MECHANICAL ENGINEERING

Numerical Study of Crossflow Enhanced Microfiltration of Oil-in-Water Emulsions

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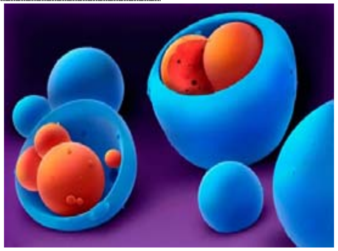
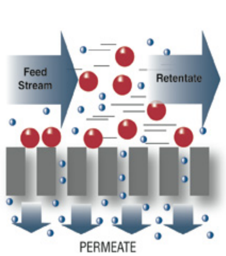
Motivation



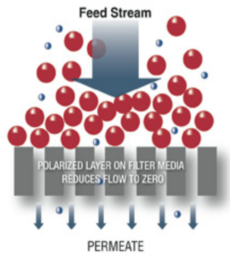
❖**Microfiltration** of Oil-in-Water Emulsions (Oil Spill, Source: http://bigpicture.ru)

❖Controlled Production of **Emulsions** (Drug delivery using Emulsions)

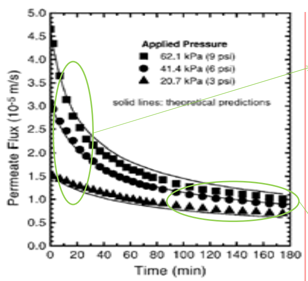
Types of Microfiltration and Typical Issues



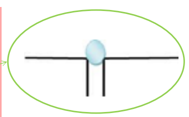
Crossflow Filtration



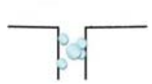
Dead-end Filtration



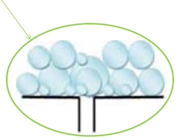
❖Flux decline in crossflow microfiltration of a silica suspension.



➢***Complete Blocking***: *Happens at the initial stages of filtration. A droplet blocks the pore completely.*



➢***Standard blocking***: *Deposition of drops inside the pore.*

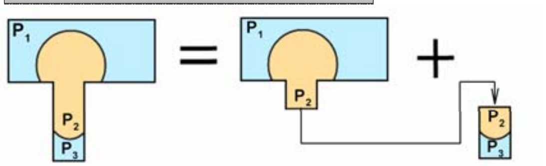


➢***Cake Formation***: *Happens at the final stages of filtration. A layer of drops forms on the surface.*

Theory and Numerical Method

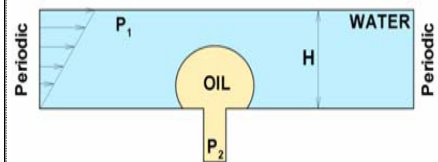
Pressure jump across static interface: **Young-Laplace Equation**

$$\Delta P = \gamma \cos\theta \left(\frac{1}{R_x} + \frac{1}{R_y}\right)$$



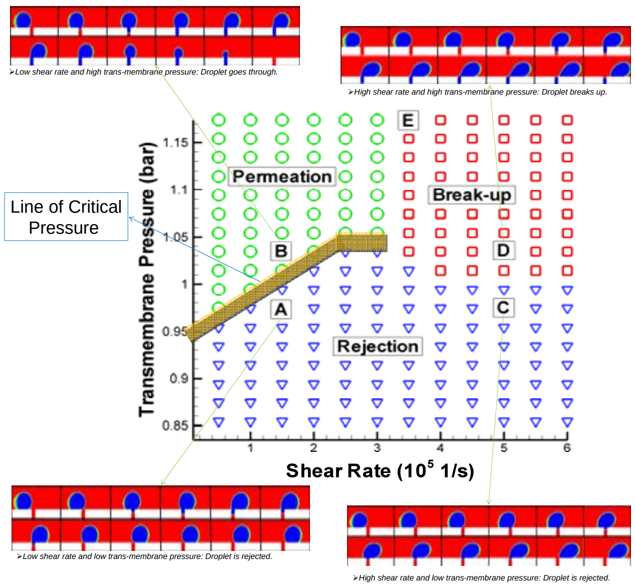
$$\Delta P(P_1 - P_3) = (P_1 - P_2) + (P_2 - P_3)$$

•Solver: FLUENT.
•Supplemented by: UDF programming (C)
•**3D-simulations** of incompressible Navier-Stokes.
•Interface tracking: **Volume of Fluid (VOF).**

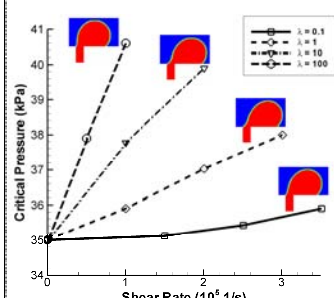


$\lambda = \mu_{oil} / \mu_{water}$	Viscosity ratio
σ	Surface tension
θ	Contact angle

Results: Effect of Transmembrane Pressure and Shear Rate

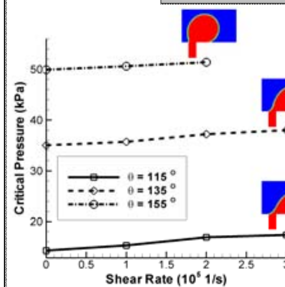


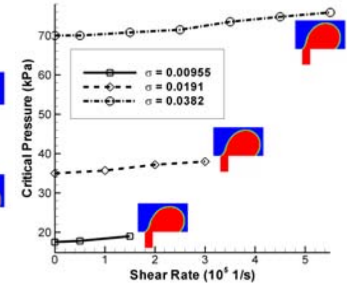
Results: Effect of Viscosity Ratio



❖Critical pressure at zero shear rate is independent of viscosity ratio.
❖Critical pressure increases with viscosity ratio.
❖Highly viscous drops break at lower shear rates.
❖Highest deformation before breakup happens for medium viscosity ratios.

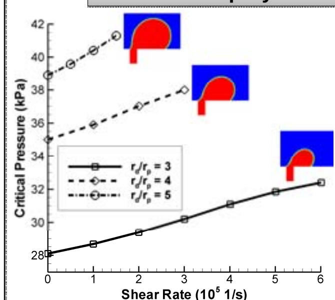
Results: Effect of Material Parameters

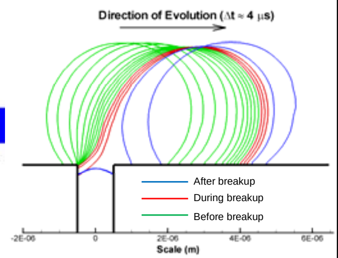




❖Drops with high contact angle and high surface tension have higher critical pressure.
❖Drops of high contact angle and low surface tension break more easily.

Results: Drop Dynamics and Effect of Drop Size





❖Larger drops break more locally. Small drops break through necking.
❖Larger drops break more easily than smaller drops.
❖Drop breakup time scale is small compared to flow time scale.

Important Conclusions

✓Behavior of a single droplet on a pore in crossflow microfiltration is one of the following: Permeation, Rejection, Breakup.
✓Critical pressure for crossflow microfiltration increases with shear rate, viscosity ratio, surface tension coefficient, and drop size.
✓Increasing viscosity ratio, contact angle, and size of the drop increases chance of breakup.
✓Increasing the surface tension coefficient decreases chance of breakup.

References

1. "Microfiltration of Water-in-Oil Emulsions", F.F. Nazzal and M.R. Wiesner, Water Environment Research, Vol. 68, No 7 (1996).
2. "Kinetics of Permeate Flux Decline in Crossflow Membrane Filtration of Colloidal Suspensions", S. Hong, R.S. Faibish, and M. Elimelech, Journal of Colloid and Interface science 196, 267-277 (1997).
3. "An Experimental Investigation of Drop Deformation and Breakup in Steady Two-dimensional Linear Flows", B.J. Bentley and L.G. Leal, Journal of Fluid Mechanics, 167, 241-283 (1986).