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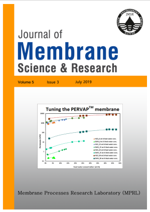

Short Communication

Influence of Membrane Sealing in Pressure-Driven Test Cells on Their Performance

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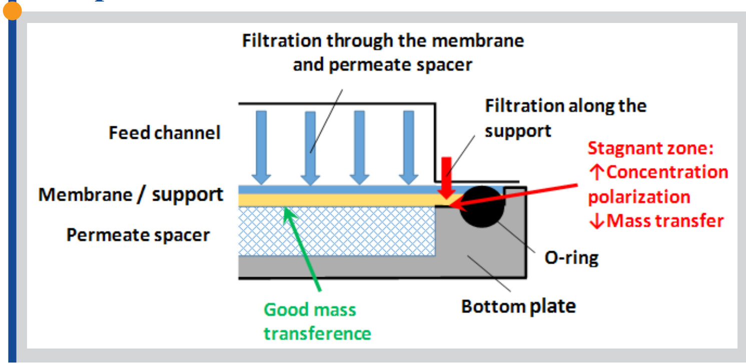
Highlights

- Membrane sealing is a relevant factor as it may influence on test cell performance
- A peripheral part of the membrane is supported on the cell body due to sealing
- The effect of impermeable surface supporting a membrane was studied experimentally
- Membrane sealing create zones where mass-transfer conditions can be much worse
- Trans-membrane flux obtained are slightly affected by the membrane blocking

Graphical abstract



Abstract

This communication demonstrates the relevance of membrane sealing in a test cell to its performance. Membranes need to be sealed, and therefore a more or less significant (depending on the test cell design) peripheral part of the membrane is supported directly by the cell body (instead of a permeate spacer). Although it may seem that there should be no filtration through the membrane when it is supported by an impermeable surface, this communication demonstrates that this is not generally true due to filtration along the membrane porous support. To confirm this, experiments were performed with a cross-flow test cell (GE SEPA™ CF II), blocking the membrane hydraulically from beneath in order to simulate the effect of having the membrane supported by an impermeable surface. The results show that the trans-membrane volume flux obtained in all cases is only slightly affected by the membrane blocking. In view of this, in the cell design, care should be taken to reduce such peripheral parts of the membrane to a minimum because it may be technically very difficult to have there the same conditions of concentration polarization as over the membrane part supported by the permeate spacer.

1. Introduction

Membrane characterization is important for the design of membrane processes since their performance and optimization depends on reliable information on the membrane properties.

In membrane modules, the membrane transport properties manifest themselves against the background of complicated flow-distribution and external-mass-transfer phenomena. Therefore, these properties (such as solute rejection and volume flux) are often studied in dedicated test cells, where attempts are made to reduce those complications to a minimum. Membrane test cells for pressure-driven measurements have various configurations [1–5]. However, irrespective of the details, in all cases the membrane must be sealed. Figure 1 shows the typical schematics of membrane sealing. The membrane is mechanically supported by a permeate spacer (or another porous material), but a strip at the membrane periphery is always put on an impermeable part of the test-cell body (red line in Figure 1b). This is due to the need to seal the membrane with an O-ring, which can be achieved only if it presses against a solid surface. Figure 1c also shows that mechanical fixation of the O-ring in a groove makes unavoidable the existence of a zone where the membrane's active surface is exposed to the feed solution but the hydrodynamic conditions are totally different from those in the principal feed channel. Moreover, the flow characteristics in this problematic zone may well be poorly reproducible because the height of the gap can be strongly dependent on the details of the test-cell assembly.

At first glance, it may appear that none of this matters because the membrane is supported by an impermeable surface, so there should be no filtration. The principal finding of this communication is that, actually, this is not generally true and there may be trans-membrane filtration within this zone due to lateral flows along the membrane support layers. Moreover, we will demonstrate experimentally that even for quite broad membrane strips of this kind the trans-membrane flux can be practically the same as for the part of the membrane supported by a permeate spacer. Understanding this is important for optimization of the design of membrane test cells.

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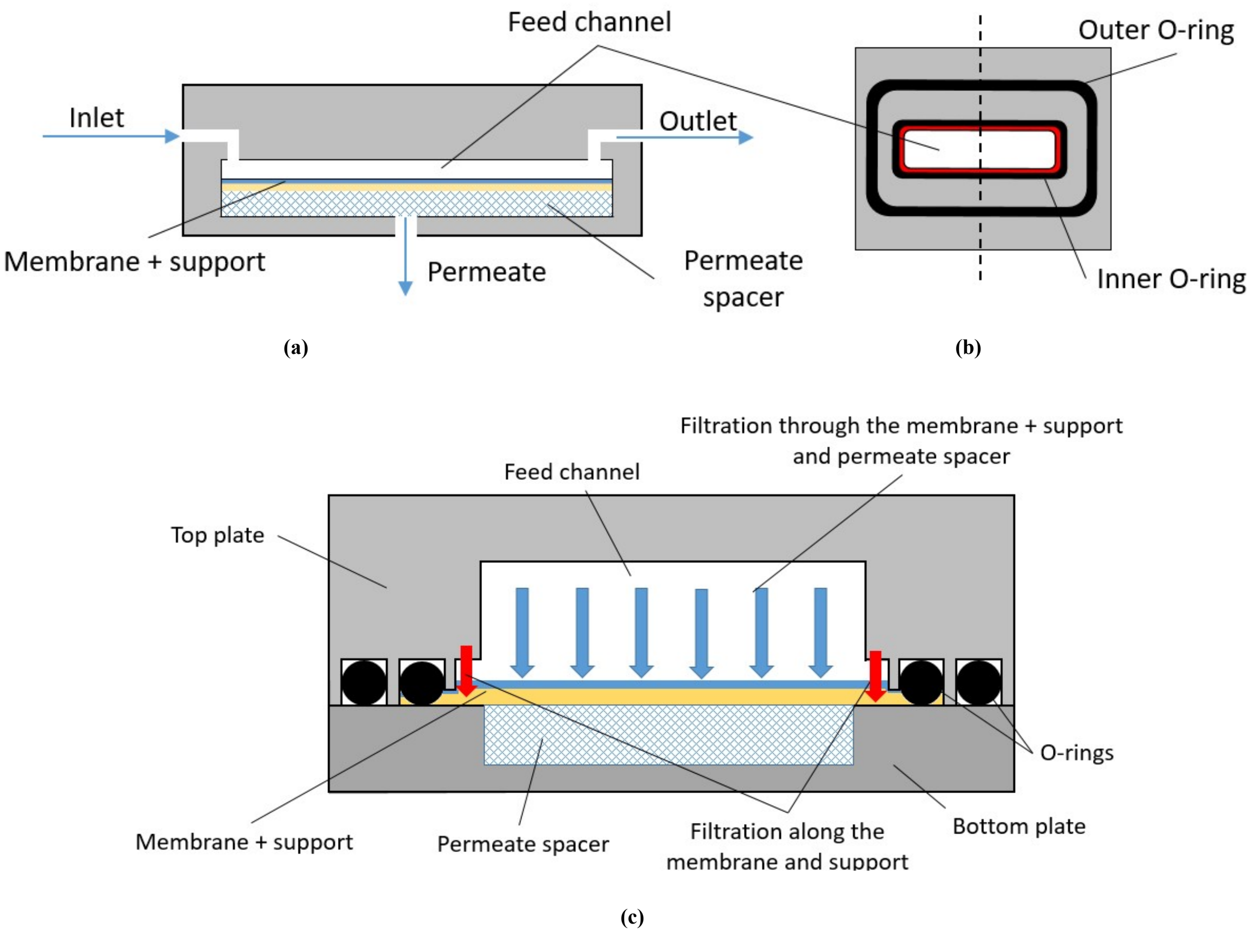

Fig. 1. Schematic diagram (not drawn to scale) of membrane sealing in a cell: a) process flow diagram; b) raised view of top plate of the cell; and c) cross-section of the cell. The dotted line in (b) indicates the cross section shown in (c).

2. Experimental

2.1. Materials

All the experiments were performed with deionized water. Experimental data were obtained with polyamide thin-film composite NF membranes NF-270 and NF-90 supplied by Dow Chemical Company (USA). Table 1 shows the specifications of both membranes.

Table 1
Membrane specifications and operating limits.

Parameter	NF270 / NF90
Membrane type	Polyamide thin-film composite
Maximum operating temperature	45 °C
Maximum operating pressure	41 bar
Maximum feed flow rate	1.4 m^3/h
Maximum pressure drop	1.0 bar
pH range, continuous operation	2–11
pH range, short-term cleaning (30 min)	1–12
Maximum feed silt density index	SDI 5
Free chlorine tolerance	< 0.1 ppm

2.2. Experimental set-up

A flat-sheet cross-flow test cell (GE SEPA™ CF II) with an effective area of 0.014 m^2 was used to perform the experiments. The experimental set-up was described previously [6]. Feed solution was refrigerated in a tank (30 L) to keep the temperature constant at around 20 ± 1 °C throughout the experiments. The set-up ran in a continuous mode and both the permeate and the concentrate streams were recirculated to the feed tank to keep the composition of the feed solution constant. The set-up also includes a filter cartridge (pore size: 100 µm, Fisher Scientific) in the concentrate stream to avoid the presence of particles in the feed tank. The inlet and outlet pressures of the membrane test cell as well as the concentrate flow rate were monitored throughout the experiments. From the inlet and outlet pressure values, the average trans-membrane pressure (TMP) inside the membrane test cell was determined.

2.3. Operation procedure

A new membrane was used for each experiment to guarantee the same initial conditions in all cases. Moreover, before starting each experiment, deionized water was pumped into the membrane test cell at 22 bar during 1.5 hours to ensure that the membrane hydraulic resistance remained constant throughout the measurements. Once it had been corroborated that the pure water flux was steady, the experiment started. Experiments were performed at a constant cross-flow rate and the TMP was increased from 2 to 12 bar. Permeate samples were collected at each TMP after the permeate flux reached a constant value.

To simulate the effect of a membrane supported by an impermeable surface, the membrane was blocked from beneath by using a plastic sheet made of low-density polyethylene (Vidrafoc) with an open strip along the channel, equidistant from the walls (Figure 2). Several plastic sheets were used, leaving open strips of various widths in order to study the correlation between the trans-membrane flow and the unblocked area. Table 2 gives the unblocked surface area versus the strip width.

3. Results and discussion

Figure 3 shows the pressure dependences of trans-membrane flux calculated by using the whole membrane area of the test cell. These dependences are largely linear so they can be quantified by the slopes. Remarkably, those slopes are only slightly reduced despite the fact that the unblocked area is 5 to 20 times smaller than the area exposed on the membrane's active side. This shows that the parts of the membrane blocked from beneath by the plastic film are performing filtration almost unimpeded. The filtration along the membrane support layers is effective as long as the pressure drop in the lateral direction remains smaller than the TMP drop. The fact that in our measurements the flux was only slightly affected by the membrane-back blocking indicates that even with the relatively broad blocked strips used in this study the lateral pressure drop remained relatively small. It can be expected to be even smaller in a major part of test cells where such problematic zones usually make up a relatively small portion of the membrane surface. However, we should keep in mind that due to the much worse mass-transfer conditions in such zones, concentration polarization there can be very strong and the solute rejection virtually zero. This can considerably increase the (negative) impact of these zones on the measured rejection.

It can also be observed that in the case of NF90 membrane (Figure 3b), decreasing the uncovered area has a larger impact on the trans-membrane flux. This may be due to a lower lateral hydraulic permeability of the support layer of NF90 membrane as compared to NF270.

Table 2
Effective surface and area uncovered by the plastic sheet according to the strip width.

Strip width (cm)	Unblocked area (cm^2)
0.5	7
1	14
2	28
No strips	140

Fig. 2. Photograph of the plastic sheets used to block the membrane for each strip width: a) 2 cm, b) 1 cm, and c) 0.5 cm.

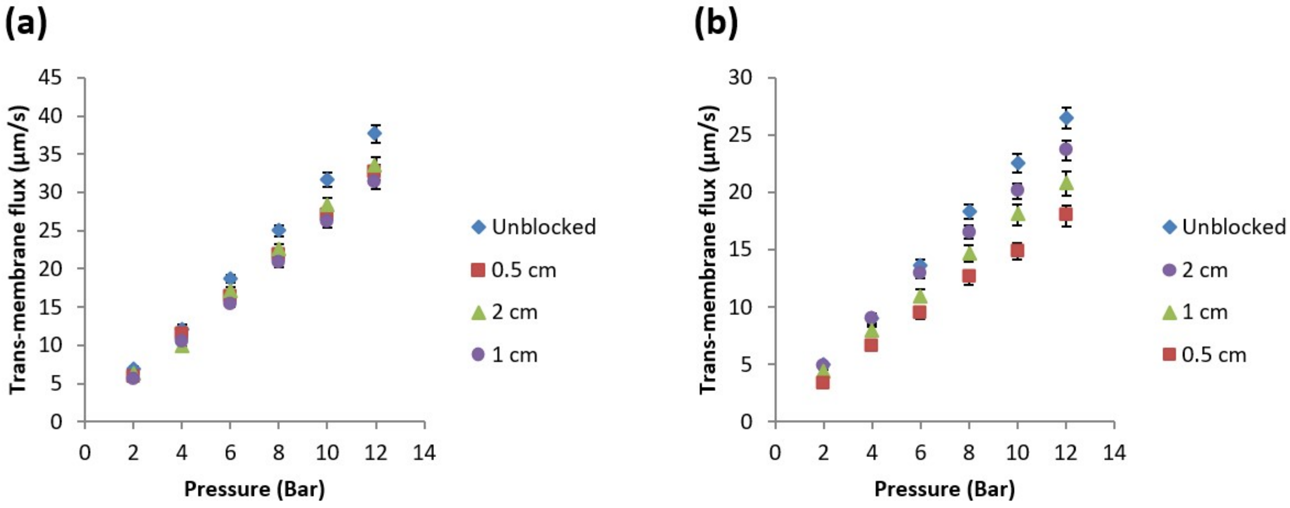

Fig. 3. Trans-membrane flux dependence on pressure for the unblocked membrane and the membrane covered by a plastic film for: a) NF270 and b) NF90. The legend gives the strip width.

4. Conclusions

Due to membrane-sealing requirements, in membrane test cells, there are always peripheral parts of the membrane supported by impermeable surfaces. This communication demonstrates that (somewhat counterintuitively) there is filtration through such parts of the membrane. This occurs due to the lateral volume transfer along the membrane support layers. Moreover, due to design constraints, it is very difficult to make the mass-transfer conditions over such parts of the membrane as good as in the feed channel. Actually, these conditions can even be expected to be much worse and poorly reproducible. Therefore, concentration polarization in such zones can be very strong, so they can make a disproportionally large contribution to the trans-membrane solute transfer, especially in the case of strongly rejected solutes. This can compromise the performance of test cells for pressure-driven membrane measurements and should be kept in mind while designing them.

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