

Mass transfer (dissolution)

The aim of the experiment is to determine the mass transfer coefficient in the laboratory equipment.

1 Theory of mass transfer

The equation of convective transfer of molecules, i.e. the diffusion, is worked up by Fick. In one y direction, Fick's law states that the component flow is proportional to the surface perpendicular to the flow and the concentration gradient:

$$\frac{dn_i}{A dt} = -D_i \frac{dc_i}{dy} \quad \text{kmol}/(\text{m}^2\text{s}), \quad (1)$$

where c_i is the concentration of the i^{th} component (kmol/m^3),
 n_i is the amount of the i^{th} component (kmol),
 D_i is the diffusion coefficient,
 y is the distance from the surface.

The negative sign indicates that the diffusion takes place in the direction of the decrease of concentration. The D_i diffusion coefficient shows that what amount of the i^{th} component is flown in perpendicular direction of the surface by $1 \text{ kmol}/\text{m}^4$ concentration gradient in unit time and unit area.

The molecular diffusion is generally slow, thus the velocity of the fluid is increased to cause turbulent flow. In this case there is a laminar boundary layer with molecular diffusion, a transitional layer and a turbulent bulk phase. In the bulk phase the mass transfer is turbulent, and the molecular transfer is negligible. The typical concentration profile is shown on Fig. 1.

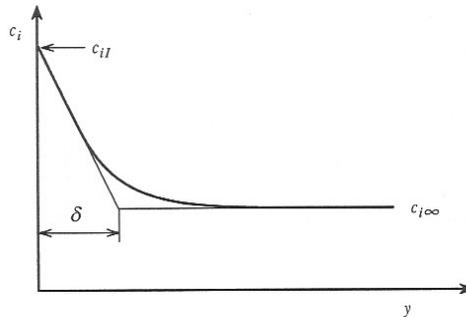


Figure 1.

The simplest model is the film model: a laminar boundary layer with molecular transfer is assumed along the surface, which is responsible for the whole resistance of the transfer. The δ thickness of the film is determined as to make the driving force zero outside the film. In this case the concentration gradient can be written as the differential:

$$-\frac{dc_i}{dy} = \frac{c_{i1} - c_{i\infty}}{\delta}, \quad (2)$$

where c_{i1} is the concentration on the solid surface, which is equal to the concentration of saturated solution at given temperature,
 $c_{i\infty}$ is the bulk concentration.

With (2) equation (1) can be written in the following form:

$$\frac{dn_i}{A dt} = \frac{D_i}{\delta} (c_{il} - c_{i\infty}) = \beta (c_{il} - c_{i\infty}) .$$

The D_i/δ ratio is called mass transfer coefficient, it's value can be determined by measurements.

In V volume the amount of the component (n_i) is increasing by the transfer through the A surface area in dt time, so the $c_{i\infty}$ volume concentration is increasing:

$$\frac{dn_i}{dt} = \frac{V dc_{i\infty}}{dt} = \beta_i A (c_{il} - c_{i\infty}) \quad (3)$$

Equation (3) can be separated and integrated:

$$\int_{c_{i\infty}^0}^{c_{i\infty}} \frac{dc_{i\infty}}{c_{il} - c_{i\infty}} = \beta_i \frac{A}{V} \int_0^t dt$$

$$\ln \frac{c_{il} - c_{i\infty}^0}{c_{il} - c_{i\infty}} = \beta_i \frac{A}{V} t , \quad (4)$$

where $c_{i\infty}^0$ the bulk concentration in the beginning.

2 Equipment

For the determination of the mass transfer coefficient we use a vessel with flat bottom equipped with a variable speed mixer. A layer of benzoic acid was molten onto the bottom of the vessel (the certain diameter can be found on the vessel). The equipment is not thermostated, so we register the temperature in order to guarantee a satisfying precision (the deviation must be below 3-4 °C). We use te mixer in it's lowest position during the experiment.

3 Experimental procedure

The revolution counter shows the time of one revolution in [ms]. The speed should be enough for the good mixing but without making the cone reach the mixer head (recommended range: 250-170 ms).

Before starting the mixer 5 metal disks should be put on the benzoic acid layer to prohibit its lift-off. The diameter of the metal disks must be registered to substract their area from the surface area. The distance of the mixer head from the benzoic acid layer is to be noted. We fill the vessel with exactly 7 dm³ of distilled water, start the mixer and the stopwatch at the same time. The rotation speed must be held constant along the measurement.

In every 10 minutes 5 cm³ sample is taken and titrated with 0.01 M NaOH and phenolphthalein indicator. The temperature is also registered with every sampling. The last sampling will be in the 90. minute.

Measurement report:

Time of one revolution: ms
Rotations per minute: min⁻¹
Diameter of the mixer head: cm
Distance of the mixer head from the layer: cm
Volume of the liquid: cm³
Concentration of the saturated solution (for average temperature): m/m%
Factor of the NaOH reagent: -

Measured values			Calculated values	
Time [min]	Temperature [°C]	x Added NaOH reagent [cm ³]	$x_I - x$	$\frac{x_I}{x_I - x}$

After finishing the measurement, the revolution counter must be switched off, the water from the vessel is thrown off and the mixer is washed and dried.

4 Treatment of data

The measurement data is processed with equation (4). The saturation concentration can be calculated with the following equation:

$$c_{i\infty} = 0.163 + 2.56 \cdot 10^{-3} \cdot \vartheta + 1.79 \cdot 10^{-4} \cdot \vartheta^2 \quad [\vartheta] = ^\circ C, [c_{i\infty}] = m/m \%$$

For simplicity this value has to be converted to equivalent added reactant volume for 5 cm³ of saturated solution (x_I). 1 cm³ of 0.01 M NaOH is equivalent with 0.001221 g of benzoic acid, for its density the solution can be treated as water, and $c_{i\infty}^0 = 0$, so equation (4) becomes:

$$\lg \frac{x_I}{x_I - x} = \frac{1}{2.303} \beta_i \frac{A}{V} t$$

The logarithm of $x_I/(x_I - x)$ ratios in the function of time are on a line, from the slope β_i can be calculated.

The diffusion coefficient of the benzoic acid on room temperature is $D_i = 5.2 \cdot 10^{-4}$ cm²/min. Let's find the δ film thickness from these data.

The film thickness can also be determined theoretically. From Chilton and Colburn *j-factor* analogy, the Sherwood number is:

$$Sh = 0.37 Re_{mix}^{2/3} Sc^{1/3},$$

where

$$\text{Schmidt number:} \quad Sc = \frac{\eta}{\rho D_i}$$

$$\text{Mixing Reynolds:} \quad Re_{mix} = \frac{d^2 n \rho}{\eta}$$

The Sherwood number is the ratio of the geometric size and the film thickness:

$$Sh = \frac{\beta_i d_{vessel}}{D_i} = \frac{d_{vessel}}{\delta_{film}}$$

From these, the film thickness can be determined and compared to the measured value. The theoretical value is an approximation, it would be larger than the measured thickness.

The report should contain the following:

- experimental report with the table of measurements
- $\lg \frac{x_I}{x_I - x} - t$ diagram
- calculated values of β_i and δ
- the ratio of $\delta_{calculated} / \delta_{measured}$