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Unconditionally Stable Sequential Schemes for All-way Coupled Thermoporomechanics: Undrained-Adiabatic and Extended Fixed-Stress Splits

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Abstract

We propose two sequential methods for the all-way coupled thermoporomechanical problems: the undrained-adiabatic split that combines together the undrained and adiabatic methods of poromechanics and thermomechanics, respectively, and the extended fixed-stress split. We perform nonlinear stability analysis for the two sequential methods, introducing a new extended norm that can encompass the all-way coupled thermoporomechanical problems. We find that the two sequential methods are unconditionally stable if $\alpha \geq 0.5$, where α is the parameter of time discretization for the generalized midpoint rule at $t_{n+\alpha}$. We also perform the spectral analysis in order to further investigate stability and convergence of the two methods. The spectral analysis shows unconditional stability of the two sequential methods, which yields the magnitudes of the amplification factor less than unity. We then show numerical examples, which support the a priori stability and convergence estimates.

Keywords: Thermoporomechanics, Sequential Scheme, Stability analysis, Unconditional stability

1. Introduction

Coupled heat, fluid flow, and mechanics, called thermoporomechanics, are currently of much interest in many areas of geosciences and reservoir engineering to model complex physics. For example, in geothermal engineering, heat energy is delivered to flowing fluid, which transports heat to the surface facilities by fluid production [1]. Heat increases fluid temperature, which changes pore-pressure and other physical variables such as fluid phases. In turn, the changes in pore-pressure or temperature affect stress of the porous media, which causes deformation and surface subsidence [2, 3]. In the gas hydrate bearing sediments, changes in stress and temperature fields influence gas hydrate formation or dissociation. This might cause well instability or possible methane emission to the surface due to geological failure [4, 5]. In the case of in-situ conversion and steam injection for heavy oil production, thermal behavior plays a critical role in hydrocarbon production. Freezing the boundary walls and injecting heat to the production wells may cause substantial surface subsidence, which can support the reservoir pressure by compaction. The changes in stress and strain fields induce different fluid-heat flow regimes.

Nuclear waste disposal to the underground requires accurate modeling of thermoporomechanics [6]. Radioactive materials generate heat, which can perturb an initial stable condition, causing fluid flow or reservoir deformation.

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