Behavior of oil droplets at the membrane surface during crossflow microfiltration of oil-water emulsions

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Many industries struggle to separate waste streams containing oil-water emulsions because few technologies are capable of separating micron sized oil droplets while remaining cost effective. Microfiltration and ultrafiltration membranes are often the best option, but overtime a fouling layer of oil develops on the membrane surface that causes the permeate flux to decline. The way in which oil fouls the membrane surface is not well understood, as the blocking laws (standard blocking, intermediate blocking, and complete blocking) do not apply to deformable particles such as oil droplets.

We utilized the Direct Observation Through the Membrane (DOTM) technique to gain insights into oil droplet behavior at the membrane surface. To our knowledge, this is the first application of a direct visualization technique used to capture real-time images of a membrane surface under conditions of fouling by emulsified oil in the presence of crossflow. DOTM experiments with hexadecane-water-SDS emulsions revealed three characteristic stages of membrane fouling by oil: 1) droplet attachment and clustering, 2) droplet deformation, and 3) droplet coalescence.

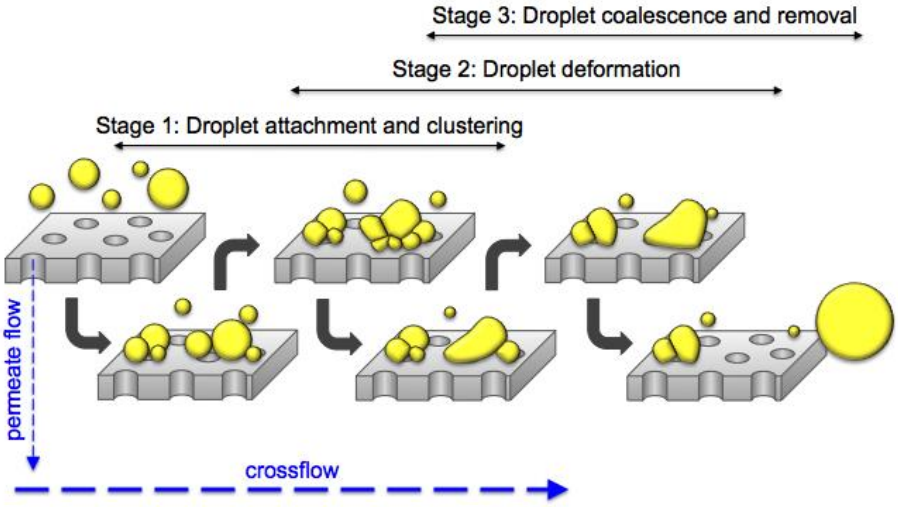


Figure 1: Three characteristic stages of membrane fouling by emulsified oil in the presence of crossflow.

The DOTM tests were conducted to screen for a range of fouling conditions; the sequence and duration of the three fouling stages are demonstrated in Figure 1. While the three stages occur sequentially for individual oil droplets and their clusters, the stages could overlap significantly when an ensemble of droplets on the entire membrane surface is considered. Figure 2 depicts a permeation event for a hexadecane oil droplet pinned at a pore entrance on the surface of a polycarbonate track-etch membrane where d_{pore} = 5 µm.

The effects of emulsion stability and membrane pore size were experimentally tested, while a force balance on a droplet helped elucidate the fate of an oil droplet pinned at a pore entrance. In qualitative agreement with visualization results, the force balance shown in Figure 3 predicted that droplets $\lesssim$ 36-40 µm would remain pinned at d_{pore} = 5 µm pores while larger droplets would be swept off the surface by the crossflow drag.

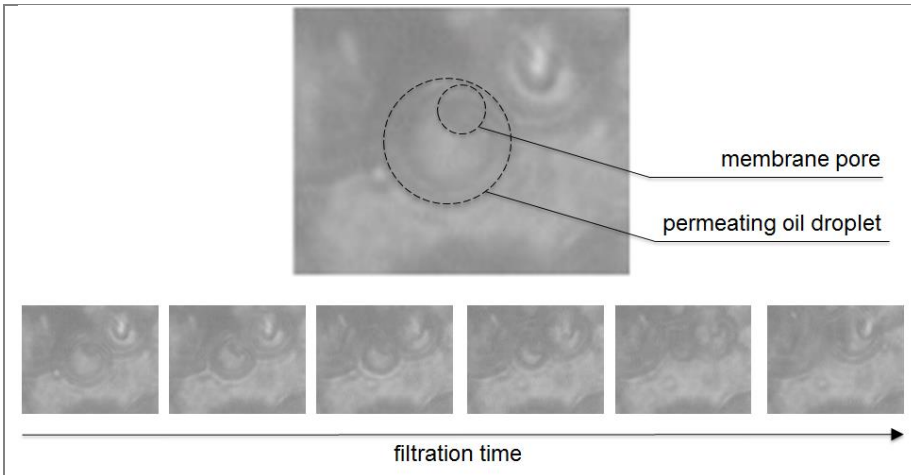


Figure 2: Different stages of oil droplet permeation through a 5 µm membrane pore in the case when $d_{drop} > d_{pore}$. The top image illustrates the initial condition of a droplet pinned at an entry to the membrane pore. The sequence of images below shows the evolution of the permeating droplet; the left most image in the sequence is the same as the large image with the pore and the droplet marked. This sequence took place in less than 2 seconds.

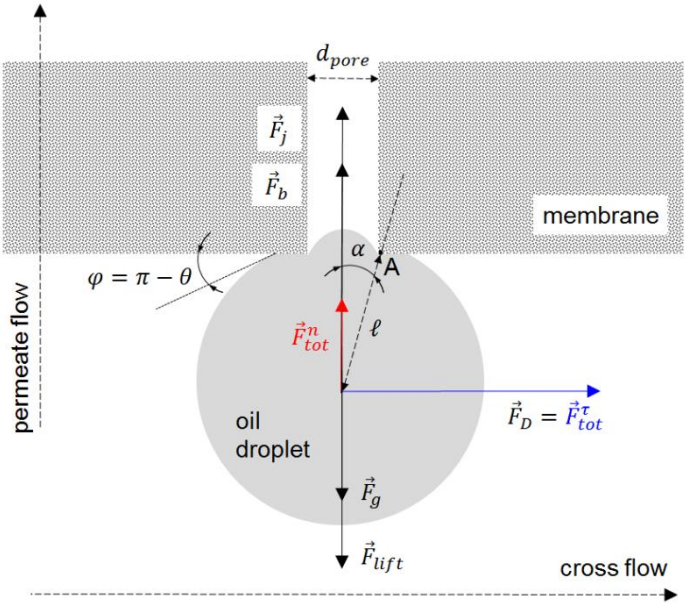


Figure 3: Hydrodynamic forces acting on an oil droplet positioned at the entry to a cylindrical pore of a membrane. The angles θ and α are the droplet's contact angle and angle of repose, respectively. For the definitions of forces see [1]. Forces are not drawn to scale. In DOTM tests, the microscope was located above the semitransparent membrane (i.e. on the permeate side) and the focal plane of the microscope was on the feed side where oil droplets were accumulating.

The results indicate that membrane fouling by emulsified oil is controlled by droplet coalescence and crossflow shear: the transport of oil to the membrane surface by the permeate flow is balanced by the shear-induced removal of the droplets that coalesce to exceed a critical size. Understanding the surface coalescence of droplets can help make optimal choices for the membrane type and operational conditions to minimize fouling and improve flux and rejection.

Reference:

[1] Tummons, E. N.; Tarabara, V. V.; Chew, J.-W.; Fane, A. G. Behavior of oil droplets at the membrane surface during crossflow microfiltration of oil-water emulsions. *J. Membr. Sci.* 2016, 500, 211-224