Chair of „Fluidverfahrenstechnik"

Absorption Studies in a Bubble Column using the Example Substance System CO_2 / N_2 / H_2O

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List of Symbols

symbol	dimension	physical quantity
a	$[m^2/m^3]$	specific survace
V	$[m^3]$	Volume
A	$[m^2]$	column cross section
D_f	$[m^2/s]$	diffusion coefficient
g	$[m/s^2]$	Gravity
v_g	$[m/s]$	superficial gas velocities
d_{col}	$[m]$	column diameter
ε_g	$[-]$	gas content
ρ	$[kg/m^3]$	Density
σ	$[N*m]$	surface tension
η	$[Pa*s]$	Viscosity
$V°, L°$	$[mol/s]$	gas or fluid stream
		concentrations in the liquid or in the gas phase
X,Y	$[-]$	* - at the phase boundary surface, and at equilibrium
Indices b and t		„bottom" and „top"

1. Theoretical Foundations

Bubble columns are apparatuses in which gas in form of bubbles is brought into contact with liquid. Often it is used to transport materials during change of state from one phase to the other. Almost always a chemical or biological reaction in the liquid phase takes place. Depending on the nature of the task, it may be useful to intensify special measures mass transfer between two phases or to pursue a specific residence of one or both phases. In comparison with other gas-liquid contact apparatus bubble columns are characterized by a high liquid content and a moderate phase boundary surface. Similar to the gas content the phase boundary between liquid and gas depends on geometry sizes, operating conditions and the substance system. The gas content is one of the key operating parameters, since it features not only the phase fractions and the dwell time of the gas phase, but it is also crucial for the mass transfer between liquid and gas.

The gas content is mainly determined by the gas load, however, to a large extent it depends on the substance system. Consequently, there is a multitude of correlations that are valid only for the particular substance under study. The gas content is defined as the proportion of the gas phase in the total volume of the dispersion:

$$\varepsilon_g = \frac{V_g}{V_g + V_f} \tag{1}$$

For appliances with diameter greater than 0.15m it shows no dependence of the gas content on the container dimensions. The relationship between gas content and gas load can be represented by the proportionality rule $\varepsilon_g \backsim V_g^n$.
In the homogeneous flow regime n assumes a value of about one. With the emergence of large bubbles n drops and grows only under proportional to the gas load. In distinct heterogeneous areas n finally takes values between 0.4 to 0.7. But it also depends on the substance system. The following relation, based on the study of a larger number of systems is used for estimated calculation of the average gas content,

$$\frac{\varepsilon_g}{(1+\varepsilon_g)^4} = C_1 \left(\frac{g \cdot d_{col}^2 \cdot \rho_f}{\sigma}\right)^{\frac{1}{8}} \cdot \left(\frac{g \cdot d_{col}^3 \cdot \rho_f}{\eta_f^2}\right)^{\frac{1}{12}} \cdot \left(\frac{V_g}{\sqrt{g \cdot d_{col}}}\right) \tag{2}$$

The constant C1 takes the value 0.2 for pure liquids and nonpolar solutions and the value of 0.25 for electrolyte solutions. The equation contains a certain dependence of the gas content of the diameters of units. However, a value of 0.6 m for dcol > 0.6 m is always to be used, so that the diameter influence is then lost in this equation. In general, a local distribution of the gas content is in the bubble column. This results in differences in the gas content in both the axial and radial directions.

A major influence on the formation of the phase boundary is the flow regime. Basically, the growth of the phase boundary interface in a homogeneous flow field with increasing gas load is greater than in the heterogeneous region. Also following relationship exists between the gas content and volume specific interfacial area:

$$a = \frac{A}{V_{ges}} = \frac{6 \cdot \varepsilon_g}{d_B} \tag{3}$$

The upward movement of the bubble swarm leads to the appearance of three different flow conditions. The decisive factor for the flow regime is the superficial gas velocity. The so-called homogeneous flow field is characterized by a narrow bubble size spectrum. This flow condition is dependent on the fuel system and gassing up to superficial velocities 0.03 to 0.08 m / s is achieved. At higher gas pressures, the uniform distribution of the gas bubbles disappears. The result is a highly turbulent flow structure. This heterogeneous flow regime leads to the formation of large bubbles which rise at high speed in the middle column. This brings partly such violent circulation flows that bubbles, which are transported to the homogeneous flow state in the vicinity of the vessel wall, back down. In small diameter columns, which are often used as laboratory apparatuses, occur high gas loads on the piston bubble flow. Basically, the growth of the interfacial area in a homogeneous flow field with increasing gas load is greater than in the heterogeneous region. This is due to the big bubbles in the heterogeneous region as the volume-specific phase boundary surface of the large bubbles is significantly lower than that of the remaining bubbles. According to Akita and Yoschida (1974), the following correlation is derived for calculating the specific interfacial area:

$$a \cdot d_{col} = \frac{1}{3} \cdot \left(\frac{g \cdot d_{col}^2 \cdot \rho_f}{\sigma_f} \right)^{0,5} \cdot \left(\frac{g \cdot d_{col}^3}{\eta_f^2} \right)^{0,1} \cdot \varepsilon_g^{1,13} \tag{4}$$

The exchange in bubble columns between gas and liquid flow can be described by the volume-specific mass transfer coefficient $\beta_f a$ representing the product of the liquid-side mass transfer coefficient and the specific interfacial area in most cases. For the determination of the transferred material flow, knowledge of the driving concentration profile is necessary. For this purpose, the mixing behavior must be known in the gas and liquid phases. Both technical equipment as well as laboratory column can be considered for the estimation thereof that both phases are completely mixed.

Like the gas content and the phase boundary, the $\beta_f a$ value also depends on the gas load and the fuel system. For the dependence of the mass transfer coefficient on the gas load, the proportionality $\beta_f a \sim v_g^n$ arises and assumes values between 0.7 to 0.92, according to the conclusions of different authors. The following equation represents a well-supported conclusion of a number of experimental results in which $\beta_f a$ description of the value is:

$$\frac{\beta_f a d_{col}^2}{D_L} = 0,6 \cdot \left(\frac{\eta_f}{\rho D_f} \right)^{0,5} \cdot \left(\frac{g \cdot d_{col}^2 \cdot \rho_f}{\sigma_f} \right)^{0,62} \cdot \left(\frac{g \cdot d_{col}^3 \cdot \rho_f^2}{\eta_f^2} \right)^{0,31} \cdot \varepsilon_g^{1,1} \tag{5}$$

Vessel diameter above 0.6 m lead to increased changes in the value of $\beta_f a$. This is therefore used as the maximum value for dcol. However, higher mass transfer coefficients are homogeneous flow field by gassing and are achievable by a factor of 2 to 3 with sintered plates. Bubble columns represent very inexpensive and adaptable apparatuses that can be implemented in very large dimensions. Main applications are chemical or biological reactors. It turns out that conventional bubble column without internals tend to be under-represented in industrial practice.

2. Experimental Setup

2.1 Structure of the plant

Main part of the plant is a 1.5m long and 5cm thick (inside diameter) column of glass, which is provided with a jacket for thermostating. The gas and liquid input currents are passed by means of two specially manufactured distributors in the column. The lines of the system are either metal pipes with a diameter of 8mm or silicone and Teflon tubing. The complex also includes a reservoir with a volume of 20 l which contains the prepared washing liquid. The washing liquid is passed through a gear pump to the upper part of the column. The amount of fluid per minute is controlled by the rotational speed of the pump and measured by a corresponding Rota meter. The dependence between the liquid flow and the speed of rotation is in the appendix of the script in the form of a graph. A mixture of CO_2 and N_2 is used as the gas feed. The gas stream is manually controlled by a Rota meter and has a predetermined composition of 21.0 vol% CO_2.

2.2 Measuring points

The column is equipped with 6 measuring points for temperature sensing and measuring point for CO_2 gas concentration. The temperatures of the two phases and the cooling water at the inlet and outlet are measured with thermocouples of type K. The CO_2 concentration is determined by a NDIR CO_2 gas analyzer. Depending on the concentration range there are two gas analyzers available - one (no. 1) measuring concentrations of 0 to 0.1vol% (0 to 1000ppm), the other (no. 2) from 0.01 to 25% by volume. The analyzers are connected to a computer, where all measured values using the LabView program online can be stored and processed.

3. Measurement Methods and Test Evaluation

The efficiency of the column is to be determined by the example of the simple fuel system CO_2 / H_2O. In the attempt the outlet concentration of CO_2 is measured in principle by a gas analyzer. A gas bottle with CO_2 / N_2 gas mixture is the source of the gas stream, where the CO_2 inlet concentration is fixed. First, the column should be filled with the solvent. The choice of solvent depends on the task. After filling, you can start the measurement acquisition system LabView. Then, the gas and liquid streams are led by means of appropriate Rota meter into the column. In the column, intensive mass transfer takes place, leading to the decrease of the CO_2 concentration in the product gas stream. The steady state is usually reached after about 20-30 min. Depending on the specific task it can be either the flow of gas or liquid flow varied to test several L / G ratios. The evaluation of the measured data takes place in two steps. First, the concentrations and mass flows are recorded on a table. The missing data, e.g. CO_2 concentration in the bottom stream is calculated by the mass balance for both phases. A second step in the evaluation is to determine the number of transmission units NTU. This is done using the following equations:

$$H_{col} = \frac{L}{\beta_f aA} \cdot \frac{X_b - X_t}{\Delta X_b - \Delta X_t} \cdot \ln \frac{\Delta X_b}{\Delta X_t} \tag{6}$$

$$H_{col} = HTU\ NTU \tag{7}$$

$$NTU = \frac{X_b - X_t}{\Delta X_b - \Delta X_t} \cdot \ln \frac{\Delta X_b}{\Delta X_t} \tag{8}$$

$$\Delta X_{b,t} = X_{b,t}^* - X_{b,t} \tag{9}$$

$$\beta_f . a = \frac{L^\circ}{H_{col} . A} \cdot NTU \tag{10}$$

In the equations, the Great have the following meanings:

L ° [mol / s] liquid stream A [m^2] the cross-sectional area of the column, Hcol [m] Height of the column,
β_f [mol / (m^2.s)] mass transfer coefficient, a [m^2 / m^3] specific surface area, X, X * [mol / mol] are the bulk or interfacial concentrations.
With a predetermined value for the height of the column Hcol and with calculated values for core and interfacial concentrations can be effective mass

transfer coefficient β_f or calculate the expression $\beta_f a$. Which experimental conditions does $\beta_f a$ depend on?

4. Task

The example of a CO_2 absorption with water is to be determined and discussed as a function of the absorption conditions for quantification of the absorption process of the mass transfer coefficient. The gas holdup (gas content) is also to be determined experimentally. This is done to create a material balance.

1. At a constant fluid flow of 7 l / h are measurements with different gas streams, for example, 30, 60, 90, 120 L / h to carry out at various temperatures, such as 20 ° C, 40 ° C and 60 ° C. The gas mixture, which is used containing 21vol% CO_2 and 79vol% N_2.

2. Create a flow chart and calculate any missing quantities - concentrations, currents, etc. In order to simplify the calculations it can be assumed that the washing liquid (water) does not evaporate during the process.

3. Calculate the superficial gas velocity in the column. What is the value of vg in the areas shown in Fig.1,?

4. Calculate for each experiment the value of NTU, and the value of $\beta_f a$

5. Enter a summary discussion with error analysis.

5. References

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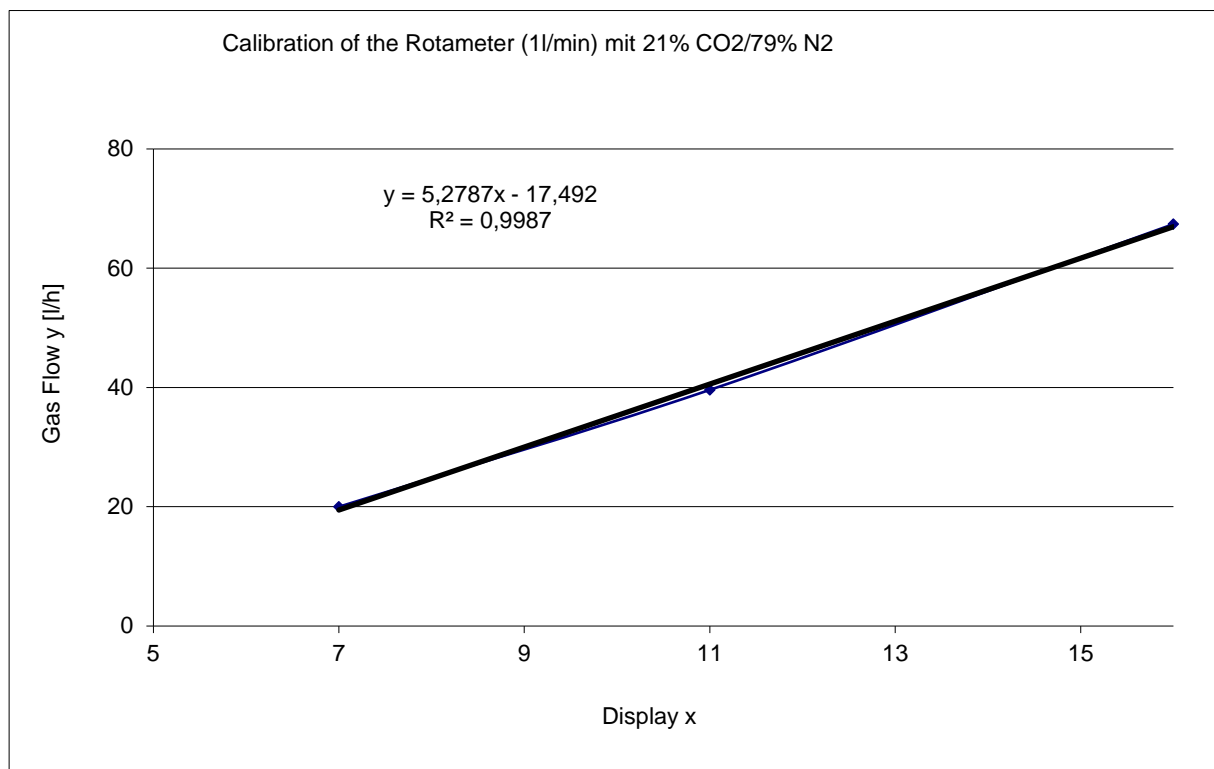
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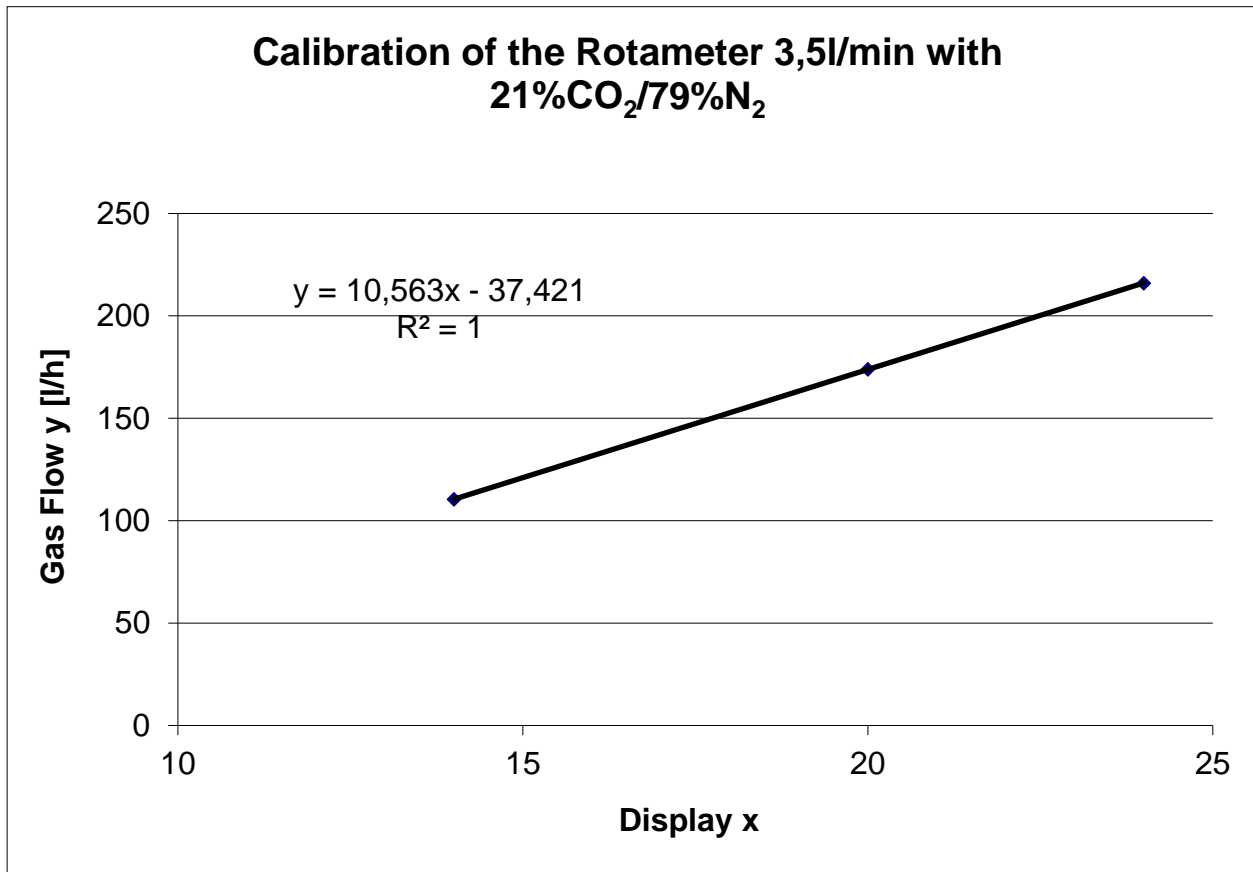
6. Annex

The Rotameter Calibration:

Gasrotameter ABB2 (1000cm^3/min)

Calibration of the Rotameter (1l/min) mit 21% CO2/79% N2

$y = 5{,}2787x - 17{,}492$
$R^2 = 0{,}9987$

Gas Flow y [l/h]

Display x

Gasrotameter ABB3 ($3500 cm^3/min$)

Calibration of the Rotameter 3,5l/min with 21%CO_2/79%N_2

$y = 10{,}563x - 37{,}421$

$R^2 = 1$

Gas Flow y [l/h] (y-axis: 0, 50, 100, 150, 200, 250)

Display x (x-axis: 10, 15, 20, 25)

Kalibrierung des Zulauf-Rotameters mit Wasser

Flüssigkeitsstrom y [l/h]

$y = 0.081x - 2.1224$

$R^2 = 0.9985$

Anzeige x