Investigation and Assessment of Technical and Economic Viability of CCUS Project in Scotian Shelf, Canada

Introduction

Carbon dioxide (CO_2) sequestration is a technique to store CO_2 into underground formations. Successful CO_2 storage into underground formations depends on many factors such as efficient sealing, no escaping from the storage, and minimum corrosion to injection tubing/casing. Therefore, proper planning involving a thorough study of reaction kinetics of CO_2 with the underground formation is necessary.

Trapping mechanism has lot of importance in evaluating CO_2 sequestration process. Four trapping mechanisms can be identified in CO_2 sequestration, which are: structural, solubility, residual, and mineral trapping. Structural trapping is the primary CO_2 geo-storage mechanism in which the CO_2 is permanently kept immobilized beneath a cap rock by a balance between buoyancy force and capillary force. Solubility trapping involves the dissolution of CO_2 into the fluids present in the formation (oil and water), which depends upon brine salinity, temperature, and pressure. Residual gas trapping consists of storing CO_2 as an immobile gas in the porous media as a result of capillary pressure where relative permeability to CO_2 becomes zero. While in mineral trapping, the CO_2 is trapped as a precipitate of carbonate minerals by interaction with metal cations (predominantly Ca^{2+}, Fe^{2+}, and Mg^{2+}) and is considered the most secure trapping mechanism (IPCC, 2005).

Different researchers have studied the potential of geological basins to store CO_2. Herzog (2001) assessed the potential of CO_2 sequestration through giving the real example of silepner oil and gas field and concluded that capturing CO_2 from power plant that produces high amount of CO_2, will be able to reduce the CO_2 emission. In addition, Beecy and Kuuskraa (2001) used “Low-Carbon World” approach which envisioned significantly greater advances in energy that involves the increased use of renewables and nuclear energy resources and a “High-Carbon World” approach with less emphasis on energy efficiency, renewables, and producing hydrocarbons at same time. They concluded that in the High-Carbon World case, sequestration needs to provide over 400 million tons of carbon emissions reduction in 2020 and over 1900 million tons of carbon per year in 2050. Furthermore, Bradshaw and Dance (2005) conducted studies to assess the CO_2 storage capacity worldwide in the earth. They reported that the geographical and technical relationships between emission sites and storage locations as well as the economic drivers affect the degree to which geological storage of CO_2 will be implemented in the future. In addition, they reported that major petroleum provinces are the most likely place for CO_2 storage to occur.

Moreover, Craig et al. (2014) compared the use of volumetric and dynamic estimation for CO_2 storage in deep saline water. Results from their work demonstrated that using suitable method (volumetric and dynamic), storage terms (open or closed system), and duration of CO_2 injection can be used to gain appropriate CO_2 storage efficiency. Based on the dynamic results, for open system condition, CO_2 storage efficiency would be 0.55% to 1.67% as opposed to 0.21% in a closed system. Furthermore, another study conducted by Guo et al. (2019) in which the influence of CO_2 and nanoparticle stabilized foam injection was examined to evaluate CO_2 sequestration in saline aquifers using microfluidic device saturated with brine. It was determined that foam injection showed a substantial increment in the CO_2 storage up to 40% more than gas injection. Thus, using nanoparticle is vital in keeping the foam quality, reducing possible leaks, and maintaining a safe CO_2 storage system.

In this research study, qualitative and quantitative assessment of the capacity of potential storage options of CO_2 in Scotian Shelf was conducted using the volumetric and material balance methods. The volumetric study was conducted on four deep saline aquifers using the data from geological maps, seismic, well logging and core analysis considering the storage efficiency of each of the examined aquifers. After that, the CO_2 storage capacity of six depleted gas fields was determined using the production data where analytical equations was applied. Meanwhile, the CO_2 storage capacity of other depleted and stranded fields was determined using published data available in previous work. Finally, the risk analysis and surface facilities design were conducted, and economic evaluation was performed.

Geological Overview

Scotian Basin is located on the coast of Nova Scotia in Canada and extends for about 1,200 km from the Yarmouth Arch / United States border in the southwest to the Avalon Uplift on the Grand Banks of Newfoundland in the northeast. The total basin area is 300,000 km^2 including a part on the passive continental margin. During the syn-rift phase (mid-Triassic), dominance of red beds and evaporate deposits occurred while grabens acted as loci for the clastic deposition. Afterwards, a break-up unconformity (BU) resulted which was coinciding with the final separation of Africa and North America. The BU resulted in a heavily graben faults and complex terranes of basement with highs along the Scotian margin which underwent a significant degree on peneplanation. Western uplift resulted in an influx of clastic sediments along with carbonate deposition and establishment mixed energy in Laurentian Subbasin, and slightly later in the Sable Subbasin (Sable Delta complex). Similar progradation in the southwestern region close to US-Canada border called Shelburne Delta. These sediments originated from Gulf of St. Lawrence region of latest Devonian to Permian sediments (Pe-Piper and Piper, 2004; Pe-Piper and MacKay, 2006). First phase of delta progradation into those subbasins recorded by MicMac formation proved by channel distribution and delta front fluvial sands cyclically interfingering with pro-delta and shelf marine shales of the Verrill Canyon Formation. The establishing of St. Lawrence River in early Cretaceous led to increase the clastics in Scotian Basin and covering the carbonates of La Have and Banquereau Platforms. Within the same period, Missisauga formation founded with mainly thick sand-rich, carbonate shoals, and shallow marine shelf successions. Sable Delta progradation covered several subbasements and platforms, while Shelburne Delta disappeared due to the exhaustion of its river's sediment supply. Instability of cretaceous and mid-Jurassic sediment deposition along the shelf caused subsidence and seaward-dipping development (act as trap). As a result of that sediment loading, salt mobilized to form complex morphologies. Shelf-edge delta complexes formed at the edges of the continental shelf along with rivers that incised exposed outer shelf sediments during low sea level periods (Cummings and Arnott, 2005; 2006). Complex delta provided turbidity associated with other mass transport deposits to the slope, opening the path to have potential reservoirs in canyons and intra-slope mini basins during Mid-Jurassic to Cretaceous.

During late early cretaceous the shelf was covered by thick shale succession called Naskapi which is a member of the Logan Canyon caused by marine transgression. This shale has been interbedded periodically by coarser classics (Cree and Marmora members) during Aptian-Cenomanian. Low relief morphology allows deep marine shales and limestones to accumulate and cover the sand that deposited along coastal plain. Scotian basin faced increase in sea level at the end of cretaceous which encourage marine marls and chalky mudstones deposits (Wyandot Formation). Eventually these deposits buried by Banuereau formation (Tertiary mudstones & conglomerates). Unconsolidated sediments were eroded and transported by fluvial into deep water and abyssal plain when sea level fall at the margin. Late tertiary period, glacial and marine sediments took place for hundred meters along the outer shelf and upper slope.

Methodology

The workflow followed in this study is shown in Figure 1 where it starts with collecting data from different sources including seismic, well logging, core analysis, well data, and geological maps (structure contour, facies, and isopach). After that, data have been analysed and reservoir characterization have been conducted. One should note that suitable values have been assumed from previous studies for any missing parameters. After that, a volumetric study has been performed for each formation of the saline aquifers where first geological model was built (structural framework) then shale volume and facies attributes (porosity and permeability) were determined. Then, pore volume has been converted to storage capacity using a storage efficiency, which depends on the characteristics of each aquifer and formations, using the following equation (Halland et al., 2013):

$$M = PV \times E \times \rho_{CO_2}, \tag{1}$$

where M is amount of CO_2 in tons, PV is pore volume, E is storage efficiency, and ρ_{CO_2} is density of CO_2. Afterwards, a seal evaluation study was performed to ensure safe and secure storage of CO_2 in different aquifers. Once the seal evaluation is performed, risk analysis has been determined using Pallisade @risk simulator.

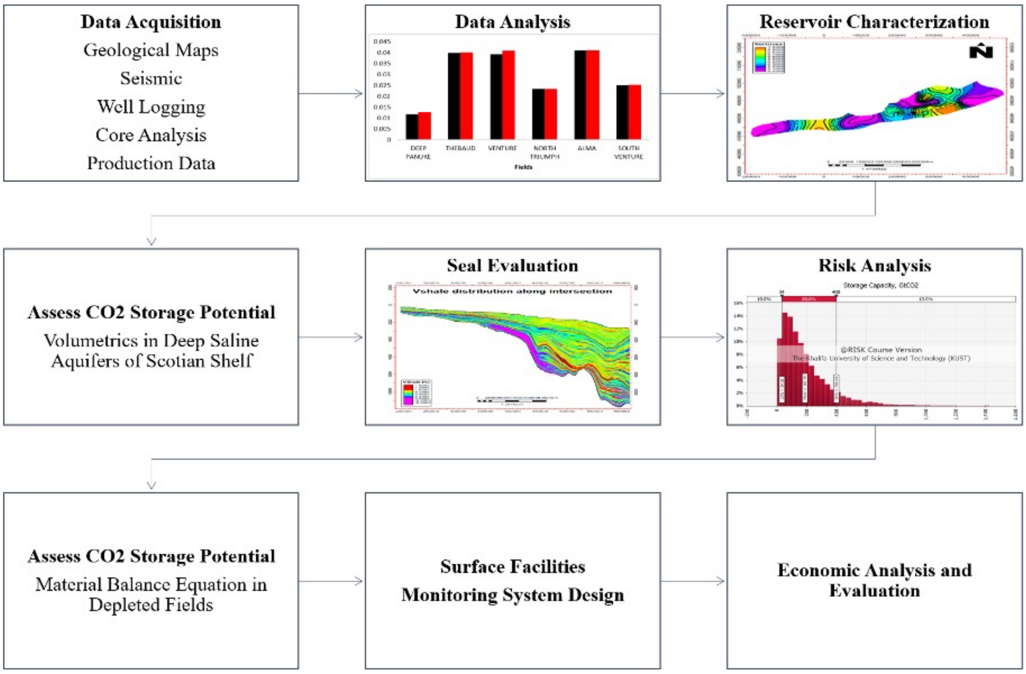

Figure 1 *Workflow for CO_2 storage potential evaluation of Scotian Shelf.*

Then, for calculating the CO_2 storage potential for the depleted gas fields, the following material balance equation was used (Gammer et al., 2011):

$$CO_2\ Capacity\ (MT) = \left(G_p \times B_g + W_P \times B_W - G_i \times B_g\right)\rho_{CO_2}, \qquad (2)$$

where G_p is cumulative gas production, B_g is gas formation volume factor, W_P is the Cumulative water production, B_W is formation volume factor, G_i gas injection, and ρ_{CO_2} is density of CO_2.

On the other hand, for calculating the CO_2 storage potential for other depleted and stranded fields, the following equation was used:

$$M_{CO2t} = URRgas_{stp} \times B_g \times \rho CO2_{2r}, \qquad (3)$$

where M_{CO2t} is the mass of CO_2 stored in tons, $URRgas_{stp}$ is the ultimate recoverable reserves of gas at standard conditions data, B_g is the gas formation volume factor, $\rho CO2_{2r}$ is density of CO_2 at reservoir conditions in ton per m^3. Furthermore, the surface facilities design and monitoring system were conducted. Finally, the economic analysis of the whole process was performed.

Conclusions

In this research, the CO_2 sequestration potential of Scotian Shelf was successfully evaluated. Based on the findings of this study, the following conclusions can be made:

- Different potential storage options were assessed i.e., deep saline aquifers, depleted gas fields, and stranded fields in the Scotian Shelf based on the volumetric and material balance approaches.

- After an extensive thorough investigation, the Scotian Shelf showed a high prospective site to store around 660 Gtons of CO_2.
- For the monitoring and surface facilities design for CO_2 sequestration potential in Scotian Shelf, integrated and energy-efficient compression system that is powered by wind energy is recommended for this project.
- Based on the economic analysis and evaluation, an annual emission of around 12 Mtons of CO2 is produced from nearby areas near Scotian Shelf. A profit of US$ 2 billion can be generated if the produced CO2 is captured and stored.

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