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Comparison of Three Concepts for Offshore CO2 Temporary Storage and Injection Facilities

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Abstract

This study proposed three concepts for the offshore temporary storage and injection facility for ship-based CO2 disposal in the deep sea geological formations. The first was floating on the sea surface, another was placed in the mid-water, and the last was stranded on the seabed. The first received the pressurized liquid CO2 from the CO2 carrier and stored it under an elevated pressure. As injection continued, the liquid level would drop, and the vaporized CO2 was supposed to make up the decrease in the liquid volume. The mid-water and stranded ones had the same functions of buffering storage and injection as the floating one. Their working principle, however, was strikingly different from the last. They were supposed to be installed in a depth where the hydrostatic pressure was greater than the liquid CO2 vapor pressure. Under the circumstance the liquid in the mid-water and stranded ones was in subcooled liquid state. The pressure difference between their interior and the surrounding water was negligible, only due to the density difference. This implied that the main structure for them did not have to be a pressure vessel.

Keywords: CO2, Temporary storage; floating storage; midwater storage; stranded storage

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Nomenclature

AUV	autonomous underwater vehicle
CCS	carbon capture and storage
ECBM	enhanced coal bed methane recovery
EIA	energy information administration
EOR	enhanced oil recovery
GBS	gravity-based structure
GHG	green house gas
ISIF	intermediate storage and injection facilities
IEC	international energy agency
LCO2	liquid CO2
OECD	organization for economic co-operation and development
ROV	remotely-operated vehicle
TLP	tension leg platform

1. Introduction

In the landscape of the world energy mix, usage of fossil fuel has been ever increasing, and so has the CO2 emissions. There are many ways of decrease CO2 emission such as blocking the CO2 emissions; capturing the CO2 and re-handling CO2, or capturing and storaging CO2 into storage site.

The CO2 capture and storage (CCS), which consists of CO2 capturing, CO2 transporting, CO2 injection and CO2 storage stages, is considered solution to reducing green house gas emissions. The IEC within the OECD indicated that the CCS should cover almost one fifth of the total reduction [1].

From the viewpoint of storage capacity, both onshore and offshore are promising sinks. Onshore storage, however, is restricted because of social and environmental conditions. Offshore sediments or seabed are considered the promising sink for the CCS chain even though they are expensive compared with onshore ones due to their harsh environment and long-distance transportation [2]. To cover the offshore storage it is impossible to avoid long-distance transport stage.

There are two transport ways – pipeline and carrier. The pipeline transportation is suitable to handle a large amount of CO2 without intermediate storage. Capital investment of pipeline is much higher than ships when the distance from CO2 source to storage is stretched [3]. Safety and economic considerations for pipeline transport have been well studied by some researchers [4, 5]. The ship transportation is more flexible than pipeline in terms of cargo capacity and storage location. For example, ship transporting is considered in the first demonstration project of Korea because of the restricted onshore condition and long-distance promised offshore sink.

When the carrier type transportation is under consideration, there are some problems with this CCS chain. Between the injection and storage stage, and over the CO2 injection period, the ship must be moored for injection for several days to the storage site condition [6]. Since the ship is expensive, the direct injection from the ship is not good compromising the ship's economy. Another problem is the arrival of a series of carriers. They should be on queue line for injection.

This study suggests one solution which addresses this challenge. An offshore temporary storage and injection facility is inserted into the supply chain to improve the carrier mobility and continuous injection. And offshore temporary storage and injection facility also have separated injection facilities so that all ships don't have to have the injection utility onboard.

2. System description

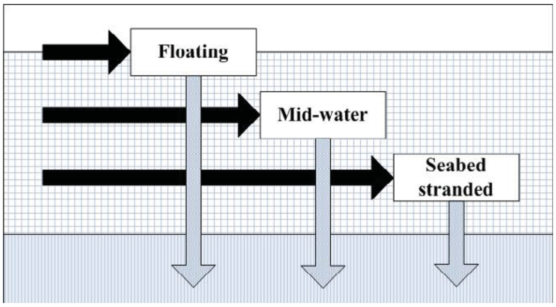

Figure 1 Three types of ISIF

The intermediate storage and injection facilities, in short the ISIF, is an offshore terminal that is capable of receiving LCO2 from the LCO2 carriers, storing the cargo for a while, and injecting it to the storage conditions. Without the ISIF, the carrier should wait until all the cargos within it is injected into the storage. In consequence, it increases the ship's mobility, ship economy, continuous injection and injection terminal.

Main function of this ISIF is buffering. It stores CO2 from the LCO2 carriers and slowly releases it by injecting the cargo into the geological formations. ISIF is divided into two main parts: the intermediate temporary storage part and the injection part. The former one stores high pressure or low temperature CO2. The storage volume should be much more than that of the CO2 carrier to accommodate all the volume of the CO2 carrier. If the volume is more than 2 times the ship's volume, it can be regarded as a CO2 injection terminal.

The main purpose of injection part is to inject CO2 into the storage site safely using the injection pumps. It should be adjustable to changes in the injection rate in harmony with the storage site conditions. This part needs an isolation system to block the injection hole when injection is stopped.

Three types are conceivable depending on the water depth: floating, mid-water and seabed type. The floating type is like a stagnant ship or a barge. An advantage of this type is that the LCO2 carrier can be converted to this without any considerable technological challenges except for the high-pressure cargo containment system and the sloshing within it.

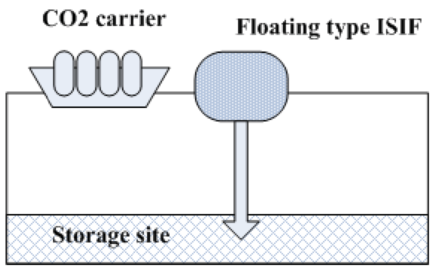

Figure 2 Floating type ISIF

Unlike the current low-temperature and low-pressure cargo containment system, this floating type may need high-temperature and high-pressure pressure vessels to avoid overpressure caused by the boil-off gas. Sloshing will be another issue since the cargo tanks are partially filled as injection proceeds. If high pressure CO2 is to be stored, the tank thickness should be thick increasing the material consumption and the containment tank weight. Another concern is the susceptibility to environmental loads. The floating type is directly affected by wind and wave.

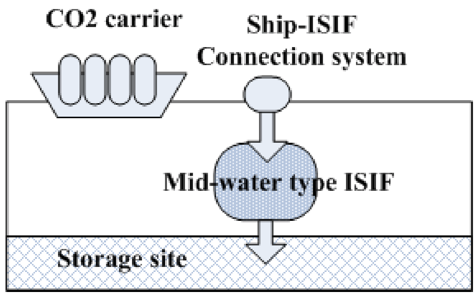

Figure 3 Mid-water type ISIF

A big advantage of the mid-water type compared to the floating type is the design pressure. The floating type is surrounded by the atmospheric pressure. To the contrary, the surrounding pressure of the mid-water type is depth-dependent. When the water depth is equal to the vapour pressure of the stored LCO2, the pressure difference between the surroundings and the cargo vanished. Even below this depth, the LCO2 remains subcooled liquid whose pressure is exactly equal to the surrounding pressure if they are connected to each other. Because of this advantage, the normal type storage tank in ISIF is preferred to the pressure tank. One of other advantages is that the mid-water type can avoid wind load. If depth is a valid deep, then there is no wind effect on the system.

But position keeping is very hard due to buoyancy change depending on stored LCO2 volume. If frequently buoyancy changes then ISIF support will be broken. Wind load effect decrease but internal wave load which caused by difference in sea water density increase. Hard to supply oxygen to mid-water type, so use deep water utilities or connect oxygen line between mid-water and floating utilities system. Cost of utilizes is expensive than ground one. When inspect ISIF monthly or yearly, it use AUV or ROV. ISIF will be located mid-water, so if connect with carrier, it need connection system like a buoy.

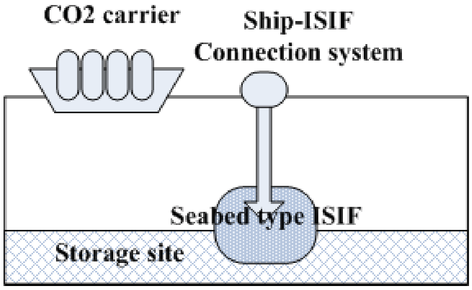

Figure 4 Seabed type ISIF

The last concept type is the seabed type. This type can use concrete as ISIF material which is cheap and heavy because it isn't influenced by buoyancy. Also this type has an advantage of the mid-water type concerning the environmental things even including the internal wave load. This type can be influenced by earthquakes. For considerable water depths, installation and inspection are formidable. In inspection, AUV or ROV can be employed to check the system. In addition other carrier connecting systems like a buoy are necessary. Figure 5 and 6 show how CO_2 is load from the ship to ISIF and offloaded from ISIF to sink.

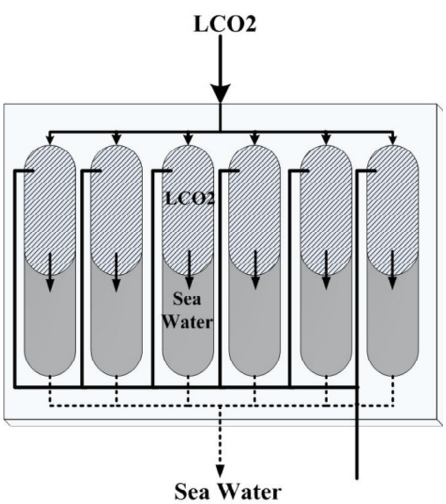

Figure 5 Loading CO_2 from ship

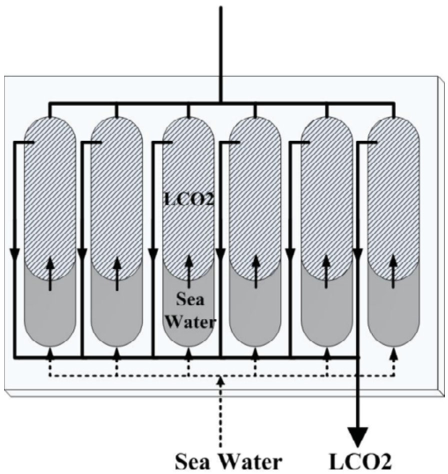

Figure 6 Offloading CO_2 from ISIF

3. Results and Discussion

In order to select the optimal solution, 8 categories are considered for comparison. The comparison results are shown in Table2. The comparison indicates that the floating type ISIF is the best than others since the underwater structure is expensive than the floating structure. Environmental effect, however, may affect the economics of ISIF. The environmental load depends on storage site environmental condition

Table 1 Comparison condition table

Comparison category	
Environmental effect	ISIF will be installed offshore. So, environmental effect is very important. Because of this effect system shutdown, it will become economic loss. Ex) Wind, wave, current, internal wave, earthquake, and so on.
Simple installation	Can't use system after system is made right away. After system is installed right place, we can use system at last. Cost is influenced by installation difficulty.
Mobility	After installation, check the movement of system to other place. Injection will continue lots of months or years according to the storage site condition. So this mobility condition is important.
Complexity	If system is complex then failure rate will increase and cost also will increase. Ex) number of system's utilities.
Continuous management	This system is very expansive so we need to inspect every year. So this condition is important. Ex) inspection difficulty.
System weight	When we install ISIF at right place, weight will influence installation cost. Ex) total weight of system include support body.
Utilities cost	Utilities cost is one of conditions to evaluate economic value. Ex) pump, generator, sensor and so on.
Operating cost	In view of a long-term perspective, operating cost is much important than capital cost. Ex) fuel volume, inspection cost, power consumptions.

Table 2 Comparison of three concepts

Compare condition	Floating type	Mid-water type	Seabed type
Environmental effect	□	△	○
Simple installation	○	□	□
Mobility	○	△	□
Complexity	○	△	△
Continuous management	○	△	□
System weight	○	△	□
Utilities cost	○	□	□
Operating cost	△	□	□

* ○ : small, few, easy, △ : medium, □ : lots of, hard

In order to reduce the environmental intervention, it is requested to install wave breakers around ISIF to block the wave effect on the floating type ISIF. It is needed to design proof mooring line for keep position when sea state condition is more than 7. If possible, then operating loss by the bad sea condition will decrease.

In mid-water type, installation and structure cost is high than floating type because this system is not existence now. And installed depth is mid-water so buoyancy is very important. The concept of existing structures like a GBS, TLP or fixed offshore platform can be one solution of this system.

Seabed type case, cost is much cheaper than other cases. No buoyancy effect, so it can use GBS type structure right away. But mobility, expensive utilities and operating cost are disadvantage of this system. Ground utilities cost is cheaper than deep-sea one because of low rate of deep-sea production utility propagation. But if propagation will increase then the cost of utilities will decrease. Then seabed type has much advantage than other systems.

4. Conclusions

The mid-water type is academically attractive and challenging with industrial significance. Depending on the surrounding conditions, however, it may accompany some drawbacks. For shallow water, the floating type should be the solution with the cargo storage system being pressure vessels. If storage site depth is shallow, then it can’t use mid-water type. The mid-water type needs a valid depth. If the depth is deep enough, the mid-water type or seabed type may be the solution. Even for deep waters, the mid-water type may be inferior to the seabed type if the seabed condition is good for installation. When deep water and seabed installation condition is not good then the mid-water type is the solution of this.

As a result, the current offshore technology can cover floating type. So if ISIF is necessary right away, then the floating type is recommended. Nevertheless, there are some problems like environmental loads or high pressure vessel and so on. Later, deep-sea technology develops as high as of the level of the floating offshore technology. Then, the mid-water type or seabed type structure will be a promising solution of CCS.

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