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Two-Phase Flow Displacement Morphologies in Cohesive Granular Media

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Multiphase flow in granular materials is intricate and subject to pattern formation resulting from the interplay between hydrodynamic and mechanical forces. While considerable effort has been devoted to studying systems with cohesionless grains, our understanding of the two-phase flow behavior through the cohesive counterpart held together by intergranular bonds is limited. Herein, we study the novel coupling between viscously unstable fluid-fluid displacement and bonded-grain deformation in a synthetic cohesive granular pack. We experimentally inject a low-viscosity fluid into a monolayer of cohesion-tuneable bonded glass beads that are initially saturated with a more-viscous fluid, with injection capillary numbers and cohesion levels varying among experiments. We map out a first-ever phase diagram showing displacement patterns transitioning from deformation-dominated fracturing with bond breakage to infiltration-dominated viscous fingering without grain motion as cohesion increases. Strikingly, we find that peak injection pressure exhibits a non-monotonic trend with increasing cohesiveness. The injection pressure reaches maximum when fracturing is favored against infiltration while begins to drop due to the regime transition irrespective of the increasing cohesion. Furthermore, we characterize the onset of fracturing via dimensional analysis, effectively capturing the transition based on the balance between viscous and cohesive forces. Our findings shed light on the multiphase flow behavior within cohesive materials which is fundamental in various subsurface technologies such as carbon geostorage, oil/gas recovery, and groundwater remediation.

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