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The impact of heterogeneity on the flow and trapping of CO2 in target UK aquifers

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The Bunter sandstone formation in the Southern North Sea and the Captain sandstone formation in the Northern North Sea represent two of the largest potential CO_2 stores in the UK, with estimated capacities of up to 14 Gt and 1.7 Gt respectively [1, 2]. With current UK CO_2 emission totalling ~400 Mt/yr [3], the Bunter and Captain formations alone have the potential to store UK emissions for many years.

In order to determine the long-term fate of the injected CO_2 in these systems, accurate characterisation of the multiphase flow behaviour and trapping is needed [4]. Conventionally, multiphase flow functions, namely relative permeability, capillary pressure and trapping, are derived from viscous limit core flood experiments, measured at high flow rates on subsurface rock cores preferentially selected for homogeneity [5], and either used directly in field scale modelling or for further upscaling.

However, for modelling low potential flows characteristic of buoyantly driven CO_2 plume migration, it is important to derive properties that capture the impacts of rock heterogeneity. Sub-metre scale capillary pressure heterogeneities will control local fluid distribution, resulting in equivalent relative permeabilties which are dependent on the flow direction, rock heterogeneity, and the capillary number [6]. Modelling studies have estimated that this can have a significant impact on plume migration and trapping from the mm-km scale [7,8]. However, no experimental protocols have been developed to inform the models with appropriate properties measured on heterogeneous rock samples in the laboratory.

To address the impacts of small scale heterogeneity on large scale flow and trapping of CO_2, we present a combined experimental and numerical study on rock cores from the Bunter and Captain sandstone formations. We analyse 38 small rock cores covering the entire 100m interval of the Captain D reservoir unit in the Northern North Sea, and a smaller selection of cores taken from the Bunter Sandstone in the Southern North Sea. We use a recently developed characterisation approach [9] to create a 3D numerical model of heterogeneous rock cores, based on laboratory observations. We incorporate hysteresis into the characterisation by building on the recent approach developed by [10]. Once characterised, the numerical cores can accurately predict equivalent relative permeabilties and trapping, dependent on the capillary number and direction of fluid flow.

The numerical models are then used to investigate multiphase flow hysteresis and trapping across the range of conditions estimated to prevail in the CO_2 storage reservoirs. Under these conditions, we systematically explore the impact of hysteresis and heterogeneity on flow and trapping at multiple scales. The migration of CO_2 may be significantly enhanced by heterogeneity when flow can align with the direction of layers. This situation may arise in gravity currents of plumes underneath a confining caprock layer. In contrast, flow is impeded by heterogeneity when the dominant direction crosses bedding layers, as may occur in predominantly upward buoyantly driven migration. In this case, the lowered mobility results in significant spreading of the plume and residual trapping is also enhanced.

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