Engineering Geology 196 (2015) 194–209

Contents lists available at ScienceDirect

Engineering Geology

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

Interaction analysis for CO_2 geological storage and underground coal mining in Ordos Basin, China

Wen Bin Fei, Qi Li *, Xiao Chen Wei, Ran Ran Song, Miao Jing [1], Xiao Chun Li

State Key Laboratory of Geomechanics and Geotechnical Engineering, Institute of Rock and Soil Mechanics, Chinese Academy of Sciences, Wuhan 430071, China

ARTICLE INFO

Article history:
Received 2 December 2014
Received in revised form 4 July 2015
Accepted 16 July 2015
Available online 17 July 2015

Keywords:
CCS
CO_2 geological storage
Coal mining
Coupled analysis
THMC
Ordos Basin

ABSTRACT

The CO_2 geological storage in Ordos Basin and coal mining activities occurring simultaneously at the same location is a highly challenging coupled thermo-hydro-mechano-chemical (THMC) problem. To address this problem, an in-house program named "AEEA Coupler" was developed by linking two commercial software packages, Simulia ABAQUS and Schlumberger ECLIPSE, both of which are widely used and highly recognized in their respective fields. The applicability and accuracy of the developed coupler were tested by benchmark studies. A coupled multi-physics analysis was conducted based on real formation data of the Ordos and Shenhua CCS Demonstration Project with an injection rate of 0.1 Mtpa (Million tonnes per annum). A larger injection rate of 1.0 Mtpa was also investigated to explore the potential for the commercialization of large-scale CCS projects in the area. The primary conclusions that were obtained from the numerical simulations are as follows: (a) The pore pressure and displacement at the top of the reservoir increase with CO_2 injection, and the displacement continues to increase even after the termination of the CO_2 injection due to the coal mining activity. (b) The displacement of the wellbore peaks at the coal seam floor where the axial strain of the well soars abruptly. Our work suggests that the distance between coal pillars should be at least 90 m to ensure that the Mises stress of the casing is below the designed safe value. (c) The tensile stress and shearing stress increase significantly in the caprock as a result of the coupling of the two engineering activities; therefore, damages in the caprock occur more easily. (d) After CO_2 injection, only the strata with a depth of less than 769 m are affected by the coal mining activity. (e) The combined activities achieve a surface subsidence reduction comparable to that of only coal mining. Finally, several recommendations are given regarding the actual engineering implementation of the combined activities.

1. Introduction

The Ordos basin is widely known as the "coal sea" in northern China. Coal-related industries dominate the local economic structure and provide the foundation for the local economy of the basin (Chen et al., 2013; Wu, 2013). The coal is primarily used for electricity generation or the coal chemical industry, both producing massive CO_2 emissions (OECD/IEA., 2013; Vishal et al., 2013a). To mitigate the environmental impact of the emission, huge amounts of anthropogenic CO_2 must be reduced, and CO_2 geological utilization and/or storage is one possible solution (IPCC, 2014; Xie et al., 2013; Li et al., 2015).

The CO_2 storage mode can be divided into the following four categories according to variations in geological sites and the morphology of the sequestration: 1) Geological storage, which injects CO_2 into deep geological bodies, such as the saline water layer, depleted oil and gas reservoirs and unminable coal seams (Ranjith et al., 2012); 2) marine storage, which traps the injected CO_2 by the pressure of the sea water and various biochemical effects (Li et al., 2009b); 3) mineral carbonation sequestration, in which carbon dioxide reacts with alkaline minerals to generate carbonate minerals (Xu et al., 2004; Pang et al., 2012); and 4) direct utilization, in which carbon dioxide can be directly used in the industry, such as for CO_2 enhanced oil recovery and CO_2 enhanced geothermal system (ACCA21, 2014; Xu et al., 2015; Yang et al., 2014; Yang et al., 2012). Only the first three categories are suitable for large-scale commercial exploitation, while the fourth category is not a long-term sequestration method because the amount of carbon dioxide that can be processed is minimal. Since the early 1990s, a series of important investigations by IPCC (Metz et al., 2005) have confirmed three geological formations that are suitable for the sequestration of carbon dioxide: deep saline formations, depleted oil and gas fields and coal seams. Of these three formations, the storage in deep saline aquifers is the most promising for large industrial-scale CO_2 geological storage (IPCC, 2014). Suitable saline aquifers for CO_2 sequestration exist in the Ordos Basin but with widely distributed superior quality coal overlaying the formation (Li et al., 2013). The formation is the target for CO_2 geological storage, but it is expected that the coal will continue to be mined even after the CO_2 sequestration (Li et al., 2014b).

* Corresponding author at: Xiaohongshan, Wuchang, Wuhan 430071, China.
E-mail address: qli@whrsm.ac.cn (Q. Li).

[1] Now at Helmholtz Centre for Environmental Research – UFZ, Permoserstraße 15, 04318 Leipzig, Germany.

http://dx.doi.org/10.1016/j.enggeo.2015.07.017
0013-7952/

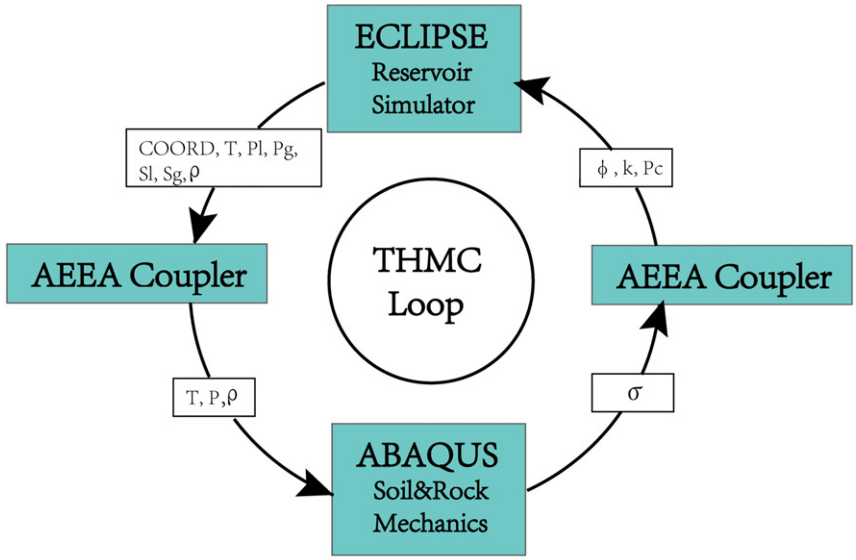

Fig. 1. Schematic diagram of the AEEA Coupler.

In coal mining, the strata above and below the coal seam gradually lose the support with the progress of mining. Because the original state of equilibrium is disturbed, roof caving and/or floor heaving may occur, and both phenomena will cause stress re-distributions in the affected strata. Because the coal seam in the basin is primarily horizontal, the mining activity will inevitably affect the stress distributions and stability in the caprock of the CO_2 storage when the mined-out area reaches a significant size (Vishal et al., 2013b). This effect will increase the risk of leakage of the sequestered CO_2 (Liu et al., 2014). However, a large-scale CO_2 injection lasts for a long time and will cause changes of stress and deformation in the rock formations above the reservoir (Wang et al., 2015), which in turn may also affect the mining activity. It is therefore important to understand how the state of rocks changes under the combination of coal mining and CO_2 storage and how the safety issues are affected under the combined activity, which remains a very challenging research topic (Fei, 2014). In other words, the combined effect of CO_2 sequestration in saline aquifers and coal mining in the overlaying strata is a problem worthy of detailed investigation.

Laboratory study is of limited value in this case because the problem involves highly complicated couplings among hydrogeology, geochemistry, thermodynamics, and rock mechanics. Studies using direct engineering implementation are not possible either because of significant difficulties and budget constraints. Numerical simulations, however, can provide a tool to address the problem. However, there is no single software package that can be used to solve this complex coupled problem. In this paper, we report a tailored thermo-hydro-mechano-chemical (THMC) coupling platform that is customized to handle the problem named “AEEA Coupler”, which was developed by linking Simulia ABAQUS (stress analysis) and Schlumberger ECLIPSE (reservoir simulation) using Python 2.7 (Fei, 2014; Fei et al., 2014). The

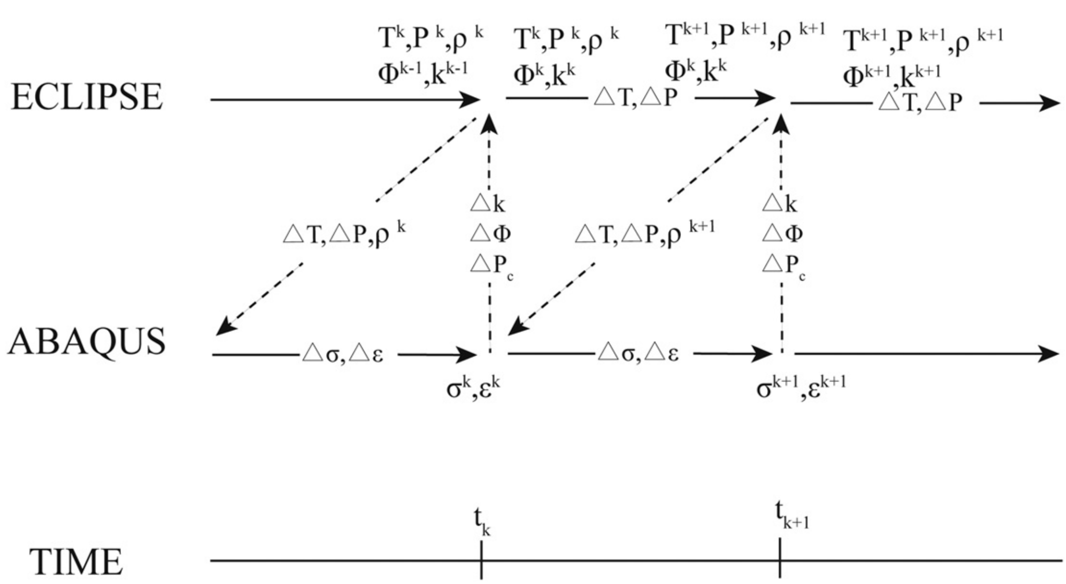

Fig. 2. Time steps and variables update in coupling analyses.