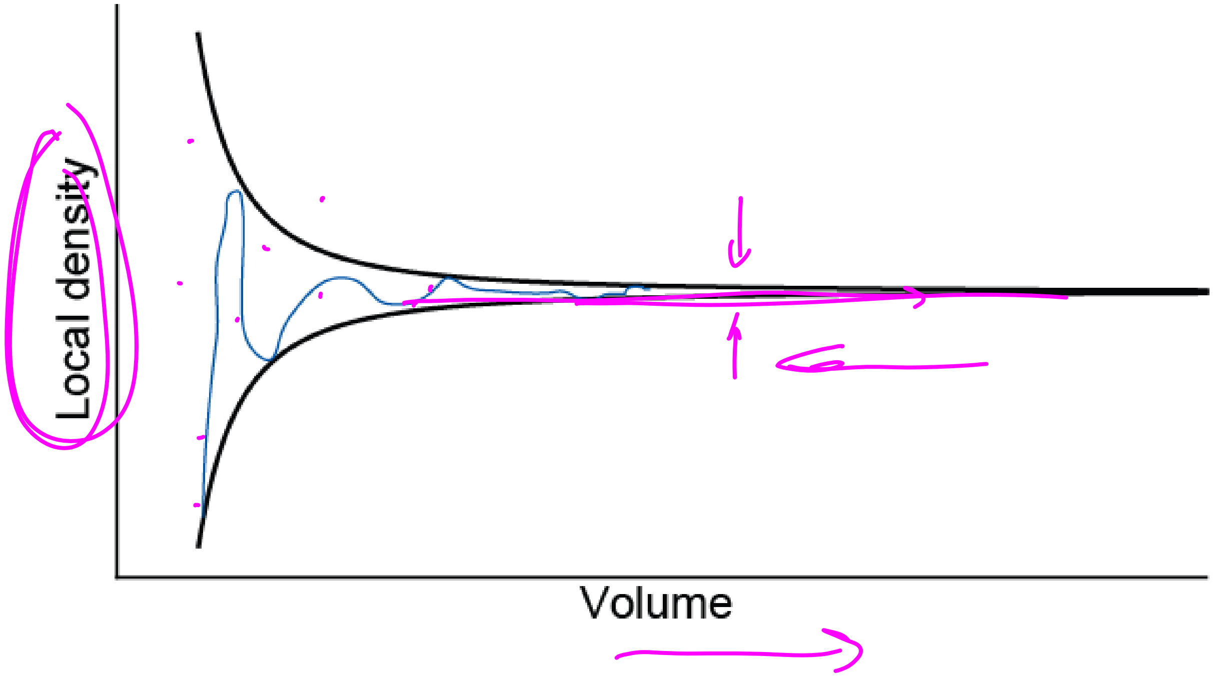
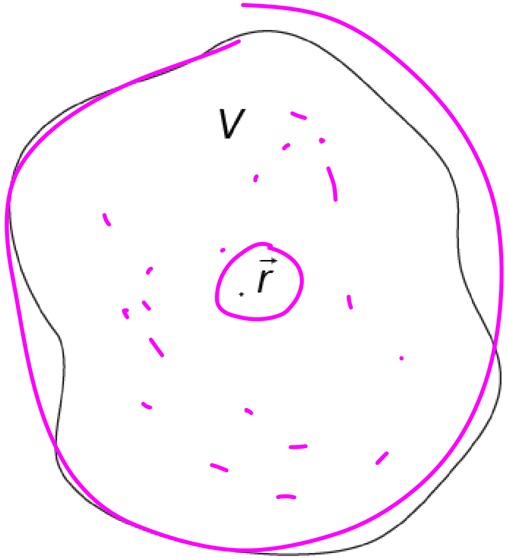
Stromingsprocessen

Lokaal Evenwicht

Vloeistofelement

- concentratie $c_V(\vec{r}) = \frac{n(V)}{V} \xrightarrow{V\to\infty} c(\vec{r})$





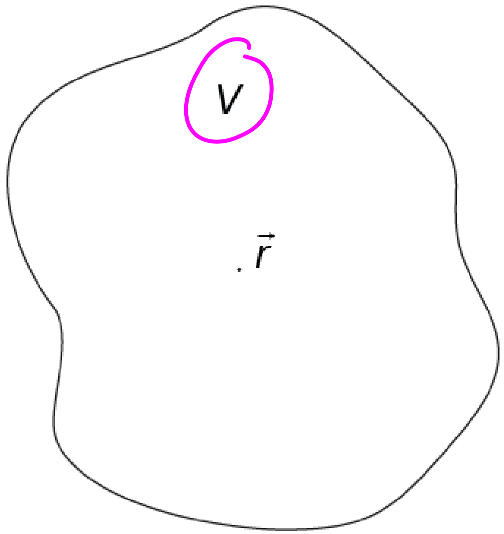
Lokaal Evenwicht

Wet van grote aantallen

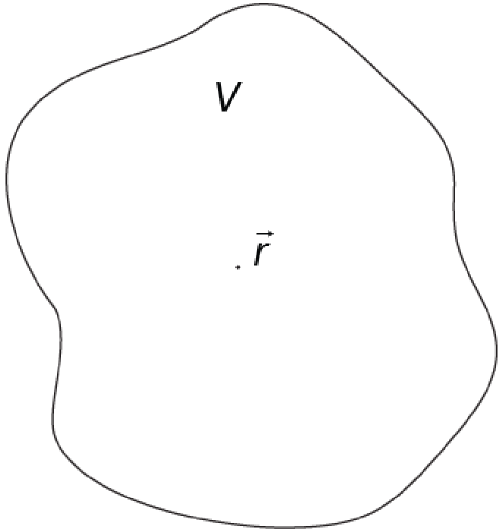
$$\frac{\sigma}{\bar{x}} \propto \frac{1}{\sqrt{N}}$$

Vloeistofelement

- grootte
  - Voorbeeld water
    - V = $(0.1\ \mu m)^3 = 10^{-21}\ m^3$
    - Molaire concentratie 55 mol/dm^3
    - Aantal moleculen $\approx 3.3\ 10^7$
    - Fluctuaties on aantal moleculen $\approx 0.02\ \%$



Lokaal Evenwicht



Hypothese

- Thermodynamica geldt binnen vloeistofelement

$$dU = TdS - pdV + \sum_k \mu_k dn_k$$

– in termen van dichtheden

$$du = Tds + \sum_k \mu_k dc_k$$

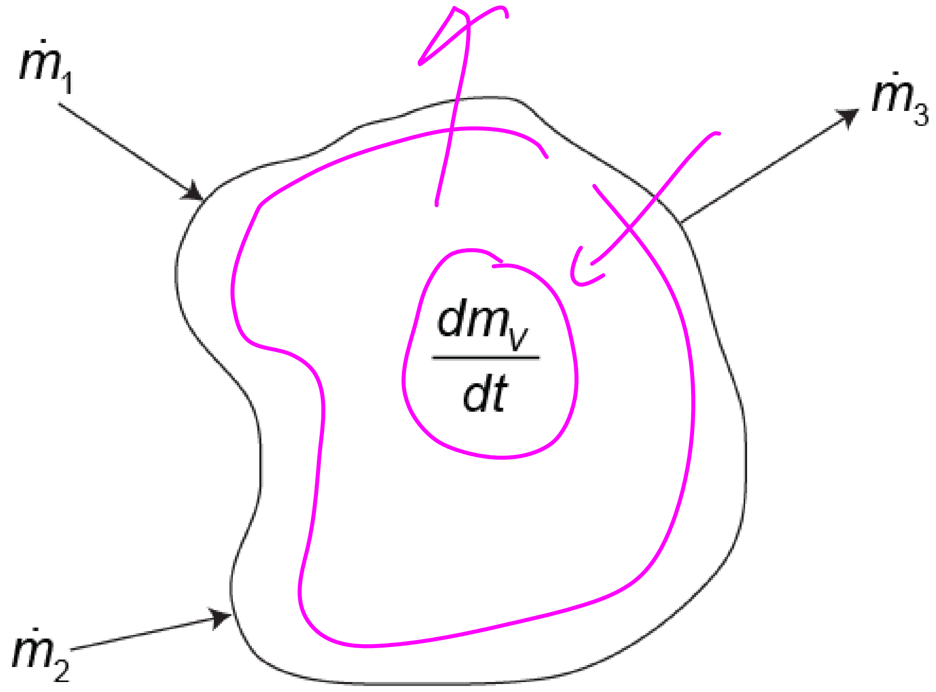
$$u = \frac{U}{m}$$

– uitzondering: grote gradiënten

Balansvergelijkingen

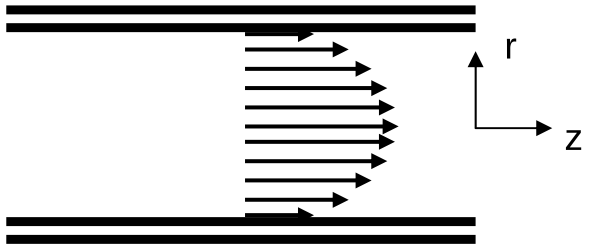
Massabalans $$\frac{dm_V}{dt} + \Delta \dot{m}_{\partial V} = 0$$

met $\dot{m} = cAv$



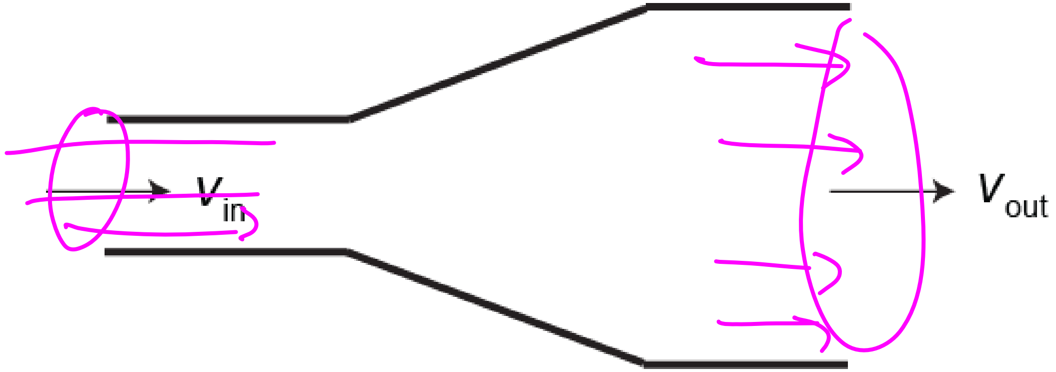
Complicaties:

- chemische reacties
- inhomogeniteit vloeistofsnelheid



Balansvergelijkingen

Massabalans voorbeeld



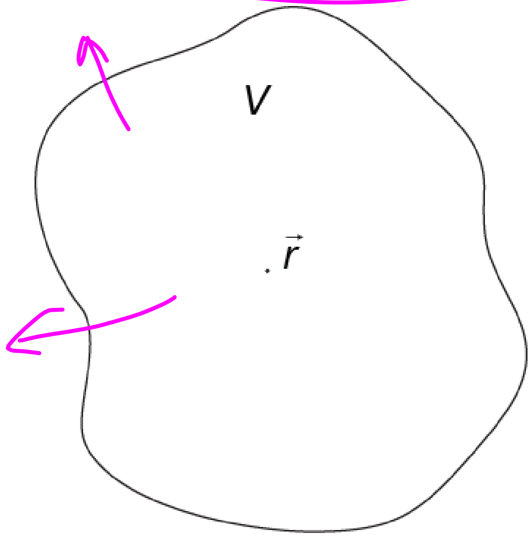
$$\left.\begin{aligned}\dot{m}_1 &= cA_1v_1\\ \dot{m}_2 &= cA_2v_2\end{aligned}\right\} \Rightarrow \frac{v_2}{v_1} = \frac{A_1}{A_2}$$

Balansvergelijkingen

Energiebalans

$$\frac{dm_V u}{dt} + \Delta\left[\left(h + \tfrac{1}{2}v^2 + gh\right)\dot{m}_{\partial V}\right] = \dot{Q} + \dot{W}$$

Geen expansie-arbeid



Complicaties:

- chemische reacties
- inhomogeniteit vloeistofsnelheid

Balansvergelijkingen

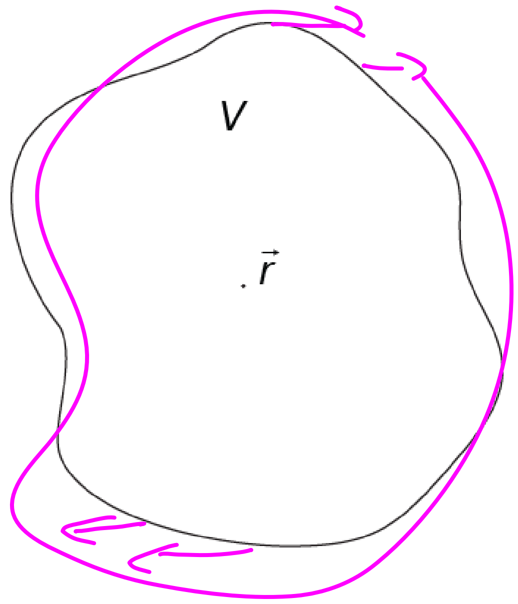
Impulsbalans

F = ma

$$\frac{dm_V v}{dt} = F_{volume} + F_{wand}$$

vb $m_V g$

afschuifkracht

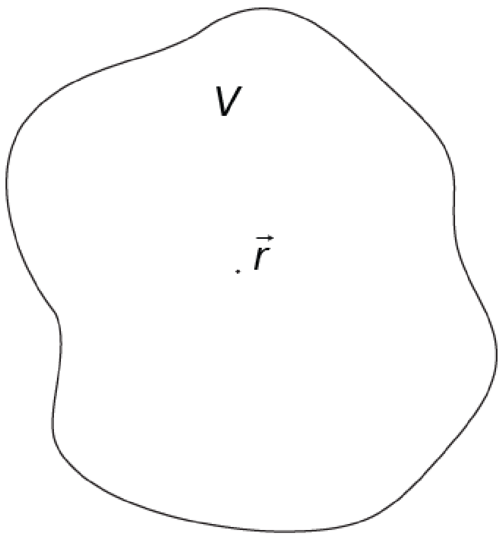


leidt tot Navier-Stokes vergelijking

Balansvergelijkingen

Entropiebalans

$$\frac{dm_V s}{dt} + \Delta s\dot{m}_{\partial V} = \frac{\dot{Q}}{T} + m_V \sigma$$



met (specifieke) entropieproductie

$$\sigma = \sum_k X_k J_k$$

en (vaak) lineaire kracht-flux-relaties

$$\begin{pmatrix} J_1 \\ J_2 \\ \vdots \end{pmatrix} = \begin{pmatrix} L_{11} & L_{12} & \cdots \\ L_{21} & L_{22} & \cdots \\ \vdots & \vdots & \ddots \end{pmatrix} \begin{pmatrix} X_1 \\ X_2 \\ \vdots \end{pmatrix}$$

Toepassingen

Adiabatische vlamtemperatuur

- reactie

$$CH_4\ (g) + 2\ O_2\ (g) \rightarrow CO_2\ (g) + 2\ H_2O\ (g)$$

- energiebalans

$$\frac{dm_V u}{dt} + \Delta\left[\left(h + \tfrac{1}{2}v^2 + gh\right)\dot{m}_{\partial V}\right] = \dot{Q} + \dot{W}$$

$$\Delta h \dot{m}_{\partial V} = 0$$

Toepassingen

Adiabatische vlamtemperatuur

- vóór reactie, bij 25 °C
  - voor verbranding
    - 1 mol CH_4
    - 2 mol O_2
  - 20% overmaat lucht
    - 0.2 x 2 mol = 0.4 mol O_2
    - 2.4 x (79/21) mol = 9.03 mol N_2
- ná reactie, bij temperatuur T
    - 1 mol CO_2
    - 2 mol H_2O
    - 0.4 mol O_2
    - 9.03 mol N_2
- Oplossing: T = 2066 K

$$H_{\text{voor}} = \begin{pmatrix} 1 \\ 2.4 \\ 0 \\ 0 \\ 9.03 \end{pmatrix} \bullet \begin{pmatrix} \Delta H^{\ominus}_{\text{CH4}} \\ \Delta H^{\ominus}_{\text{O2}} \\ \Delta H^{\ominus}_{\text{CO2}} \\ \Delta H^{\ominus}_{\text{H2O}} \\ \Delta H^{\ominus}_{\text{N2}} \end{pmatrix} = -74.5 \text{ kJ}$$

$$H_{\text{na}} = \begin{pmatrix} 0 \\ 0.4 \\ 1 \\ 2 \\ 9.03 \end{pmatrix} \bullet \left[\begin{pmatrix} \Delta H^{\ominus}_{\text{CH4}} \\ \Delta H^{\ominus}_{\text{O2}} \\ \Delta H^{\ominus}_{\text{CO2}} \\ \Delta H^{\ominus}_{\text{H2O}} \\ \Delta H^{\ominus}_{\text{N2}} \end{pmatrix} + \left(T - T^{\ominus}\right) \begin{pmatrix} C_{p,\text{CH4}} \\ C_{p,\text{O2}} \\ C_{p,\text{CO2}} \\ C_{p,\text{H2O}} \\ C_{p,\text{N2}} \end{pmatrix} \right]$$

$$= -877.1 + (T - 298) \times 453.9 \text{ J}$$

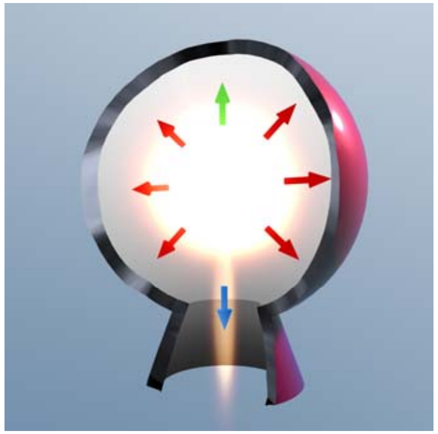
Toepassingen

Raketmotor

$$\frac{dm_V u}{dt} + \Delta\left[\left(h + \tfrac{1}{2}v^2 + gh\right)\dot{m}_{\partial V}\right] = \dot{Q} + \dot{W}$$

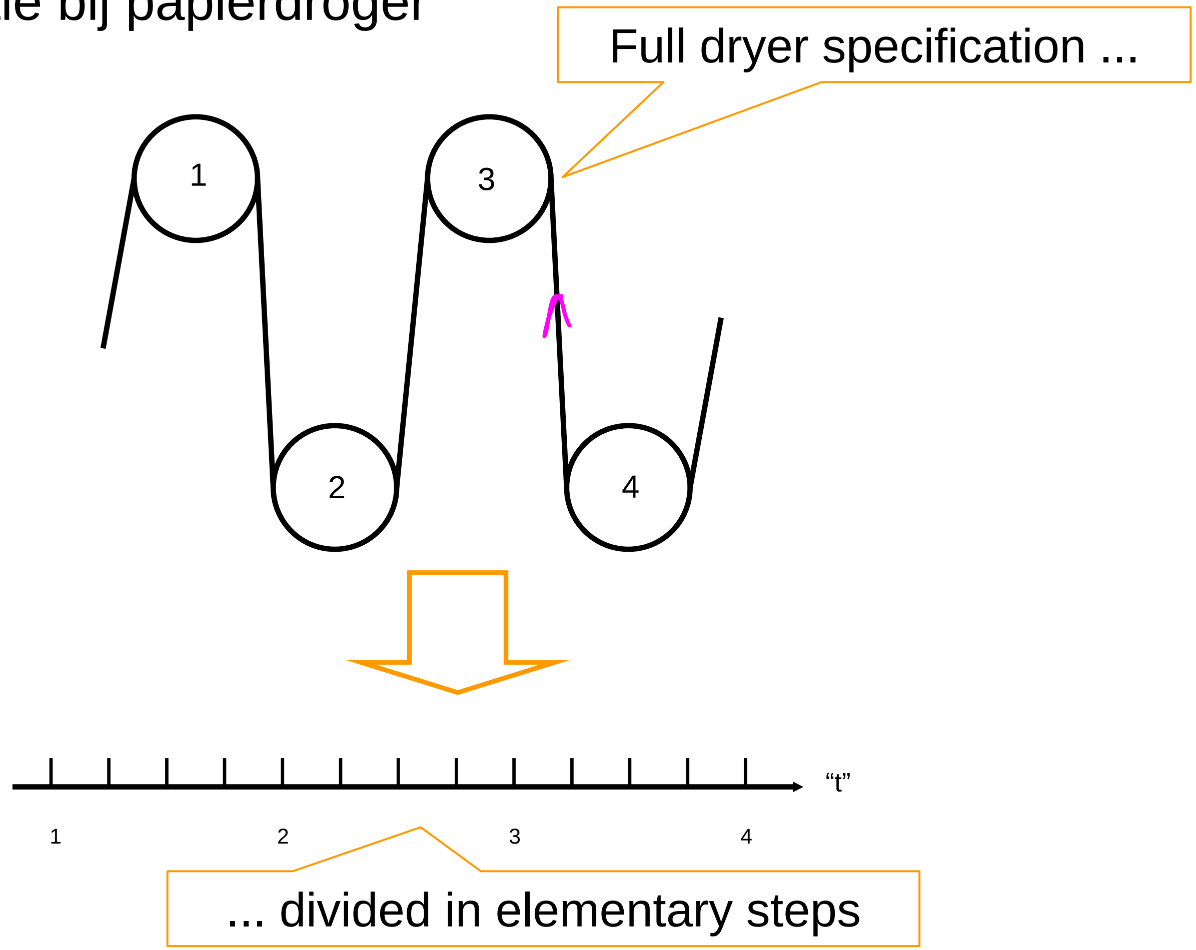
$$\Downarrow$$

$$\Delta\left[\left(h + \tfrac{1}{2}v^2\right)\dot{m}_{\partial V}\right] = 0$$



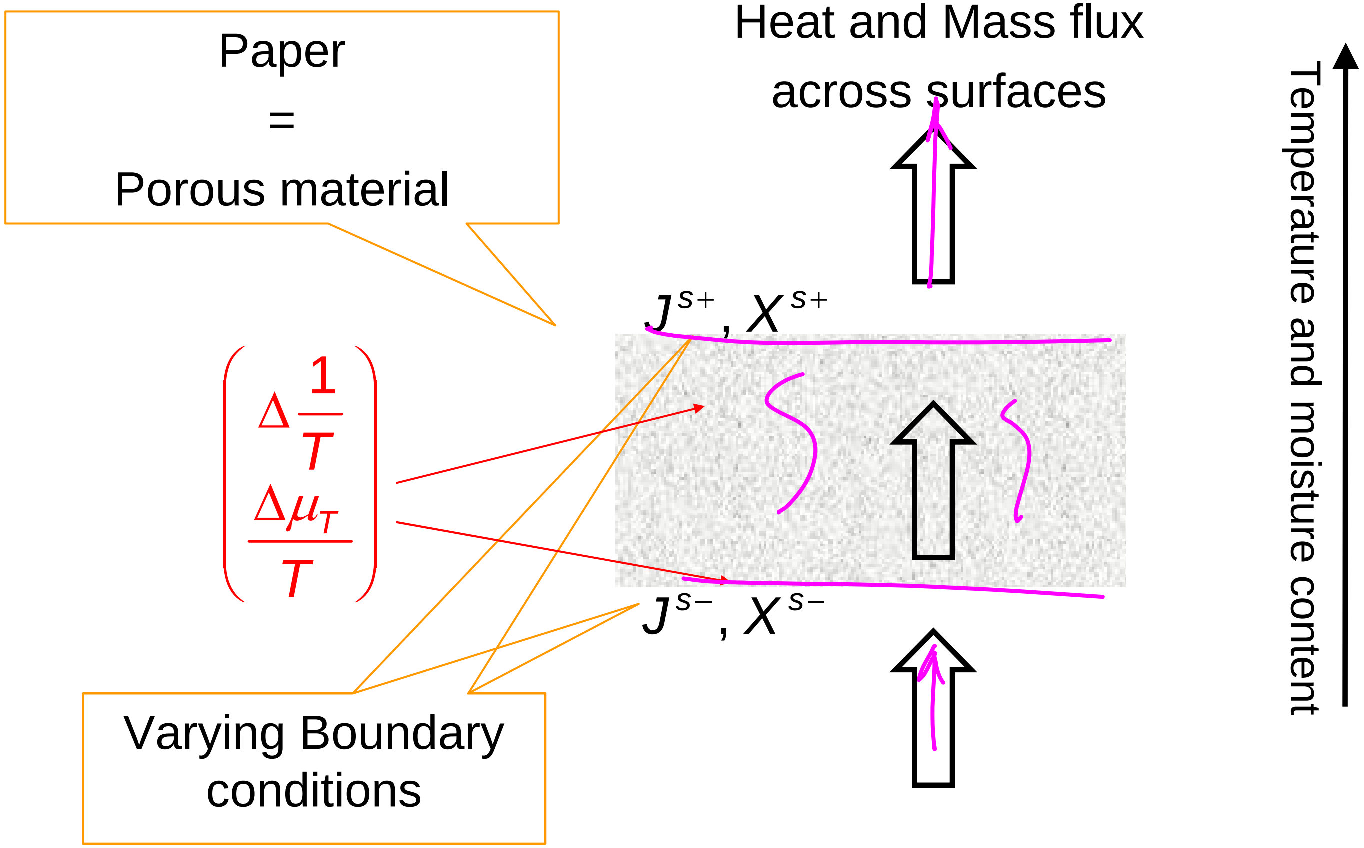
Toepassingen

Entropieproductie bij papierdroger



Toepassingen

Entropieproductie bij papierdroger



Toepassingen

Entropieproductie bij papierdroger

Bijdragen

- verdamping

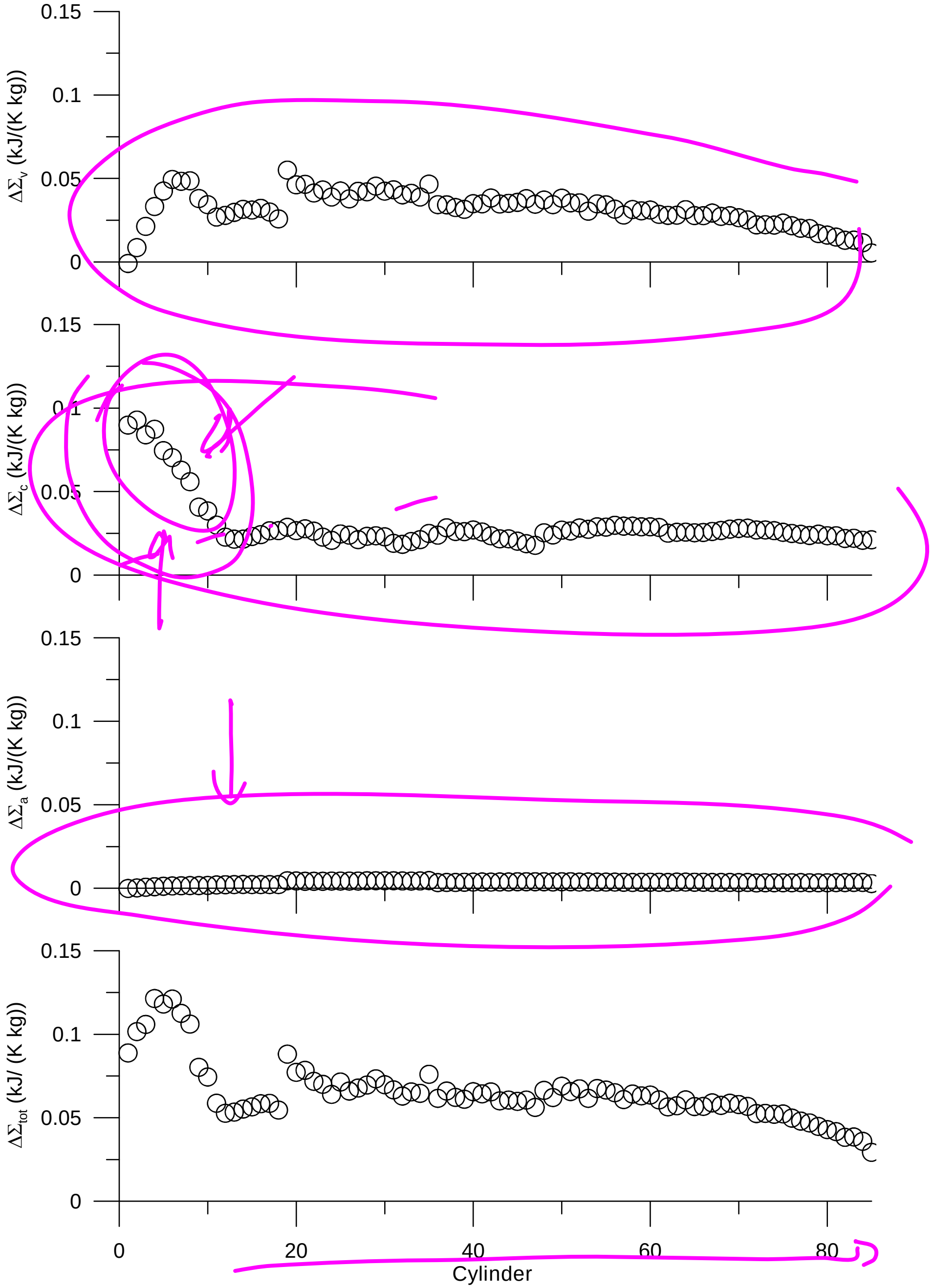
$$\sigma_v = -J_w R \ln \frac{p_w}{p^*_{pw}}$$

- cylinderverwarming

$$\sigma_c = -J'_{qc} \left(\frac{1}{T_c} - \frac{1}{T_p} \right)$$

- Warmte-afgifte

$$\sigma_a = -J'_{qa} \left(\frac{1}{T_p} - \frac{1}{T_a} \right)$$



Toepassingen

Entropieproductie bij papierdroger

- “Lost work” ongeveer 20% totale energiekosten *!*

Total entropy production per kg dry paper, its components and the lost work assuming an environmental temperature of 300 K

Paper machine	Evaporation (kJ/kg K)	Conduction (kJ/kg K)	Convection (kJ/kg K)	Total (kJ/kg K)	Lost work (kJ/kg)
LB183	0.75	0.90	0.04	1.69	507
LB205	0.79	0.90	0.01	1.69	507
LB337	0.94	1.20	0.11	2.26	678
NP1	0.37	0.59	0.10	1.06	318
NP2	0.58	0.81	0.03	1.42	426