Journal of Cleaner Production 184 (2018) 12–20

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Numerical simulation of enhancement in CO_2 sequestration with various water production schemes under multiple well scenarios

Li Chen [a], Danqing Liu [b], Ramesh Agarwal [a, *]

[a] Washington University in St. Louis, 1 Brookings Dr., St. Louis, MO 63130, USA
[b] State Key Laboratory of Biogeology and Environmental Geology, China University of Geosciences, Wuhan, 430074, China

ARTICLE INFO

Article history:
Received 9 October 2017
Received in revised form
14 December 2017
Accepted 21 February 2018
Available online 22 February 2018

Keywords:
CO_2 enhanced brine production
Reservoir pressure
CO_2 storage capacity
Multiple well scenarios

ABSTRACT

To determine the best CO_2 injection and brine production strategy for achieving both the optimal water production and the optimal CO_2 storage capacity while maintaining operational safety in CO_2 enhanced brine production, three injection scenarios based on the typical geological parameters of the Junggar Basin in China are compared. They are the sole CO_2 injection, sole water production and combined CO_2 enhanced water recovery, and for the combined CO_2 enhanced water recovery scenario, both the co-production of brine and pre-production of brine are considered. It is found that compared to the pre-production of brine, the combination of pre- and co-production of brine can be more effective in controlling the pressure perturbation and in increasing the CO_2 storage capacity. However the volume of co-produced brine plays a smaller role in the pressure build-up. The influence of number of pumping wells is also analyzed. Although increasing the number of wells can enhance the CO_2 storage, the economic analysis reveals that the revenue in water production and CO_2 storage cannot compensate the expensive investment required in well drilling. The injection strategy is essential to the efficiency of CO_2 enhanced water recovery; this paper compares the strategies for pre-production and co-production of brine on CO_2 enhanced shale gas recovery. The conclusions given in this paper can serve as a reference for the design engineers interested in CO_2 storage with co-production of brine.

1. Introduction

Over the past several hundred years, carbon dioxide (CO_2) concentrations in the atmosphere have steadily increased. Increase in atmosphere's carbon dioxide (CO_2) concentrations is mainly caused by burning coal, oil and natural gases for electricity generation, transportation, industrial and domestic uses (International Energy Agency, 2012). Carbon Capture and Storage (CCS) is an effective way to decrease the CO_2 concentrations (Bachu et al., 2007). However, the expensive investment required for of the CCS has hindered its rapid development, although other more economically viable Carbone Capture, Usage and Storage (CCUS) technology are gradually emerging, namely the CO_2 enhanced oil recovery (CO_2-EOR) (Ampomah et al., 2016; Dai et al., 2016), the CO_2 enhanced coalbed methane recovery (CO_2-ECBM) (Busch and Gensterblum, 2011; Koperna et al., 2009) and the CO_2 enhanced shale gas recovery (CO_2-ESGR) (Dahaghi, 2013; Liu et al., 2017) among others. Recently proposed, a novel geo-engineering approach of CO_2 geological utilization and storage, called the CO_2 geological storage combined with deep saline water/brine recovery (CO_2-EWR) has shown the potential of simultaneously increasing the CO_2 sequestration and producing the underground water from the aquifers.

During the sequestration process in CCS, a large-scale CO_2 injection can lead to significant increase in reservoir pressure. The increase in pressure may lead to rupture of overlying caprock or fault resulting in CO_2 leakage (Birkholzer and Zhou, 2009). Considering the problems faced by traditional CCS, Bergmo et al. (2011) proposed to produce water from dedicated water production wells to actively control the pressure perturbation caused by CO_2 injection. Buscheck et al. (2011) also investigated the effect of utilizing complex extraction schemes to control the pressure build-up and to manipulate the CO_2 plume behavior. Recently, Hosseini and Nicot (2012) and Li et al. (2012) have shown with analytical and numerical methods that the pressure in CO_2 sequestration operations could be managed by brine production;

* Corresponding author.
E-mail address: rka@wustl.edu (R. Agarwal).

https://doi.org/10.1016/j.jclepro.2018.02.237

this geo-engineering approach to carbon capture, utilization and storage is known in the literature as the CO_2 geological storage combined with the deep saline water recovery (CO_2-EWR). The main idea behind the CO_2-EWR technology is to inject CO_2 into deep saline aquifers for CO_2 sequestration and simultaneously achieve the saline water (brine) recovery.

Brine extraction from the reservoir can be scheduled before the CO_2 injection, during the CO_2 injection and after the CO_2 injection. Pre-injection brine production scheme schedules the brine production before the CO_2 injection. In this scheme CO_2 is injected when the pressure drawdown is greatest during the brine production before the CO_2 injection. This concept has been employed by Buscheck et al. (2015). This method has multiple benefits compared to the injection only scheme. First, it can be employed as a pressure management strategy, wherein the brine extraction is scheduled before the CO_2 injection which can lower the reservoir pressure and thus the reservoir may have more room for CO_2 storage resulting in less overpressure for a given quantity of CO_2. Second, the brine produced could be used for industrial and agricultural purposes, and even could be used for drinking water after appropriate desalination and treatment. Furthermore, when the brine is extracted before CO_2 injection, the resulting pressure drawdown provides direct and specific information about potential for CO_2 storage as well leakage through the caprock. Co-injection and brine production scheme is another effective method for injecting more CO_2 in the geological formation when accompanied by the brine production. It has all the advantages mentioned above of the pre-injection brine production scheme since it also has scheduled brine extraction. The difference between the pre-injection and co-injection brine production schemes is the time of brine extraction and its duration. Based on the co-injection brine production schemes, Li et al. (2014) analyzed the sensitivity of various parameters on the effect of CO_2 enhanced water recovery, while Liu et al. (2016) optimized the CO_2-EWR scenario to determine the trade-off between the water recovery and the CO_2 storage safety. However, the previous work does not compare and illustrate the relative advantages and disadvantages of pre-injection and co-injection schemes which are addressed in this paper. In addition, the effect of multiple wells on brine production is considered first time in this paper.

This paper analyzes both the CCS and CO_2-EWR technology under different CO_2 injection scenarios and determines by numerical simulation an optimal scenario that could store more CO_2 in the reservoir while simultaneously producing brine using a single production well or multiple production wells. A three-dimensional CO_2 injection - brine extraction model is established using the DOE TOUGH2/Petrasim code utilizing the typical parameters from a coal based chemical industry in the Xinjiang Uyghur Autonomous Region of China and geological formation parameters from Junggar Basin in China. Various water production and CO_2 injection schemes under single and multiple production wells scenarios are considered in order to determine the advantages and disadvantages of each scenario to maximize the CO_2 storage. The different scenarios considered are the sole CO_2 injection, sole water production, and combined CO_2 enhanced water recovery. For the combined CO_2 enhanced water recovery scenario, both the co-production of brine and pre-production of brine are considered. CO_2-EWR is analyzed for two-, three- and five-wells and the results are compared to determine the effect of production wells on CO_2 storage and water recovery.

2. Methods

2.1. Geological background

Junggar Basin is located in the Uygur Autonomous Region of Xinjiang, northwestern China, covering an area of 130,000 square kilometers. Fig. 1 shows the geological map of Junggar basin.

The Junggar Basin is a multicycle superimposed basin formed from the late Paleozoic to the Mesozoic and Cenozoic periods. Hydrocarbon generation sags characterized by multiple hydrocarbon-generation centers and hydrocarbon accumulation zones have been found in the northwestern, northern, central, eastern and southern parts of the basin (Zhao et al., 2003). However, this region experiences the worst water shortage problem in China. The oldest layer of bedrock in the eastern region is Silurian, followed by Devonian, Carboniferous, Permian, Triassic, Jurassic, Tertiary and Quaternary from the bottom up in turn. The Permian, Triassic and Jurassic layers with lithology-fine sandstone and siltstone, locally coarse sandstone or large-coarse sandstone, are considered the best reservoir due to their wide distribution and large thickness. Thus, applying CO_2-EWR to this basin is a very feasible and reliable choice. In this paper, the exact geological parameters of the Junggar Basin are chosen as initial inputs for the numerical model for CO_2-EWR analysis.

2.2. Model description

The TOUGH2/Petrasim, the numerical program which can simulate non-isothermal multi-phase and multi-component flow in the porous/fractured media is to establish the simulation model. The PetraSim is the graphical interface for the TOUGH2 family of simulators developed at Lawrence Berkeley National Laboratory. PetraSim integrates the TOUGH family of codes into a

Fig. 1. Geological map of Junggar basin.