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Pore-scale simulation of dissolution-induced variations in rock mechanical properties

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ABSTRACT

Reactive transport is simulated on rock geometries to explore the variation of mechanical properties of porous media. A numerical framework is developed to model reactive transport in sandstones and carbonates. Fluid flow, solute transport and chemical reactions are simulated directly on micro-CT images. Porosity profiles along the flow direction are computed during the dissolution to describe the change in the pore structures. Stress load cases on porous media are simulated and maps of deformation in the rocks are compared. Uniform deformation is observed in high Péclet regimes. Young's modulus and Poisson's ratio are calculated separately for a range of Péclet and Damköhler regimes. The findings show that mechanical properties in low Péclet regimes are more sensitive to porosity variations. For the same reaction regime, carbonates present a lower decrease in Young's modulus after reactions but a higher decline in Poisson's ratio in comparison with sandstones. This work reveals the strong dependency of mechanical properties on Péclet and Damköhler regimes in reactive transport.

1. Introduction

Numerical studies of reactive transport in porous media is of importance in several applications including sequestration of carbon dioxide, remediation of nuclear wastes, fuel cell developments, transport of contaminants in soil and acid injection to reduce skin factor around wellbores. In the subsurface environments, chemical reactions occur at the surface of minerals as the reactive fluid flows through the rocks [1]. It can lead to significant alteration of the pore structures affecting hydrological and mechanical properties of the reservoir rocks [2].

Reactive transport is governed by advection, diffusion and chemical reaction. These mechanisms are characterised by two dimensionless numbers, Péclet and Damköhler numbers [3]. Péclet number compares the strength of advection to that of diffusion while Damköhler number is the ratio of reaction rate to molecular diffusion. A large collection of numerical methods have been developed to simulate flow, transport and reaction in porous media [1,3–10]. The effect of Péclet and Damköhler numbers on hydrological properties during reactive transport has been investigated for several applications [2,3,11–15]. A comprehensive review of reactive transport models is provided in Yoon et al. [16]. More recently, Mostaghimi et al. [4] applied a pore scale model to investigate reactions in reservoir rocks with different degrees of heterogeneity. They performed numerical simulations in regimes of different Péclet and Damköhler numbers. Their results illustrated the impact of the geometrical heterogeneity on permeability variations. Alhashmi et al. [17] applied a fluid-fluid reaction model to explore the effect of pore structure on the average reaction rates. Reactive flow was simulated in three types of porous media for a range of flow conditions. They found that the effective reaction rate has strong dependency on the pore structure. Liu and Mostaghimi [18] combined lattice Boltzmann and finite volume methods to explore the impact of mineralogical heterogeneity on reactive transport. Simulations were performed in sandstones containing eight different minerals. They compared multi-mineral simulations with the single mineral simulation results. They found that mineralogical heterogeneity can lead to large discrepancy in determination of the reaction regimes.

However, very limited number of studies has focused on the effect of reactions on the mechanical properties of porous media. In reactive transport, porosity and pore structure change due to reaction. This results in significant variations in mechanical properties of the porous media [19,20]. One of the main applications is the wellbore stability problem during acid stimulation. The effective Young's modulus decreases as dissolution occurs in the rocks. This may lead to rock failure and increase the risk of wellbore collapse [21]. Another example is the risk of carbon dioxide

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sequestration in reservoirs. An acidic solution is formed as carbon dioxide is dissolved into the formation brine [22]. The acid reacts with the host rocks and reduces their mechanical strength. It may cause the leakage of carbon dioxide from the subsurface reservoirs [23]. Hence, it is crucial to understand the effect of reactive flow on rock mechanical properties.

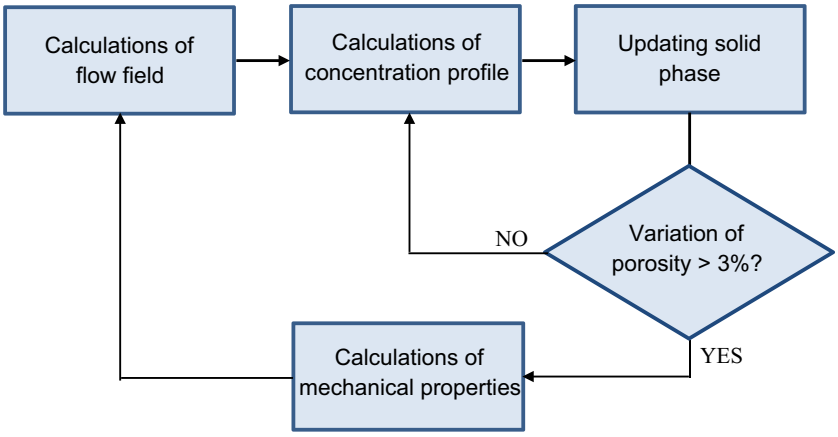

Fig. 1. The flowchart for numerical simulation of reaction and mechanical properties.

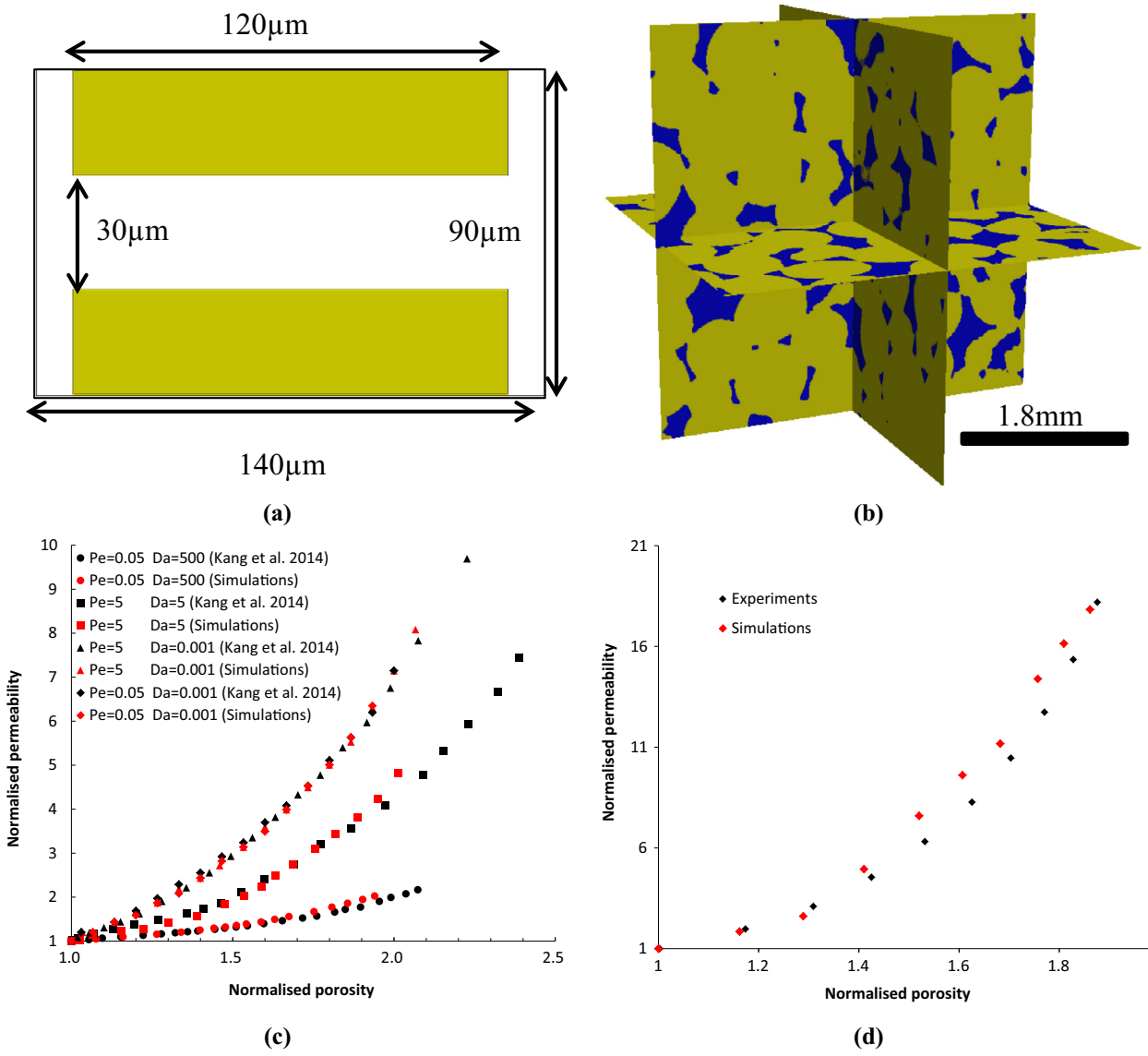

Fig. 2. (a) The geometry of the fractured medium; (b) 3D orthogonal slices of the Ketton carbonate; (c) comparison of permeability-porosity relationships with Kang et al. [15]; (d) comparison of permeability variations with dynamic imaging experiments of Menke et al. [22].