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Shear-enhanced membrane filtration of synthetic microalgae lipids for applications in biorefinery

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INTRODUCTION

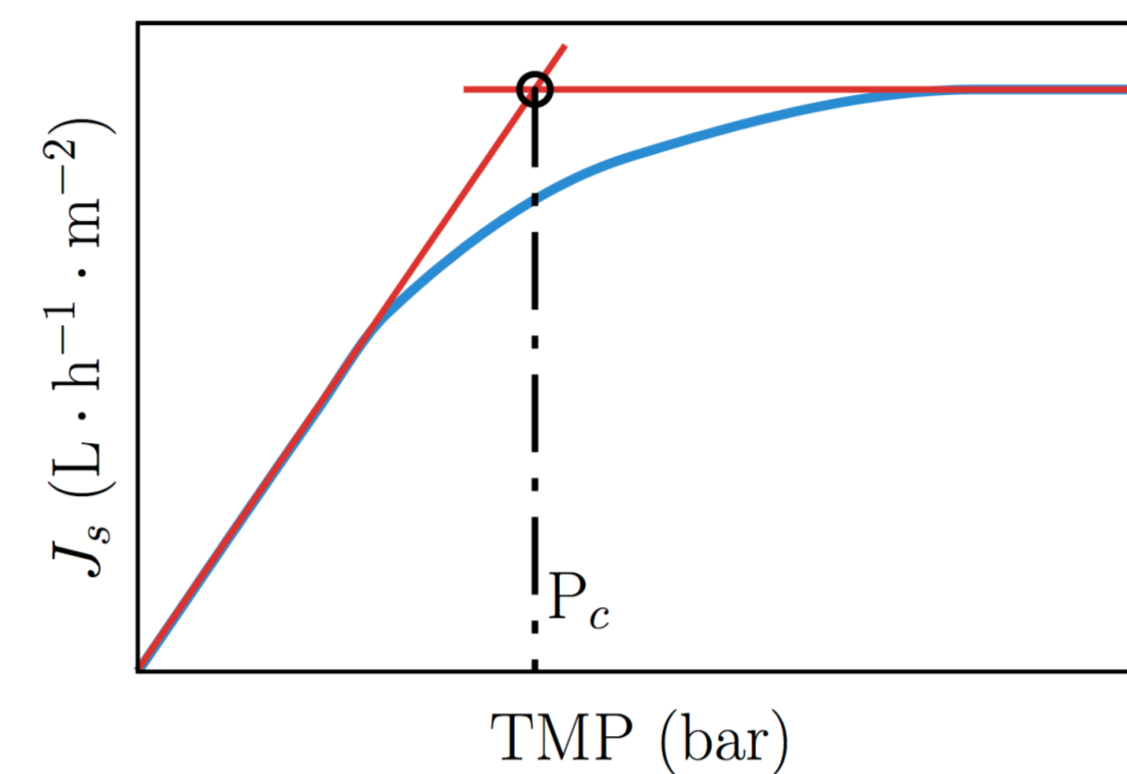
Cell disruption and lipid extraction from harvested microalgae cells are two critical steps in the third generation biofuel production. Lipid recovery from disrupted cells can be improved using filtration methods applying the wet pathway, thus reducing the energy consumption. These methods can be automated and can treat large volumes of suspensions while avoiding the use of solvents and chemicals. Recently, the shear-enhanced or dynamic filtration technique has emerged as a promising option that reduces membrane fouling and provides high permeate fluxes at a steady shear rate, with good separation performance and low energy requirements.

THEORY

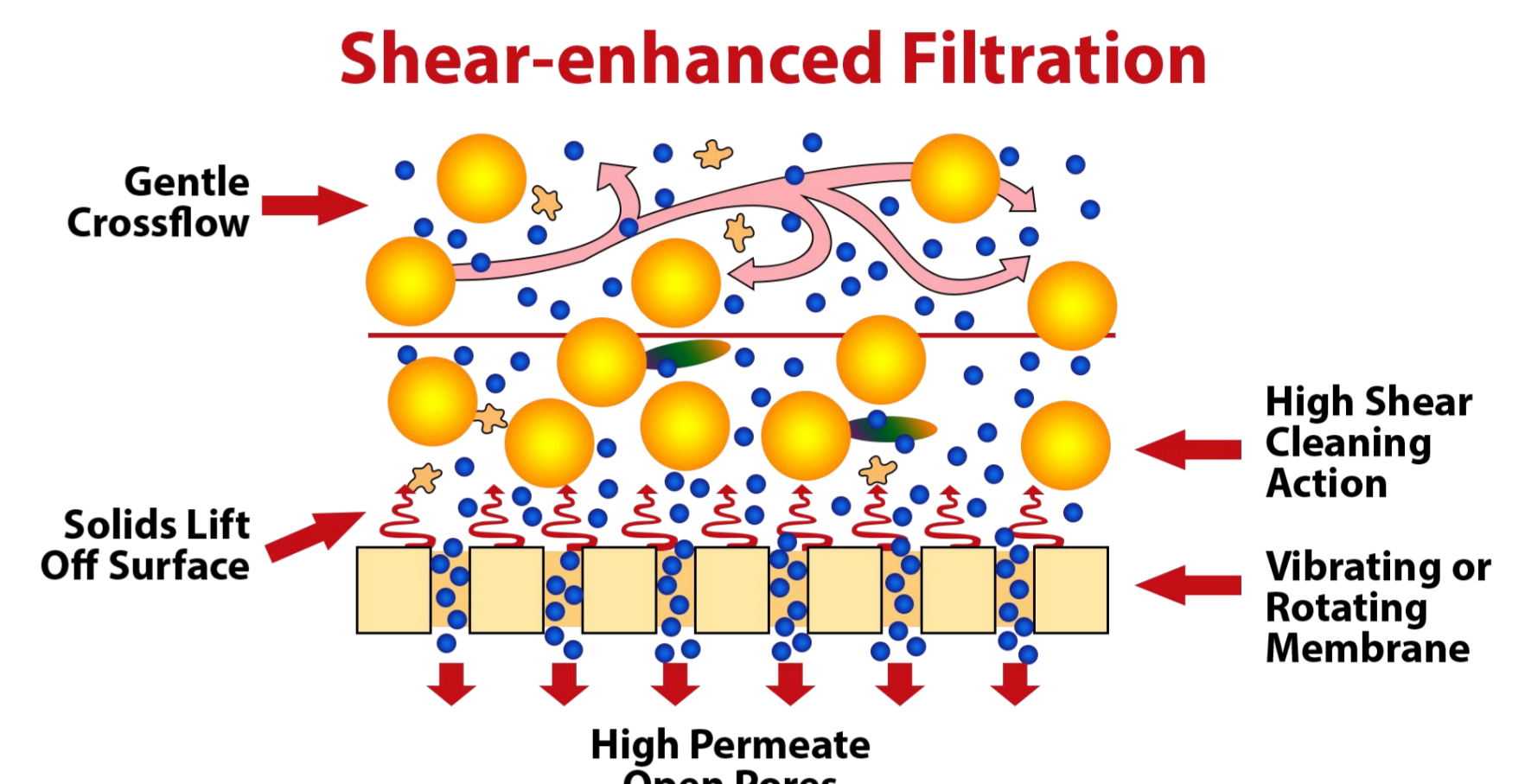
The global objective is to **define separation strategies for real biomass**. In this work, we evaluated the feasibility of dynamic filtration for the concentration of lipids with four different membranes. The concentration experiments were conducted at a pressure below the critical pressure to limit the fouling.

We compare the filtration performances (relative flux reduction % RFR, oil retention rate % R, % cleanability, and global fouling resistance $R_{Fouling}$) of both the crossflow and shear enhanced filtration modules during lipid recovery from a model emulsion.

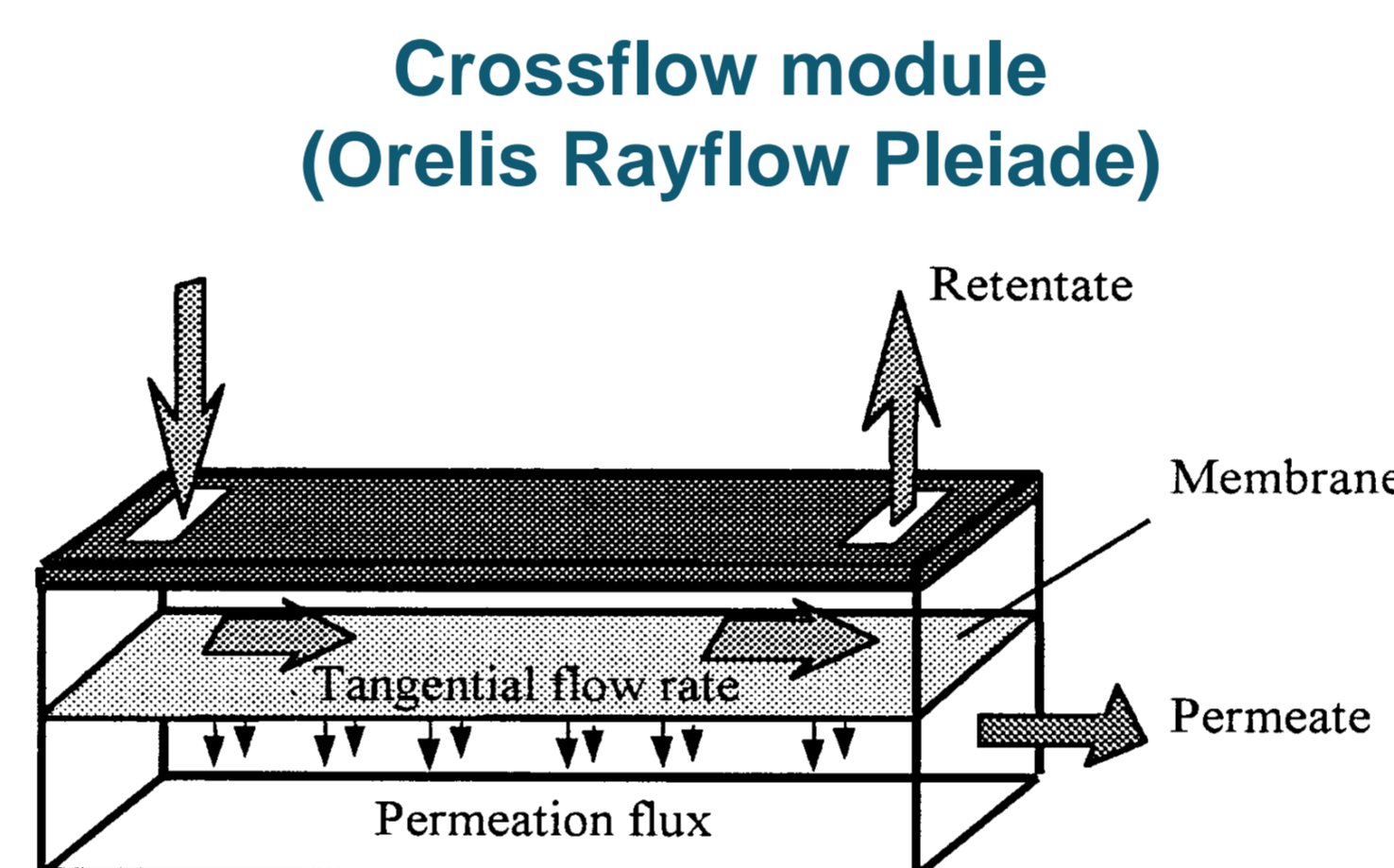
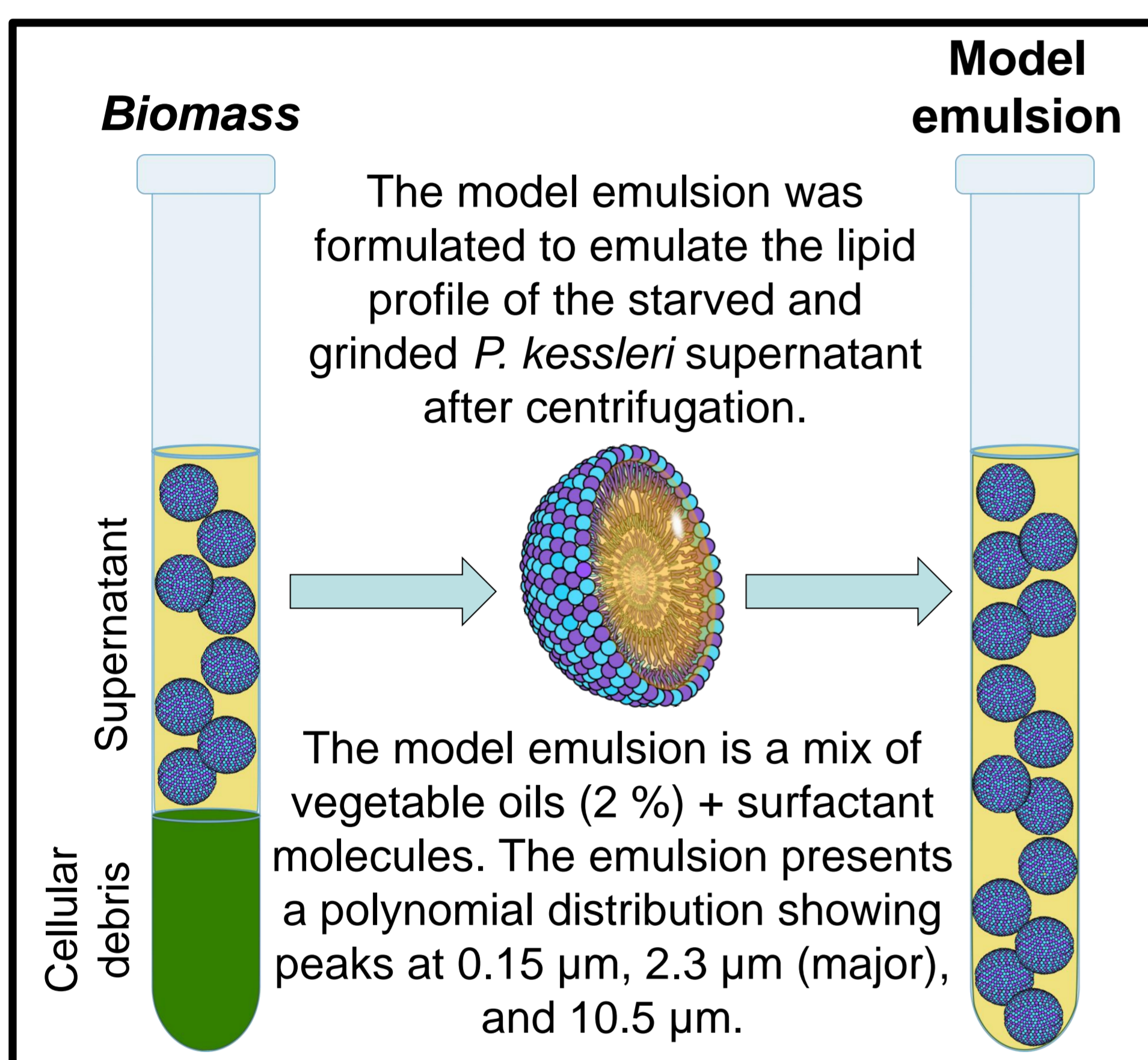
$$\% R = \left(1 - \frac{C_p}{C_r}\right) \times 100 \quad \% RFR = \left(1 - \frac{J_s}{J_0}\right) \times 100 \quad \% \text{ Cleanability} = \left(\frac{J_r}{J_0}\right) \times 100 \quad \% R_{Fouling} = \left(\frac{R_{Tot} - R_{mb}}{R_{Tot}}\right) \times 100$$



Graphical determination of P_c .



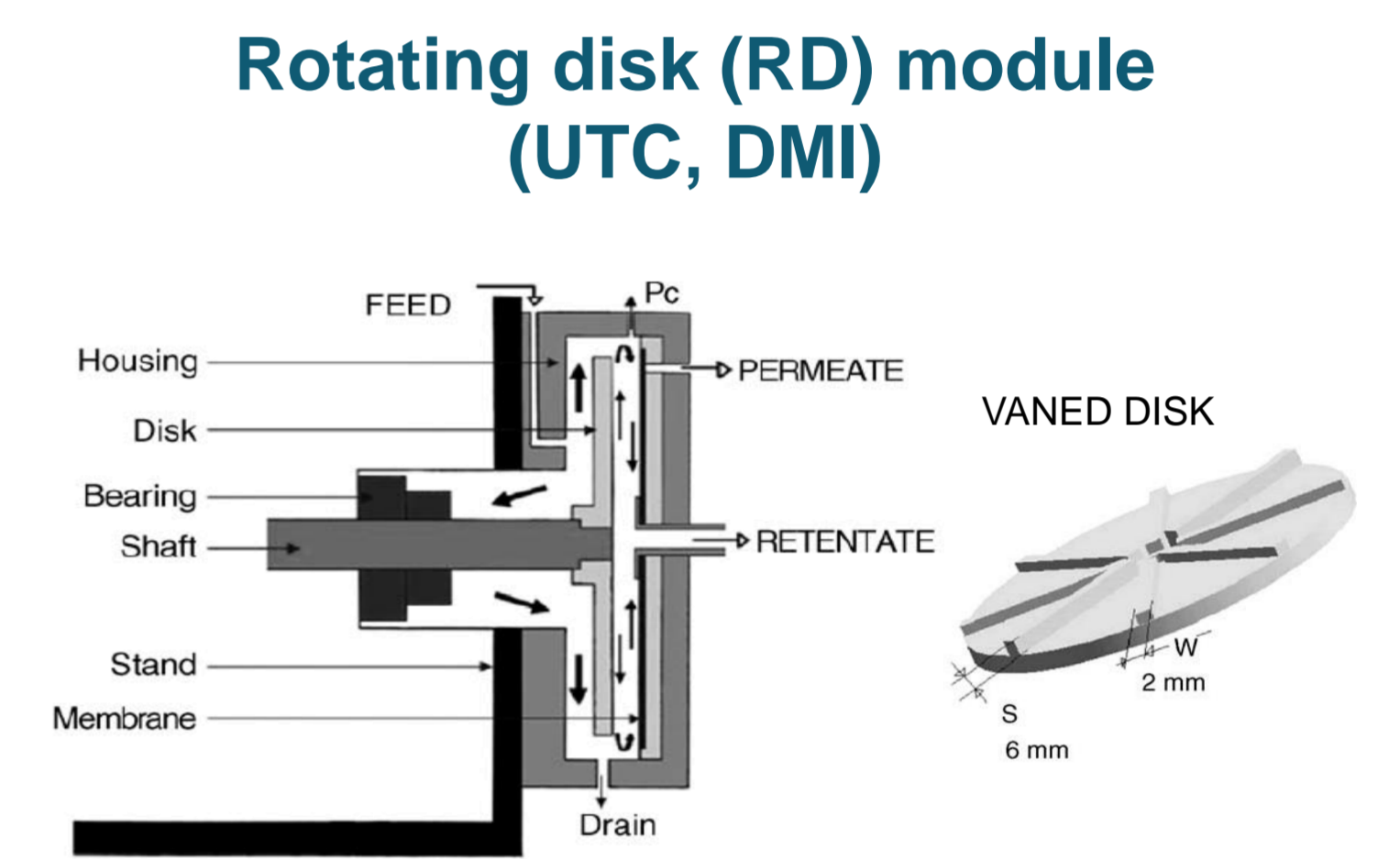
MATERIALS & METHODS



Shear rate : 10,000 – 50,000 (s^{-1})

$$\dot{\gamma} = \frac{8}{e} \cdot v$$

e = thickness of the module channel (m)
 v = flow velocity (m/s)
 [Delaunay et al. 2008]



Shear rate: 10,000 – 500,000 (s^{-1})

$$\dot{\gamma}_{max} = 0.0296 \cdot \nu^{-\frac{4}{5}} \cdot (k\omega)^{\frac{9}{5}} \cdot R_d^{\frac{8}{5}}$$

k = velocity factor
 (smooth disk = 0.42, vaned disk = 0.89)
 [Bouzerar et al. 1999], [Frappart et al. 2006]

RESULTS

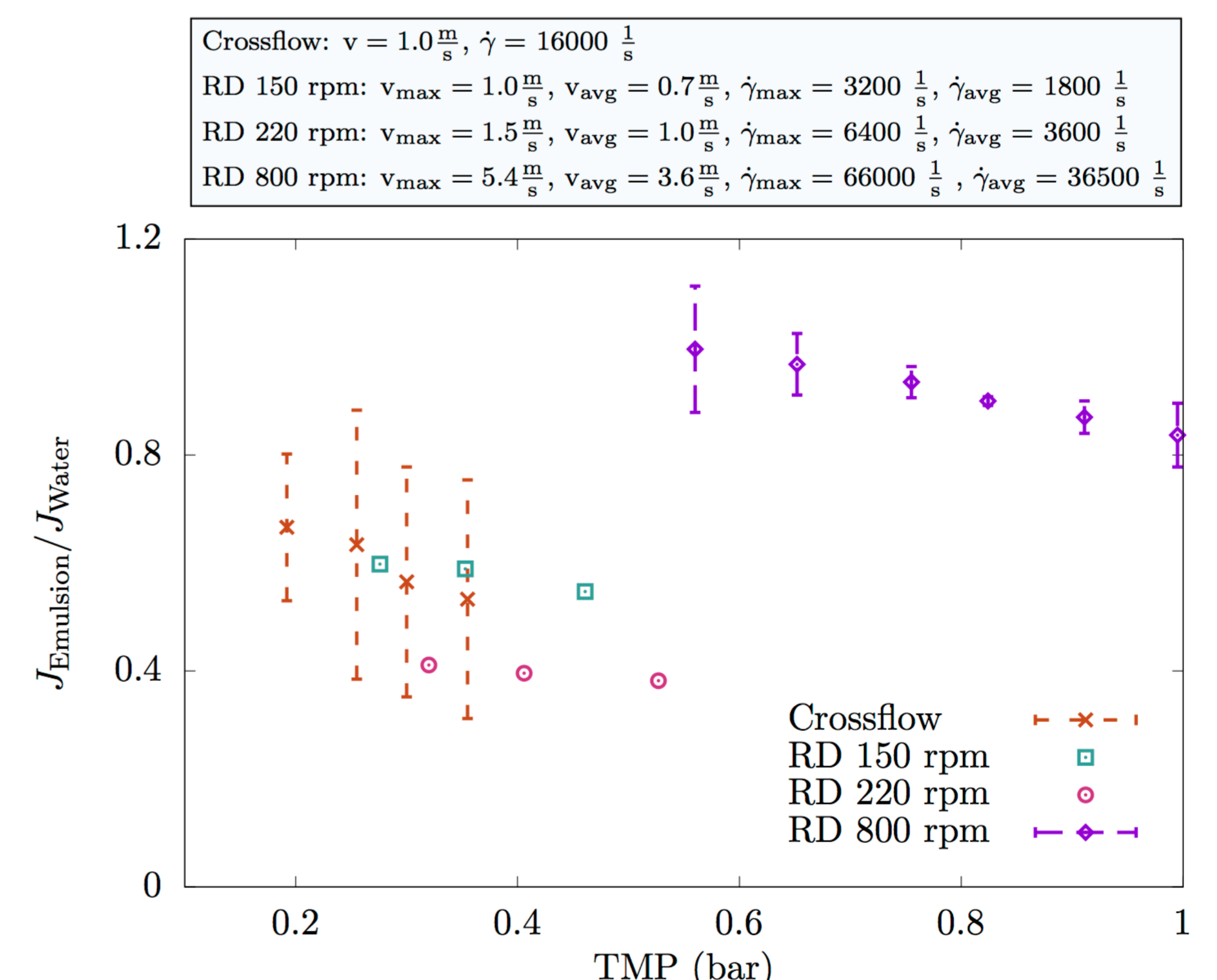
Screening characteristics for different commercial membranes used in the rotating disk module at 800 rpm ($T=30^\circ C$). All membranes present a % R greater than 94 %. **The PAN 500 kDa and PVDF 0.4 μm membranes seem to be the most promising candidates for oil droplet concentration.** The crossflow filtration results also suggest that the PAN 500 kDa membrane presents the best concentration characteristics.

Polymer	MWCO	P_c (bar)	%RFR	% Cleanability	% $R_{Fouling}$	Lp_{Water} ($L \cdot h^{-1} \cdot m^{-2} \cdot bar^{-1}$)	$Lp_{Emulsion}^i$ ($L \cdot h^{-1} \cdot m^{-2} \cdot bar^{-1}$)	$Lp_{Emulsion} / Lp_{Water}$
PAN	500 kDa	0.6 – 0.9	38 – 46	44	32 – 46	32 – 57	20 – 31	0.5 - 0.6
PES	200 kDa	0.8 – 1.5	74 – 84	20	73 – 84	48 – 71	8 – 19	0.2 – 0.3
PVDF	0.4 μm	0.4 – 0.7	38 – 40	70	31 – 37	50 – 255	30 – 157	0.6
PVDF	1.5 μm	0.5 – 0.6	5 – 84	49	83	28 – 152	24 – 26	0.2 – 1.0

Crossflow and shear-enhanced filtrations, for the PAN 500 kDa membrane, were compared in the same conditions ($v=1$ m/s, and $T=30^\circ C$). All conditions lead to a % R greater than 97 %. **PAN membrane performance is similar in both systems.**

System	P_c (bar)	% RFR	% Cleanability	% $R_{Fouling}$	Lp_{Water} ($L \cdot h^{-1} \cdot m^{-2} \cdot bar^{-1}$)	$Lp_{Emulsion}^i$ ($L \cdot h^{-1} \cdot m^{-2} \cdot bar^{-1}$)	$Lp_{Emulsion} / Lp_{Water}$
Crossflow	0.25 – 0.4	20 – 50	92	47	82 – 325	63 – 160	0.5 – 0.8
Rotating disk	0.3	48	77 – 140	34 – 50	72 – 100	37 – 52	0.5

Comparison of $J_{Emulsion}/J_{Water}$ in the critical pressure (P_c) determination for the PAN 500 kDa membrane using the crossflow and rotating disk modules. The values differ slightly from the table; this calculation uses data from the P_c determination, while the table corresponds to the final value of the concentration experiment. The error bars correspond to experimental replicates.



- ✓ The RD appears to have same performance as the crossflow technique at similar velocity conditions.
- ✓ Membrane performance seems slightly enhanced with the RD velocity by increasing P_c and reducing $R_{Fouling}$.

CONCLUSION

- The membrane screening suggests that PVDF and PAN polymers are the most viable options for effective lipid recovery by concentration.
- Membrane fouling is lower for the RD than the crossflow module. However, at low velocity (1 m/s), filtration performance remains fairly close and both modules are more readily cleanable as the fouling seems mostly superficial.
- At higher velocity, the fouling process is still unclear as the cleanability and fouling resistance are lowered. Further studies must be conducted in order to clarify the fouling mechanism as function of fluid velocities and/or shear rates.