A Mixed-dimensional Discontinuous Galerkin Method for Coupled Flow and Transport in Fractured Porous Media

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Publication date:
2019

Document Version
Publisher's PDF, also known as Version of record

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Several hydrocarbon production wells in the North Sea reservoirs suffer from productivity reduction during primary production. Since the affected reservoirs are highly fractured, closure of natural/induced fractures around wells, due to an increase in effective stress is expected to be one of the main reasons for this reduction. Traditionally, the fracture conductivity is determined by its aperture through a cubic law 1. While the fracture aperture is commonly assumed either constant or uniformly distributed, it is well-known that the aperture distribution is heterogeneous and changes with varying contact stress at each point on the fracture surface. This heterogeneous aperture field can affect the flow performance, and fracture aperture evolution due to thermo-poroelastic stresses 2. Moreover, variance, prior distribution, and correlation length, which are used to populate the heterogeneous field, can further enhance this effect 3. Hence, this study aims to investigate and highlight the impacts of fracture aperture variation, including initial stage and deformed behaviour, on the well productivity through a conceptual steady-state single-fracture reservoir.

Coupled solid deformation and fluid flow in porous media is modelled utilising Complex Systems Modelling Platform (CSMP), an object-oriented application programme interface [4], 5. The investigation is separated into three main parts: (i) the effect of variance, (ii) the effect of prior distribution length, and (iii) the effect of correlation length/angle on well productivity index. Moreover, the comparison among the calculation of the well productivity using the homogeneous, heterogeneity aperture field, and its arithmetic average is also investigated. Taking into consideration the limitations and assumptions made in this study, the following findings are drawn: (i) well productivity tends to be higher when the heterogeneity aperture field is introduced than the homogeneous and arithmetic average ones, (ii) this effect is enhanced when the variance is increased, (iii) there is not much difference between the well productivity results when different prior distributions, i.e. uniform, normal, and log-normal distributions, are utilised, (iv) the increase in the correlation length that perpendicular to the well direction enhances the productivity of the system, and (v) the increase in the correlation length that parallel to the well direction hinders the productivity of the system.

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Fluid flow and solute transport in fractured porous media are phenomena that control key processes in groundwater monitoring, generating thermal energy, earthquake prediction, and biomedical engineering, e.g. model activities of the heart or brain from noninvasive measurements on the chest or scalp. The mathematical representation of the fluid interaction between fracture and rock matrix domains is not straightforward because these two domains usually possess vastly different flow properties. For instance, fluid conductivity through a system of fractures can be much greater than that of the rock matrix. To tackle this issue, there are three main approaches, (i) equidimensional, (ii) mixed-dimensional representing fractures as split surfaces, and (iii) mixed-dimensional representing fractures as internal walls [1, 2]. The first method demands excessively refinement of the fracture domain, more computationally burdens, while the second method requires a sophisticated contact model when mechanical deformation is included in the model 3. Hence, the third method is selected in this study because of its favourable computational cost and straightforward implementation when it is incorporated more phenomena.

Researchers have traditionally used the continuous Galerkin (CG) method to solve flow and transport in fractured porous media problems for decades. However, it is not suitable for solving the transport equation because it may not satisfy mass conservation. Moreover, it cannot represent fractures that act as flow barriers [4]. This study aims to present the advantages of using the discontinuous Galerkin (DG) method for solving coupled flow and transport in fractured porous media. A mixed $DG \times CG$ space is utilised to solve the pressure equation. Subsequently, a velocity field is established using CG or $Raviet - Thomas$ function space; then the transport equation is solved on DG space. This procedure provides more accurate solutions in a convection-dominated regime, in which a sharp flood-front of the tracer is established, than those of CG formulation. The result of this work is compared to relatively new numerical methods, including hybrid-finite-element-finite-volume, lowest order Raviart-Thomas mixed finite elements, and multi-Point flux approximation methods as part of "Verification benchmarks for single-phase flow in three-dimensional fractured porous media [4, 5, 6]."

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Atomistic Simulation of the Adsorption and Transport of Naturally Occurring Radioactive Materials in Clay Nanopores in the Context of Shale Gas Exploration

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