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ScienceDirect
Energy Procedia 4 (2011) 3801–3808
Energy Procedia
www.elsevier.com/locate/procedia

Field-case simulation of CO_2-plume migration using vertical-equilibrium models

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Abstract

When injected in deep saline aquifers, CO_2 moves radially away from the injection well and progressively higher in the formation because of buoyancy forces. Analyzes have shown that after the injection period, CO_2 will potentially migrate over several kilometers in the horizontal direction but only tens of meters in the vertical direction, limited by the aquifer caprock [1, 2]. Because of the large horizontal plume dimensions, three-dimensional numerical simulations of the plume migration over long periods of time are computationally intensive. Thus, to get results within a reasonable time frame, one is typically forced to use coarse meshes and long time steps which result in inaccurate results because of numerical errors in resolving the plume tip.

Given the large aspect ratio between the vertical and horizontal plume dimensions, it is reasonable to approximate the CO_2 migration using vertically averaged models. Such models can, in many cases, be more accurate than coarse three-dimensional computations. In particular, models based on vertical equilibrium (VE) [3] are attractive to simulate the long-term fate of CO_2 sequestered into deep saline aquifers. The reduced spatial dimensionality resulting from the vertical integration ensures that the computational performance of VE models exceeds the performance of standard three-dimensional models. Thus, VE models are suitable to study the long-time and large-scale behavior of plumes in real large-scale CO_2-injection projects [4, 1, 2, 5]. We investigate the use of VE models to simulate CO_2 migration in a real large-scale field case based on data from the Sleipner site in the North Sea. We discuss the potential and limitations of VE models and show how VE models can be used to give reliable estimates of long-term CO_2 migration. In particular, we focus on a VE formulation that incorporates the aquifer geometry and heterogeneity, and that considers the effects of hydrodynamic and residual trapping. We compare the results of VE simulations with standard reservoir simulation tools on test cases and discuss their advantages and limitations and show how, provided that certain conditions are met, they can be used to give reliable estimates of long-term CO_2 migration.

1. Introduction

Carbon capture and storage (CCS) is a promising technology for reducing CO_2 emissions to the atmosphere. To become an effective part of the solution to the climate problem, CCS technology will have to be applied at a very large scale to store a significant part of the increasing CO_2 emissions [6]. CO_2 injection into deep saline aquifers would provide large volumes to store CO_2. Investigations of the risk of CO_2 leakage from the aquifers will require simulations that consider large temporal and spatial scales and because of the inherent uncertainty of geological characterizations, simulation of multiple realizations of a given storage scenario will be required for risk analysis. This is the main motivation for the development of fast simulation tools.

The CO_2–brine system is simpler than the fluid system used in the oil industry, where black-oil or component-based formulations are standard. In particular, it is expected that at typical injection conditions, strong gravity segregation will occur over relatively short time-scales because of the large density differences between the resident brine and the injected supercritical CO_2. This feature of the flow system can be used to develop fast simulation tools particularly tuned for simulating the long-term migration of the injected CO_2.

Models based on a vertical equilibrium (VE) assumption have been used for long time to describe flow in porous media. Dupuit's approximation, which is commonly used in groundwater hydrology, is an example of this kind of models. In the oil industry, VE models were extended during the 50's and 60's to simulate two-phase and

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doi:10.1016/j.egypro.2011.02.315