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Original article

Numerical simulation of two-phase flow in deformable porous media: Application to carbon dioxide storage in the subsurface

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Abstract

In this paper, conceptual modeling as well as numerical simulation of two-phase flow in deep, deformable geological formations induced by CO_2 injection are presented. The conceptual approach is based on balance equations for mass, momentum and energy completed by appropriate constitutive relations for the fluid phases as well as the solid matrix. Within the context of the primary effects under consideration, the fluid motion will be expressed by the extended Darcy's law for two phase flow. Additionally, constraint conditions for the partial saturations and the pressure fractions of carbon dioxide and brine are defined. To characterize the stress state in the solid matrix, the effective stress principle is applied. Furthermore, the interaction of fluid and solid phases is illustrated by constitutive models for capillary pressure, porosity and permeability as functions of saturation. Based on this conceptual model, a coupled system of nonlinear differential equations for two-phase flow in a deformable porous matrix (H^2M model) is formulated. As the displacement vector acts as primary variable for the solid matrix, multiphase flow is simulated using both pressure/pressure or pressure/saturation formulations. An object-oriented finite element method is used to solve the multi-field problem numerically. The capabilities of the model and the numerical tools to treat complex processes during CO_2 sequestration are demonstrated on three benchmark examples: (1) a 1-D case to investigate the influence of variable fluid properties, (2) 2-D vertical axi-symmetric cross-section to study the interaction between hydraulic and deformation processes, and (3) 3-D to test the stability and computational costs of the H^2M model for real applications.

Keywords: Porous media; Two-phase flow consolidation; Heat transport; Carbon capture storage (CCS); OpenGeoSys (OGS)

1. Introduction

For about two decades, most of the earth's inhabitants have been experiencing increase in the average temperature in their living environment. Although there are different opinions, most of environmental scientists believe that global

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