Nanopores integrated with macropores: modelling weight loss in nuclear reactor cores and the relative permeability of tight-oil shale

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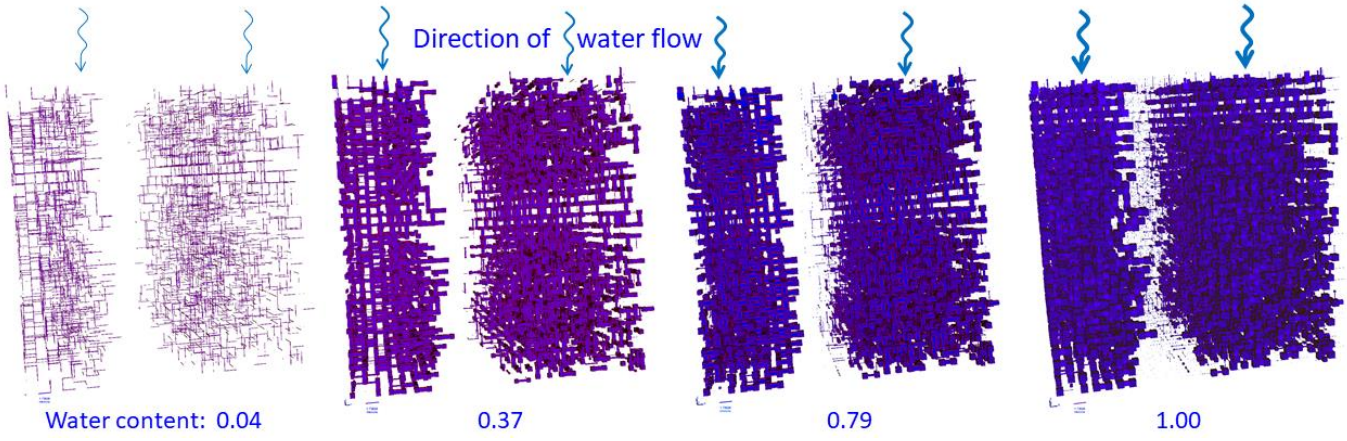
The void networks and pore fluid behaviour within nanoporous materials are highly challenging to investigate experimentally and to model. Even more challenging is to measure and model the behaviour in materials with non-hierarchical, i.e. fully integrated, behaviour extending from nanopores to macropores. However, such characterisation is of extreme scientific and commercial importance. In this presentation I shall discuss two examples – GilsoCarbon graphite[1], the weight loss in which limits the lifetime of some UK Advanced Gas-Cooled nuclear Reactors (AGRs), and tight-oil shale, the relative permeability of which determines the efficiency of abstraction by hydraulic fracturing (fracking).

The experimental characterisation of the porous materials is by mercury intrusion porosimetry, surface area measurement and helium pycnometry. Prior to that, Gilsocarbon graphite is irradiated in a test reactor, and then sub-sampled within a radiation-secure environment. Tight-oil shale is sub-sampled from core samples, and washed benignly to remove mobile, but not static, oil. The experimental measurements are combined to produce an effective intrusion curve covering the range of interest – typically 1 nanometre to 100 microns – i.e. five orders of magnitude of size. An inverse modelling approach is then used to produce a void network with the same porosity and intrusion characteristics as the experimentally based curve. As with all inverse modelling, there is no single answer, so a statistically central result should be taken as representative. Traditionally, percolation characteristics have been misinterpreted by use of the first derivate of the curve as representing the void size distribution and by ignoring void clusters[2]. Both of these potential errors are avoided.

Once a realistic, representative void network is generated, the behaviour of pore fluids within the network can be simulated. Permeability is calculated using Navier Stokes equations applied to each pore-throat-pore arc within the fully three-dimensional void networks of around 45000 voids. The flow capacities are combined to form mapped flow routes. The geometries of the pores and throats can be modified to represent either weight loss through the action of highly irradiated carbon dioxide coolant, in the case of AGRs, or obstruction by static surface oil (in oil-wet shale) or water ganglia. Examples are given of the effect of Gilsocarbon weight loss on its permeability, and the relative permeability characteristics of oil-wet shale, which vary with oil-wettability and flow rate, and are entirely different to the guessed values currently used by oil majors within their reservoir simulators for unconventional fields. All the results are based on explicit flow maps. The example below shows a flow mapping for aqueous relative permeability at different water contents within the same simulated void network.



[1] K. L. Jones, G. M. Laudone, G.P.Matthews. *Carbon*, **158**, 256, 2020

[2] G.P.Matthews, C.L. Levy, G.M. Laudone et al., *Transp. Porous Med*. **124**, 631, 2018