Journal of Computational Physics 543 (2025) 114406

Contents lists available at ScienceDirect

Journal of Computational Physics

journal homepage: www.elsevier.com/locate/jcp

Fixed-stress sequential schemes for a black-oil model in poroelastic media

Maicon R. Correa [a], Marcio A. Murad [b,*]

[a] Departamento de Matemática Aplicada, Universidade Estadual de Campinas (UNICAMP), IMECC, Campinas, SP, Brazil
[b] Laboratório Nacional de Computação Científica (LNCC-MCTI), Brazil

ARTICLE INFO

Keywords:
Black-oil
Poroelasticity
Fixed stress sequential scheme
Mixed finite elements
Central-upwind finite volume
Undrained response

ABSTRACT

We propose a new computational model for solving the Black-Oil flow model, incorporating geomechanical coupling within the framework of the fixed-stress-split scheme. The extended flow equations describing the movement of two slightly compressible liquids and a highly compressible gas are recast in terms of multiphase–multicomponent flow. Here, we construct a nonlinear extension of the fixed-stress split proposed in earlier work (Correa and Murad, J. Comput. Phys. v.373, pp. 493-532, 2018), which also allows for the compressibility of the liquid phases, dissolution of the gas in the oil phase, and gas phase appearance and disappearance. Flow and transport subsystems are rephrased in terms of compositions, and two alternative sequential coupling strategies at different levels are introduced to link the flow/transport and mechanics subsystems. These strategies incorporate a suitable definition of a trusted saturation variable within the flow equations, ensuring the full resolution of a three-equation system of conservation laws for the compositions and thereby enhancing the overall stability and accuracy of the proposed scheme. Flow and mechanics subsystems are discretized by mixed finite element formulations, whereas the transport system is solved by an innovative semi-discrete central-upwind finite volume scheme for hyperbolic conservation laws, capable of capturing spatial and temporal variability in the Lagrangian porosity and also obviating the need to adopt operator-splitting schemes for the storativity in the transport equations. The innovative numerical model clearly demonstrates its ability to capture the intricate interaction between geomechanical effects and phase change in the vicinity of the bubble point. Numerical experiments are performed, including an undrained setting upon cyclic loading and water-flooding problems, illustrating precisely the influence of the bubble point pressure upon the evolution of the poromechanical variables and hydrocarbon production.

1. Introduction

In many geoengineering applications, the challenge of performing fluid withdrawal technologies in geologically complex formations, where petrophysical properties may change dynamically during fluid movement due to deformation, has been the turning point for incorporating reservoir geomechanics in flow simulators [1–3]. In particular, in the context of hydrocarbon exploration in deep waters, complex challenges involving the presence of strong discontinuities, such as faults and fractures, highly susceptible to damage, activation, and closure, have driven the pursuit of developing a more robust hydro-mechanical computational model that couples multi-phase flow and geomechanics and, consequently, for supporting the decision-making process. In this highly complex scenario,

* Corresponding author.
E-mail addresses: maicon@ime.unicamp.br (M.R. Correa), murad@lncc.br (M.A. Murad).

https://doi.org/10.1016/j.jcp.2025.114406
Received 1 December 2023; Received in revised form 14 September 2025; Accepted 23 September 2025
Available online 27 September 2025