Plume flow through porous media

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There is very strong evidence for anthropogenically-induced climate change and in particular that carbon dioxide (CO_2) emission into the atmosphere is causing rising temperatures globally, with potentially catastrophic consequences. The focus of the proposed PhD will be on the fluid flow associated with injection and geological storage of CO_2; a technique for storing captured pure CO_2 (or CO_2 with minor gaseous impurities, including SO_2, NOx) underground in, for example, saline aquifers or depleted oil and gas reservoirs in deep sandstones.

The United Kingdom has major potential for carbon capture and storage (CCS) in offshore Permo-Triassic sandstones. These strata comprise complex sequences of interbedded sandstones, mudstones and evaporite deposits (e.g., gypsum, anhydrite and halite). They can be characterised in terms of their porosity, permeability and sedimentological, diagenetic and structural heterogeneities within the pore network. These types of rocks are commonly influenced by tectonic and burial-related structures, including subseismic “deformation bands” that occur at multiple length-scales as a result of their geomechanical stress history. This can result in (i) the formation of faults which may be associated with open fracture networks leading to a dual-permeability system, (ii) particle attrition leading to pore blocking and reduction in permeability, or (iii) a cemented seam with little or no permeability and that acts to redirect flow. Assessing the occurrence and impact of subseismic deformation bands is problematic. Understanding the effects of deformation bands on injected fluid flow through a porous medium is therefore key to the UK’s ability to efficiently and effectively store CO2. The long-term effects of CO2 storage in the UK’s primary target host rock (Permo-Triassic sandstone) need to be understood so that the security of the UK’s CCS policies can be guaranteed.

Fluid flows through porous media have been classically studied using both a two-dimensional Hele-Shaw cell approach to visualize the flow and a Darcy flow approach that assumes inertial effects on the fluid are negligible. Here we advance these classical techniques by considering a multiphase flow that includes the effects of chemistry on the fluid and surrounding rock and the variable porosity due to deformation bands.

The proposed research will take a three-pronged approach to tackling the problem:

- Mathematical modelling. The most powerful deliverable of the project will be a mathematical model that captures the underlying physics of CO2 plume migration within Permo-Triassic sandstone under different scenarios and configurations for deformation bands. The model will exploit the key physical processes identified and will be applicable in a wide range of applications across a large number of scales. The success of the modelling will be assessed through benchmarking and validation against experimental data sets.
- Numerical modelling. It is essential that the complex fluid flow systems are modelled numerically using state-of-the-art computational fluid dynamics (CFD) software. This will provide an independent validation of any mathematical modelling, and also provide valuable insight into a flow that is otherwise demanding to visualize as it takes place within rock, often many hundreds of metres below ground. The transferable skills developed will also be an asset to any successful graduate.
- Experimental/Empirical validation: The British Geological Survey will provide access to key realistic data sets for Permo-Triassic sandstone samples, material flow properties and seismic interpretation of reservoir deformation band types. This will be used to inform and validate new modelling and understanding. It is key that a successful investigation should be guided by real-world data.