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Energy Procedia 37 (2013) 4612 – 4619

Energy Procedia

GHGT-11

Effective Storage Capacity Study in a Deep Saline Aquifer within a Young Sedimentary Basin

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Abstract

The thermal power plants which belong to Taiwan Power Company are major Carbon Dioxide(CO_2) emitting sources in Taiwan. Thus, Taiwan Power Company launched a series of projects since 2008 to look for sites suitable for CO_2 geological storage around Taiwan. After 3 years of research, Taiwan Power Company chose a deep saline aquifer sandy formation in the Taihsi basin to be the candidate site for CO_2 geological storage. By this research, we established a three dimension geological model of the cap rock and reservoir rock in Taihsi basin storage site, and refer the America Department of Energy (DOE) and Japan RITE experiences to suggest an unit grid conception formula for evaluating storage capacity. Finally, we evaluated effective capacity is about 6 billion tons in the Taihsi basin site by using Geological Information System.

keywords: Effective Storage Capacity; Deep Saline Aquifer; Sedimentary Basin

1. Introduction

There are nine main thermal power plants which belong to Taiwan Power Company (TPC), shows in Figure 1. These thermal power plants emitted Carbon Dioxide(CO_2) about 70~84 megatons per year from 2007 to 2008[1] and are major CO_2 emitting sources in Taiwan. In order to deal with the carbon tax problems expectably in the future, Taiwan Power Company cooperated with Sinotech Engineering Consultant Inc., launched a series of research projects since 2008 to look for sites suitable for CO_2

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Selection and/or peer-review under responsibility of GHGT
doi:10.1016/j.egypro.2013.06.369

geological storage around Taiwan. After three years of research, we chose Taihsi basin to be the candidate site for CO_2 geological storage.

Taihsi basin is a serially young sedimentary formations formed during the late Miocene to early Pliocene under the western offshore near Taiwan island. The biggest coal-fired thermal power plant (TaiChung PP, see in figure 1) is located on Taihsi basin, thus the advantage of this site is transportation costs would be lower and public perception and acceptance of Carbon Capture and Storage (CCS) would be good.

This article illustrates the sedimentary history, geological conditions, rock parameters for CO_2 storage of Taihsi basin site, and built up a three dimensional geological model of the cap rock and reservoir rock in Taihsi basin storage site. We suggested an evaluating formula for storage capacity that based on the America Department of Energy (DOE) and Japan RITE experiences. This formula considers parameters such as reservoir volume, sandstone percentage in reservoir rock, density of CO_2, storage effect and CO_2 saturation (Sg) in supercritical phase. By using 3-D GIS tool and unit grid conception, we set 1,000m×1,000m unit grid in reservoir rock and each rock grid has its own attributes such as depth, thickness, porosity and CO_2 density. We calculate the storage capacity quantity of each grid and sum up them as the total effective storage capacity of Taihsi basin site.

2. Geological Storage Conditions of Taihsi Basin

2.1. Geological History of Taihsi Basin and Basic Conditions for CO_2 Storage

Taihsi Basin is a Paleogene subsidence basin which enclosed by Kuanyin Uplift, Nanjihtao Basin and Ridge, Penghu Platform, Peikang Basement High area. The location of Taihsi Basin is shown in figure 1. The Cenozoic tectonic history in Taihsi Basin can be divided into three steps (Lin, 2001[2]). The three steps are called (1) Paleocene–Eocene Syn-Rift episode (58~37 Ma), (2) Oligocene-Miocene Post-Break-Up episode (30~6.5 Ma) and (3) Latest Miocene-Recent Foreland Basin episode (6.5~0 Ma) respectively. Toukoshan formation, Cholan formation, Chinshui shale and Kueichulin formation were all formed at Latest Miocene-Recent Foreland Basin episode, and the depths of these formations are more suitable for CO_2 geological storage than other older or deeper formations in Taihsi Basin.

Figure 2 shows the seismic profile across the southern Taihsi Basin which shows several normal faults at Syn-Rift episode. However, these normal faults stopped to act at Foreland Basin episode and gradually formed a sequence of slightly eastern-dip sedimentary formations. The geological structure in central offshore Taiwan has become very simple since Miocene.

Figure 3 shows the seismic profile of the northern part of Taihsi Basin (Fu et al., 1997 [3]). In the northern part of Taihsi Basin, the pre-existing faults had reactivated in the form of reverse faults because the orogeny effect. The density of faults in this area is higher and some faults extend upward to Pliocene and Pleistocene strata.

Stefan Bachu(2006 [4]) suggested some criteria suitable for CO_2 geological sequestration of saline aquifer formation in sedimentary basin, such as,

1. Adequate thickness and depth, high porosity of reservoir rock for CO_2 geological storage.
2. Low permeability of cap rock that ensures CO_2 does not escape from the reservoir rock.
3. Simple structures action and minimum faults.
4. Fitness of sedimentary sequence formations.
5. Temperature and pressure conditions in the reservoir rock can suit for storing CO_2 in super critical phase.

According to figure 2 and figure 3 results and Stefan Bachu's criteria, we can realize that if CO_2 migrated to the northern part of Taihsi Basin may escape from the pre-existing faults. Comparing with the northern part of Taihsi Basin, the tectonic stability in southern part is better and CO_2 can be stored here. Therefore, we can define a conservative boundary to evaluate the CO_2 geological storage capacity especially for the southern part of Taihsi Basin.

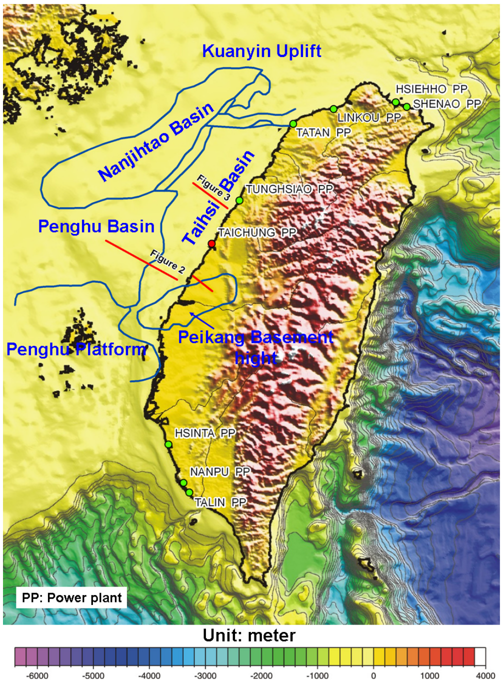

Fig. 1 The location of Taihsi Basin and nearby tectonic basins and thermal power plants of TPC

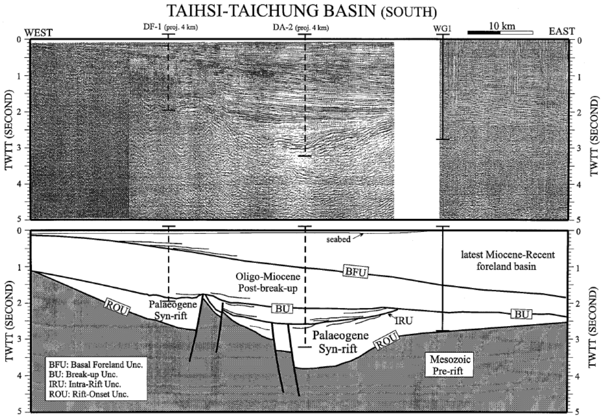

Fig. 2 Seismic profile across the southern Taihsi Basin (Lin, 2001[2])

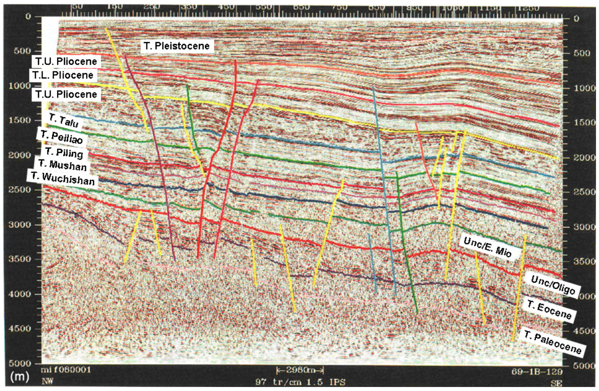

Fig. 3 Seismic profile across the northern Taihsi Basin

(Fu et al., 1997 [3])

2.2. Range and Boundary for CO_2 Geological Storage of Taihsi Basin Site

1. The Northern Boundary

In figure 3, the seismic profile shows that the northern part of Taihsi Basin exists several normal faults across through the Late Miocene and Pliocene strata and some reverse faults are still active. So this region is not suitable for CO_2 storage, we set the northern boundary of Taihsi Basin storage site is the south part area of Tachia town, Taichung, see in the figure 4.

2. The Western Boundary

According to the depth structure map of the basal foreland unconformity described by Lin (2001)[2], we can decide the western boundary of Taihsi Basin site which is the isobath line equals to zero. We also considered the thickness of cap rock (Chinshui shale) to set the western boundary of Taihsi Basin.

3. The Southern Boundary

The southern part of Taihsi Basin is flat strata and stable tectonic action (Lin et al. (1998)) [5]. The attitude of strata formed in Miocene-Recent is about N15° W/dip 5.5° E. Chou (2002) [6] showed faults in this area decreased obviously and the length of faults were not long. Therefore, Chou (2002) supposed that the Peikang Basement High area resisted the pressing stress come from southeastern in Taiwan. Thus, we can choose the Peikang Basement High area as the southern boundary for CO_2 storage.

4. The Eastern Boundary

According to active fault map in Taiwan which published by Central Geological Survey in 2010, the eastern boundary of Taihsi Basin site is Changhua fault which is a Holocene active fault. To avoid CO_2 escaping from this fault plane to ground surface, the eastern boundary of Taihsi Basin site is set far from Changhua fault 2~5 kilometers distance.

The range and boundaries for CO_2 Geological Storage of Taihsi Basin Site is shown in figure 4.

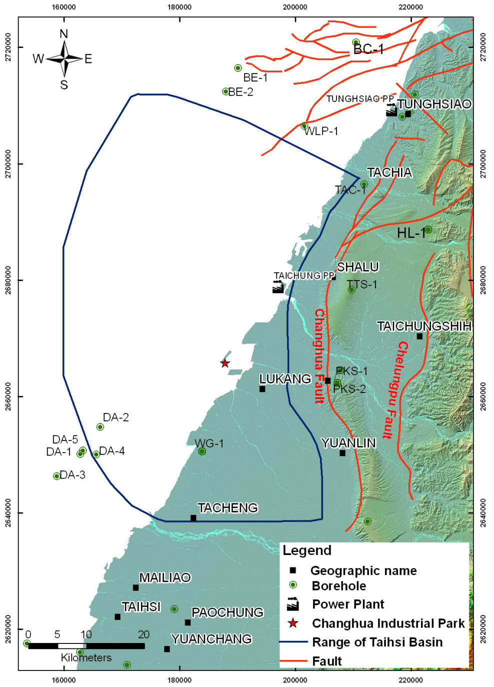

Fig. 4 Boundaries of Taihsi Basin site suitable for CO_2 geological storage

2.3. Parameters for CO_2 Geological Storage of Taihsi Basin Site

According to CO_2 storage standard, the porosity of storage formations is one of the important parameters related to storage capacity evaluation. This research referred to the depth-porosity relative curves of the Cenozoic sediments in five tectonic regions from Lin (2001) [2] is shown in figure 5, and the curves tell us that the porosities of rock inverse proportion to the depth. In figure 5, the geological sedimentary environment of BD1 region is similar to Taihsi Basin, so we use the regression relation of BD1 to be the formations' porosity in Taihsi Basin site. The porosities of target formations in Taihsi Basin site summarize as follows:

Toukoshan formation: 32%~35%.

Cholan formation: 32%.

Chinshui shale (main cap rock): 8%~17.54%.

Kueichulin formation (main reservoir rock): The porosities of sandstone members are 15.11%~23.53%.

This research suggested the sandstone member of Kueichulin formation as reservoir rock in Taihsi basin site. The average porosity of the sandstone member in Kueichulin formation is about 15~23%, which conform to the CO2CRC's empirical porosity of suitable reservoir rock in Australia (shown in figure 6) [7]. On the other hand, although the average porosity of Chinshui shale cap rock is about 8~17% which exceeds a little bit the Japan's standard, we still suggested this shale as cap rock because Chinshui shale is good lateral extension, enough thickness and no faults cutting through it, Chinshui shale cap rock would be good performance to seal CO_2.

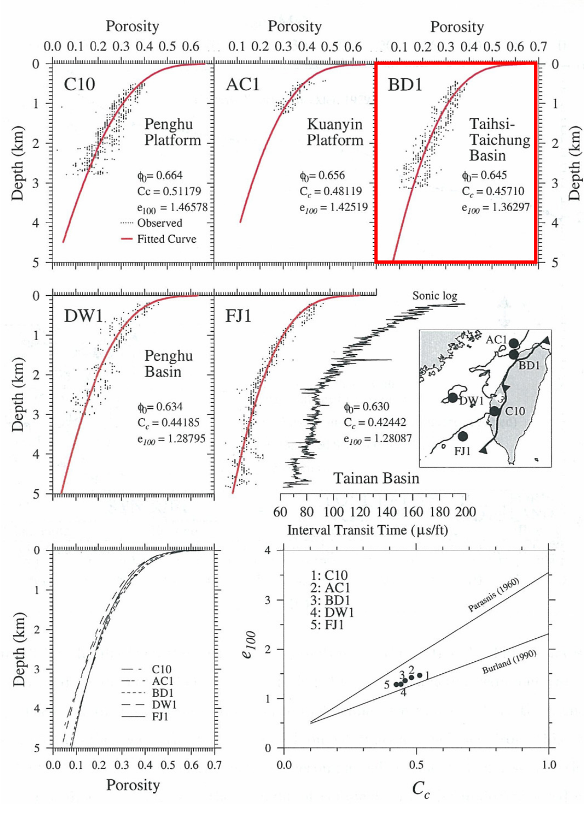

Fig. 5 Porosity-depth relative curves for the Cenozoic sediments from five tectonic regions. (Excerpt from Lin, 2001)

P.S.: ϕ_0: initial porosity, Cc: compression index，e_{100}: void ratio.

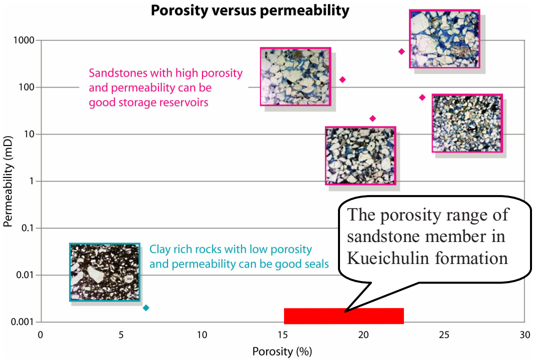

Fig. 6 The empirical porosity and permeability relationship of suitable cap rock and reservoir rock. (Excerpt from CO2CRC website, 2010)

3. Evaluation of Effective Storage Capacity in Taihsi Basin Site

3.1. Definition of Effective Storage Capacity

Figure 7 shows the concept of storage pyramid which indicates if we get more accurately geological storage data thus we could decrease the uncertainty of evaluation of storage capacity. In figure 7 [8], different stages of the storage pyramid from bottom to top are (1) Theoretical Capacity, (2) Effective Capacity, (3) Practical Capacity and (4) Matched Capacity. Considering the present accurateness of the geological storage data in Taiwan, the stage of storage capacity which we evaluated is about effective capacity.

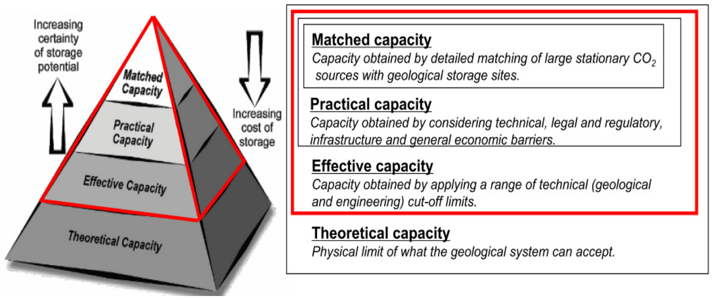

Fig. 7 Storage pyramid concept of considering the uncertainties of storage capacity

3.2. Methodology of Evaluation of Effective Storage Capacity in Taihsi Basin Site

According to different countries' empirical evaluation method for storage capacity such as the U.S. Department of Energy (US DOE), the Carbon Sequestration Leadership Forum (CSLF), the Australia (CO2CRC) and Japan RITE etc., and different methods consider different conditions and scales but the basic principles for storage capacity evaluation are similar. We concluded some basic items as follows and used them for evaluating of effective storage capacity in Taihsi Basin Site.

1. Volume of reservoir formation: The volume of reservoir formation in Taihsi basin site is based on the definition of north, west, south and east boundaries mentioned above. For evaluating effective capacity purpose, this study set the east boundary as the 2 kilometer away from Changhua fault, and the Chinshui shale cap rock thickness is at least 30 meters to be the effective covered area in Taihsi Basin site. In this study, we divided reservoir rock in Kueichulin formation into 1000×1000 meters unit grids by using GIS, and each unit grid has its own thickness. There are 2,589 unit grids of reservoir rock in Taihsi Basin site, and the total volume of these grids is 3.5×10^{11} m^3.
2. Porosity of formation: Refer to the porosity–depth relative curve of BD1 in figure 5, this study calculated the porosity distribution of reservoir formation which ranges from 14% to 33%.
3. CO_2 density properties in Supercritical phase: The geothermal gradient of Taihsi Basin is about 20℃/km (Huang, 1990)[9] and match to the cold basin status of CO_2 density-depth curve shown in figure 9. This study calculated the CO_2 density of reservoir formation which ranges from 706 to 768 kg/m^3.
4. Factors of storage efficiency: The factors include the site sequestration efficiency for saline aquifer in sedimentary basin case and the saturation of CO_2 (Sg) in supercritical phase. This study refereed to Japanese empirical value [10] and set the sequestration efficiency in saline aquifer case is 0.25 and the Sg is 0.5.
5. Percentage of Sandstone in Reservoir formation: The reservoir sandstone percentage of Kueichulin formation in Taihsi basin site is about 78.9%.

We multiplied above parameters to be the effective storage capacity formula for Taihsi basin site is shown in equation (1).

Effective storage capacity＝ (Volume of reservoir formation × Sandstone percentage × Porosity × CO_2 density × Site sequestration efficiency of saline aquifer × Sg) (1)

According to equation (1), this study divided the storage formation into unit grid by using the spatial analysis functions of GIS, and each grid has its own geological storage parameters and attributes. Calculating the individual storage capacity of each unit grid and summing all grids of capacity, we can get the total effective storage capacity. The concept of calculating the effective storage capacity by using geological unit grids is shown in figure 8.

This study summed the 2,589 unit grids' storage capacities in Taihsi basin site, and the total effective storage capacity is 6.0633 billion tons. The effective storage capacity distribution of geological unit grid in Taihsi Basin site is shown in Figure 10.

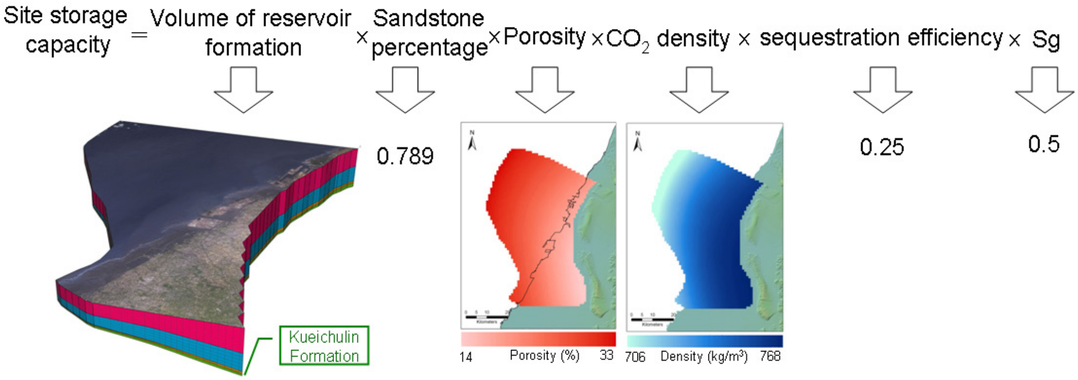

Fig. 8 Schematic diagram of geological unit grid and GIS method for effective storage capacity evaluation

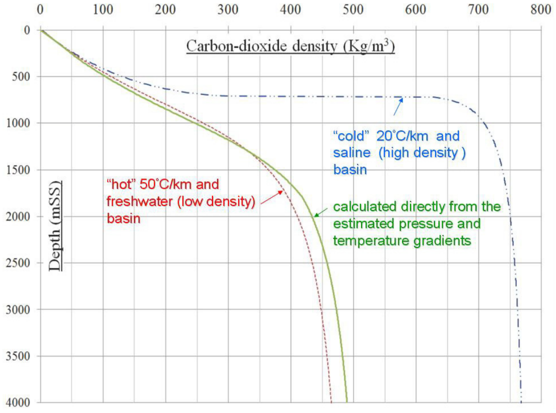

Fig. 9 CO_2 density dependence on depth in cold and warm basin

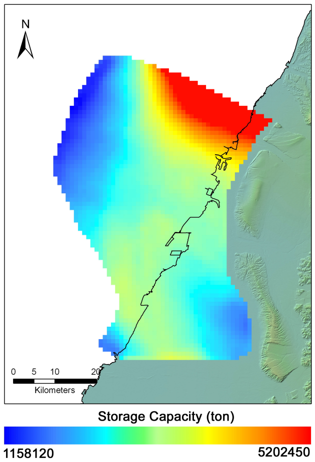

Fig. 10 The distribution map of effective storage

status capacity for geological unit grids

4. Conclusion

According to Stefan Bachu's criteria for saline aquifer in sedimentary basin, the southern part of Taihsi basin is a suitable site for CO_2 geological storage. Because this site matches some conditions such as stable tectonic action and less faults existing, good lateral extension and enough thickness cap rock to seal CO_2, high porosity in reservoir rock, huge capacity in storage formations. The biggest coal-fired thermal power plant is located on this site, so the CO_2 transportation costs would be lower.

Refer to America DOE and Japan RITE experiences, we suggested an evaluating formula for effective storage capacity which considered parameters such as storage volume, sandstone percentage in reservoir rock, density of CO_2, site sequestration efficiency in saline aquifer and CO_2 saturation in supercritical phase.

By using the spatial analysis functions of GIS and 3D geological model, this study introduces an unit grid concept to evaluate the effective storage capacity. After Calculating the individual storage capacity of each unit grid and summing all grids of capacity, we can get the total effective storage capacity is about 6 billion tons in Taihsi basin site.

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