8.2 Principles of Membrane Crystallization Technology

In a membrane crystallizer, the level of supersaturation and its generation rate are controlled by acting on the transmembrane flux of solvent (or antisolvent) through the membrane. As a foreign interface, the membrane also induces heterogenous nucleation whose extent depends on its physicochemical properties. Moreover, the possibility to promote specific interactions between solute molecules and the membrane surface (by selecting the appropriate membrane material, or by properly functionalizing the membrane surface) might guide the nucleation mechanism towards polymorph selection or crystal habit modification.[8–10]

Temperature-driven membrane crystallization is a thermal process in which a microporous hydrophobic membrane separates two solutions kept at different temperatures.[11] The hydrophobic nature of the membrane prevents the filtration of liquid but allows the transport of the volatile solvent in vapor phase (Figure 8.1a) under a vapor pressure gradient. The mass transfer mechanism consists of three steps: solvent evaporation at membrane interface exposed to the warm feed side, diffusion of the vaporized solvent through the membrane, and condensation on the opposite side (distillate).

Osmotic-driven membrane crystallization is a technological configuration in which the removal of the volatile solvent from the feed side is obtained by using a hypertonic draw solution contacting the opposite side of the membrane. This configuration is used for the crystallization of thermo-labile species, such as biological macromolecules, since the system is operated under isothermal bulk condition. The diffusion of vapour through the membrane pores is driven by the partial pressure difference across the membrane generated by the different activities of feed and draw solutions (Figure 8.1b). Since the mass transport involves the evaporation of the solvent, the latent heat flux slightly decreases the temperature from bulk to the membrane interfaces (the temperature difference is usually lower than 1 °C for operations at room temperature), thus leading to a negligible reduction of the transmembrane flux.[12]

Solvent/antisolvent demixing mediated by a membrane can take place under different configurations. In Figure 8.1c, due to the higher volatility of antisolvent with respect to solvent, a net transmembrane flux of antisolvent moves towards the feed side under a temperature gradient. Here, the fraction of antisolvent in the feed solution increases progressively and, above a certain threshold, the lower solubility of the solute generates supersaturation.

Additional requirements for this configuration are that: (i) the antisolvent and the solvent are miscible; (ii) the solute is under its solubility limit in the initial solvent/antisolvent mixture; and (iii) the solvent and the antisolvent do not form azeotropes or, if they do, supersaturation has to be reached below the azeotropic composition.