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Geothermal energy production coupled with CCS: a field demonstration at the SECARB Cranfield Site, Cranfield, Mississippi, USA

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Abstract

A major global research and development effort is underway to commercialize carbon capture and storage (CCS) as a method to mitigate climate change. Recent studies have shown the potential to couple CCS with geothermal energy extraction using supercritical CO_2 ($ScCO_2$) as the working fluid. In a geothermal reservoir, the working fluid produces electricity as a byproduct of the CCS process by mining heat out of a reservoir as it is circulated between injector and producer wells. While $ScCO_2$ has lower heat capacity than water, its lower viscosity more than compensates by providing for greater fluid mobility. Furthermore, CO_2 exhibits high expansivity and compressibility, which can both help reduce parasitic loads in fluid cycling. Given the high capital costs for developing the deep well infrastructure for geologic storage of CO_2, the potential to simultaneously produce geothermal energy is an attractive method to offset some of the costs and added energy requirements for separating and transporting the waste CO_2 stream.

We present here the preliminary design and reservoir engineering associated with the development of direct-fired turbomachinery for pilot-scale deployment at the SECARB Cranfield Phase III CO_2 Storage Project, in Cranfield, Mississippi, U.S.A. The pilot-scale deployment leverages the prior investment in the Cranfield Phase III research site, providing the first ever opportunity to acquire combined CO_2 storage/geothermal energy extraction data necessary to address the uncertainties involved in this novel technique. At the SECARB Cranfield Site, our target reservoir, the Tuscaloosa Formation, lies at a depth of 3.0 km, and an initial temperature of 127 °C. A CO_2 injector well and two existing observation wells are ideally suited for establishing a CO_2 thermosiphon and monitoring the thermal and pressure evolution of the well-pair on a timescale that can help validate coupled models. It is hoped that this initial demonstration on a pre-commercial scale can accelerate commercialization of combined CCS/geothermal energy extraction by removing uncertainties in system modeling.

Keywords: geothermal systems; carbon dioxide; carbon sequestration;

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1. Introduction

The objective of our research effort is to demonstrate coupled CO_2 sequestration with geothermal energy production to validate reservoir/power plant models, which can be used in the design and operation of commercial scale systems. To accomplish this objective we have undertaken a program in which we have (1) developed a coupled reservoir-wellbore model which contains key thermophysical processes needed to accurately capture subsurface behavior, (2) designed an optimal power plant for harnessing the energy from geothermally heated CO_2, and (3) plan to fabricate and operate the geothermal heat recovery engine at the Southeast Regional Carbon Sequestration Partnership (SECARB) Cranfield CO_2 storage field site to validate the coupled models that have been developed.

Brown first proposed the novel use of CO_2 as a working fluid for geothermal energy extraction, citing CO_2's greater expansivity and compressibility as compared to water, resulting in lower parasitic energy losses, its lower viscosity, which more than offsets its reduced heat capacity in improving heat mining efficacy, and its reduced geochemical reactions with minerals, avoiding many of the scaling and pore plugging issues associated with circulating water [1]. Pruess investigated the detailed hydrological and thermodynamic behavior of a CO_2/geothermal system within a reservoir that is part of a 5-spot well pattern [2,3]. His research further identified beneficial pressure/temperature conditions for CO_2 heat extraction, but the model considered only a highly simplified wellbore under isenthalpic and gravitationally stable conditions. While he conjectured that the natural thermosiphon would reduce parasitic loads, his model did not have the requisite wellbore physics to quantify what that reduction might be.

Atrens et al [4–6] considered a coupled wellbore reservoir model, making several simplifying assumptions that we have relaxed in our modeling effort. They considered a highly simplified reservoir model wherein Darcy flow is along a single streampath and temperature increase occurs as a fixed linear function of distance from injector well to producer. While they do consider frictional losses within the wellbore, fluid flow within them is still considered isentropic, ignoring heat transfer with the formation.

Our approach uses a generalized wellbore-reservoir model T2WELL[7], which relaxes many of the simplifying assumptions mentioned previously. It is based on the integral finite difference heat and mass transport simulator TOUGH2 which can incorporate complex flow geometries and heterogeneous porous media[8]. Using the appropriate thermodynamic equations of state, it incorporates the behavior of CO_2, CH_4, and brine systems permitting generalized heat and mass transport numerical simulations while ensuring complete adherence to mass and energy balance constraints.

We propose to use the SECARB Cranfield Site in Cranfield, Mississippi, USA, as the field demonstration location for initial testing of our heat engine because of the significant knowledge base gained during a Regional Carbon Sequestration Phase III demonstration program and the existing infrastructure [9-11]. At the site of the Cranfield Detailed Area Study (DAS) there are three existing deep wells completed in the Tuscaloosa Sandstone to a depth of 3.1 km. CO_2 injection commenced at the Cranifeld DAS Site in the CFU-31F1 well in December 2009 and the nearby CFU-31F2 and CFU-31F3 with offsets of ~70 m and ~100 m respectively were used to perform time-lapse geochemical and geophysical monitoring of the evolution of the CO_2 plume. The reservoir has been under a nearly continuous CO_2 flood, ensuring that water is at or near residual conditions and that the reservoir is for the purposes of our geothermal test dry. Given that the timescale for our project will only permit a few months of field testing, we plan to continue to use the CFU-31F1 well as an injector with the CFU-31F3 well as a producer. The modeling we have performed indicates that the ~100 m separation will allow pressure and temperature transients associated with the injection and withdrawal of CO_2 to settle down quickly, allowing us to obtain a practical dataset for performing model validation.