Surface-washing of contaminated porous substrates

Francesco P. Contò[a]*, Merlin A. Etzold[a], Emily Butler[b], Julien R. Landel[b], Stuart B. Dalziel[a]

[a] University of Cambridge, DAMTP, Wilberforce Road, Cambridge, CB3 0WA, UK
[b] University of Manchester, Dept. of Mathematics, Oxford Rd, Manchester, M13 9PL, UK
* Email address: fpc25@cam.ac.uk

The cleaning of porous surfaces is a challenging problem in everyday life and industrial practice since it can lead to redistribution of the absorbed contaminant within the porous material instead of a complete removal of the unwanted agent. The role of decontamination is particularly crucial when contaminants (such as chemical weapons agents and pathogens) pose serious risks to human health [1].

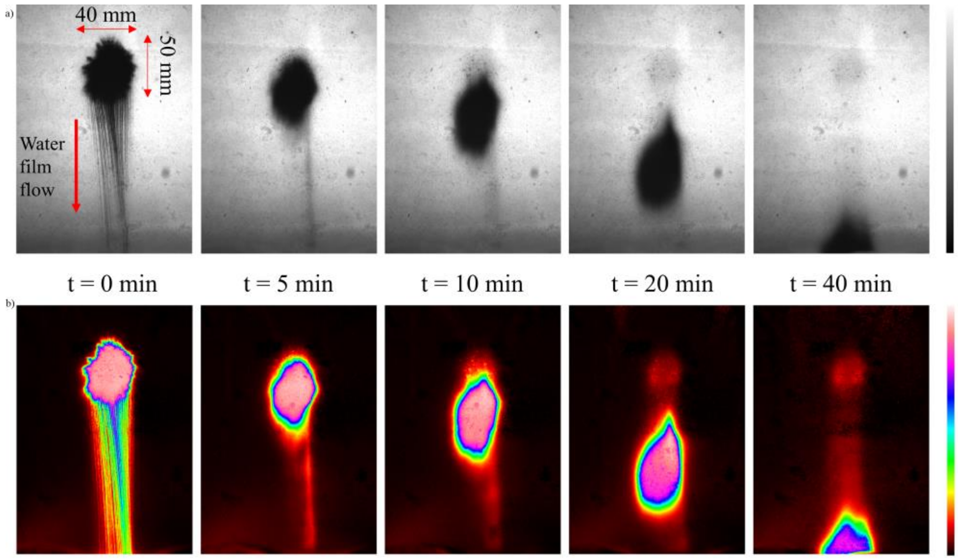
In this work, we present surface-washing experiments modelling the decontamination of porous substrates.

Firstly, we report a protocol to manufacture mechanically stable porous media by sintering soda-lime glass ballotini (< 1 mm) to form free-standing homogeneous porous plates or composite structures where a porous matrix is sintered onto solid glass backing and surrounds. The ability to incorporate directly a solid glass backing provides a method of preventing any liquid leaks through their rear.

These samples are then integrated into a surface-washing apparatus [2] equipped with camera-based and in-line UV-Vis diagnostics. A dyed fluid is placed onto the porous substrate to simulate the region of contamination. The surface-washing is simulated by a thin (~ 1 mm) gravity-driven film of water flowing over an inclined porous-glass surface.

The resulting interaction between the cleansing film flow and the contaminating dye is then tracked using direct image analysis based on dye-attenuation techniques, enabling us to study the space-time evolution of the contaminant field over the porous medium. Moreover, the camera visualization is complemented with a UV-Vis spectrometer monitoring in real-time the contaminant concentration in the effluent during the washing.

Our experiments provide insights on the role of initial conditions (wet/dry substrate, ingress of contaminant, contamination-washing time gap), the impact of cleaning strategies on industrial performances (e.g., amount of cleansing resources and decontamination time), and the relevant transport mechanisms of the contaminant (gravity/capillary-driven advection, diffusion, and dispersion in both liquid and porous phases). Importantly, they demonstrate a decontamination-induced redistribution of the contaminant within the porous matrix.



Surface-washing of a 0.2 mL disodium-fluorescein water droplet of concentration C_0 = 20 g/L injected into an initially wet porous substrate through a gravity-driven water film. *a) Greyscale sequence (raw images); b) Colour concentration map C/*C_0*.*

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References:

[1] Landel, JR, Wilson, DI (2021) "The fluid mechanics of cleaning and decontamination of surfaces". Annu. Rev. Fluid Mech. 53, 147-171.
[2] Landel, JR, Thomas, A, McEvoy, H, Dalziel, S (2016) "Convective mass transfer from a submerged drop in a thin falling film". J. Fluid Mech. 789, 630–668.