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# Pressure driven membrane processes
# Calculations

Here we give some important calculation tools for the successfull development of membrane processes. They will help to calculate the results of whole membrane processes based on measurement results from lab tests.

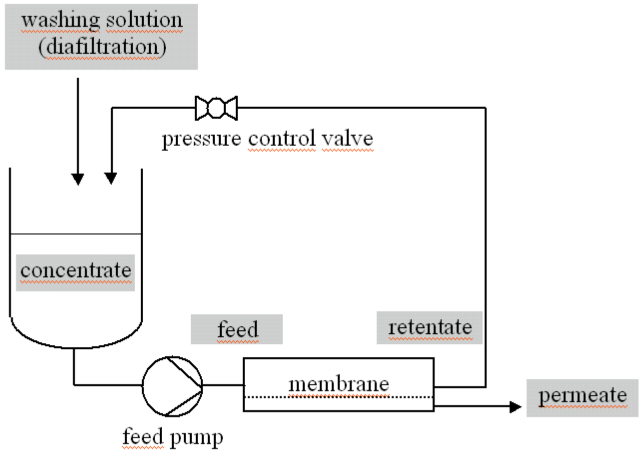
**Rejection:**

For all calculations we assume a concentration independent rejection

$R = 1 - \frac{c_P}{c_F}$ with R = momentary or spot- rejection, $c_P$ = momentary permeate concentration, $c_F$ = feed concentration

**Batch process:**

In a batch process after filling the feed vessel with the starting volume, concentration and/or diafiltration (washing) starts until the final volume or desired washing is reached. Product is either in the vessel or the collected permeate.




**Concentration:**

$X = \frac{V_0}{V_K}$ with X = concentration factor, $V_0$ = starting volume, $V_K$ = end volume

$c_K = c_0 \cdot X^R$ with $c_K$ = end concentration of concentrate

$\overline{c}_P = c_0 \cdot \frac{X}{X-1}\left(1 - X^{R-1}\right)$ with $\overline{c}_P$ = concentration of collected total permeate

$\eta_K = X^{R-1}$ with $\eta_K$ = yield in concentrate

Explanations with an example: when you concentrate a batch with a starting product concentration of $c_0$=10g/l and you concentrate by a volumetric factor of X=5 e.g. from 500ml to 100ml and the spot rejection for the product on the tested membrane is 95% than the end concentration of product will reach $c_K$=46.1 g/l, the concentration of the total permeate will be $\overline{c}_P$ = 0.966 g/l (loss of product) and the yield in concentrate will be $\eta_K$ = 92.3%. This example clarifies the dependency of yield and rejection.

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**Diafiltration (washing at constand level):**

$D = \frac{V_{LM}}{V_K}$ with D = diafiltration factor, $V_{LM}$ = diafiltration volume used, $V_K$ = volume of concentrate (or feed as we operate at constant level here)

$$\frac{c_K}{c_0} = e^{(D\cdot(R-1))}$$

Explanation of symbols with an example: a product volume $V_K$ = 500ml is washed with $V_{LM}$ = 1000ml, that means diafiltration factor D = 2. Rejection of a componet to be washed out (e.g. a salt from a solution of larger molecules) may be 0. Than the concentration of the salt after this washing process will reach $c_K/c_0$ = 13.5% of the starting value. The same calculation done for the product molecule with R = 95% shows that the end concentration of the product will be $c_K/c_0$ = 90.5% of the starting concentration.

The overall permeate concentration for a dissolved component calculates as follows

$$\bar{c}_P = \frac{c_0}{D} \cdot \left(1 - e^{(D(R-1))}\right)$$

And the yields:

$\eta_K = e^{(D\cdot(R-1))}$ with $\eta_K$ = yield in concentrate

$\eta_P = 1 - e^{(D\cdot(R-1))}$ with $\eta_P$ = yield in permeate

Explanation again with our example of diafiltration of a salt: yield of the product will be 90.5 %. Yield of salt in the permeate will be 86.5%. Yield in this case can mean efficiency of the washing process (if an undesired component is washed out) or yield of a low molecular weight product in the permeate.

Of course calculations of concentration and diafiltration can be combined for combined processes

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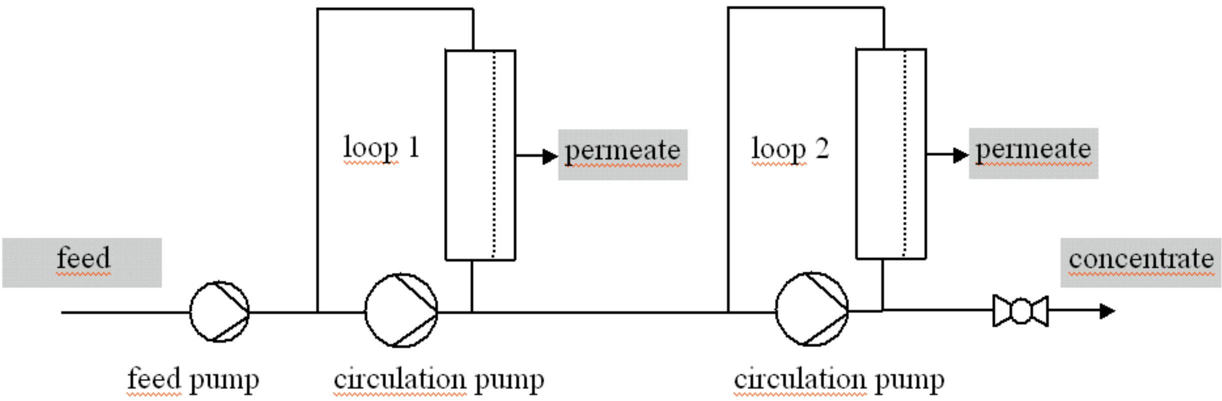
**Concentration in a continuous process:**

The following sheme shows a continuous membrane filtration unit with 2 loops. In principle a such a unit may have one or more loops.




The following formulae are resulting from material balance calculated for a continuous membrane process with one loop.

$$\frac{c_K}{c_F} = \frac{X}{(1-R)\cdot(X-1)+1} \qquad \eta_K = \frac{1}{(1-R)\cdot(X-1)+1}$$

Again using our example of a membrane with product spot rejection of 95%: if our one-loop unit is concentrating by a volumetric factor of 5 that means the feed stream is separated in a concentrate stream of 1/5 of the volume and a permeate stream of 4/5 the volume, the concentrate concentration will be 4.16 times higher than the feed concentration and yield will be 83.3%

Continuous processes in bigger plants have normally several loops which optimizes the process but only in the best case with infinite number of loops they would reach the performance of a batch process. The yield in a continuous process with n-loops and with X as the overall volumetric concentration factor (equally distributed over all loops) would be:

$$\eta_K = \left( \frac{1}{(1-R)\cdot\left(X^{\frac{1}{n}}-1\right)+1} \right)^n$$

In a 4-loop system with a concentration factor of X=5 and product spot rejection of 95%, the overall yield would be 90.6%. For comparison: the batch process would have 92.5% yield