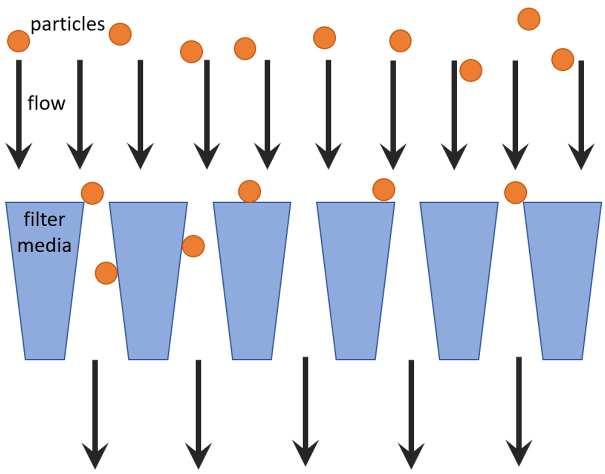
Optimizing the performance of a conical ceramic membrane
Smart Separations

Introduction

Smart Separations fabricates ceramic membranes with micron-sized conical pores that offer great potential for applications in the filtration of different media/particles, with applications for the filtration of beers and wines, blood, and removal of dust and pollen from the air. A fundamental challenge is how to design the pore structure to maximize performance in a given filtration scenario. For instance, pores that open out with depth offer the same selectivity but require less energy to drive through fluid than their cylindrical counterparts. However, this must take into account design constraints. For instance, a critical maximum porosity and a minimal overall thickness are enforced to ensure the filter does not collapse during operation, while pores with larger angle are less likely to survive during the manufacturing process. The balance of energy minimization and design constraints therefore suggests an optimum pore angle and number of pores, which can be identified using mathematical modelling.

The fabricated membranes are 3-5 mm thick, and can have pore radii in the range 8–100 microns. 3D tomographic images exist that show what is currently possible.



Challenges

Smart Separations are interested in understanding the behaviour and performance of these filters. Below we itemize all of the challenges that they ultimately wish to address. The Study Group will serve as a first step towards tackling some of these questions.

1. Flow rate prediction and maximization

- Determine the relationship between the air or liquid flow rate through the filter and the pore spacing, top pore radius, and conical pore angle. What is the critical concentration of pores of a specific diameter per unit area and the contribution of the remaining porosity of the skeleton?

2. Filtration performance

The filters may be used to filter a variety of fluids:
1. Biological fluids: e.g., blood, urine, tears, sweat, saliva (characterized by deformable cells).
2. Beverage fluids: e.g., wines, juices, beer, fermented liquids, dairy products (larger debris).
3. Molten metals: e.g. molten aluminium (hard microparticles).
4. Air: e.g., pollen and dust.

- Given a filter structure (characterized as in Challenge 1), how fast will the membrane become clogged with different types of particles? What role does the fluid being filtered play (e.g., viscosity, temperature)?

- What role does volume of required fluid play? e.g., higher volumes of beverages are required than biological fluids.

- How can we modify the filter protocol (e.g., changing membrane orientation relative to the flow field) to reduce clogging?

- How do the filters behave when operating in a diffusive rather than convective mode? For example, how do glucose and H_3O^+ molecules diffuse between two chambers separated by our membrane filters? This mode may also be used to selectively filter elements (e.g., bacteria, red cells, white cells, carcinogenic cells).

3. Catalytic activity across microstructure in coated membranes

- The membranes may be coated with catalytic substrates. If this is done, where do reactions primarily take place? If the reactions are only occurring, for instance, at the beginning of the pores, then the membrane may not need to be coated in its entirety but only near the surface. Are the reactions taking place within the channels or is the porosity in the nanopores important? Does catalysis take place in more confined pores? Is the time that the molecules reside in the filter of any importance in the design of the pores?