# Absorption

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# Absorption

- In absorption a gas mixture is contacted with a liquid solvent to remove one or more components from the gas phase.
- The opposite of absorption is stripping, where in a liquid mixture is contacted with a gas to remove components from the liquid to the gas phase.
- Distinction should be made between physical absorption and chemical absorption.



Concentration profile of a solute A diffusing through two phases.

$$N_A = K_y \Big( y_{AG} - y_A^* \Big)$$

, where  $K_y$  is the overall trasfer coefficient (mol/(m<sup>2</sup>s))  $y_A^*$  would be equilibrium with  $x_{AL}$ .



#### Single-stage equilibrium process



Figure 10.3-1. Single-stage equilibrium process.

Total balance equation

 $L_0 + V_2 = L_1 + V_1$ 

Component balance equation

$$L_0 \cdot x_0 + V_2 \cdot y_2 = L_1 \cdot x_1 + V_1 \cdot y_1$$

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Figure 10.3-3. Number of stages in a countercurrent multiple-stage contact process.

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#### **Balance equations**



 $L_0$ 

$$L_0 + G_{N+1} = L_N + G_1$$
  
·  $x_{i0} + G_{N+1} \cdot y_{iN} = L_N \cdot x_{iN} + G_1 \cdot y_{i1}$   $i = 1, 2, \dots, I$ 

L and G are constant along the column.  $y_{N+1} >> y_1$  $x_N >> x_0$ 



This straight line is the operating line.



Figure 10.3-3. Number of stages in a countercurrent multiple-stage contact process.



Given:  $y_1$  $\mathcal{Y}_{N+1}$  $\mathcal{Y}_{0}$ Result: N L or  $x_N$  can be estimated If L/G is large: N decreases  $x_N$  decreases If L/G is small: N increases  $x_N$  increases



Mole fraction, x

Figure 10.6-8. Theoretical number of trays for absorption of SO<sub>2</sub> in Example 10.6-2.

# Minimum slope of the operation line (minimum liquid to gas ratio)



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### **Balance equations, simplified**



| x - x [kmol absorptivum/solute]   |
|---|
| $x = \frac{1}{1-x} \begin{bmatrix} -x \\ -x \end{bmatrix}$ kmol solvent                                       |
| $Y = \frac{y}{1 - y} \left[ \frac{\text{kmol absorptivum/solute}}{\text{kmol absorptivum/inert gas}} \right]$ |
| $\dot{L} = L \cdot (1 - x)$ solute-free solvent   |
| $G' = G \cdot (1 - y)$ solute-free gas  |
| Form of Henry's law:  |
| $\frac{Y}{1+Y} = \text{He'} \cdot \frac{X}{1+X}$  |
| Form of total component balance equation:   |

$$\dot{L} \cdot X_0 + \dot{G} \cdot Y_{N+1} = \dot{L} \cdot X_N + \dot{G} \cdot Y_1$$

### **Operating line**



Component balance equation of the control area:

$$\dot{L} \cdot X_{m} + G' \cdot Y_{N+1} = \dot{L} \cdot X_{N} + G' \cdot Y_{m+1}$$

$$Y_{m+1} = \frac{L'}{G'} X_m - \frac{L'}{G'} \cdot X_N + Y_{N+1}$$

This straight line is the operating line.

# Analytical determination of the number of theoretical stages Lo, xo (L and G are constants)

• If both the operationg line and the equilibrium curve are linear:

– L/G is constant

- y=m·x  $G \cdot (y_2 - y_1) = L \cdot (x_1 - x_0)$   $y_2 = y_1 + L/G \cdot (x_1 - x_0)$   $y_1 = m \cdot x_1 \rightarrow x_1 = \frac{y_1}{m} \text{ and } x_0 = \frac{y_0}{m}$ , where  $y_0^*$  is hypotetical concentration, in equilibrium with x<sub>0</sub>. Introducing the absorption coefficient:  $A = \frac{L}{m}$ 

 $\begin{array}{c|c}
m \\
m \\
m+1 \\
\hline
G_{N+1} \\
y_{N+1} \\
\hline
L_N \\
x_N
\end{array}$ 

G1 , y1

1

n

### Analytical determination of the number of theoretical stages $y_2 = y_1(1+A) - A \cdot y_0^*$

Component balance equation of the second thoretical stage:

$$G \cdot (y_3 - y_2) = L \cdot (x_2 - x_1)$$
  

$$y_3 = y_2 + L/G \cdot \left(\frac{y_2}{m} - \frac{y_1}{m}\right) = y_2 + \frac{L}{G \cdot m}(y_2 - y_1)$$
  

$$= y_2(1 + A) - A \cdot y_1$$
  

$$y_3 = \left[y_1(1 + A) - A \cdot y_0^*\right](1 + A) - A \cdot y_1$$
  

$$y_3 = y_1(1 + 2A + A^2 - A) - (A + A^2) \cdot y_0^*$$

might be continued

# Analytical determination of the number of theoretical stages

$$y_{N+1} = y_1 \left( 1 + A + A^2 + A^N \right) - y_0^* \cdot \left( A + A^2 + A^N \right)$$
$$y_{N+1} = y_1 \frac{1 - A^{N+1}}{1 - A} - y_0^* \cdot A \frac{1 - A^N}{1 - A}$$

$$y_{N+1} = y_1 \frac{1 - A^{N+1}}{1 - A} - m \cdot x_0 \cdot A \frac{1 - A^N}{1 - A}$$

$$\frac{y_{N+1} - y_1}{y_{N+1} - m \cdot x_0} = \frac{A^{N+1} - A}{A^{N+1} - 1}$$
 Kremser (1930)  
Brown-Sauders (1932)

$$N = \frac{\log_{10} \left[ \frac{y_{N+1} - m \cdot x_0}{y_1 - m \cdot x_0} \cdot \left(1 - \frac{1}{A}\right) + \frac{1}{A} \right]}{\log_{10} A}$$
  
when A=1  $N = \frac{y_{N+1} - y_1}{y_1 - m \cdot x_0}$ 

#### Typical locations of operating line at absorption and at stripping



Figure 10.6-10. Location of operating lines: (a) for absorption of *A* from *V* to *L* stream; (b) for stripping of *A* from *L* to *V* stream.

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Figure 10.6-11. Operating line for limiting conditions: (a) absorption; (b) stripping.

### **Differential columns**



dH is the differential height of column (m)

$$d(G \cdot y) = K_y a(y - y^*) A \cdot dH$$

$$d(G \cdot y) = d\left(G' \cdot \frac{y}{1-y}\right) = G'd\left(\frac{y}{1-y}\right) = G'\frac{dy}{(1-y)^2} = G\frac{dy}{1-y}$$

$$Y = \frac{y}{1 - y} \left[ \frac{\text{kmol absorptivum/solute}}{\text{kmol absorptivum/inert gas}} \right]$$

$$G' = G(1 - y)$$

Modified component balance equation

$$G\frac{dy}{1-y} = \frac{K_y \cdot a \cdot (1-y)_{av} \cdot (y-y^*) \cdot A \cdot dH}{(1-y)_{av}}$$
$$dH = \frac{G}{K_y a (1-y)_{av} A} \cdot \frac{(1-y)_{av}}{(1-y) \cdot (y-y^*)} dy$$

$$\int_{0}^{H} dH = \int_{y_{0}}^{y_{1}} \frac{G}{K_{y}a(1-y)_{av}A} \cdot \frac{(1-y)_{av}}{(1-y)\cdot(y-y^{*})}dy$$

Each parameters on the right side are dependent on concentration, thus numerical integration is needed.

Assumptions:  $K_y a(1-y)_{av}$  is independent of concentration  $K_y$  is proportional to G<sup>0,8</sup>

Thus:  $G/G^{0,8}$  is roughly independent from concentration.

$$H = \frac{dy}{1-y} = \frac{G}{K_{y}a(1-y)_{av}A} \int_{y_{0}}^{y_{1}} \frac{(1-y)_{av}}{(1-y)\cdot(y-y^{*})} dy$$

#### **Transfer Units**

 $H = NTU_G \cdot HTU_G$ 

$$\frac{\left(1-y\right)_{av}}{\left(1-y\right)} \approx 1$$

$$H = \frac{G}{K_{y}a(1-y)_{av}A} \int_{y_{0}}^{y_{1}} \frac{1}{(y-y^{*})} dy$$

$$HTU_{G} = \frac{G}{K_{y}a(1-y)_{av}A}$$
$$NTU_{G} = \int_{y_{0}}^{y_{1}} \frac{1}{(y-y^{*})}dy$$

height of a transfer unit (m)

number of transfer units

#### **Absorbers**



#### **Absorbers**

![](_page_24_Figure_1.jpeg)

spray column

bubble column

plate-type absorbers

![](_page_25_Figure_0.jpeg)

Figure 10.6-3. Packed tower flows and characteristics for absorption.

#### **Random packings**

![](_page_26_Figure_1.jpeg)

Figure 10.6-4. Typical random or dumped tower packings: (a) Raschig ring; (b) Berl saddle; (c) Pall ring; (d) Intalox metal, IMTP; (e) Jaeger Metal Tri-Pack.

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# **Typical applications**

- separation of gases
  - production of HNO<sub>3</sub>

![](_page_28_Figure_0.jpeg)

# **Typical applications**

- separation of gases
  - production of HNO<sub>3</sub>
  - separation of produced gases
  - fractionation of hydrocarbons
  - sweetening of natural gases (acid gas removal)
- waste gas purification

![](_page_30_Figure_0.jpeg)

# Typical applications, waste gas purification

- removal of gaseous pollutants, such as hydrogen halides, SO<sub>2</sub>, ammonia, hydrogen sulphide
- or volatile organic solvents
- removal of  $CO_2$  or  $H_2S$  from natural gas
- but also removal of dust with certain types of scrubbers

# Typical absorbents in waste gas purification

- water, to remove solvents and gases such as hydrogen halides or ammonia
- alkaline solutions, to remove acid components such as hydrogen halides, sulphur dioxide,
- phenols, chlorine; also used for second-stage scrubbing to remove residual hydrogen halides after first-stage aqueous absorption; biogas desulphurisation

# Typical absorbents in waste gas purification

- alkaline-oxidation solutions, i.e. alkaline solutions with sodium hypochlorite, chlorine dioxide, ozone or hydrogen peroxide
- sodium hydrogensulphite solutions, to remove odour (e.g. aldehydes)
- Na<sub>2</sub>S<sub>4</sub> solutions to remove mercury from waste gas
- acidic solutions, to remove ammonia and amines
- monoethanolamine and diethanolamine solutions, suitable for the absorption and recovery of hydrogen sulphide.

## **THANK YOU!**