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Can we predict diffusion-driven cleaning-in-place reliably?

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ABSTRACT

Cleaning-in-place (CIP) operations are widely used in the food, pharmacetial and bioproducts sectors to remove residual material from process equipment surfaces between batches, during product changeover, or to ensure hygienic operation. Most CIP operations feature the circulation of cleaning solutions through the equipment to deliver the combination of chemical action, shear stress and mass transport required to remove the soiling material from the solid surface. Many CIP systems are overdesigned, resulting in significant overexpenditure of energy, chemicals and extended production downtime. Reducing each of these will have direct benefit for the sustainability of the manufacturing process.

Understanding how a particular soil is removed is key to optimising a CIP operation. Dissolution is one mechanism, where the soil dissolves into the liquid and the rate of removal is determined by mass transfer. Larger flow rates increase local mass fluxes: this apparently straightforward mechanism nevertheless poses challenges in CIP operations as it is not the removal of the first 95% or so of soil that determines the cleaning time: it is the removal of the final patches, usually located in regions of slow moving fluid, *e.g*. a switching valve rather than a pipe. These lead to interesting mass transfer problems featuring moving fronts and non-uniform local flux profiles.

This presentation will sumarise recent computational and experimental work on diffusion-driven cleaning in place in our group. The experiments employ readily soluble soil layers (dried instant coffee, caramel) exposed to flows of water under laminar and turbulent conditions in different geometries: a radial flow cell, a rectanglar slit and a series of backward-facing steps. Video monitoring of removal indicates highly non-linear and 3-dimensional phenomena. The ability of computational fluid dynamics simulations of the flows, coupled with mass transport, to predict the observed removal behaviour, is discussed and challeges posed by these apparently simple systems identified. Finally, work on the underlying Stefan-Graetz problem that arises at the cleaning front is outlined.

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KEY WORDS

Cleaning; CFD; diffusion; mass transport

BIOGRAPHY

Ian Wilson is the Professor of Soft Solids and Surfaces in the Department of Chemical Engineering and Biotechnology at the University of Cambridge. He has been at Cambridge since 1994, conducting research on topics related to fluid flow, rheology and surface science related to the food, pharmaceutical and consumer goods sectors. He completed two terms as Editor-in-Chief (Food) of the IChemE journal *Food & Bioproducts Processing* in June 2026. He is attending Chemeca 2026 as part of a Hood Fellowship at the University of Auckland.

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