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Advanced computational multi-fluid dynamics: a new model for understanding electrokinetic phenomena in porous media

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We present results from a new computational multi-fluid dynamics code, designed to model the transport of heat, mass and chemical species during flow of single or multiple immiscible fluid phases through porous media, including gravitational effects and compressibility. The model also captures the electrical phenomena which may arise through electrokinetic, electrochemical and electrothermal coupling. Building on the advanced computational technology of the Imperial College Ocean Model, this new development leads the way towards a complex multiphase code using arbitrary unstructured and adaptive meshes, and domains decomposed to run in parallel over a cluster of workstations or a dedicated parallel computer. These facilities will allow efficient and accurate modelling of multiphase flows which capture large- and small-scale transport phenomena, while preserving the important geology and/or surface topology to make the results physically meaningful and realistic.

Applications include modelling of contaminant transport in aquifers, multiphase flow during hydrocarbon production, migration of carbon dioxide during sequestration, and evaluation of the design and safety of nuclear reactors. Simulations of the streaming potential resulting from multiphase flow in laboratory- and field-scale models demonstrate that streaming potential signals originate at fluid fronts, and at geologic boundaries where fluid saturation changes. This suggests that downhole measurements of streaming potential may be used to inform production strategies in oil and gas reservoirs. As water encroaches on an oil production well, the streaming-potential signal associated with the water front encompasses the well even when the front is up to 100 m away, so the potential measured at the well starts to change significantly relative to a distant reference electrode. Variations in the geometry of the encroaching water front could be characterized using an array of electrodes positioned along the well, but a good understanding of the local reservoir geology will be required to identify signals caused by the front. The streaming potential measured at a well will be maximized in low-permeability reservoirs produced at a high rate, and in thick reservoirs with low shale content.