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Forchheimer gravity currents in porous media

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The displacement of one fluid by another in porous media is of interest in reservoir engineering, groundwater remediation, and subsurface heat recovery. In several instances, i.e. in coarse or macro porous media, or in heavily fractured rocks, the threshold Reynolds number is exceeded and inertial effects cannot be neglected. Consequently, the Forchheimer extension of Darcy's law describes the motion, and a novel quantity, the Forchheimer or inertial coefficient, enters the picture, entailing implications on several coupled phenomena. We study plane gravity currents propagating in a homogeneous porous medium of given permeability saturated with a lighter fluid, but results are also valid for the displacement of a heavier ambient fluid (brine) by a lighter one advancing below the roof of a porous layer such as in CO_2 injection. The injected fluid volume is given by a global conservation of mass and varies as a power-law function of time. Under the lubrication approximation, the pressure gradient is hydrostatic and the one-dimensional transient problem governing the current depth, when expressed in dimensionless form, depends uniquely by a pure number equal to the combination of a Reynolds number multiplied by a Forchheimer number and divided by the square of a densimetric Froude number. We explore the two limit cases of dominating inertial effects or prevailing viscous effects and demonstrate that in both cases the governing equations are amenable to a semi-analytic similarity solution governed by the aforementioned pure number. For a current with constant volume, the solution takes a closed form.