Comparative Analysis of Six Geologic Sequestration Methods

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Abstract. With the extensive use of fossil fuels[1] since the advent of the industrial age, the amount of carbon dioxide emitted is also increasing dramatically, which has also led to a severe greenhouse effect[2]. The method of carbon capture and carbon sequestration[3] proposed in recent years is a good way to deal with too much carbon dioxide. However, Carbon Sequestration is a new idea without enough practice and verification, and its development is not perfect yet. This paper reviews six commonly used geological Carbon dioxide storage methods and compares the advantages and disadvantages of them. It can be concluded that hydrodynamic force sequestration is the most suitable, effective and promising method of Carbon sequestration[4]. This study aims to provide scientific suggestions and theoretical basis for the future development of carbon sequestration, and it also provides effective help and support for environmental protection.

1. Introduction
As we all know that carbon dioxide is the main gas causing the increase greenhouse effect. In order to curb the speed of global warming and protect the environment for human survival, scientists capture and store carbon dioxide emitted from production and daily life in deep geological formations. According to the stratigraphic depth and geological differences, six different storage methods have been invented based on the continuous research and practice. These six methods are tectonic strata sequestration[5], bound gas sequestration[6], dissolution sequestration[7], mineralization sequestration[8], hydrodynamic force sequestration[9] and coal seam absorption[10]. This paper will compare and analyze these six geological storage methods’ advantages and disadvantages. As the concept of carbon capture and storage has been proposed and applied in the short term, many problems are waiting to be confirmed and resolved. For example, when the salinity of the formation water, the injection rate, the initial porosity or the initial permeability are different, what effect will it have on geological reserves, and what effect will it have on storage time and diffusion rate. This study reviews and summarizes six commonly used carbon dioxide methods, and points out the direction of future research.

2. Analysis

2.1. Tectonic storage
Mechanism: The impermeable layer prevents the gas or one-phase fluid in the liquid phase from migrating and stays here, thus forming a structural stratigraphic trap. When carbon dioxide gas is stored in structural strata, although the buoyancy of carbon dioxide gas is relatively large, it is blocked by the impermeable layer, making it unable to migrate in the lateral and lateral directions. At the early stage of carbon dioxide injection, the tectonic stratum storage begins to work, and it acts on the entire
carbon dioxide geological storage stage. Tectonic stratigraphic storage is the most basic mechanism for geological storage of carbon dioxide and has excellent structural sealing. The porosity of the formation rock is the most direct factor influencing the storage of carbon dioxide. Generally speaking, the porosity of the rock formation is directly proportional to the carbon dioxide storage capacity. The advantage of the tectonic formation storage mechanism is that it takes effect immediately after the carbon dioxide is injected, which is beneficial to engineering construction. The disadvantages are low safety and low carbon dioxide storage potential.

![Figure 1](image1)

Figure 1. Schematic diagram of the pore filling of the rock formation when the structural formation is sealed

2.2. Bound gas storage
Mechanism: During the migration of carbon dioxide in the reservoir, part of the carbon dioxide stays in the pores of rock particles for a long time under the action of gas-liquid interfacial tension, which is bound gas storage. When a large amount of carbon dioxide passes through the porous medium, it is usually isolated in the middle of the rock pores in the form of spherical droplets. Therefore, the carbon dioxide bound in the pores of the rock is proportional to the amount of carbon dioxide passing through the rock. However, this storage mechanism can only suppress carbon dioxide in a large amount when the carbon dioxide passes through the rock and the groundwater re-infiltrates the pore space occupied by the carbon dioxide. Generally speaking, the binding gas storage mechanism is combined with the dissolution storage mechanism, and the carbon dioxide bound in the rock pores will eventually be dissolved in the formation fluid. The binding gas storage mechanism will last for several decades from the injection of carbon dioxide.

On the whole, the advantage of the restrained gas storage method is that the safety is guaranteed to a certain extent, and the risk is slightly lower. The disadvantage is that the storage mechanism will not work until decades after the injection of carbon dioxide, the onset time is slightly slower, which is not conducive to engineering development, and the storage potential of carbon dioxide is small.

![Figure 2](image2)

Figure 2. Schematic diagram of bound gas storage mechanism

2.3 Dissolution storage
Mechanism: When carbon dioxide migrates in the rock pores and is in contact with formation water or crude oil, it will dissolve in it, which is dissolution and storage. Time and the saturation of carbon dioxide in the formation water and crude oil will determine whether the carbon dioxide can be
completely dissolved. The chemical composition of formation water, the composition of crude oil, and the contact rate of carbon dioxide with unsaturated formation water and crude oil will determine the amount and rate of dissolution of carbon dioxide in the formation fluid. The dissolution rate of carbon dioxide is proportional to the contact rate of carbon dioxide and fluid. Over time, when the density of the carbon dioxide-saturated fluid is higher than that of the surrounding unsaturated fluid, the formation fluid saturated with carbon dioxide will migrate downwards toward the center of the basin due to gravity.

Therefore, the storage efficiency of this storage method is higher, and the storage volume is also larger. The time range of dissolution and storage is between 100-1000 years. In summary, the strengths of this method are its high safety, the risk of harm to the environment during the development process is small and it has an abundant storage potential.

However, the dissolution and storage method takes too long to work, and usually takes hundreds of years to start sealing. So it is very unfavorable to actual project development.

2.4 Mineralization storage
Mechanism: When carbon dioxide chemically reacts with rocks and formation water to precipitate carbonate minerals, this is mineralized storage method. The mineral composition, fluid type and chemical reaction process of the formation rock will determine the time of mineralization and storage. The mineral composition of reservoir rocks is different, and the precipitation ratio after the injection of carbon dioxide also changes greatly. The chemical reaction of carbonate formation is very fast; There is no chemical reaction between the basically stable sandstone formation and the quartz particles, or the reaction time is very long. In most cases, the effect of mineralization and storage is very long, and it is speculated that the time scale of storage is 100-10,000 years.

In summary, the advantage of the mineralization storage method is that it is extremely safe and the risk of developing a mineralization storage method is extremely small.

However, the problem is that the mineralization storage takes hundreds or even tens of thousands of years, which is extremely unfavorable. The practical applicability is not high, the carbon dioxide storage capacity is not large enough, and the storage potential is not high.

2.5 Hydrodynamic storage
Mechanism: The condition of hydrodynamic storage is hydrodynamic trap. The formation condition of a hydrodynamic trap is that the flow pressure of groundwater in the seepage process is opposite to the buoyancy direction of carbon dioxide migration, and the magnitude is approximately equal. At this time, carbon dioxide can be blocked and accumulated, forming a hydrodynamic trap. The location where the hydrodynamic storage mechanism takes effect is the deep saline layer under the enclosed formation. The formation water in deep saline aquifers flows in a regional or basin-level flow system on a longer time scale. In this type of system, the fluid velocity unit is generally cm per year, and the migration distance unit is generally several tens or hundreds of kilometers. Carbon dioxide can move along the dip of the stratum at a very slow speed under the action of buoyancy, and it still takes tens of thousands or even millions of years to move to the shallow emission zone. During this period of migration, other storage mechanisms will also take effect, and eventually no carbon dioxide will reach the shallow formation. In addition, carbon dioxide may also encounter structural stratigraphic traps and be trapped. The hydrodynamic storage mechanism starts to work immediately after the carbon dioxide is injected.

On the whole, the advantage of the hydrodynamic storage method is that the action time is extremely short. After the carbon dioxide is injected, the hydrodynamic storage mechanism works immediately, which is extremely convenient for project implementation. Another major advantage is that the estimated storage of carbon dioxide in deep saline aquifers is extremely high, and there is a great potential for carbon dioxide storage.

As for the obvious disadvantage of the hydrodynamic storage, the safety is very low, and the risk in the carbon dioxide storage process is higher.
2.6 Coal seam absorption

Mechanism: The adsorption energy of coal seams for carbon dioxide is much higher than that for methane and other hydrocarbon gases, so coal seams have great potential for carbon dioxide storage. After the carbon dioxide is injected, the coal seam’s adsorption mechanism for carbon dioxide begins to work. Because the methane in the coal seam is released during the process of storing carbon dioxide, methane is more harmful to the atmosphere than carbon dioxide. In addition, since the permeability of coal decreases as the depth of the coal seam increases, after the injection of carbon dioxide into the coal seam, the expansion of the volume of coal will also significantly reduce the permeability of the coal, and the ability to store carbon dioxide in the coal seam will also decrease. If the pressure is too low, carbon dioxide will be released. The ability of coal seams to adsorb carbon dioxide is relatively limited, and the research on coal seam adsorption is just in its infancy.

Generally speaking, the advantage of coal seam absorption is that it has a large carbon dioxide storage potential.

The problem is that the process of coal seam absorption and storage of carbon dioxide is interfered by other gases, volume expansion, pressure and many other factors, which make the coal seam’s ability to absorb carbon dioxide extremely limited, so the actual effect of coal seam absorption and storage of carbon dioxide is very unsatisfactory.

3. Comparative analysis

Figure 4. Schematic diagram of the action time scale of various carbon dioxide geological storage mechanism (CLSF, 2007)
Figure 5. Schematic diagram of the contribution ratio and safety of various storage mechanisms over time (CLSF, 2007)

Table 1. The world's carbon dioxide storage capacity in reservoirs assessed by the Intergovernmental Panel on Climate Change (IPCC)

| Storage type          | Global carbon dioxide storage (10^9 t) | Percentage of total emissions from 2005-2050 (%) |
|-----------------------|----------------------------------------|-----------------------------------------------|
| Oil layer             | 690                                    | 34                                            |
| Gas layer             | 120                                    | 6                                             |
| Deep saline layer     | 400-10000                              | 20-500                                        |
| Unminable coal seam   | 40                                     | 2                                             |

The coal seam storage method is affected by other gas interference, volume expansion, pressure changes and other factors in the process of carbon dioxide storage in the coal seam, which makes the efficiency of carbon dioxide storage very low. The current level of technology cannot solve these problems well. Therefore, when comparing and analyzing the most promising geological storage methods, the coal seam storage method may not be considered. Based on the above analysis and Figure 4, it can be concluded that after carbon dioxide is injected, the sequence of action time from short to long is hydrodynamic storage, structural formation storage, bound gas storage, dissolution storage and mineralization storage. According to Figure 5, it can be known that the longer the effective time of the storage method after injection is stopped, the higher the safety of the method. The order of safety performance from low to high is: dynamic storage, structural stratigraphic storage, combined gas storage, dissolution storage and mineralized storage. From the above analysis and Table 1, it can be seen that the carbon dioxide storage capacity of the five geological storage methods in descending order is mineralized storage, bound gas storage, structural stratigraphic storage, dissolved storage and hydrodynamic storage.

4. Conclusion
This study summarizes and compares six carbon dioxide methods. It can be concluded that from the engineering point of view, the most promising geological storage method is hydrodynamic storage. From the perspective of safety, the most promising geological storage method is mineralization storage. From the perspective of storage potential, the most promising geological storage method is hydrodynamic storage. Considering the above three aspects, the best choice is hydrodynamic storage. This review provides scientific suggestions for the development direction and key research areas of
geological storage on a certain theoretical basis, and makes contributions to the suppression of global warming.

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