Evaluation of caprock integrity for geosequestration of CO2 in low-temperature reservoirs (Flexible Funding 2022). [Blog post]

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More information is available on UKCCSRC's flexible funding project webpage, available from: https://ukccsrc.ac.uk/research/flexible-funding/flexible-funding-2022/efenwengbe-aminaho/

Evaluation of Caprock Integrity for Geosequestration of CO_2 in Low-Temperature Reservoirs (Flexible Funding 2022)

Efenwengbe Nicholas Aminaho at Robert Gordon University (Aberdeen) was awarded funding in the UKCCSRC's Flexible Funding 2022 call to look at the "Evaluation of Caprock Integrity for Geosequestration of CO_2 in Low-Temperature Reservoirs".

Carbon dioxide (CO_2) geosequestration refers to its injection and storage in underground formations. It has been proven to be a good option for reducing atmospheric emissions of CO_2. Carbon dioxide can be injected and stored in salt caverns, aquifers or depleted oil and gas reservoirs. However, a larger amount of CO_2 can be stored in aquifers and depleted oil and gas reservoirs, compared to salt caverns. Generally, underground reservoirs for fluid storage are overlain by a caprock (a low permeability rock that acts as a seal), to prevent reservoir fluids from migrating to the earth's surface. During carbon capture, a small amount of some gas impurities (such as hydrogen sulphide [H_2S], sulphur dioxide [SO_2], nitrogen oxides [NO_x], etc.) are co-captured with CO_2. Therefore, during geosequestration, some amount of gas impurities are co-injected with CO_2 into the reservoir, and fluctuations in pore pressure in the reservoir might result in the reservoir fluid migration to a few layers in the caprock closer to the reservoir-caprock interface, when the capillary (entry) pressure of the caprock is exceeded or due to diffusion of gas stream over a long period. Therefore, it is important to investigate the impact of co-injecting and storing these gas impurities with CO_2 in underground formations. Hence, in this research project, the changes in porosity, permeability and brittleness index of the formations during CO_2 geosequestration were evaluated.

Two-dimensional (2-D) radial flow models were developed to simulate CO_2 geosequestration, with or without a gas impurity (2.5 mol% H_2S or SO_2). One of the models was developed to simulate cyclic injection and withdrawal of CO_2 through a dual-tubing string well completion system (Figure 1). In this approach, the CO_2 gas stream is injected for 10 years, before the well is shut-in for 3 months, then some amount of the injected gas is withdrawn for 2 years before the well is shut-in again for another 3 months. This cycle was repeated up to seven times. The motivation for developing the model was based on the possibility of withdrawing some of the injected CO_2 to produce low-carbon and sustainable fuels such as methanol and hydrogen in the future. The other model (non-cyclic approach) was based on CO_2 geosequestration without any consideration for withdrawing the injected gas in the future (Figure 2). The integrity of the formations was evaluated based on their changes in porosity, permeability and brittleness index during CO_2 geosequestration. To investigate the change in the brittleness index of the formations (sandstone and carbonate reservoirs, and shale caprock) during CO_2 geosequestration, a mathematical model was developed, taking into consideration the molecular weight, the molar volume and volume fraction of minerals in the formations, as well as their relative level of brittleness. Furthermore, a machine learning model was developed to evaluate the impact of fluid chemical properties and petrophysical characteristics of the formations on their brittleness index.

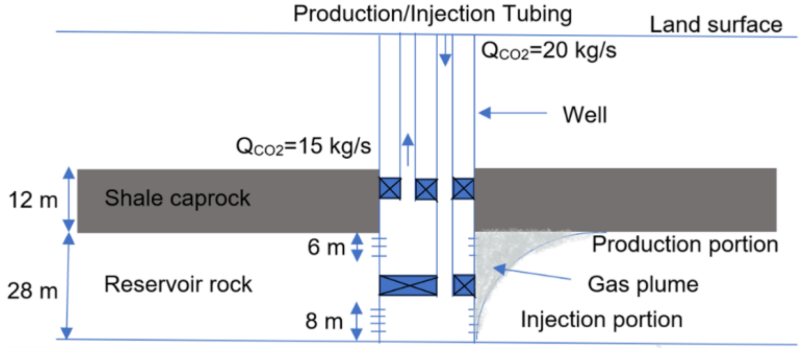

Figure 1 – cyclic approach of CO_2 geosequestration

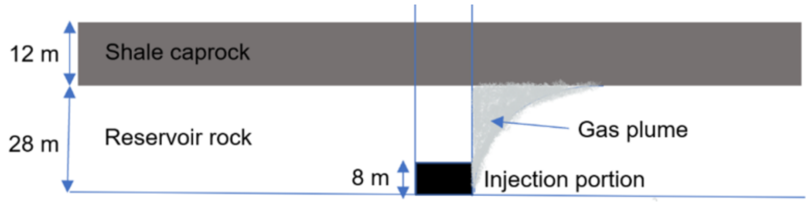

Figure 2 – non-cyclic approach of CO_2 geosequestration

The findings of the study revealed that wellbore instability issues and migration of fines from the reservoir towards the well or subsurface production facilities are key challenges during the implementation of the cyclic approach of CO_2 geosequestration. This was not the case for the non-cyclic approach of CO_2 geosequestration. However, the major challenge for the non-cyclic approach was anhydrite precipitation during CO_2-SO_2 geosequestration, which resulted mainly in a decrease in porosity, permeability and brittleness index of the reservoir, especially the sandstone reservoir and carbonate reservoir (mainly made up of calcite mineral). Anhydrite precipitation was not a major issue for the carbonate reservoir made up of calcite and dolomite minerals. The dolomite mineral dissolution resulted in calcite precipitation, thereby limiting anhydrite precipitation. The impact of H_2S co-injection with CO_2 was negligible compared to SO_2 during the geosequestration of the CO_2 gas stream. In all the numerical simulations, the brittleness index of the shale caprock decreased slightly, which is desired for a good caprock (an increase in brittleness index would have increased the chance of fracturing when the caprock deforms). At the low-temperature condition (up to 40^0C) considered in this study, the changes in porosity and permeability of the shale caprock are less than 1.2% and 3.9%, respectively; while the changes in porosity and permeability of the reservoirs are significant and up to 7.9% and 36.3%, respectively.

It appears that a carbonate reservoir (mainly made up of calcite and dolomite minerals) might be suitable for the geosequestration of CO_2 (with or without some amount of H_2S or SO_2) for a short period (up to 100 years), without significantly altering its brittleness index. A significant decrease in the brittleness index and petrophysical properties (porosity and permeability) of the sandstone reservoir was observed during CO_2 (with 2.5 mol% of SO_2) geosequestration. However, sandstone reservoirs might be preferable for longer periods of geosequestration (non-cyclic approach) to promote mineral trapping of CO_2.

Overall, for all the geosequestration approaches and cases, the change (or decrease) in the brittleness index of the shale caprock is negligible, thereby maintaining its integrity. Therefore, shale caprocks are suitable for geosequestration of the CO_2 gas stream. Based on the machine learning model, the change in the brittleness index of the formations is influenced more by the change in sulphate (SO_4^{2-}) concentration of the formation fluids, compared to other fluid and rock properties considered. The slight change in the brittleness index of the formations during CO_2 geosequestration, or the significant decrease in the brittleness index of the sandstone reservoir for the CO_2-SO_2 case, suggests that if these formations fracture during CO_2 geosequestration, the fracture would not be due to an increase in brittleness of the formations. The fracture might be due to other events or conditions, such as an increase in formation pressure during the CO_2 geosequestration period.