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Carbon (CO_2) Capture and Sequestration (CCS) into Deep Saline Aquifers. Z. U. Yussif, A. Ahangar Asr, M. Babaie

Abstract
Carbon dioxides capture and Sequestration (CCS) is a widely deliberated discussed topics for the minizine CO2 emissions. Carbon storing in deep saline aquifers is a feasible option in the reduction of CO2 emission. The technique however requires the capturing of anthropogenic CO2 from the exiting process and fossil-fuel power plants, and compression for the transportation in either pipelines or tankers for its storage in the deep saline aquifers. The method is characterized with potential issues of evaporation of the brine during CO2 injection operations due to high formation of salinity and hence near well bore formation dry out effect which in turns causes salt precipitation on the CO2 injection rate. This salt precipitation will cause a significant reduction on the permeability and the porosity of the medium. Brines with different NaCl concentrations were prepared as; 3wt.%, 8wt.%, 13wt.% ,18wt.% and 22wt.%. Their salinity, density and viscosity were measured. The core flooding test was carried out in three distinct stages. The initial stage of the core flooding test for the samples (Leopard and Berea Upper Gray) were saturated in distilled water blended with CO2 to determine the CO2 flow rate at differential pressures. The second stage samples saturated in a low salinity brine (3wt.%) concentration of NaCl to measure the CO2 flow rate at dissimilar differential pressures. It was found that, the was a reduction in the volume of CO2 collected with time and the was a greater reduction in the volume of the CO2 using the Berea Gray core sample. The final stage is the core flooding test with the sandstone core samples saturated in a higher salinity brine (22wt.%) concentration of NaCl to measure the CO2 flow rate at dissimilar differential pressures. At the end of the core flooding test, it was observed that, the was a porosity and permeability damage when CO2 was injected in the core samples saturated in the formation brine solutions.

Introduction
Greenhouse gases in the atmosphere which are mainly (water vapor, Carbon dioxide (CO2), Methane (CH4), Nitrous oxide (N2O) and Ozone) are gases so called as both absorb and emit radiation within the thermal infrared range. The greenhouse gas level has been in the increase with the start of the industrial era in the 1700's and hence the phenomena of global warming due to the increase in the concentration of these gases in the atmosphere. This process is the ultimate cause of the greenhouse effect. (IPCC 1990). It's a well propended scientific fact that, these Greenhouse Gases (GHGs) affect significantly the Earth's temperature as without them it was predicted that, the Earth's surface would be about 33 ^{0}C colder than the present 14 ^{0}C averagely. Hence techniques of carbon capture and storage (CCS) as well as Mitigation of global warming procedures need to establish as necessary to reduce the GHGs concentration at a certain level and in turns limit the increase of the global temperature. Major research works focus more on the carbon dioxide due to it large quantity in the atmosphere as it has the highest percentage of the total GHGs emissions.

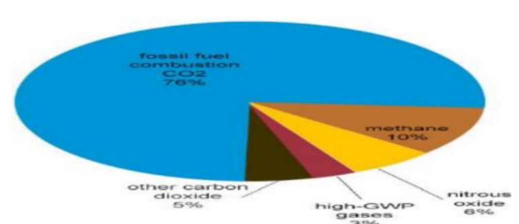

Figure 1: percentage of gases in the atmosphere. Source (*C. A. R. Schlögl, A. Azapagic, "Vovel carbon capture and utilisation technologies " SAPEA, Berlin, 2018).*

Carbon Capture and Storage (CCS) and Geological Storage is the most promising combination of technologies of reducing the contents CO2 in the atmosphere hence emission control. It is the process of capturing the waste carbon from primary sources such as fossil fuel power plant and other industries flue gases, transporting and transmitting it to a storage site by pipelines or ship, injecting it in the subsurface in underground geological formation for permanent storage. The geological storage of carbon dioxide (CO2) is accomplished by injecting it into a rock formation below the Earth's surface with a relatively high-density (supercritical state) as it is neither strictly gas nor liquid at this form with a known pressure and temperature.

Aim and Objectives
This dissertation is aimed to accomplished and established the effect of Sodium Chloride (NaCl) precipitation on CO2 storage efficiency and study the dilution of brine concentrations with different salinities in improving the injectivity. This aim will realize in the objectives below; 1. To carry out core flooding tests to mimic reservoir conditions for (Berea Upper Gray and Leopard) sedimentary sandstone core samples, which were saturated in different brine concentrations and injecting with CO2. 2. To examine the effect of brine concentrations (NaCl wt.%) on the petrophysical properties of the core samples before and after core flooding test. 3. To determine the porosities, the liquid and gas permeabilities of the stated core samples. 4. Providing an overview and discussion of the relevancy of the various

physical and chemical processes to be associated with the geological storage of the CO2 at a site and thereby serve as a bridge between the detailed process discretions and modelling techniques.

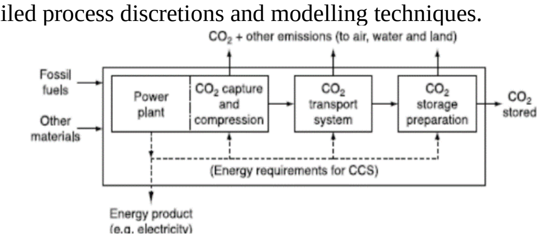

Figure 2.0: Illustrates the steps involves in CCS project (source R. Miri and H. Hellevang, "Salt precipitation during CO2 storage—A review," International Journal of Greenhouse Gas Control, vol. 51, pp. 136-147, 2016.)

Global Worming and The Role of CO2 Emission
The word global warming has been the common research point of all countries and academic experts in the recent years due to the realization and increasing in the global temperatures universally. It is clear to the environmental experts that, the emissions of CO2 and other GHG are liable to the global warming as in recent years the concentrations of GHG in the atmosphere has increase with 280 ppm CO2 equivalent to about 450 ppm CO2. And after the industrial revolution the global average temperature increases to about 0.76 ^{o}C , the global surface temperature had increase to about 0.2 ^{o}C per decade. Carbon dioxide is a main GHG with a very high percentage thus a rise in the concentration of CO2 leads to a corresponding rise in the mean of the atmospheric temperature, a phenomenon known as global warming which have a dramatic environmental significances, such as rising sea levels, loss of fragile ecosystems, increased intensity of meteorological phenomena and increased frequency of extreme droughts and floods. Therefore, new technologies are needed to mitigate the effects of global warming by having a system that will to stabilises this rises in the CO2 concentration levels and manage CO2 emissions and hence greatly reduces the amount of CO2 emitted into the atmosphere.

CO2 Capture and Storage Options
As a new technique of CO2 justifying and decreasing GHG from the energy area, the subsurface underground storing or geological sequestration of CO2 is gradually purchase respect throughout the world. The storage of CO2 in geological subsurface formations is an attractive greenhouse mitigation choice for large reduction in atmospheric release.

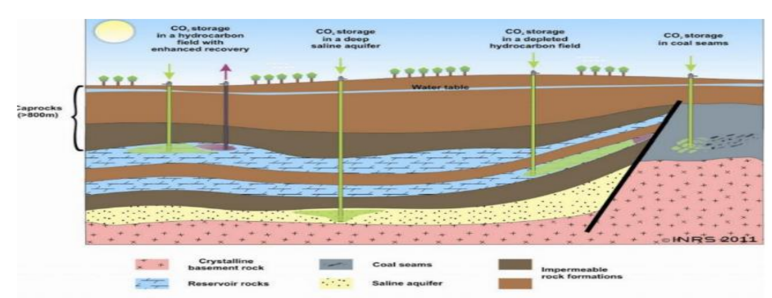

Figure 3: *Different types of reservoirs for the geological storage of CO2. Source (Q. L. B. Cai, G. Liu, L. Liu, T. Jin, H. Shi, "Environmental concern-based site screening of carbon dioxide geological storage in China," Scientific Report Beijing, 2017).*

CCS into Deep Saline Aquifers
Deep saline formations have been recommended as promising storing places of the realize CO2 due to their great abundance and theoretically large volume. The IEA – GHG guess potential storage volume in deep formations of 8 x 1011 tons CO2 in northwest Europe. They present a tantalizing resource for global storage of CO2. However, they remain relatively unexploited in most regions of the world thus, they required much longer lead times that could be considered as viable for geological subsurface storage of CO2, and they are characterized with some setbacks. One of such is that the potential efficiency of the caprock acting as a seal in avoiding pollution of surface groundwater resources by CO2 is regularly untested past to CO2 injection. Additional problem is that there are often limited quantities of data obtainable for site description, needing important calculation charges.
Saline aquifers are permeable, geological formations that contain salty water and are considered a viable option for disposing of CO2 emissions because of their large potential capacity for CO2 storing. The pore space of the sedimentary sandstone that can be employed by injected CO2 is measured by reservoir heterogeneity, gravity separation, movement and the effectiveness of the injected CO2. From industrial opinion, the main concerns of CO2 disposal in the aquifers are connected by, 1. The accessible storage volume. 2. The characterization of suitable aquifer. 3. The injection flow rate of CO2 during the injection. 4. The attendance of cap rock of low permeability.

Trapping Mechanism
Depending on the rock formation and the reservoir category CO2 can in be surrounded in the subsurface by a number of dissimilar mechanisms. These trapping mechanisms are, (A) Structural and stratigraphic trapping which occurs as buoyant CO2 flows up and becomes trapped against the overlying cap rock (the seal) usually in a dome-shaped structures.
(B) Solubility trapping where CO2 dissolves into the brine in the reservoir rock and it also occurs to create both natural and manufactured carbonated beverages. (C) Capillary or residual gas trapping is the processes in which the CO2 bubbles are left trapped in the core pores of the rock as CO2 and water flows through the reservoir and water in-fills the pores previously occupied by CO2. This residual process is what occur in the oil reservoir as water replaces oil and prevents full recovery motivating various enhanced oil recovery technics. (D) Mineral trapping is the mechanism that occurs as CO2 is dissolved in the native water reacts with minerals and other dissolved constituents to form new carbonate minerals.

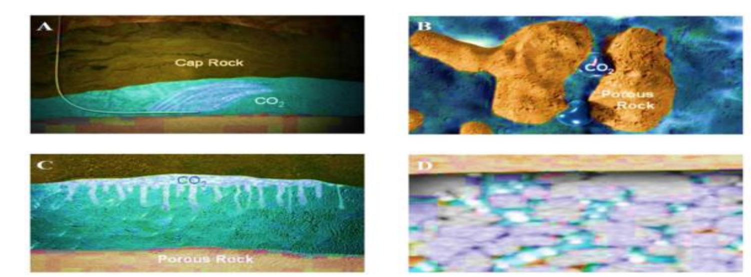

Figure 4: *Trapping mechanisms in saline aquifers for safe CO2 storage. Source (C. M. Oldenburg, "Geological Carbon Sequestration as a Global Strategy to Mitigate CO2 Emissions: Sustainability and Environmental Risk," Lawrence Berkeley National Laboratory, Berkeley, CA 94720, 2019).*

CCS Injection technics
Previous studies carried out on CO2 injection stream performance on the thermodynamic conditions of the process facilities revealed that, the constituents and large volumes of supercritical CO2 can be securely, dependably and strongly injected and stored into the subsurface saline aquifer by modelling many new injection methods. These strategies include, 1. CO2- brine surface injection 2. Typical CO2 injection 3. CO2- alternating brine 4. CO2- water surface mixing.

Risks, Challenges and potential impact OF CCS on the environment
The primary risk in CO2 storage is leakage of CO2, and perhaps displaced brine, into overlying resource bearing layers, protected groundwater aquifers, shallow soil zones, and the atmosphere. Such leakage can potentially contaminate drinking water and other geological subsurface resources, destruction vegetation, and lead to increased atmospheric emissions. Probable leakage pathways include transmissive faults and fractures, although these can often be avoided through careful site selection and characterization and or through active pressure management of the storage site. A more common leakage pathway is along defective wells, particularly in regions with an extremely large number and density of wells. Care must be taken in any storage operation to avoid over pressurization of the injection formation to the extent that fractures can be created in the caprock acting as a seal. In the case of CO2 storage in depleted oil and gas reservoirs, whose pressure has been lowered below the initial

reservoir pressure due to production, regulatory agencies generally allow depressurization until pressure recovers back to its initial value. In these cases, the risk of leakage includes leakage through faulty reservoir wells as possibly through fractures in the caprock developed as a result of thermal stresses if the injected CO2 is significantly colder than the background initial temperature.

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