Study on Pressure Responses at Injection and Observation Wells in an Aquifer by CO_2 Geological Storage

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論 文 名：Study on Pressure Responses at Injection and Observation Wells in an Aquifer by CO_2 Geological Storage　（帯水層中へのCO_2地中貯留による圧入井および観測井の圧力応答に関する研究）

区　　分：甲

論文内容の要旨

CO_2 capture and geological storage (CCS) is a method of reducing CO_2 emissions into the atmosphere. It is operated by CO_2 capture from large-scale CO_2 emission sources such as power plants. The CO_2 gas is further sequestered into underground reservoirs with relatively high permeability and porosity, such as deep saline aquifers. From the previous and on-going CCS projects, it has been implemented that CCS is technically feasible. For further CCS projects implemented to mitigate global warming and climate change, it is indispensable to establish safe operation of CO_2 storage and monitoring system of the reservoir and surrounding environment, because it is expected to increase the CO_2 injection rate and cumulative injection amount to promote commercial CCS projects.

In this study, the pressure build-up and fall-off at the CO_2 injection well and the pressure response in the observation well drilled at a distance of 1 to 5 km were investigated by numerical simulations. In particular, the present research objective is to provide design data for the distance of the observation well and the required measurement sensitivity of the pressure transmitter installed in the observation well by clarifying the relationship between the aquifer conditions and the pressure response in the observation well. Furthermore, a prediction method of the pressure responses using an approximate analytical solution was also presented.

This dissertation consists of the following 6 chapters.

Chapter 1 introduces the recent CCS projects in the world and the technological development challenges for monitoring systems related to the safe CO_2 geological storage. The focus was directed towards three world-famous CCS commercial projects including the Tomakomai CCS demonstration project (hereinafter Tomakomai CCS). The aquifer characteristics and differences between them are highlighted. CO_2 geological storage in a deep aquifer is characterized by pressure build-up (PBU), pressure fall-off (PFO), convection flow of CO_2 plume, and pressure propagation in the aquifer. One of the monitoring items carried in the current CCS projects is the pressure response at an observation well drilled at few kilometers away from injection well. In the case of Tomakomai CCS, the observation well is located at approximately at 3 km from the injection well.

Chapter 2 describes the aquifer and injection well modeling for CO_2 storage; all defined in the three dimensional cylindrical coordinate system. The model was referred to the Moebetsu layer mainly targeted by Tomakomai CCS. The base model of the aquifer with 1000m in depth, layer thickness H=100m, horizontal permeability k_r= 370 md, vertical permeability k_z= 37 md, porosity ϕ= 30 %, and open boundary at outer radius r_e= 10 km was used for the numerical simulation using the multiphase reservoir simulator CMG-STARS^{TM}. The block model consists of (149, 6, 10) grid cells in the coordinate (radius, azimuth, altitude). The vertical injection well OUTER radius r_w= 0.100 m (inner radius=0.080 m) was set at the aquifer center. As for Tomakomai CCS, supercritical CO_2 (10 to 14 MPa, 40 °C) is injected from perforated halls in all wellbore blocks contacting with the aquifer. Specifically, PBU, that is the increase from the initial aquifer pressure (=10 MPa), was controlled less than 4 MPa (the average PBU in Tomakomai CCS is reported as 0.45 MPa). In addition, the injection period (100 to 500 days) and two injection schemes with single and multiple PBU and PFO were created to compare the pressure response, because in the Tomakomai CCS 7 sets of CO_2 injection with PBU and PFO were conducted during 6 months just after the beginning of CO_2 storage, so.

On the other hand, the approximate prediction method, that uses the analytical solution of the linearized one-dimensional unsteady reservoir flow equation obtained by assuming open boundary, uniform permeability and uniform fluid saturation, was presented to predict rough PBU, PFO and pressure response at a radial position. It was shown that the main parameters in the solution are permeability-thickness product, $k_r \cdot H$ and hydraulic diffusivity, η.

Chapter 3 is a band for a single scheme that blocks the well after performing CO_2 injection for a certain period (50 to 500 days) at the injection rate q_m= 100 to 800 t-CO_2/day in the initial stage of CO_2 underground storage. It describes the CO_2 saturation distribution in the aquifer and the numerical simulation results for PBU and PFO in the injection well. The increase in PBU was inversely proportional to $k_r \cdot H$. In addition, until the elapsed time t = 100 days from the start of CO_2 injection, the radius position of the CO_2 plume front observed at the aquifer top expands in proportion to $t^{1/2}$, and after the shut-in it gradually expands in proportion to $0.1t$ due to buoyancy force on CO_2. Was shown. The CO_2 saturation around the injection well increases to about 0.35 with the elapsed time and reduces the effective fluid viscosity. However the decrease in PBU is about 5% compared to the case of salt water. It was the reason that the CO_2 saturation in the aquifer is limited by the irreducible water saturation of 0.65, and PBU does not decrease significantly even if the CO_2 viscosity is less than 1/10 of water. On the other hand, it was confirmed that the time required to reduce by half the PBU decreases exponentially with increasing η.

Chapter 4 summarizes the numerical simulation results of the pressure response in the observation well to the CO_2 injection with a single set of PBU and PFO. In particular, the pressure ratio R (= maximum response pressure at the observation well / PBU at the injection well) was obtained against the parameters such as permeability k_r, CO_2 injection rate q_m, and the distance of the observation well from the injection well, r_m. The value of R does not change significantly with q_m, but it decreases in inverse proportion to r_m. For example, when r_m= 3 km, the range of the pressure ratio is estimated to be R= 0.04 to 0.06. It was also shown that the time delay Δt_{max}, which is the time difference between the shut-in time and the time that the maximum pressure response is recorded at the observation well, is also inversely proportional to η and increases in proportion to r_m^2. For instance, when the well distance is r_m= 3 km, it was estimated Δt_{max}= 2 to 10 days.

In Chapter 5, the numerical simulation results of pressure ratio, R and the time delay, Δt_{max} for multiple scheme (6 sets of CO_2 injection with PBU and PFO), as shown in the initial stage of Tomakomai CCS, are compared with the single CO_2 injection scheme. It was revealed that R gradually increases with each repetition of multiple CO_2 injections, but Δt_{max} does not show any difference between single and multiple schemes.

Finally, when the pressure response at the observation well is used to estimate the aquifer condition based on the numerical simulation results, it was shown that the distance to the observation well and the minimum sensitivity of the pressure transmitter installed are important design factors for the observation well function. For example, in the case of the distance to the observation well is equal to r_m= 3 km, the minimum sensitivity of the pressure transmitter needs approximately 1 kPa order under the absolute pressure (or pressure resistance) of 10 to 11 MPa to obtain an accuracy of 2 digits. However, in the case in event in which the minimum sensitivity is 5 to 10 kPa order, the well distance required should be lesser than, r_m= 1 km.

Chapter 6 summarizes the conclusions of this thesis and also explains future research topics.