# Mass Transfer: Evaporation

## Evaporation at a liquid surface
## - Stefan Flow -

Prof. Dr.-Ing. Reinhold Kneer

Prof. Dr.-Ing. Dr. rer. pol. Wilko Rohlfs

HEATQUIZ

UNIVERSITY OF TWENTE.

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## Problem:

- Understanding of the particularities of mass transfer on a liquid semi-permeable surface
- Knowledge about the Stefan flow

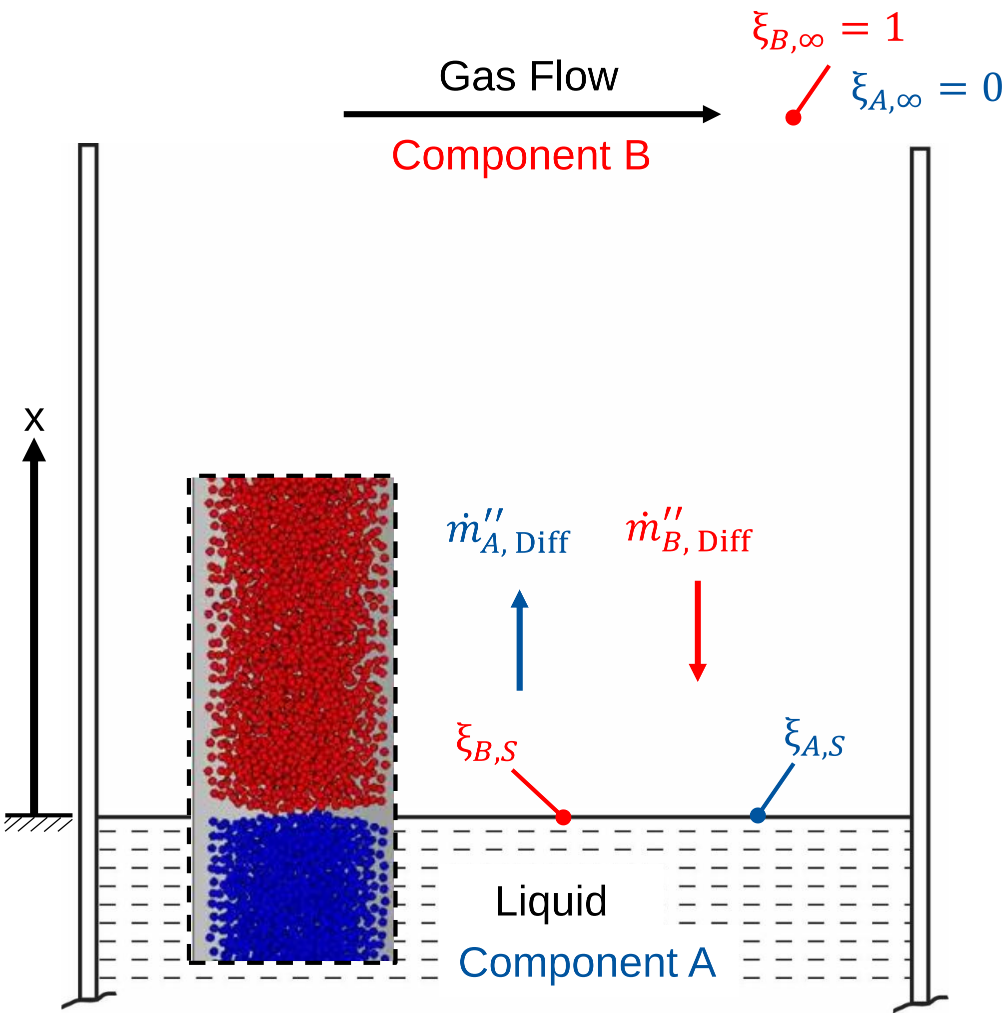
- Component B (gas) does not dissolve in component A
- Component A (liquid) evaporates
  ⇨ the liquid surface is semi-permeable

## Question:

- How large is the evaporating mass flow?

Water glass
in laboratory

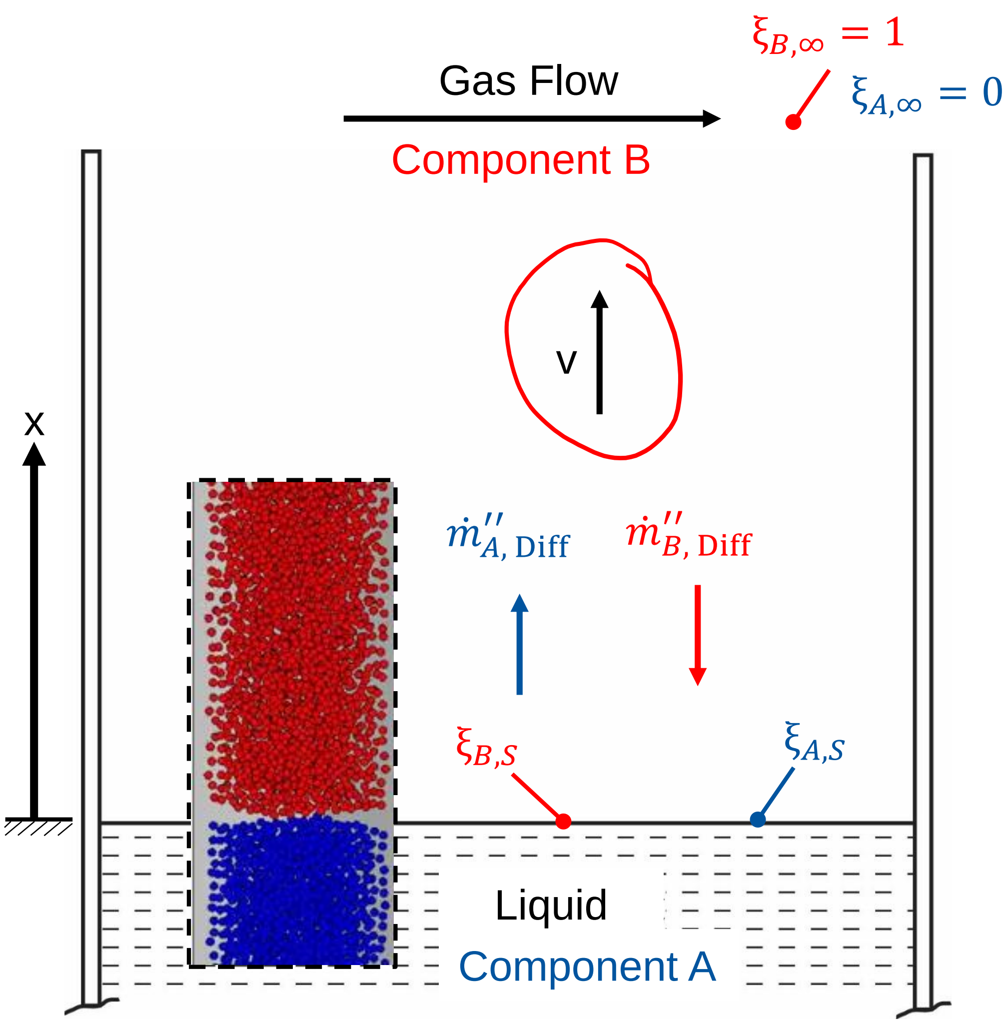
# Evaporation at a liquid surface

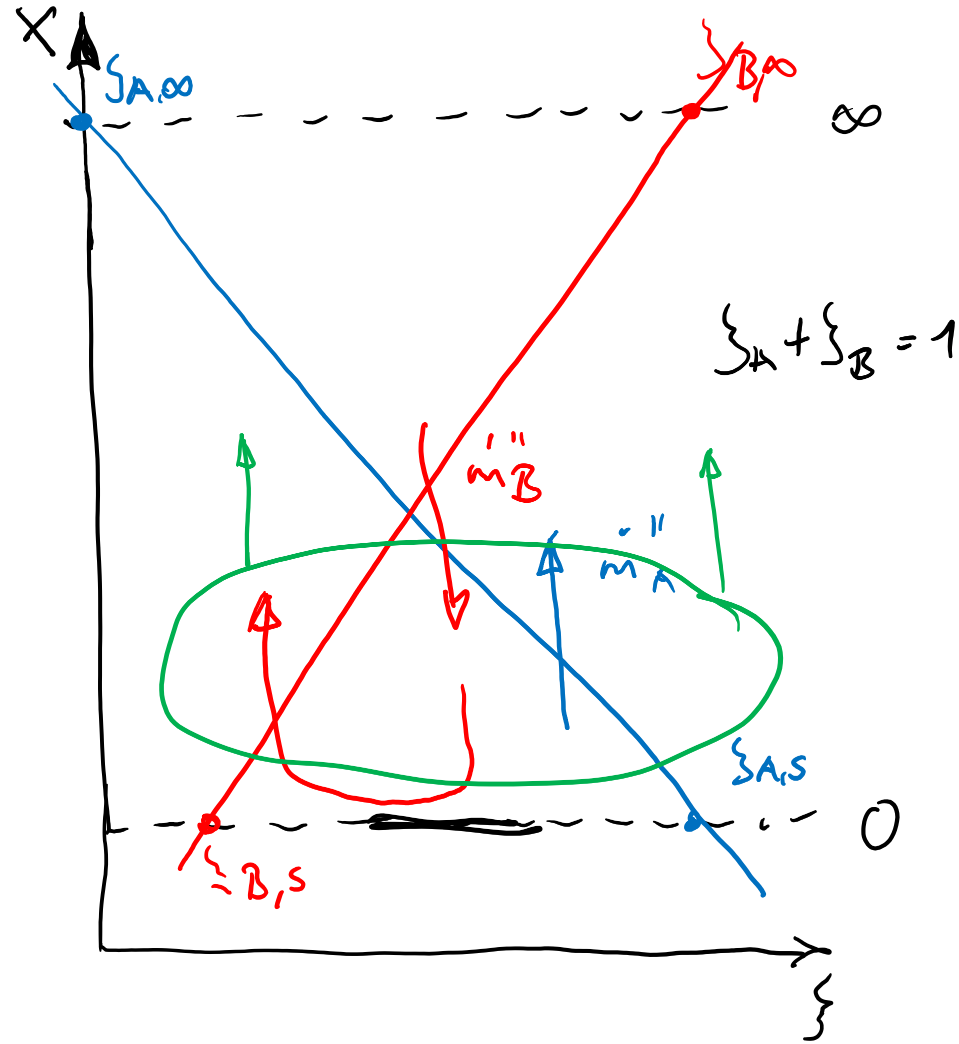



**Problem:**

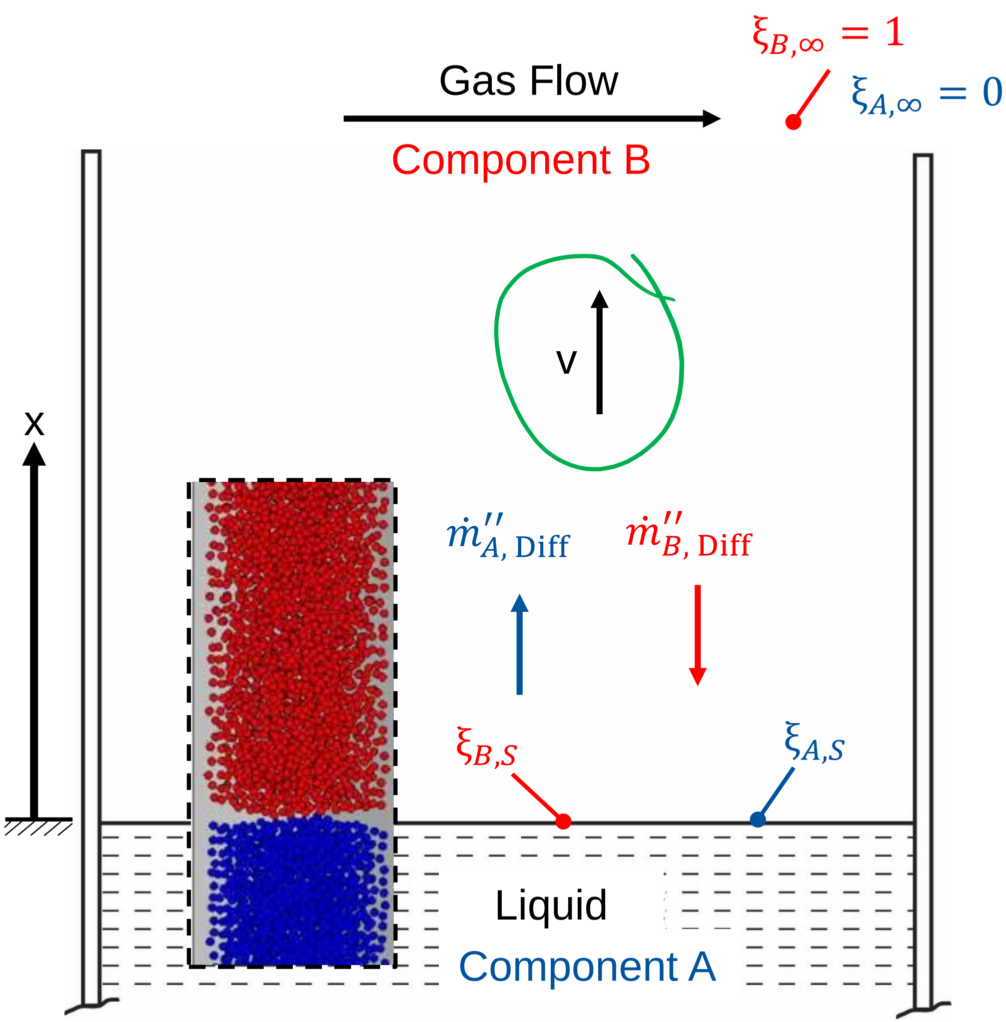
- At the liquid surface, the concentration of component A corresponds to the saturation concentration $\xi_{A,S}$
- Only component B is present in the outside gas flow: $\xi_{B,\infty} = 1 \quad (\Rightarrow \xi_{A,\infty} = 0)$
- Due to the driving potentials: $(\xi_{B,\infty} - \xi_{B,S})$, $(\xi_{A,\infty} - \xi_{A,S}) \neq 0$;
  ⇨ diffusional flows establish
- The liquid surface is impermeable to B, but of course liquid vapor can leave the surface:
  ⇨ the liquid surface is semi-permeable (**video**)

# Evaporation at a liquid surface



# Evaporation at a liquid surface




**Analysis:**

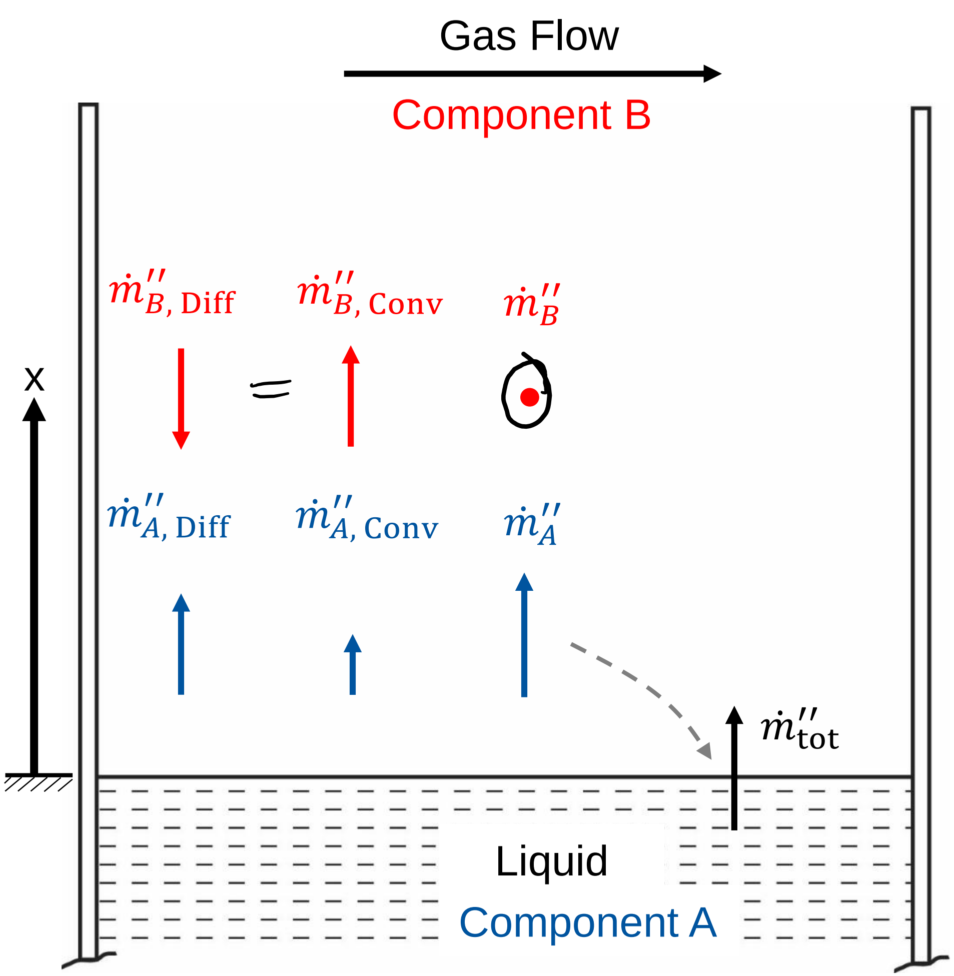
- The liquid surface is impermeable to B, but of course liquid vapor can leave the surface:
  ⇨ the liquid surface is semi-permeable
- The diffusional flow of B must be balanced by a convective flow in opposite direction:

⇨ $\dot{m}''_{B,\,\mathrm{Diff}} = -\,\dot{m}''_{B,\,\mathrm{Conv}}$

⇨ $\dot{m}''_{A,\,\mathrm{Diff}}$ gets enhanced by $\dot{m}''_{A,\,\mathrm{Conv}}$

Some math

# Evaporation on a liquid surface




## Determination of evaporating mass flow of component A:

Mass flow in steady state:

$$\dot{m}''_A = \dot{m}''_{A,\,\mathrm{Diff}} + \dot{m}''_{A,\,\mathrm{Conv}} = j''_A + \rho v \xi_A \qquad (1)$$

$$\dot{m}''_B = \dot{m}''_{B,\,\mathrm{Diff}} + \dot{m}''_{B,\,\mathrm{Conv}} = j''_B + \rho v \xi_B \qquad (2)$$

Analysis:

$$\dot{m}''_B = 0 \qquad (3)$$

(3) in (2): $\rho v \xi_B = -j''_B \qquad (4)$

(1) + (2): $\dot{m}''_A + \dot{m}''_B = \underbrace{(j''_A + j''_B)}_{0} + \rho v \underbrace{(\xi_A + \xi_B)}_{1} \qquad (5)$

$$\dot{m}''_A = \rho v = \dot{m}''_{tot} = \dot{m}'' \qquad (6)$$

(6) in (1): $\dot{m}'' = \dot{m}'' \xi_{A,S} + j''_{A,S} \qquad (7)$



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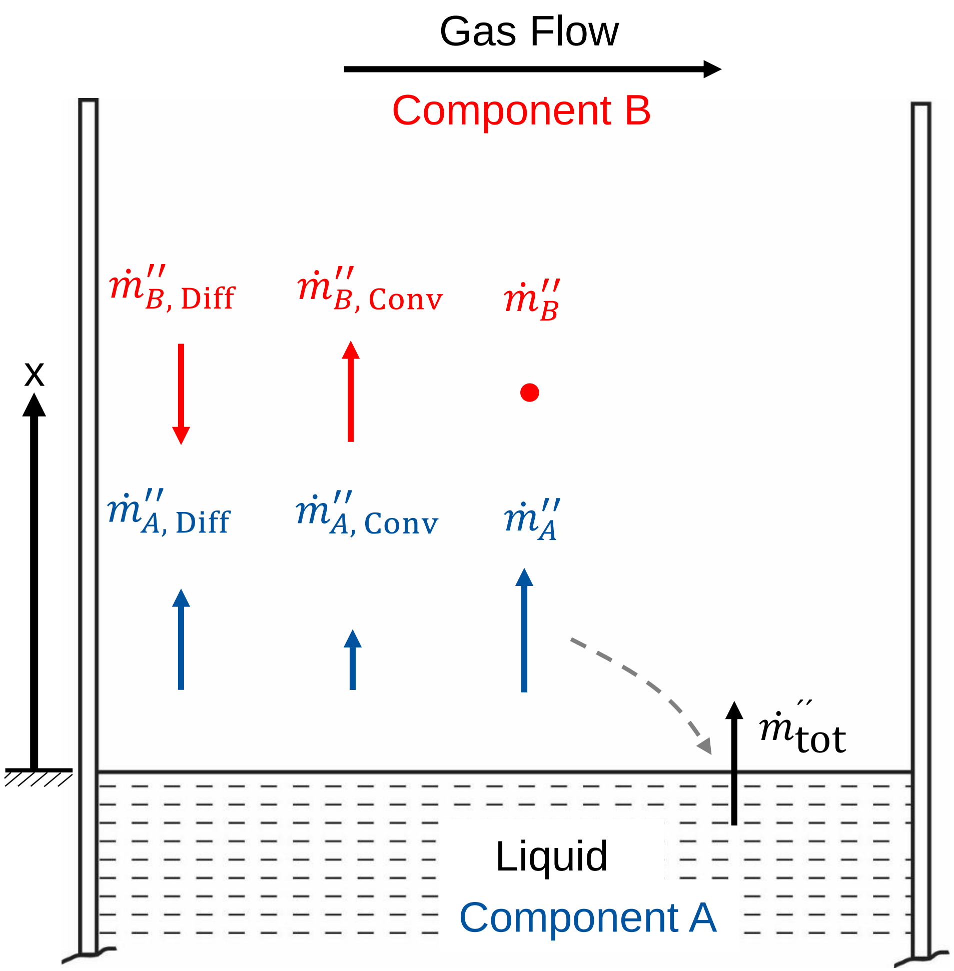
# Evaporation on a liquid surface




**Determination of evaporating mass flow of component A:**

continue with ⑦

$$\dot{m}'' = \dot{m}''_{\mathrm{tot}} = \dot{m}''\,\xi_{A,S} + j''_{A,S}$$

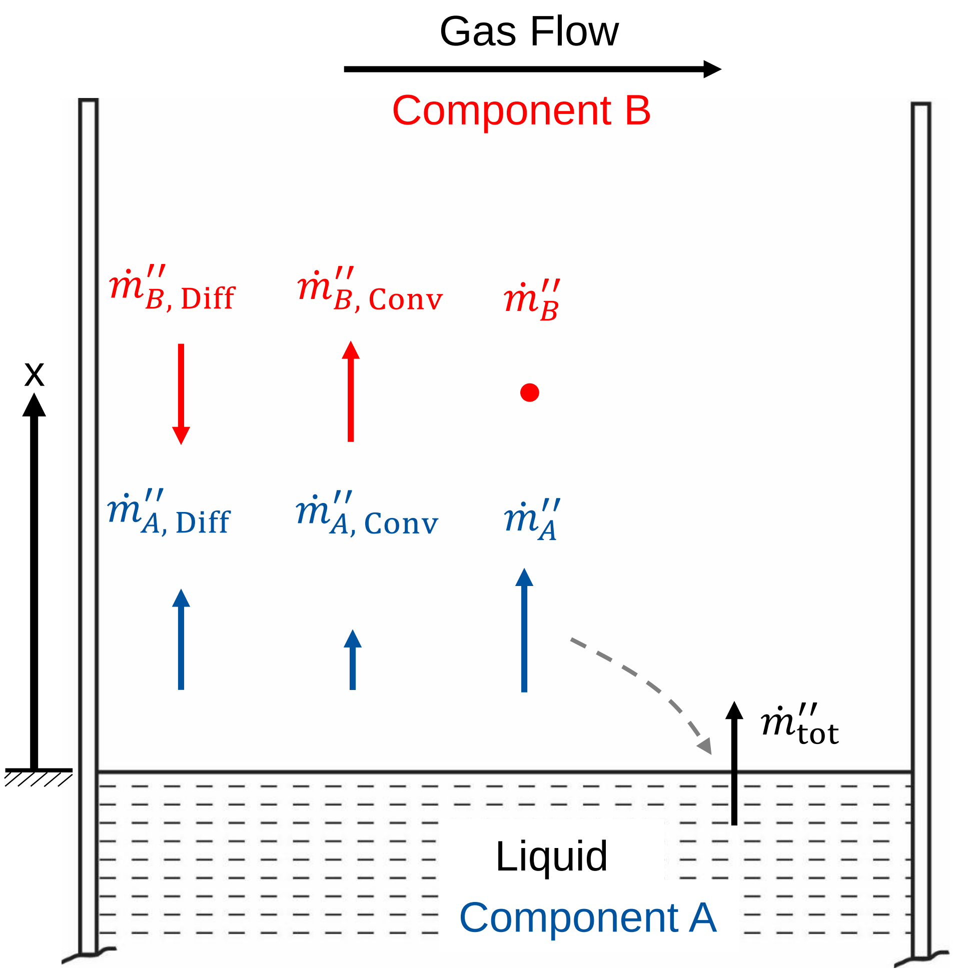
$$\boxed{\Rightarrow \dot{m}'' = \underbrace{\frac{1}{1-\xi_{A,S}}}_{\text{Stefan-Factor}}\, j''_{A}}$$

Described with the mass transfer coefficient g:

$$j''_{A} = g\,(\xi_{A,S} - \xi_{A,\infty})$$

$$\boxed{\Rightarrow \dot{m}''_{A} = g\,\frac{\xi_{A,S} - \xi_{A,\infty}}{1-\xi_{A,S}}}$$

# Evaporation on a liquid surface




## Determination of evaporating mass flow of component A:

$$\Rightarrow \dot{m}''_A = g\,\frac{\xi_{A,S} - \xi_{A,\infty}}{1 - \xi_{A,S}}$$

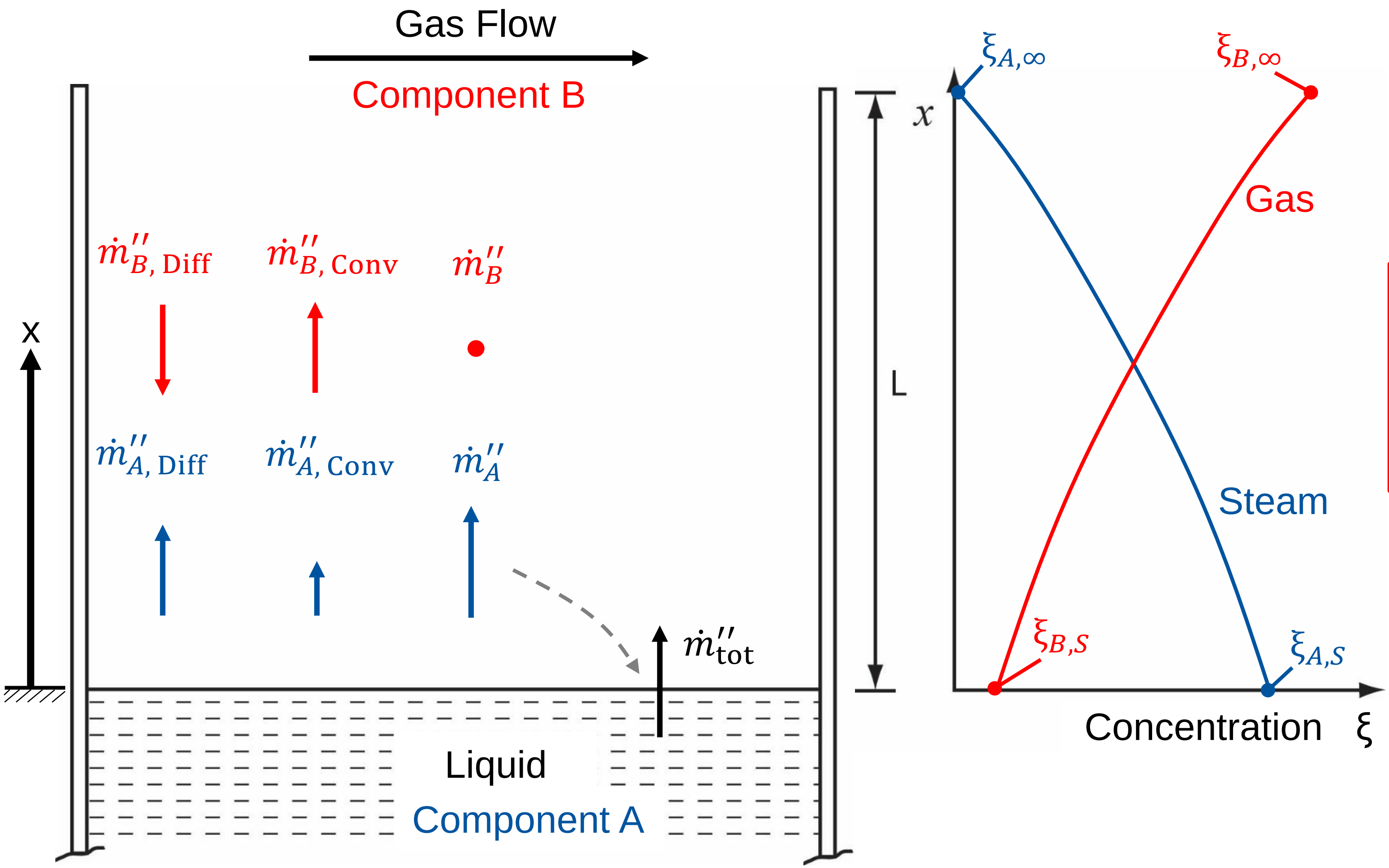
Dimensionless notation:

$$\mathrm{Sh} = \frac{gL}{\rho D} \Rightarrow g = \mathrm{Sh}\,\frac{\rho D}{L} = \mathrm{Sh}\,\underbrace{\frac{\rho D}{\eta}}_{1/Sc}\,\underbrace{\frac{\eta}{\rho v_\infty L}}_{1/Re}\,\rho v_\infty$$

Substituting:

$$\Rightarrow \frac{\dot{m}''_A}{\rho v_\infty} = \frac{\mathrm{Sh}}{\mathrm{Sc}\,\mathrm{Re}}\,\frac{\xi_{A,S} - \xi_{A,\infty}}{1 - \xi_{A,S}}$$

# Correct profiles for $\xi_A$ and $\xi_B$




The derivation of the concentration profile is part of master courses



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# Comprehension questions

**What causes the additional convection ?**
**What does it compensate for?**

**Which parameter influences the amplification of the evaporation mass flow by convection in a significant way?**