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Storage capacity enhancement and reservoir management using water extraction: Four site case studies

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ABSTRACT

Water extraction from carbon dioxide (CO_2) storage reservoirs may be a method to enhance storage capacity and to actively manage storage reservoirs. Previous investigations into the use of water extraction have utilized homogeneous models to assess the feasibility of this technology. This study addressed water extraction based on four hypothetical CO_2 storage sites, which varied with respect to heterogeneous lithology, variable structure, and complex internal geometry. The simulation results showed the increased CO_2 storage capacity achieved through the use of water extraction varies greatly based on site conditions, ranging from 4% to 1300% in the four cases investigated. In all scenarios, water extraction reduced the maximum reservoir pressures approximately 10–20% during injection. In most scenarios, CO_2 plume movement could also be influenced through the use of water extraction. The last two aspects may be very beneficial for risk management and monitoring, verification, and accounting practices for all of the CO_2 storage projects.

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1. Introduction

Carbon capture and storage (CCS) is a technology to reduce carbon dioxide (CO_2) emissions to the atmosphere by storing large quantities of CO_2 in deep geologic reservoirs. Several geological options for CCS have been considered, including coal beds (White et al., 2005; Liu and Smirnov, 2007, 2008), depleted oil/gas reservoirs (Shaw and Bachu, 2002; Kovscek, 2002; Flett et al., 2005), and deep saline formations (DSFs) (Bachu and Adams, 2003; Kumar et al., 2005; Holloway et al., 2004; Liu, 2012). DSFs are the largest potential CO_2 storage resources and have received increased attention in recent years. According to the Intergovernmental Panel on Climate Change (IPCC) report, the lower estimate of storage capacity in DSFs is 1000 Gt of CO_2, which is far greater than estimations for oil and gas fields and unminable coal seams (Metz et al., 2005). Therefore, the utilization of DSFs plays a crucial role in successfully implementing the scale-up of storage from pilot and demonstration projects to commercial operations. Deep saline water extraction from CO_2 storage formations has been proposed as one potential method to enhance CO_2 storage, manage reservoir pressure, and alter CO_2 plume movement (Buscheck et al., 2010; Celia and Bachu, 2003; Hosseini and Nicot, 2012; Eke et al., 2011; Burtin and Bryant, 2009; IEA Greenhouse Gas R&D Programme, 2009, IEAGHG, 2014; Saini et al., 2013; Gorecki et al., 2013).

Most publications have demonstrated the basic concept of water extraction from a CO_2 storage reservoir based on reservoir simulations of idealized geologic models (Buscheck et al., 2010; Hosseini and Nicot, 2012; Eke et al., 2011; Burtin and Bryant, 2009). For example, Buscheck et al. (2010) modeled the effects of water extraction on CO_2 storage by comparing the results with and without water extraction to an idealized system. Their conclusions indicate that water extraction may be effective for CO_2 plume manipulation and reduction of pressure buildup based on an assumed 1:1 ratio of water extraction to CO_2 injection (Buscheck et al., 2010). In addition, the thermal footprint area, thermal drawdown, and cumulative CO_2 storage were investigated based on 5-, 12-, and 16-well patterns over various time periods and well spacings for CO_2 injection and water production (Buscheck et al., 2010). Hosseini and Nicot (2012) developed an analytical system to test the injectivity impacts and pressure reduction gains through brine extraction from CO_2 storage reservoirs and reinjection into shallower reservoirs based on a generic model. Most of the studies do not include any heterogeneity effects or reflect real field structures or conditions, nor do they aim to optimize strategies related to injection and extraction. Therefore, more questions related to the capacity and injectivity of DSFs, especially pressure behavior, CO_2 plume

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movement, and extraction rates, remain. Additional research is needed that takes into account the real/potential CO_2 storage site structure and geologic properties with various optimization scenarios for injection and production wells (IEA Greenhouse Gas R&D Programme, 2012), ultimately estimating CO_2 storage capacity dynamically with consideration of injectivity and reservoir pressure interference through the use of reservoir simulation. As a result, this study was undertaken to investigate (1) how much CO_2 storage capacity can be increased by implementing water extraction; (2) how reservoir pressure buildup varies under different reservoir conditions, including geologic heterogeneity structures, and fluid properties; (3) the effects on the CO_2 plume movement with water extraction; and (4) how injection and extraction scenarios can be optimized (IEA Greenhouse Gas R&D Programme, 2012; Liu et al., 2013; Klapperich et al., 2013; Saini et al., 2013).

In this study, four CO_2 storage sites were selected: the Ketzin project site in Germany, the Zama oil field in Canada, the Gorgon project site in Australia, and the Teapot Dome oil field in the United States, as shown in Fig. 1 (IEA Greenhouse Gas R&D Programme, 2012). These sites represent offshore and onshore cases with pilot- and commercial-scale plans and differing formation water qualities, injectivities, climates, and beneficial water use opportunities. The following describes the methods employed, case studies by site, and conclusions for the entire investigation.

2. Method

To achieve the goal of understanding reservoir dynamics for CO_2 storage with water extraction, four “idealized” real-world storage sites were selected and modeled. Selected sites were chosen to represent a range of reservoir types that could be used for commercial-scale CO_2 storage targets. Another goal of the study, not discussed in this paper, was to assess the utility of extracted water as a resource at these sites. Therefore, factors such as regional climate and water quality were also taken into consideration when identifying possible sites. The selected sites represent a range of geologic and geophysical conditions as well as variations in their climates and regional water demands. The quality of the reservoir water also varied substantially among the four sites. These properties are summarized in Table 1.

Geologically, the sites represent both traditional clastic reservoir environments (Ketzin, Teapot Dome, and Gorgon) and carbonate reservoir systems (Zama). Structurally speaking, domes (Ketzin and Teapot Dome), anticlines (Gorgon), and reef structures (Zama) are represented by the sites. Water quality ranged from nearly fresh at Teapot Dome to concentrated brine (>180,000) at Zama and Ketzin. Additional variability was achieved in terms of climate and regional water stress. Sites ranged in climate from arid (Gorgon) to temperate (Ketzin), with regional water supply ranging from high regional water stress (Teapot Dome and Gorgan) to low regional water stress (Ketzin).

In addition to testing various behaviors of injected CO_2 in heterogeneous reservoirs within structures in response to injection and extraction designs, different sites enabled specific testing of other operational aspects. Specifically;

- For the Ketzin model we tested open vs. closed boundary conditions and the effect of adding more injection and production wells.
- The Zama model tested injection and production rates from a small, closed structure in order to maximize storage.
- The Gorgon model tested injection and production rates for a reservoir with very large capacity, and how water extraction behaves when pressure maintenance is not necessary, and also how the reservoir behaves under a much larger injection.
- The Teapot Dome model tested different combinations of injectors and producers, and also the use of horizontal wells.

CO_2 storage capacity estimates in this study are based on a dynamic evaluation that takes into account geologic heterogeneity, reservoir pressure interference, well configuration, injectivity/productivity, and boundary condition. The effect of water extraction on dynamic storage capacity was investigated by adding and varying number of water extraction wells and CO_2 injection wells. This is typically accomplished by constructing geocellular models of the injection volume and running numerical simulations. The pressure and CO_2 plume movement are estimated based on the simulation results.

3D geocellular models were developed for each study site and populated with data related to porosity, permeability, structure, lithology, formation water quality, temperature, and pressure by using a deterministic model populated with geostatistically simulated data to produce one realization per site representing the P_{50} case (Schlumberger, 2012). Heterogeneities of these sites were assigned according to variogram ranges attributed to depositional environments from GSLIB (Deutsch and Journel, 1998). The lack of input data did not provide enough variation to create multiple realizations without performing detailed petrophysical analysis, which was beyond the scope of this work. Multiple realizations were attempted, however, by only changing the seed number on the geostatistical property simulation. These results did not provide significant change in the geologic model, and results were near identical when ranked in an attempt to reduce geologic uncertainty. The Ketzin and Gorgon sites were modeled following published methodologies for the two sites, which included a combination of object modeling and truncated Gaussian simulation processes (Court et al., 2010; Klapperich et al., 2013; Fleury et al., 2010; Schilling et al., 2009; CO2CRC Technologies Pty Ltd., 2008, 2009). Teapot Dome utilized over 1200 well tops from the field which were used to identify and model the structure of different horizons. The Zama Field pinnacle reefs contain complex internal geometry and variable structure. These systems were modeled using a combination of object modeling and multipoint statistics using an interpreted reef structural diagram as a training image. The facies model was populated with site-specific heterogeneity and properties developed through Plains CO_2 Reduction (PCOR) Partnership characterization activities. It is important to note that two of the selected sites (Zama and Teapot Dome) are depleted oil and gas reservoirs and, as such, are likely to contain varying concentrations of hydrocarbons, which may increase overall treatment costs and/or limit the potential for beneficial use. However, the authors have chosen to use these sites as analogs for similar saline formations in lieu of adequately described formations for the purposes of storage capacity calculations by water extraction.

A compositional reservoir simulator was used for all dynamic modeling and simulations (Computer Modelling Group, 2014a). All scenarios/simulations were run under isothermal conditions with negligible geomechanical behaviors, limited by the maximum cap rock pressure for cap rocks of each respective site. All of the geologic information and modeling parameters, including residual saturations, capillary pressure, relative permeability curves, boundary conditions, and initial reservoir pressure for each site, were derived from published material. If specific data elements were not available from publications, the parameters were referenced from similar reservoir types within the Average Global Database (IEA Greenhouse Gas R&D Programme, 2009).

Evaluation of fluids and flow was limited to formation water, CO_2, and various compositions of CO_2 dissolved in the formation water. The properties of fluids in models for the four sites were generated by the phase behavior and fluid property

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