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NUMERICAL MODELING AND ECONOMIC ASSESSMENT OF CO_2 STORAGE IN DEEP SALINE AQUIFER BASED IN UAE

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ABSTRACT

Geological carbon dioxide (CO_2) sequestration is the most sought after method to store CO_2 in supercritical form. Of all the geological formations, deep saline aquifer are preferred due to their high storage capacities and wide availability. A saline aquifer based in Shuaiba formation of the United Arab Emirates, situated at a depth of 3000 m has been investigated. A numerical model has been developed in an open source code STOMP and sensitivity of CO_2 plume to parameters such as salinity and Corey residual gas saturation has been studied. The results for total CO_2 mass (aqueous and gas CO_2) are plotted as a function of simulated time. The results show that the effect of salinity and Corey residual gas saturation is significant.

The cost of CO_2 storage in such deep saline aquifers is also estimated. The source of CO_2 is considered from a chemical looping reforming plant producing hydrogen and capturing about 0.73 Mt/year. The cost of CO_2 storage is estimated to be $4.58 per ton of CO_2 stored. The results obtained are promising, however, more comprehensive assessments are required in order to increase the accuracy of the costs.

Keywords: geologic CO_2 sequestration, Carbon capture and storage, reservoir modeling, United Arab Emirates, economic assessment, deep saline aquifer

1. INTRODUCTION

Global warming has led scientists and researchers to find alternatives to deal with rapidly increasing carbon dioxide (CO_2) levels in atmosphere. Due to an increase in energy demand, the consumption of fossil fuel is increasing and consequently the release of greenhouse gases into the atmosphere is increasing. CO_2 is the major part of it and hence, its concentration has increased from 280 ppm to over 400 ppm in the last 250 years [1]. This is a very rapid increase, which has triggered the interest in capture and storage of CO_2 in geological formations. Geologic sequestration is referred to as the injection of supercritical CO_2 into the formations which are at appropriate depth and which can keep the CO_2 in supercritical form forever. Among all geologic formations, deep saline aquifers possess all the essential requirements. They are unused due to high salinity, have high storage capacities, possess high reactivity among water-salt-rock-CO_2 and are widely available [2]. The trapping of CO_2 in deep saline aquifers can be divided into four main types as (i) structural trapping due to the overlying cap rock; (ii) hydrodynamic trapping of the gas in supercritical phase; (iii) dissolution trapping in liquid phase; and (iv) mineral trapping of solid phase [3]. United Arab Emirates (UAE) has many unused saline aquifers which have a potential to be used as CO_2 storage reservoirs. The formations found in the UAE are of carbonates, which are highly reactive, and aid in mineralization of CO_2 and hence, the UAE has a high potential for a major carbon storage project. This project is an attempt to model the sequestration of CO_2 in heterogeneous carbonate saline aquifers found in the UAE. The region focused in this study is the Shuaiba formation, which is at a depth of around 3000 m and is overlaid by the regionally continuous seal called Nahr-Umr formation [4]. A two dimensional model with all the necessary petro-physical properties has been executed. The mobility of CO_2 in the formation over 10,000 years

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has been studied. The effect of varying salinity, pore compressibility, Corey residual gas and liquid saturation and van Genuchten m value on the total CO_2 mass, aqueous CO_2 mass and gas CO_2 mass at a particular position in the domain has been studied. Only the results for total CO_2 mass for different salinities and residual gas saturation are presented in this paper.

2. METHODOLOGY

2.1 Numerical model development

The present study develops a numerical model considering a region with five layers and another layer of Kharaib formation is added at the bottom. A schematic of computational domain is shown in Fig 1. All these layers have different porosities, permeabilities, densities and thicknesses. The total thickness is 238 m and the formation length is taken as 10,000 m. The computational domain is divided into 200 cells in x-direction and 34 cells in z-direction. The CO_2 is injected at the center at a rate of 0.1 kg/s for 20 years. The numerical simulations were carried out in Subsurface Transport over Multiple phases (STOMP) code developed by Pacific Northwest National Laboratory (PNNL) [5]. Flow and transport processes in porous media can be simulated in STOMP by solving the governing equations with the integral volume finite difference method and Newton-Raphson iteration [4]. For this problem, the STOMP Operational mode: STOMP-CO_2 is used. The primary assumptions for this mode are isothermal conditions, no nonaqueous phase liquid (NAPL) phase, no dissolved oil and local thermodynamic equilibrium. The governing equations used are conservation of mass for water, CO_2 and salt whereas the constitutive equations used are Millington and Quirk for tortuosity, van Genuchten for capillary pressure-saturation function, Mualem formulation for aqueous relative permeability function and Corey formulation for gas relative permeability function. Due to the unavailability of the practical/experimental data, the model is verified by reproducing the results of the benchmark problem on CO_2 injection in brine formation available in STOMP user guide [5]. Real-time data is difficult to obtain for the aquifers based in UAE.

2.2 Economic assessment

The economic assessment is performed based on the methodology presented by European technology platform for zero emissions fossil fuel power plants [6]. The capital expenditure (CAPEX) includes all the costs associated with wells and platforms. The operation and maintenance expenditure (OPEX) is assumed to be 4% of the CAPEX [6]. The other main assumptions adopted for the current study are listed in Table 1.

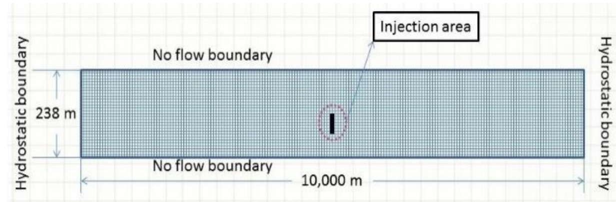

Fig 1 Schematic representation of model domain

Table 1 Economic assumptions

Item	Value
Well injection rate	0.8 Mt/year/well
Liability transfer costs	\$1.12 /ton CO_2
Wt. average capital cost	8%
Well depth	3000 m
Onshore well costs	4.9 M\$ [7]
Observation wells	1
Exploration wells	4
Injection wells	1
Contingency wells	1
Well re-tooling cost	10% of well costs [6]
OPEX	4% of CAPEX [6]
Injection testing	1.12 M\$ [6]
Modeling/logging costs	5% of seismic survey
Seismic survey costs	3 M\$ [8]
Monitoring, measurement and verification costs (MMV)	\$0.03 /ton of CO_2 [9]
MMV recurring costs	10% of MMV baseline
Permitting costs	1.12 M\$ [6]
Well remediation costs	30% of well costs [6]
Platform costs	33 M\$ [10]
Decommissioning	15% of CAPEX [6]
Post-closure monitoring	20 years
Economic Life	40 years
Annual CO_2 emissions	0.73 Mt/year [11]

3. RESULTS AND DISCUSSIONS

3.1 Numerical simulation results

The saturation of injected CO_2 at different times of the simulation is shown in Fig 2. At the beginning, the supercritical CO_2, which has density like liquid, and viscosity like gas starts migrating upwards towards the seal (cap rock) which is a no flow boundary. It will trap the CO_2 just beneath it. After 1 year, the CO_2 plume extends laterally over 1500 m around the injection point. At 20 years, which is the end of injection period, the gas saturation is the highest in the vertical region along the injection area. At this time, a low saturation area (blue region) is observed in between the relatively high saturation area (green) because of low permeability of that region. Due to low permeability, the CO_2 mobility is very slow. After the injection period of 20 years, the maximum saturation is no longer stable and shifts upwards due to buoyancy and spreads radially. This can be observed at 100, 1000 and 5000 years. After, 10,000 years, all the gaseous CO_2 moves upwards and gets trapped by the cap rock for several thousand years to come.

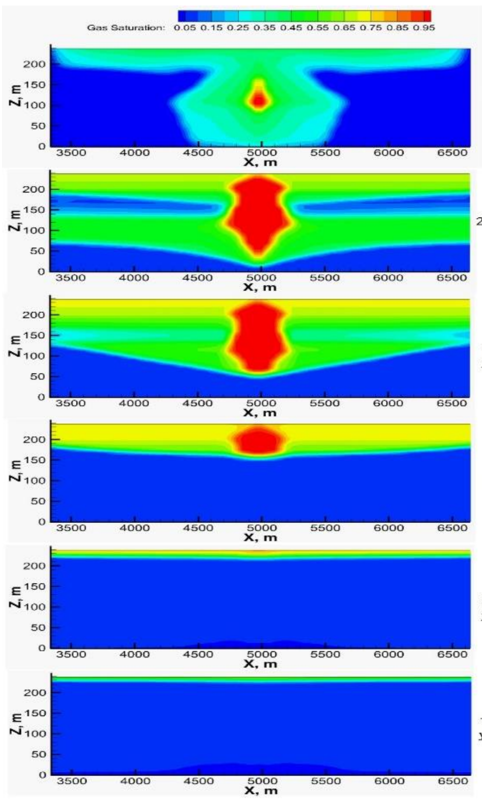

Fig 2 Gas saturation at different times

In the current study, a parametric investigation has also been conducted to observe the effect of important parameters such as salinity, pore compressibility, and constitutive relation constants on the total CO_2 mass at a particular point. The salt mass fraction is varied from 0 to 0.3 with 0.2 as the base case value. The results show that total CO_2 mass increases as the injection starts and reaches its peak value at the end of injection (see Fig 3). After the injection, the CO_2 mass decreases till the end of the simulation time. Higher the salinity, lower is the total CO_2 mass. It was expected since higher salinity means there are more sodium and chorine ions present in water, which makes it difficult for CO_2 to dissolve. The total CO_2 mass is the sum of aqueous and gas CO_2 masses, the results of which are not shown in this paper for brevity. The Corey residual gas saturation is varied from 0.05 to 0.3 and the results are shown in Fig 4. The total CO_2 mass is higher for high residual gas saturation. This is due to the presence of residual gas and at the same time, the addition of CO_2 due to injection.

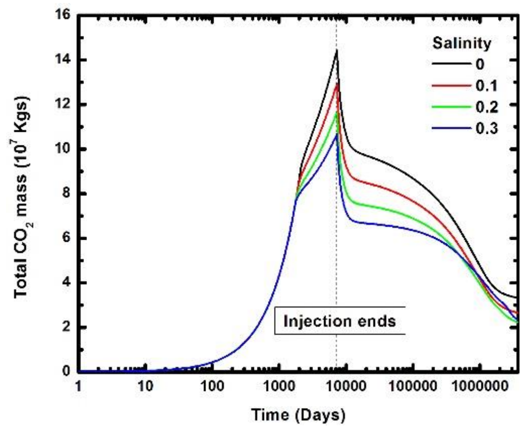

Fig 3 Total CO_2 mass for different salinity

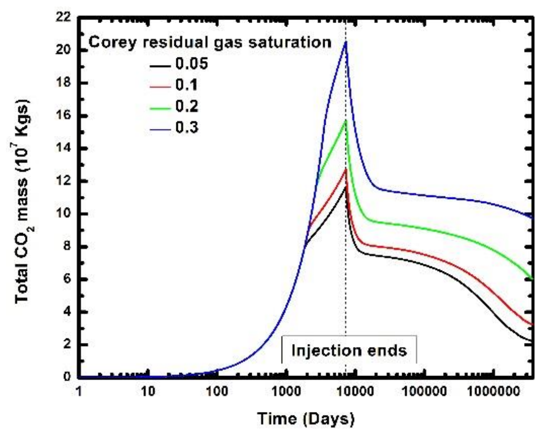

Fig 4 Total CO_2 mass at different residual gas saturation

3.2 Economic assessment results

Table 2 presents the results of the economic assessment. The major contribution to the CAPEX comes from the costs associated with wells and platform. The cost for well drilling and completion for one well is \$4.9 M. All together six wells are considered in the current study, which corresponds to \$29.4 M of CAPEX. The cost for constructing a platform is \$33.4 M. On a year basis, the CAPEX is estimated to be \$2.44 M whereas the OPEX is estimated to be \$0.09 M. As mentioned earlier, the CO_2 source is the chemical looping reforming plant producing hydrogen and capturing CO_2 at a rate of 27.3 kg/s. This corresponds to 0.73 Mt/year. Therefore, the cost of CO_2 storage is estimated to be \$4.58 /ton of CO_2.

4. CONCLUSIONS

In this study, a multiphase model is developed for studying the geologic carbon sequestration in Shuaiba formation in UAE which deep saline aquifer. The aquifer with layers of different properties is modeled in STOMP-CO_2. A sensitivity study has been performed by varying the parameters such as salinity and Corey residual gas saturation. The CO_2 plume has been analyzed and the total CO_2 mass is observed as a function of simulated time. The results show that salinity and Corey residual gas saturation are the influential parameters.

An economic assessment to calculate the cost of CO_2 storage in the saline aquifer under study has also been performed. The major contribution to the CAPEX comes from drilling wells and constructing platforms. The cost of CO_2 storage is estimated to be \$4.58 /ton of CO_2. The estimated value is very promising. The current study can be considered as the first steps towards having an estimation of CO_2 storage costs in UAE. However, a comprehensive assessment is required in order to estimate more accurate CO_2 storage costs.

Table 2 Economic assessment results

Costs	
Total wells costs	29.40 M$
Total well retooling cost	2.94 M$
Injection testing	1.12 M$
Modeling/logging costs	0.15 M$
Seismic survey costs	3.00 M$
MMV baseline	1.32 M$
MMV recurring costs	0.13 M$
Permitting costs	1.12 M$
Well remediation costs	8.82 M$
Platform costs	33.10 M$
Decommissioning	9.37 M$
Annualized CAPEX	2.44 M$
Annualized OPEX	0.09 M$
Cost of storage	4.58 $/ton

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