Stagewise Operations
Fall 2010

Absorption & Stripping

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Absorption

One or more components of a gas stream are removed by being taken up in a nonvolatile liquid

Separating agent is not heat but a liquid solvent

Application: removal of CO$_2$ from natural gas
**Stripping** is the opposite of absorption

One or more components of a liquid stream are removed by being vaporized into an insoluble gas stream

Unlike distillation where heat is the separating agent, in **stripping**, a gas stream is the separating agent
Physical absorption

Gas is removed because of its greater solubility in the solvent than the other gases

Removal of C4 and C5 from refinery gas with heavy oil

Chemical absorption

Gas to be removed reacts with solvent and remains in solution

Removal of CO₂ from natural gas With MEA

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Equipment for absorption and stripping similar to distillation equipment

But no use for reboilers and condensers

Can use packed or plate towers
Absorption & stripping equilibria

Assumptions:

1/ carrier gas is insoluble

2/ solvent is non volatile

3/ system is isobaric and isothermal

\[ F = C + P - 2 = 3 \]

If \( T \) and \( P \) are set then only one degree of freedom is left
Equilibrium data

1/ Plot solute composition in vapor vs. solute composition in liquid

2/ Use henry’s law (valid at low solute concentrations) if $H_B$ is given.

$$y_B = \frac{H_B}{P_{tot}} x_B$$
<table>
<thead>
<tr>
<th>$T^\circ C$</th>
<th>$CO_2$</th>
<th>$CO$</th>
<th>$H_2S$</th>
</tr>
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<tbody>
<tr>
<td>0</td>
<td>728</td>
<td>35,200</td>
<td>26,800</td>
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<td>5</td>
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<td>84,500</td>
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<td>90</td>
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<td>84,600</td>
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</tr>
<tr>
<td>100</td>
<td>—</td>
<td>84,600</td>
<td>148,000</td>
</tr>
</tbody>
</table>
Large H-values for CO$_2$ implies that this gas is very sparingly soluble in water

H is independent of $P_{tot}$

More gas is dissolved if one uses high $P_{tot}$

Can make carbonated beverages

$H$ temperature dependence follows Arrhenius law

\[ II = II_0 \exp \left( \frac{-E}{RT} \right) \]
Operating lines for absorption

One can apply McCabe & Thiele method if operating lines are straight

Energy balance is automatically satisfied if:

1/ Heat of absorption is negligible

2/ Operation is isothermal
L = flow rate of nonvolatile solvent

G = flow rate of insoluble carrier gas

Overall flow rates of liquid and gas may vary significantly because a large amount of solute may be absorbed
Need to define compositions as mole ratios:

\[ Y = \frac{\text{moles of } B \text{ in gas}}{\text{moles of pure carrier gas}} = \frac{y}{1 - y} \]

\[ X = \frac{\text{moles of } B \text{ in liquid}}{\text{moles of pure solvent}} = \frac{x}{1 - x} \]
Mass balance at steady state operations

Input = Output

\[(\text{Moles of B/hr})_{\text{in}} = (\text{Moles of B/hr})_{\text{out}}\]

\[Y_{j+1}G + X_0L = X_jL + Y_1G\]
Operating line is a straight line with a constant slope \( \frac{L}{G} \) and an intercept \( Y_1 - \left( \frac{L}{G} \right) X_0 \)

\[
Y_{j+1} = \frac{L}{G} X_j + Y_1 - \left( \frac{L}{G} \right) X_0
\]
Steps to follow:

1/ Plot $Y$ vs. $X$ (equilibrium data must be converted to mole ratios)

2/ $X_0$, $Y_{N+1}$, $Y_1$ and $L/G$ known

$(X_0, Y_1)$ is on the operating line because streams 0 and 1 are passing streams

3/ constant slope is $L/G$. Plot operating line

4/ start at stage 1 and step off stages by alternating between equilibrium curve and operating line
Distillation:
volatile component is transferred from liquid phase to vapor phase

Equilibrium curve is above operating line

Absorption:
Solute is transferred from vapor phase to liquid phase

Equilibrium curve is below operating line
\((L/G)_{min}\) can be obtained graphically

\[ \begin{align*}
(\text{Slope of operating line from } (Y_1, X_0) \text{ to intersection of equilibrium curve with } Y=Y_{N+1}) \end{align*}\]
Stripping
Mass balance

\[ Y_{j+1} = \frac{L}{G} X_j + Y_1 - \left( \frac{L}{G} \right) X_0 \]
Steps to follow:

1/ Plot $Y$ vs. $X$ (equilibrium data must be converted to mole ratios)

2/ $X_0$, $X_N$, $Y_{N+1}$ and $L/G$ known

$(X_N,Y_{N+1})$ is on the operating line because streams $N$ and $N+1$ are passing streams

3/ constant slope is $L/G$. Plot operating line

4/ start at stage $N$ and step off stages by alternating between equilibrium curve and operating line
Stripping:

Solute is transferred from liquid phase to vapor phase

Equilibrium curve is above operating line
\((L/G)_{max}\) can be obtained graphically

Minimum amount of stripping gas

\[
\text{Slope of operating line from } (Y_{N+1}, X_N) \text{ to } X=X_0
\]

intersection of equilibrium curve with \(X=X_0\)

vertical line
Kremser Equation

If solution is quite dilute, one can do entire analysis using mole fractions

Total liquid and vapor flow rates are almost constant.

Operating line is a straight line with slope $L/V$.

$$y_{j+1} = \frac{L}{V} x_j + y_1 - \left( \frac{L}{V} \right) x_0$$

One can use the McCabe & Thiele method
Assume equilibrium line is a straight line:

\[ y_j = mx_j + b \]

Number of stages \( N \) is given by

\[
N = \frac{y_{N+1} - y_1}{y_1 - \frac{L}{V}x_0 - b} \quad \text{when } mV = L
\]

\[
N = \frac{ln\left(\frac{L}{mV}\right)}{ln\left(\frac{(1 - \frac{mV}{L})\left(\frac{y_{N+1} - y_1^*}{y_1 - y_1^*}\right) + \frac{mV}{L}}{\frac{L}{mV}}\right)}
\]

\[
\text{when } L \neq mV \text{ with } y_1^* = mx_0 + b
\]