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Formulation by membrane emulsification

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Figure 1. Two different approaches used to obtain fine droplets of oil-in-water emulsion in membrane emulsification (ME): (a) “bottom-up” approach (direct ME); (b) “Top-down” approach (premix ME).

Membrane emulsification (ME) is a process of forming emulsion by passing a pure dispersed phase or pre-emulsion through a microporous membrane (Fig. 1). The most commonly used membranes for ME are Shirasu Porous Glass (SPG) membrane and microsieve membranes. In direct ME, fine droplets are produced at the membrane/continuous phase interface by injecting a pure liquid (the dispersed phase) through the membrane into a second immiscible liquid (the continuous phase) (Nakashima et al. 1991). The dispersed phase should not wet the membrane wall, i.e. hydrophobic and hydrophilic membranes are used to produce water-in-oil and oil-in-water emulsions, respectively. At low transmembrane fluxes, uniform droplets can be formed without applying any shear on the membrane surface, solely by the action of interfacial tension (Kukizaki 2009). In order to achieve commercially significant throughputs in ME, the shear stress is applied at the continuous phase/membrane interface, usually by cross flow or stirring (Fig. 2 a-d). Cross-flow systems are easy to scale up and can offer a continuous operation and constant shear stress along the membrane surface. Stirring systems are operated batchwise, do not provide constant shear stress on the membrane

surface, but are easier to operate because a closed loop recirculation of the continuous phase stream is not needed and a batch size can be very low, just 10 mL or even less.

The shear stress can also be generated by dynamic membrane (Fig. 1e) or pulsed flow (Fig. 1f), in which case the droplet detachment from the membrane surface is facilitated by rotating (Vladislavljević and Williams 2006) or vibrating (Holdich et al. 2010) the membrane within the otherwise static continuous phase or providing periodic flow pulsations in the continuous phase (Holdich 2012). In the dynamic and pulsed flow membrane systems, the shear stress on the membrane surface is decoupled from the cross-flow velocity and consequently, sufficiently high shear stress can be achieved at any cross flow velocity and emulsions with high dispersed phase concentrations can be produced in a single pass through the module.

Figure 2. Different ME systems used to control shear stress on membrane surface.

In the dripping regime, the droplet size is determined by a balance between the shear force and the capillary force. The size of the droplets produced is mainly affected by the

microstructure of the membrane (the pore size distribution, pore shape, and spacing), transmembrane flux, surface shear stress, physical properties of the continuous and dispersed phase, and emulsion formulation. Surfactant molecules must not adsorb to the membrane surface and thus, cationic surfactants must not be used in association with negatively charged membrane (such as SPG membrane and oxidised silicon microsieves) (Nakashima et al. 1993). The transmembrane pressure should not exceed 10 times the capillary pressure and the shear stress on the membrane surface is usually in the range from 2 to 10 Pa (Vladisavljević et al. 2004). The droplet size is typically 2–10 times higher than the pore size and decreases with increasing the shear stress on the membrane surface.

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