ABSORPTION

1. INTRODUCTION

Absorption is a unit operation where concentrations of some components in the gas phase are reduced by absorbing them to the liquid phase. This is usually done to remove a noxious component from the gas phase or to recover a valuable component to the liquid phase. So, absorption is an operation where mass transfer occurs between gas and liquid phase.

In order to transfer a component between the two phases, the following two conditions must be met:

1. The phases must be in contact.
2. The phases must not be in equilibrium state.

In absorption, phases are typically contacted countercurrently without reflux in equipment, which provides a great surface area for mass transfer. As a process, without reflux and in countercurrent flow, absorption can be described as follows:
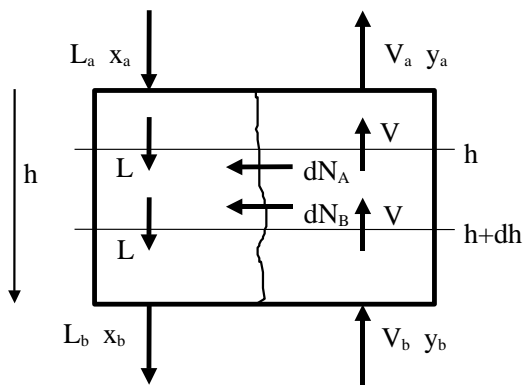

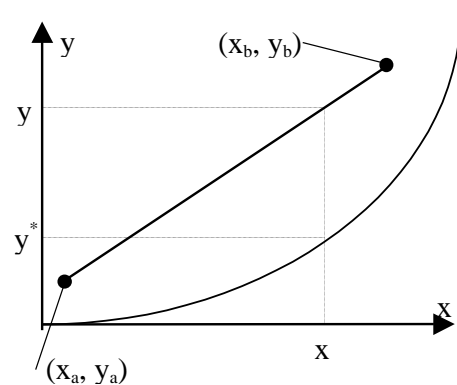**Figure 1. Absorption in countercurrent flow**

Figure 2. Operating line

Since mass transfer in absorption occurs from gas to liquid, the operating line is above the equilibrium line in x,y coordinates (The corresponding concentration y in the gas phase for every concentration x in the liquid phase is greater than the equilibrium concentration y^*.) As it can be seen in figure 2, the concentration y in gas phase reduces and the concentration x in the liquid phase increases. A common way of nomenclature is used: that end of the absorption tower where liquid is fed is marked with a.

1.1 ABSORPTION AND ABSORBER

Absorption and distillation are processes (an absorption process and a distillation process), so these terms shouldn't be mixed with equipment used (an absorber and a distiller). Typical absorbers and distillers are absorber columns and distillation columns

Both absorption and distillation can be done in a plate column or in a packed column.

1.2 COMPARING PLATE AND PACKED COLUMNS

A packed column is usually favorable, when
- Only a small pressure drop is allowed in the column (for example in vacuum columns)
- The components are corrosive
- The diameter of the column is small (below 1 m)
- The hold-up must be small (for example due to thermal decomposition)
- The liquid foams

A plate column is usually favorable, when
- Liquid flows are too large or too small; then the hold-up can be adjusted with the structure of plates
- Liquid flows vary a lot
- A big hold-up is required to lengthen the contact time, for example in reactive distillation
- The designed column is very high (for effective separation); then packed columns are unfavorable due to channeling and too huge the weight of packing
- Cooling coils are needed inside the column
- The column has to be cleaned from time to time due to solids in the process fluids

Often the pressure drop is critical in absorption and the components may be very corrosive (for example the absorber in chemical and pulp industry compared to distillers in oil refineries) so it is profitable to choose a packed column.

Probably that's way McCabe et al. (1993, chapter 22) only discusses packed towers in context of absorption. On the other hand, packed towers are not discussed anywhere else in the book. So, notice that the process and equipment are not the same thing. In order to emphasize this, processes and equipment should be discussed separately as in Treyball (1980) and Perry and Chilton (1973).

2. THEORY

2.1 HEIGHT OF THE PACKING

The height of the packing h can be calculated in two ways:

$$h = N \cdot HETP \tag{1}$$
$$h = NTU \cdot \overline{HTU} \tag{2}$$

According to equation (1) the height of the packing is the product of the number of ideal stages N in the theoretical stage model and the corresponding height of one ideal stage *HETP* (Height Equivalent to a Theoretical Plate).

The disadvantages in the HETP method is that it has to be defined experimentally to every packing type and size, to every combination of components and to every different flow conditions. HETP varies strongly as a function of flow rates and concentrations and is not a constant.

2.2 CALCULATIONS

The calculations in this work is done with Aspen Plus -simulator, using as the unit model RADFRAC. The column should be specified as column without a reboiler and a condenser

2.3 PHASE EQUILIBRIUM

As the phase equilibrium model an activity coefficient model with specified Henry components must be specified. As in the example below
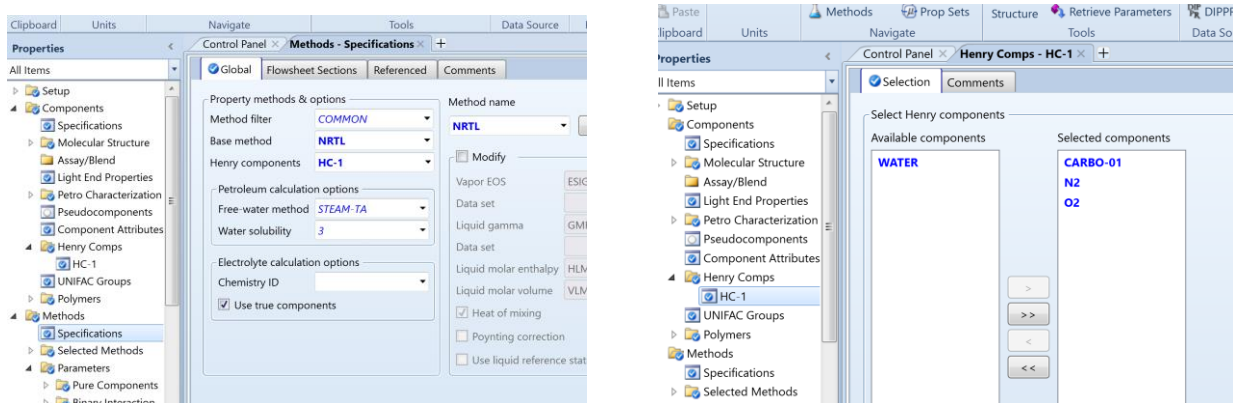
3. EQUIPMENT USED IN THE LABORATORY WORK

3.1 COLUMN

The equipment is shown in figure 7. The height of the packing is 1700 mm and the inner diameter of the column is 100 mm. The column is packed with 12,7 mm (0,5 in) ceramic Berl saddles. The inlet water comes straight from the tap and the flow rate is adjusted with a valve and measured with a rotameter. Gas concentration (CO_2) are taken with a sampling valve, directs the in gas flow or the out gas flow through Vaisala CO_2 meter. The gas phase is pure carbon dioxide from a gas bottle mixed with compressed air.
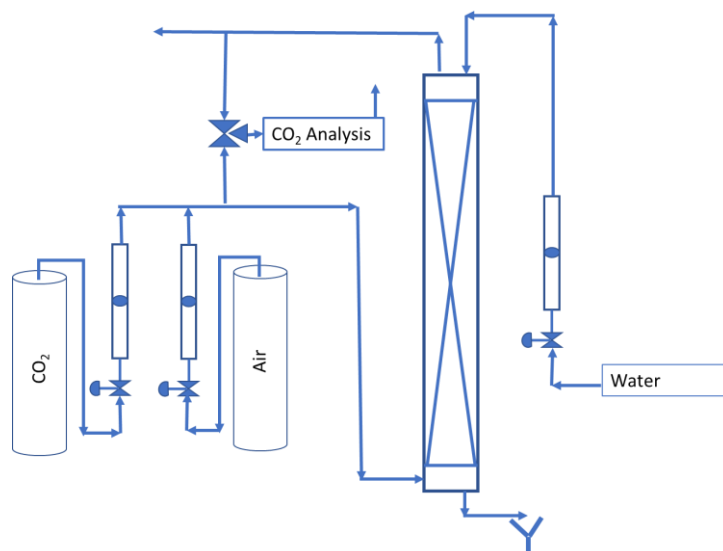
Figure 3. Equipment.

3.2 MEASURING EQUIPMENT

In the absorber there are already fitted:
- A rotameter for the inlet water
- The carbon dioxide rotameter
- The air rotameter

In order to define the concentration of the carbon dioxide also the following are needed:
Part of the flow of the gases in/out to/from the column can be regulated by a valve in front of the the Vaisala CO_2 meter.

4. OPERATING THE COLUNM

4.1 STARTING THE WORK

- Check that all needed measuring devices are available.
- The assistant gives the flow rates.
- 2 x 6 (gas flow x water flow) measurements
- Adjust the inlet water flow to desired value.
- Adjust the liquid level so that it is between the gas inlet and column liquid outlet by adjusting the outlet water rate with the control valve.
- Adjust the gas flow rate to desired value.
- At first, let the column stabilize for 20-30 minutes.

4.2 MEASUREMENTS

- Adjust both the flow rates (gas/liquid) to desired values.
- After the adjustment, let the column stabilize for 10 to 15 minutes.
- Measure the outlet water flow temperature with a thermometer
- Read the carbon dioxide concentration for both the inlet and outlet gas streams from the Vaisala CO_2 meter (Volume %). The reding has a tendency to fluctuate watch the value a couple of minutes and take an average value

4.3 FINISHING THE WORK

Show the results to the teaching assistant and after permission

- Close both the feed valves for the gases.
- Close the control valves below the rotameters.
- Wash the dishes.
- Clean up the working place.

5. CALCULATIONS AND ANALYSIS

- Tabulate your measured values
- Draw pictures of the trends from the measurements
- Calculate the mass balances of CO_2 for your measurements, pay attention on how much of CO_2 has been absorbed. You can use the ideal gas law.
- Estimate the amount/composition of CO_2 in outlet water
- Draw conclusions from the measurements
- Determine the HETP of the column
- Do this by simulating with Aspen how many ideal stages are needed to get the separation right by trial and error
- Draw your conclusions of the simulations and the HETP you obtained
- Discuss the possible error sources in the experiment

6. REFERENCES

Geankoplis, C.J., Transport Processes and Unit Operations, 3rd ed., Prentice Hall, 1993.
McCabe, W.L., Smith, J.C. and Harriot, P., Unit Operations of Chemical Engineering, 5th ed., McGraw-Hill, 1993.
Perry, R.H. and Chilton, C.H., eds., Chemical Engineers' Handbook, 5th ed., McGraw-Hill, 1973.
Treyball, R.E., Mass Transfer Operations, 3rd ed., McGraw-Hill, 1980.

7. APPENDICES

1. Solubility of carbon dioxide in water

8. NOMENCLATURE

a   surface area, m^2/m^3
A   cross-sectional area, m^2
h   height of the balance area, height of the packing, m
H   height of transfer unit, m
HETP Height Equivalent to a Theoretical Plate
HTU   Height of Transfer Unit, m
k   mass transfer coefficient, mol/m^2s
k^L mass transfer coefficient, m/s
K   overall mass transfer coefficient, mol/m^2s
L   total molar flow rate in liquid phase, mol/s
m   mass, kg
m   slope of the equilibrium line, dimensionless
n   amount of substance, mol
n_V molar concentration, mol/m^3
n_m molar concentration, mol/kg
N_c molar flux of component c, mol/s
N   number of transfer units, dimensionless
N   number of ideal stages in equation (1), dimensionless
p   partial pressure, at
T   temperature, ^oC
V   total molar flow rate in gas phase, mol/s
x   mole fraction in liquid, dimensionless

x_c mole fraction of component c in liquid, dimensionless
X   molar ratio in liquid, dimensionless
y   mole fraction in gas, dimensionless,
y_c mole fraction of component c in gas, dimensionless
z   mass transfer ratio for component A, dimensionless

Greek letters

ε porosity of the packing = (empty space)/(whole volume), dimensionless
η viscosity, Pas =Ns/m^2 = kg/ms
λ Solubility of carbon dioxide to water, Ncm^3(CO_2)/g(H_2O)/at
ρ density, kg/m^3
ϕ factor of superficial velocity, dimensionless

Subscripts

a   end of the device where L phase is fed
b   end of the device where V phase is fed
A   substance A
B   substance B
c   substance c
i   interface
Ox   overall quantity in the liquid phase
x   liquid phase
y   gas phase

Superscripts

x^* equilibrium value of quantity x
$\overline{H}$ mean value of quantity H in device

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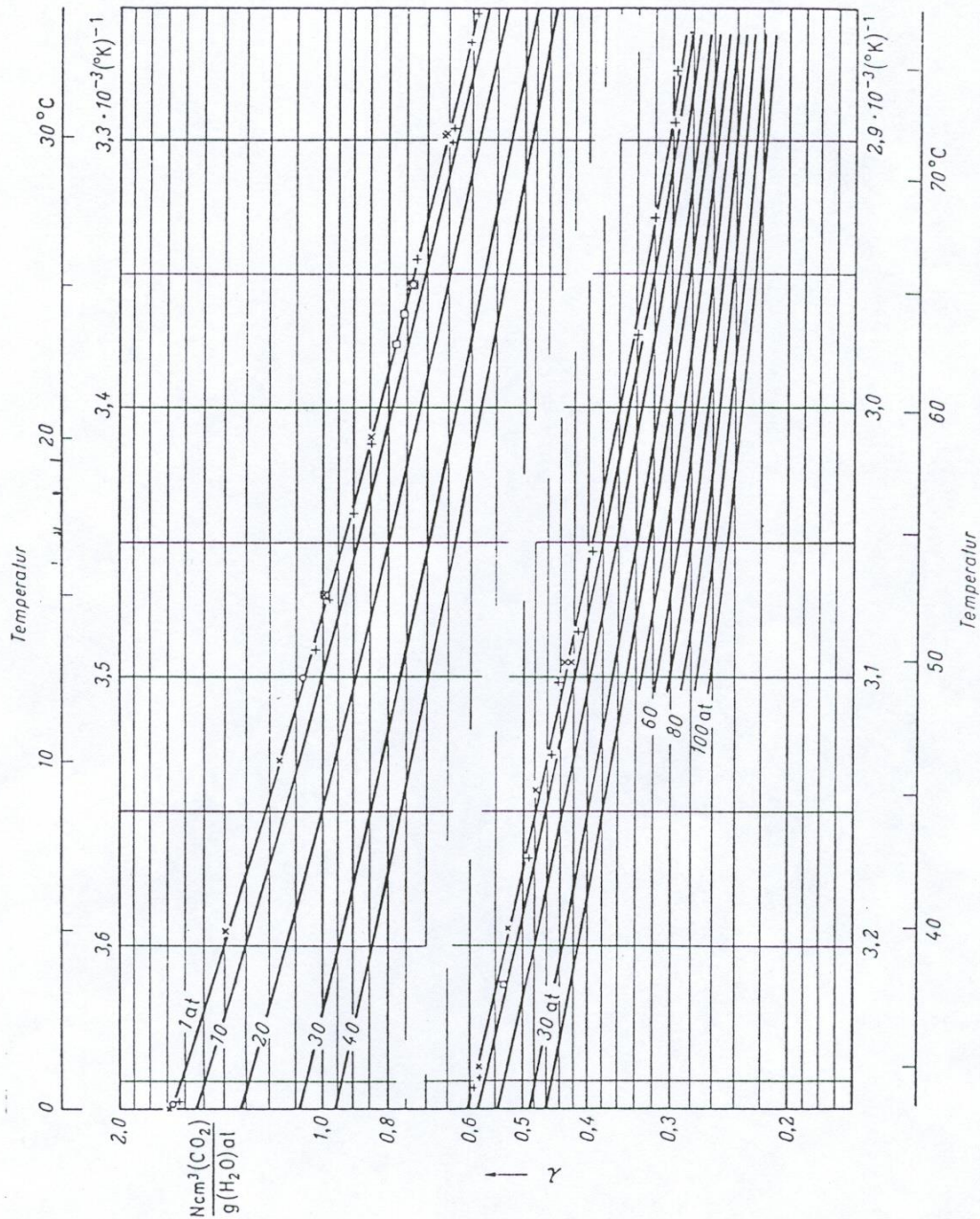
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-Zahlenwerte und Funktionen, 6.painos, Íl/2b Lösungs-
gleichgewichte I, Springer Verlag, Berlin 1962, s. 1-157.