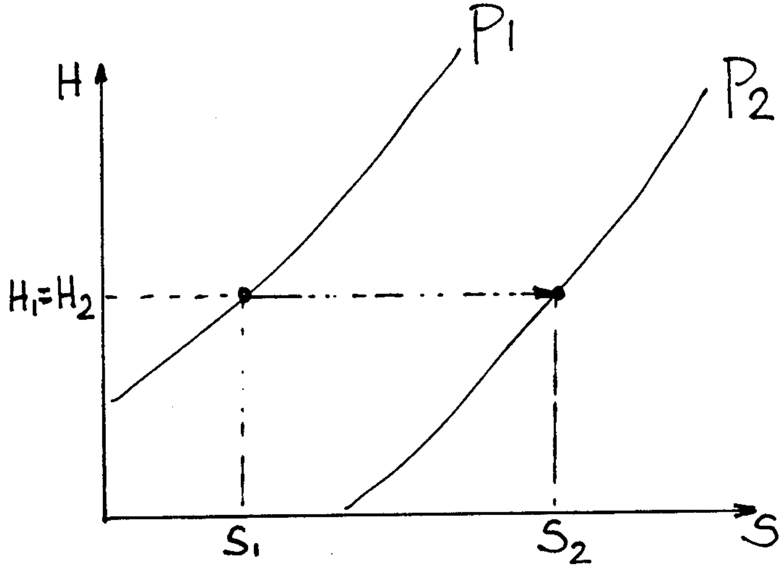


$$S_{gen} = \frac{W_e}{T} = \frac{Ui}{T} \qquad (5)$$

3. HEAD LOSS

Internal Flow





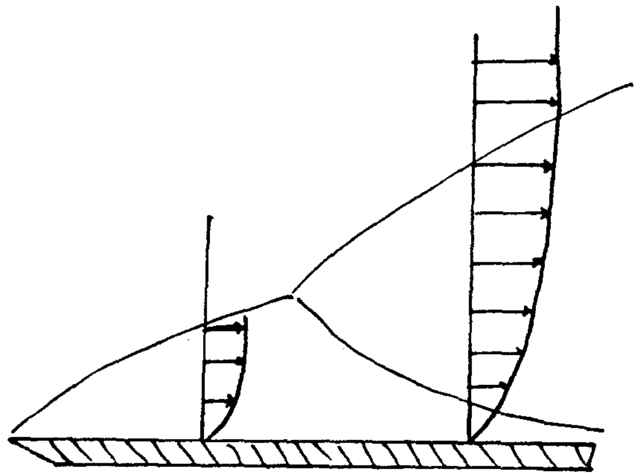
$$H_2 = H_1 \qquad and \qquad S_{gen} = (S_2 - S_1)\dot{m} \qquad (6)$$

Considering

$$Tds = dh - vdp \qquad (7)$$

For an isenthalpic process: h = cte $\rightarrow \dfrac{ds}{dp} = -\dfrac{v}{T}$ or $\left(\dfrac{\partial s}{\partial p}\right)_h = -\dfrac{v}{T}$ or $\partial p \langle 0$ and $\partial s \rangle 0$

External Flow

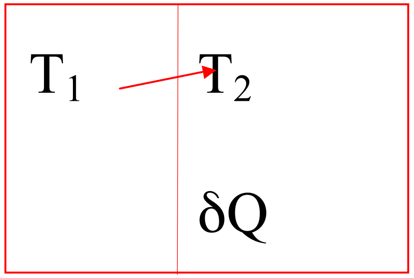


$$F_A \, . \, U_\infty = \frac{dU}{dt} \qquad (8)$$

$$S_{gen} = \frac{dS}{dt} \qquad (9)$$

$$dU = T_\infty dS - p_\infty d\forall \quad \Rightarrow \quad \boxed{S_{gen} = \frac{F_A . U_\infty}{T_\infty}} \qquad (10)$$

4. HEAT TRANSFER



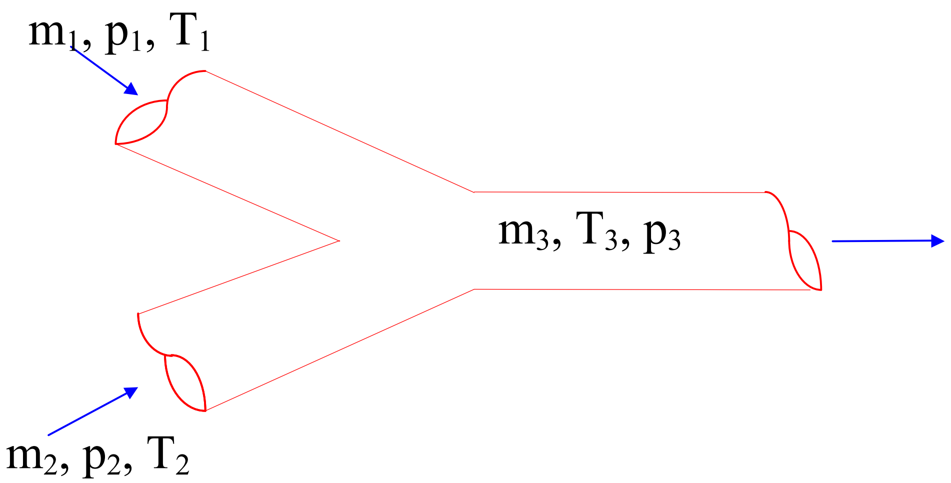
$$dS_{sist} = S_{gen}$$

$$S_{gen} = (\Delta S)_1 + (\Delta S)_2 = \frac{-\partial Q}{T_1} + \frac{\partial Q}{T_2} \qquad (11)$$

$$\boxed{S_{gen} = \partial Q \frac{(T_1 - T_2)}{T_1 \, T_2}} \qquad T_{final} = \frac{C_1 \, T_1 + C_2 \, T_2}{C_1 + C_2} \qquad (12)$$

with $C = m\,c$ (13)

5. MIXTURE



$$(\Delta S)_{CV} = S_{gen}$$

a) Same fluid

$$T_3 = \frac{m_1\, T_1 + m_2\, T_2}{(m_1 + m_2)} \qquad ds = \frac{C_p\, dT}{T} - \frac{1}{\rho}\frac{dP}{T} \tag{14}$$

$$S_{gen} = m_3 s_3 - m_2 s_2 - m_1 s_1 \tag{15}$$

$$S_{gen} = m_1 (s_3 - s_1) + m_2 (s_3 - s_2) \tag{16}$$

$$S_{gen} = m_1 C_p \ \ell n \frac{T_3}{T_1} + m_2 C_p \ \ell n \frac{T_3}{T_2} - \\ -m_1 \left(\frac{1}{\rho T_1} (P_3 - P_1) \right) - m_2 \left(\frac{1}{\rho T_2} (P_3 - P_2) \right) \tag{17}$$

$C_p = C$ (incompressible fluid) (18)

b) Mixture of perfect gases

Equation of state: $p = \rho R T$ (19)

$$\frac{1}{\rho}\frac{dp}{T} = R\frac{dp}{p} \tag{20}$$

$$S_{gen} = m_1\, C_p\, \ell n \frac{T_3}{T_1} + m_2\, C_p\, \ell n \frac{T_3}{T_2} - m_1\, R_1\, \ell n \frac{(p_3)_1}{p_1} - m_2\, R_2\, \ell n \frac{(p_3)_2}{P_p} \tag{21}$$

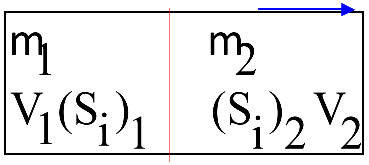
$(p3)_1$ = Partial pressure of gas 1

$(p3)_2$ = Partial pressure of gas 2

If: $p_1=p_2=p_3$

$$\left.\begin{array}{l} p_1 = p_2 = p_3 = p \\ \frac{(p_3)_1}{p} = \frac{m_1}{m} = y_1 \\ \frac{(p_3)_2}{p} = \frac{m_2}{m} = y_2 \end{array}\right\} S_{gen} = -Rm_1 \ell n y_1 - Rm_2 \ell n y_2 \tag{22}$$

$$\frac{S_{gen}}{Rm} = -\left[y_1 \ell n y_1 + y_2 \ell n y_2 \right] \tag{23}$$

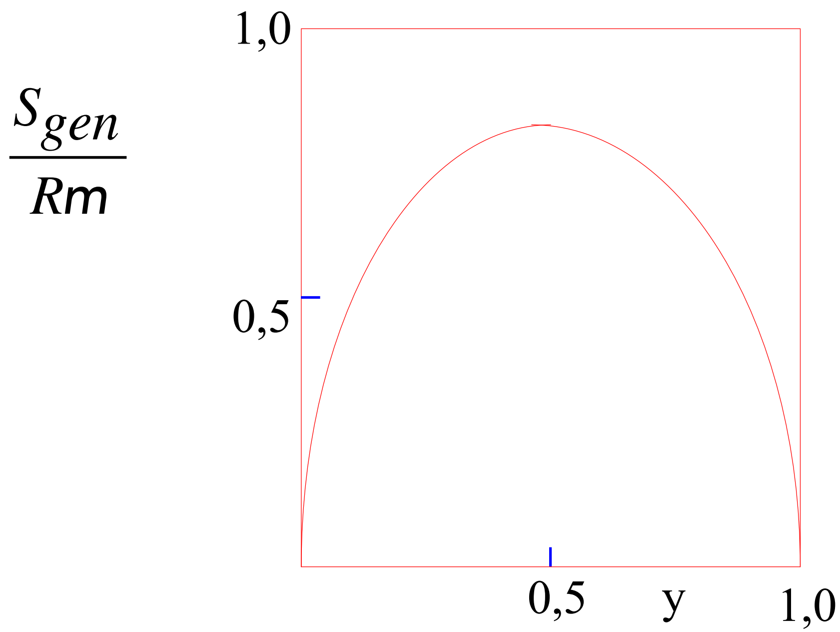


$m = m_1 + m_2$

$V = V_1 + V_2$

(S_f)

For perfect gases, ΔS_{gen} is independent of the gas (O_2, N_2, H_2, etc.)



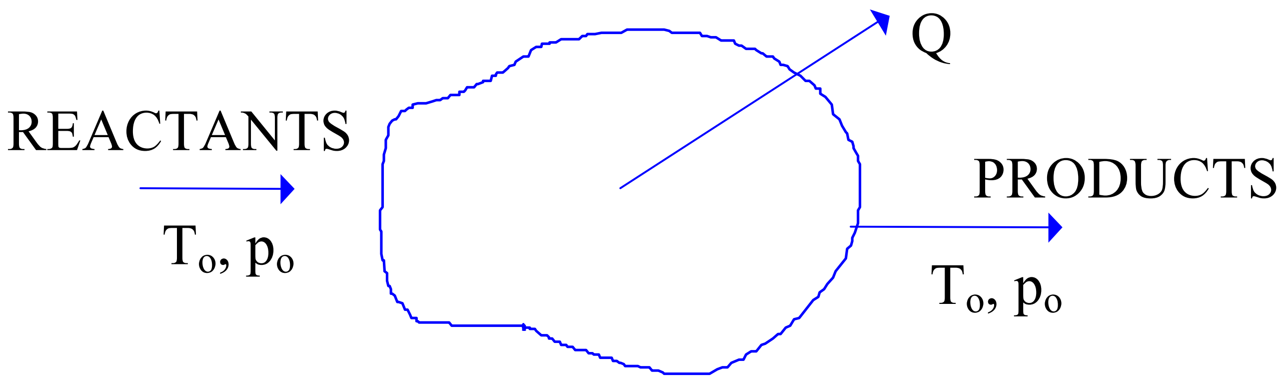
If there is only one gas then:
$y_1 = y_2 = 1$
and
$\therefore (S_{gen})_{mist} = 0$

For a mixture with n gases at p, T ctes:

$$\frac{S_{gen}}{Rm} = \sum_{i=1}^{n} y_i \, \ell n \frac{1}{y};\qquad (24)$$

with $\sum y_i = 1$ (25)

6. CHEMICAL REACTION (COMBUSTION)



$\bar{h}$ = *molar partial enthalpy*

$\bar{s}$ = molar partial entropy

$$H_p - H_r = \frac{\dot{Q}}{\dot{n}_{fuel}} \tag{26}$$

$$\sum_{i=1}^{n} \nu_{pi} \bar{h}_{pi} - \sum_{i=1}^{m} \nu_{ri} \bar{h}_{ri} = \dot{Q} / \dot{n}_{fuel} \quad (27)$$

with $\nu_{r1} = 1$

$\dot{n}_{ri} = \nu_{ri}\, \dot{n}$

$\dot{n}_{pi} = \nu_{pi}\, \dot{n}$

$\dot{n}$ = reaction velocity

$$n_{fuel}\, C_{fuel} H_{fuel} + \nu_2\, n_{fuel}\, O_2 \rightarrow \nu_3\, n_{fuel}\, H_2O + \nu_4\, n_{fuel}\, CO_2 \quad (28)$$

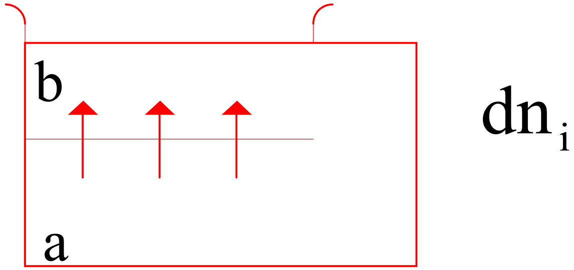
$$\frac{1}{\dot{n}_{fuel}} S_{gen} = -\frac{\dot{Q}}{\dot{n}_{fuel} T_o} - \sum \nu_{ri} \bar{s}_{ri} + \sum \nu_{pi} \bar{s}_{pi} \quad (29)$$

$$S_{gen} = (\sum \nu_{ri} \mu_{ri} - \sum \nu_{pi} \bar{\mu}_{pi}) \frac{\dot{n}_{fuel}}{T_o} \quad (30)$$

$$S_{gen} = \frac{A}{T_o} \dot{n}_{fuel} \quad (31)$$

$$\mathrm{A} = \left(\sum \nu_{\mathrm{ri}} \mu_{\mathrm{ri}} - \sum \nu_{\mathrm{pi}} \mu_{\mathrm{pi}} \right) = \text{chemical affinity} \quad (32)$$

7. DIFFUSION



Chemical potential reduction:

$$S_{gen} = \frac{dn_i}{T}\left(\mu_i(a) - \mu_i(b)\right) \quad (33)$$