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Comparison of two purification methods by membranes

Separation by washing with membrane filtration

An important application of membrane technology is the separation of two (or more) dissolved components due to their different molecular weight.

The component with the higher molecular weight is better retained by the membrane than the small molecule, so the two substances can be separated by adding washing water. It is called washing out the small molecule.

In the following we will name main product the component with the highest molecular weight (this is our valuable product that we want to purify) and by-product the component with the lowest molecular weight (this is an impurity that needs to be washed out). Of course, there is also the reverse case where the molecule to be washed out is the desired product.

The prerequisite for successful separation is that the retention of the main component is close to 100% and that the retention of the by-product is close to 0%. In order to achieve this, the rule of thumb is that the molecular weights should differ by at least a factor of 5. The cut-off of the membrane must be chosen so that it is between the molecular masses of the two components. As an example, if the main component has 1000g/mol and the by-product 200g/mol, then the separation with a membrane with a cut off of 500-700g/mol is conceivable.

There are basically two possibilities to carry out this separation in practice:

1. Stepwise washing out by multiple dilution - concentration. This is the oldest and simplest method. The product solution is first concentrated, then the container is filled again with washing water and concentrated again. This dilution - concentration sequence is repeated until the desired purity of the main product is achieved.

2. Continuous diafiltration. Here, washing water is continuously added with the aid of an external pump at the same rate as permeate is removed, so that the level in the tank remains constant. This is called diafiltration at a constant level.

When we say washing water here and in the following text, this can be any washing solvent in general and the diafiltration can also be used for solvent exchange, replacing one solvent by another, often used in chromatography.

Comparison of the two methods

Using the classical formulas for the calculation of membrane processes, we can compare the efficiency of the two methods.

The different parameters are defined as follows:

Component 1 = main product (high molecular weight)
Feed concentration: CF1
Retention: R1

Component 2 = By-product (low molar weight)
Feed concentration: CF2
Retention: R2

Concentration factor: X = VF / VK
with VF: Feed volume = start volume of the solution
VK: Volume of concentrate
Diafiltration factor: D = V_{H2O} / VK
with V_{H2O}: diafiltration volume = washing water volume

1. Case of stepwise washing out

The feed (volume VF) is concentrated first by factor X. The concentrate obtained is then diluted back to the original volume VF with washing water, and concentrated again by factor X. This dilution-concentration sequence (which we can call washing out) is repeated n-times.

It can be shown that the final concentration of component i (i=1 or 2) after the nth washout can be calculated as follows:

$$CK_i = CF_i \cdot X^{(n \cdot (R_i - 1) + R_i)}$$

And the corresponding relative amount of washing water (based on the concentrate volume VK):

V_{H2O} / VK = n · (X-1)

The purity of the washed main product can be described with the concentration ratio of main product to by-product: CK1 / CK2. High values mean high purity.

Since the main product is never 100% retained, a certain loss of yield must be expected:

Yield loss = 100 · (1 - CK1 / (CF1· X))

This can be illustrated by a numerical example:
Concentration factor: X=3
<u>Main product</u>:
CF1=10g/l
R1=0.99 (99%)
<u>By-product</u>:
CF2=5g/l
R1=0.2 (20%)

Figure 1 shows the purity and the main product loss as a function of the relative washing water quantity. Each point in the graph corresponds to one washout (n=1, 2, 3, etc).

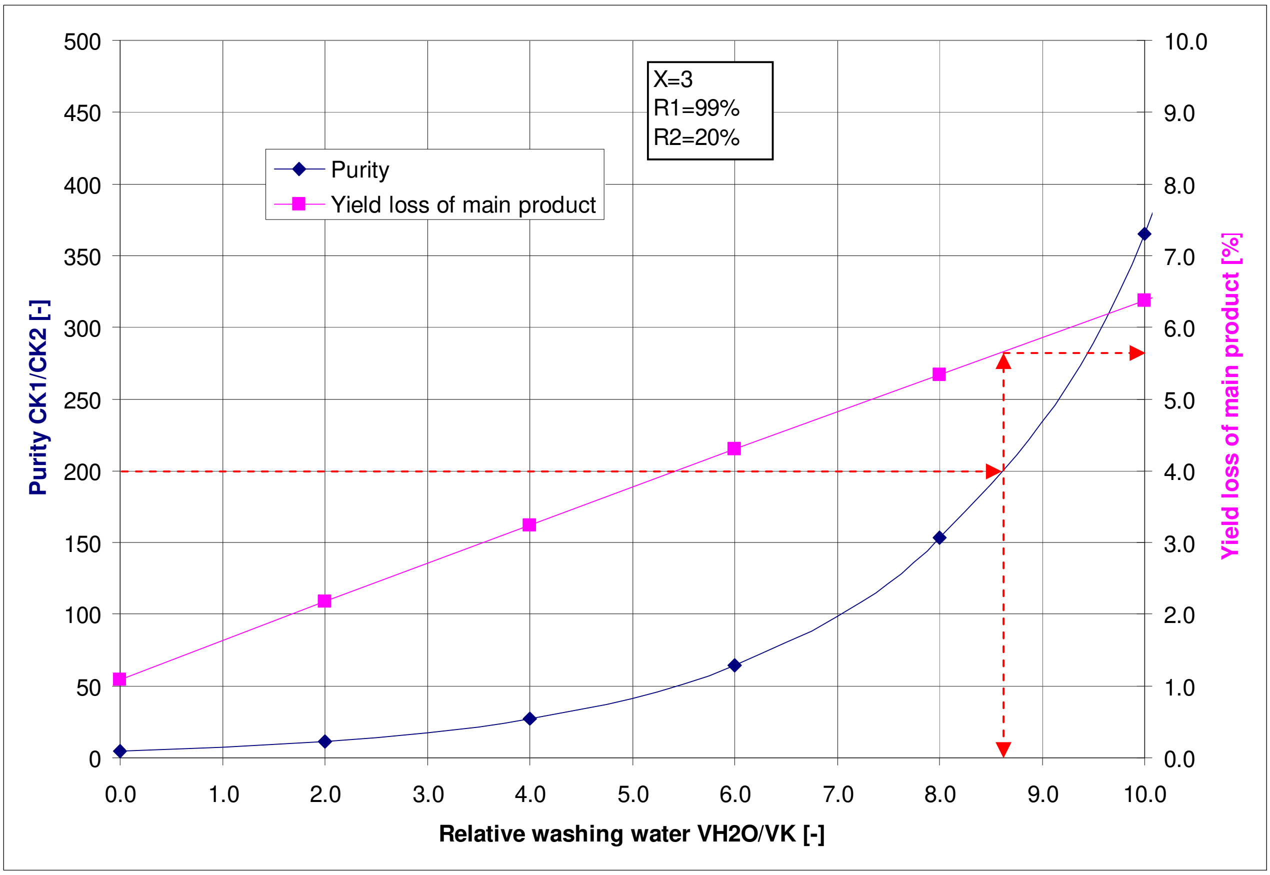

Figure 1: Purity and product loss curves in a stepwise washing process

Assuming a purity of 200 is desired, the required relative amount of washing water is approx. 8.7, resulting in a yield loss of 5.8%.

2. Case of diafiltration

The feed (VF) is concentrated by factor X once only. Wash water is then continuously added to the concentrate at a constant level.

The final concentration of component i is then calculated as follows:

$$CK_i = CF_i \cdot X^{R_i} \cdot \exp(D \cdot (R_i - 1))$$

And the relative amount of wash water simply corresponds to the diafiltration factor:

$V_{H2O} / VK = D$

The purity and yield loss are as defined as above.

Using the same numerical example, the corresponding diafiltration curves can be displayed:

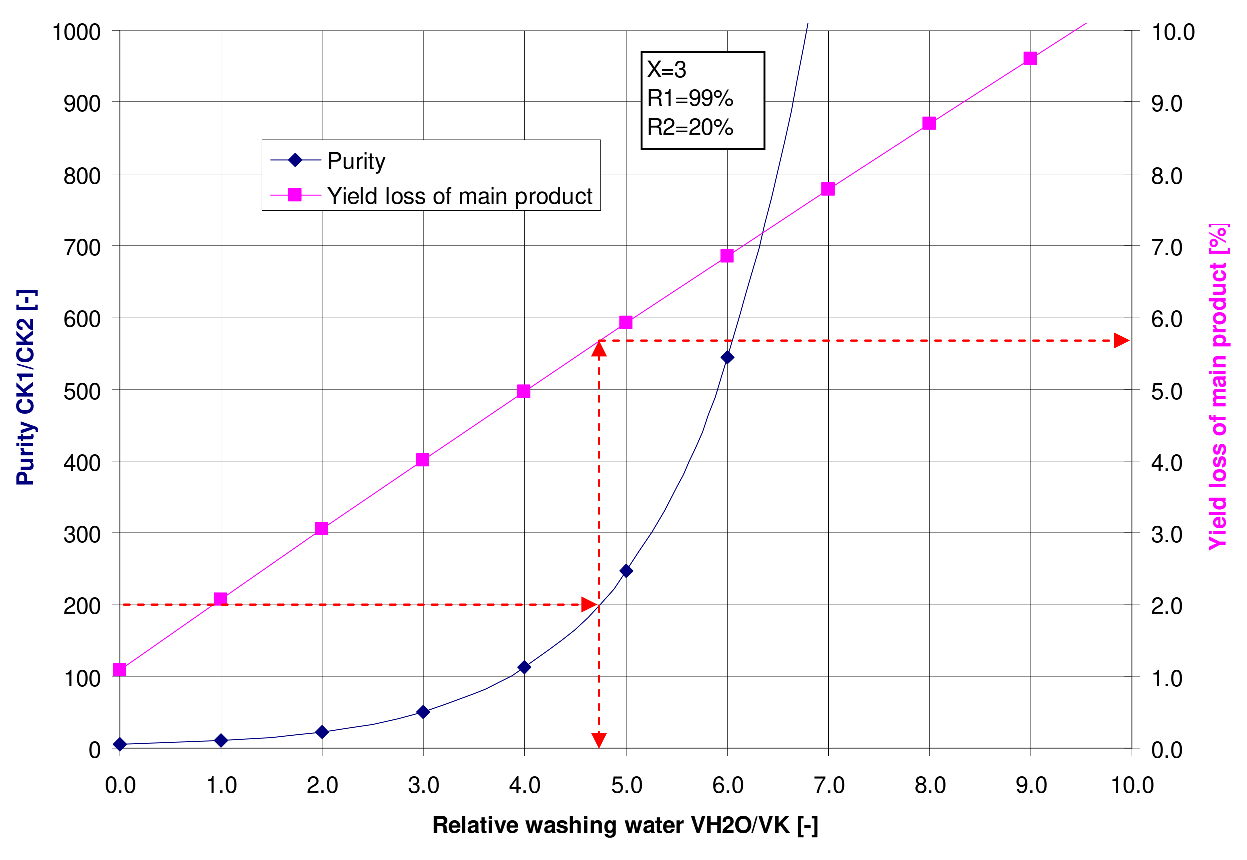

Figure 2: Purity and product loss curves in a diafiltration process

Assuming one wants to achieve a purity of 200 as before, the required relative washing water quantity is approx. 4.8 and the yield loss approx. 5.8%.

One can immediately see that the required washing water quantity in this example is 8.7 / 4.8 = 1.8 times smaller than with the stepwise washing out. The product losses are identical.

Comparison of stepwise washing and Diafiltration

These differences in efficiency can be made clearer by logarithmically representing the purities obtained by the two methods in the same diagram:

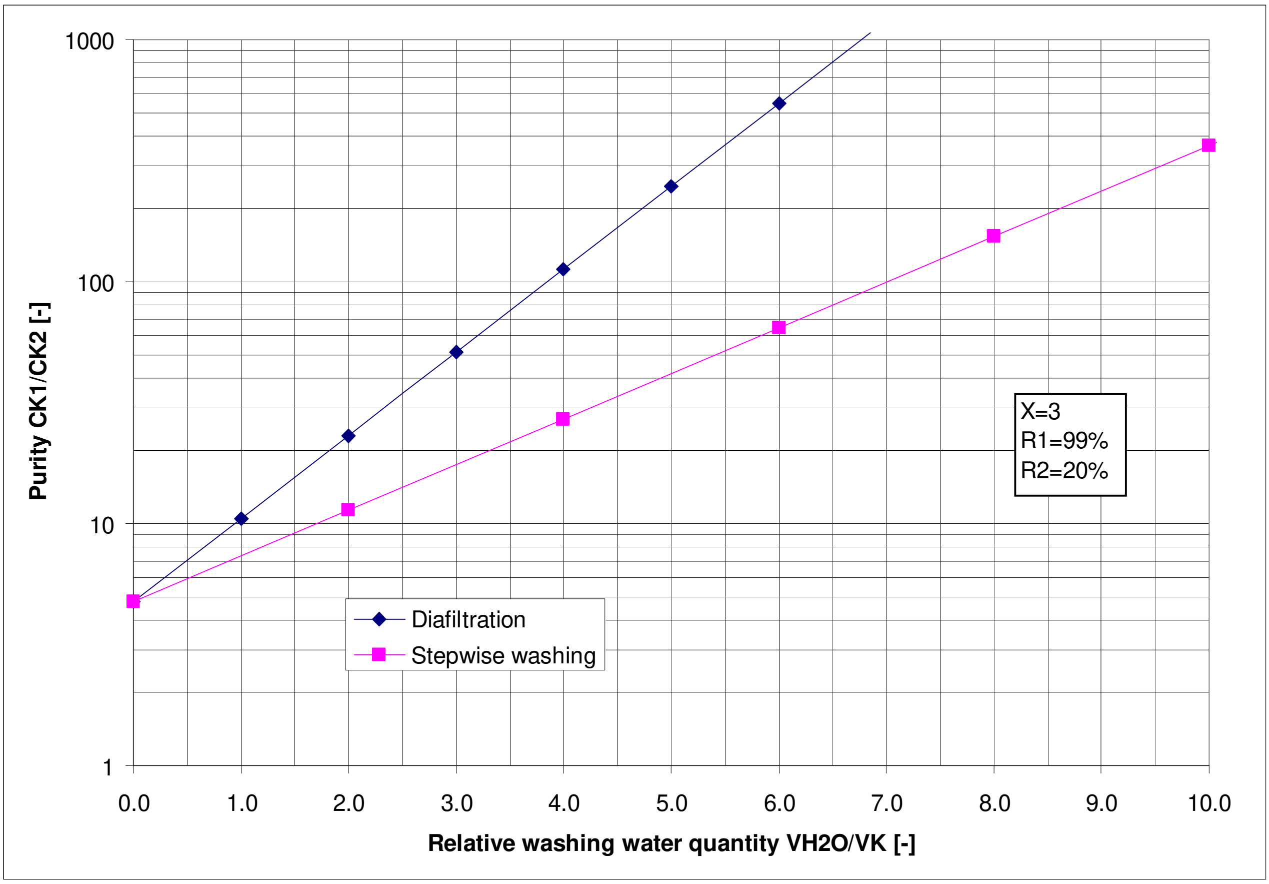

Figure 3: Purity curves: comparison diafiltration / stepwise washing out

The ratio of the amounts of washing water required by both methods to achieve a given purity is a constant, and is about 1.8 for this numerical example. In other words, no matter what purity one wants to achieve, diafiltration requires 1.8 times less washing water than stepwise washing. However, this ratio depends on the concentration factor X. It can be shown that:

Ratio = (X-1) / Ln(X)

If X becomes smaller and approaches 1, then this ratio comes closer to 1, and with X=1 both methods are identical. It is also interesting to note that at a given purity the product losses of the two methods are identical. Less washing water means a more concentrated product in case the product is washed out. This is another advantage.

Conclusions

The following conclusions can be drawn from this theoretical consideration:

- Continuous diafiltration is always more efficient than stepwise washing. For a desired purity of the main product, less washing water is required for diafiltration. This also means that it is faster if the permeate flow is good. However, the yield losses of the two methods are identical
- The higher the concentration factor, the higher the efficiency of diafiltration compared to stepwise washing
- Diafiltration is well suited for automation, for example with our AutoMem system. A practical advantage of AutoMem is, of course, that you do not have to manually monitor several concentrations and re-dilutions.