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Study of long term fouling in crossflow ultrafiltration

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Introduction

Ultrafiltration (UF) is a membrane technique whereby water and microsolutes are separated from macromolecules. It has several applications in wastewater treatment and it is also widely used in chemical and food industries.

The main disadvantage of UF is membrane fouling, which causes a decline in permeate flux with time. As permeate flux decline highly increases the operation costs, the time-dependence of permeate flux has been studied in many occasions. Most of these studies use protein aqueous solutions (bovine serum albumin, hemoglobin, cheese whey among others) [1, 2] as feed. However, as proteins are charged molecules, they interact with the membrane and their interactions are influenced by the pH of the solution, so the models applied to these kinds of feed solutions should include membrane-solute interaction. When using polyethylene glycol (PEG) these interactions may not be considered and the models are simplified.

Materials and methods

UF experiments were performed with a 5 g/L PEG aqueous solution (molecular weight of 35 kDa) and different transmembrane pressures (TMPs) (0.1; 0.2; 0.3; 0.4 MPa) and cross flow velocities (CFVs) (1; 2; 3 m/s). The temperature was kept constant at 25ºC. The molecular weight cut off (MWCO) of the membrane used in the experiments (Carbosep M2 supplied by Orelis S.A., France) was 15 kDa.

Two fouling models were fitted to experimental data using MathCad. Model 1 [1] describes the dependence of permeate flux with time in UF processes as well as the influence of TMP and CFV on membrane fouling by means of the following equation:

$$J = \alpha + \beta \cdot e^{-\gamma \cdot t} \quad (1)$$

J: permeate flux ($m^3/m2 \cdot s$); α: steady state permeate flux ($m^3/m^2 \cdot s$); β: exponential factor (m^3/s); γ: constant in flux decline (s^{-1}); t: time (s).

Model 2 [2] considers that the filtration curve (permeate flux vs. time) can be divided in two periods, which correspond to macromolecular deposition and long-term fouling, respectively. These periods are all included in the following equation:

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$$J = (J_0 - J_{est1}) \cdot e^{\delta \cdot t} + (J_{est1} - J_{est2}) \cdot e^{\lambda \cdot t} + J_{est2} \quad (2)$$

J: permeate flux ($m^3/s \cdot m^2$); J_0: pure water permeate flux ($m^3/s \cdot m^2$); J_{est1}: permeate flux when first period ends ($m^3/s \cdot m^2$); J_{est2}: permeate flux when second period ends ($m^3/s \cdot m^2$); δ: constant describing the rate of flux decline caused by membrane fouling (s^{-1}); λ: constant describing the rate of flux decline caused by concentration polarization (s^{-1}); t: time (s).

Results and discussion

The parameters obtained for Models 1 and 2 are shown in Tables 1 and 2, respectively.

Table 1: Estimated values of the parameters (Model 1) at the different CFVs and TMPs.

TMP (MPa)	CFV (m/s)	R^2	*α*	*β*	*γ*
0.1	1	0.900	$9.35 \cdot 10^{-6}$	$8.378 \cdot 10^{-7}$	$-1.658 \cdot 10^{-4}$
0.2	1	0.969	$1.066 \cdot 10^{-5}$	$2.752 \cdot 10^{-6}$	$-3.57 \cdot 10^{-4}$
0.3	1	0.977	$1.205 \cdot 10^{-5}$	$6.077 \cdot 10^{-6}$	$-2.607 \cdot 10^{-4}$
0.4	1	0.988	$1.419 \cdot 10^{-5}$	$2.843 \cdot 10^{-5}$	$-4.162 \cdot 10^{-4}$
0.1	2	0.692	$1.353 \cdot 10^{-5}$	$9.246 \cdot 10^{-7}$	$-4.395 \cdot 10^{-5}$
0.2	2	0.925	$1.766 \cdot 10^{-5}$	$2.555 \cdot 10^{-6}$	$-1.811 \cdot 10^{-4}$
0.3	2	0.985	$1.979 \cdot 10^{-5}$	$4.598 \cdot 10^{-6}$	$-9.946 \cdot 10^{-5}$
0.4	2	0.975	$2.153 \cdot 10^{-5}$	$1.068 \cdot 10^{-5}$	$-4.14 \cdot 10^{-4}$
0.1	3	0.790	$1.644 \cdot 10^{-5}$	$1.458 \cdot 10^{-6}$	$-1.596 \cdot 10^{-4}$
0.2	3	0.931	$2.188 \cdot 10^{-5}$	$2.773 \cdot 10^{-6}$	$-1.377 \cdot 10^{-4}$
0.3	3	0.922	$2.677 \cdot 10^{-5}$	$5.143 \cdot 10^{-6}$	$-2.558 \cdot 10^{-4}$
0.4	3	0.959	$2.891 \cdot 10^{-5}$	$4.938 \cdot 10^{-6}$	$-1.792 \cdot 10^{-4}$

Model 1 was observed to accurately predict the permeate flux decline with time. For high TMP values ultrafiltration is first controlled by pore blocking followed by long term PEG deposition on the membrane surface. For low TMPs the dominant mechanism is PEG deposition.

For low TMPs (0.1 MPa) and all the CFVs tested (1, 2 y 3 m/s) membrane fouling is very small. Low values of γ (obtained for 0.1MPa and 2 m/s; and 0.3 MPa and 2 m/s) indicate that, once the PEG deposit layer is formed, permeate flux is practically constant.

Table 2: Estimated values of the parameters (Model 2) at the different CFVs and TMPs

TMP (MPa)	CFV (m/s)	R^2	J_0	J_{est1}	J_{est2}	δ	λ
0.1	1	0.855	$9.548\cdot10^{-6}$	$1.143\cdot10^{-5}$	$9.439\cdot10^{-6}$	$-7.029\cdot10^{-4}$	$-3.455\cdot10^{-4}$
0.3	1	0.983	$1.895\cdot10^{-5}$	$1.702\cdot10^{-5}$	$1.187\cdot10^{-5}$	$-1.575\cdot10^{-3}$	$-1.940\cdot10^{-4}$
0.4	1	0.999	$4.467\cdot10^{-5}$	$2.643\cdot10^{-5}$	$1.263\cdot10^{-5}$	$-9.375\cdot10^{-4}$	$-1.505\cdot10^{-4}$
0.1	2	0.710	$1.401\cdot10^{-5}$	$1.453\cdot10^{-5}$	$1.377\cdot10^{-5}$	$-4.500\cdot10^{-3}$	$-7.845\cdot10^{-5}$
0.2	2	0.952	$1.938\cdot10^{-5}$	$2.086\cdot10^{-5}$	$1.775\cdot10^{-5}$	$-2.667\cdot10^{-3}$	$-2.541\cdot10^{-4}$
0.3	2	0.990	$2.048\cdot10^{-5}$	$2.491\cdot10^{-5}$	$2.008\cdot10^{-5}$	$-1.108\cdot10^{-3}$	$-1.304\cdot10^{-4}$
0.4	2	0.984	$3.414\cdot10^{-5}$	$2.997\cdot10^{-5}$	$2.131\cdot10^{-5}$	$-2.527\cdot10^{-3}$	$-3.011\cdot10^{-4}$
0.1	3	0.884	$2.058\cdot10^{-5}$	$1.755\cdot10^{-5}$	$1.616\cdot10^{-5}$	$-3.879\cdot10^{-3}$	$-7.869\cdot10^{-5}$
0.2	3	0.955	$2.323\cdot10^{-5}$	$2.560\cdot10^{-5}$	$2.204\cdot10^{-5}$	$-1.354\cdot10^{-3}$	$-2.111\cdot10^{-4}$
0.3	3	0.920	$3.191\cdot10^{-5}$	$3.953\cdot10^{-5}$	$2.677\cdot10^{-5}$	$-2.558\cdot10^{-4}$	$-2.558\cdot10^{-4}$
0.4	3	0.965	$3.425\cdot10^{-5}$	$3.279\cdot10^{-5}$	$2.867\cdot10^{-5}$	$-7.905\cdot10^{-4}$	$-1.240\cdot10^{-4}$

For Model 2, low values of λ and δ indicate that permeate flux decline by concentration polarization and membrane fouling are not the dominant mechanisms. According to the values of R^2 shown in Tables 1 and 2, the models are able to predict the variation of permeate flux with time in UF processes at different CFVs and TMPs. Permeate flux prediction was better for both models when the UF system worked under severe fouling conditions (TMP = 0.4 MPa and CFV = 1 m/s, R^2 = 0.99).

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