IDENTIFICATION OF POTENTIAL HAZARDOUS EVENTS OF UNLOADING SYSTEM AND CO_2 STORAGE TANKS OF AN INTERMEDIATE STORAGE TERMINAL FOR THE KOREA CLEAN CARBON STORAGE PROJECT 2025

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ABSTRACT

Carbon capture and storage (CCS) is regarded as one of key technologies to meet global greenhouse gas emission reduction goal. In this manner, South Korea is developing a one-million-ton-scale offshore CCS project to reduce national greenhouse gas emission, entitled the Korea Clean Carbon Storage Project (KCCS) 2025. In this project, the CO_2 is captured from power plants on coast, loaded to CO_2 carriers, and transported to an intermediate storage terminal, which is located on shoreline nearby offshore storage reservoirs at the Ulleung Basin. Then the CO_2 is exported via an offshore pipeline to offshore platform for injection to geological storage site for a permanent containment. Since the concept of the KCCS 2025 includes CO_2 carriers as a transportation method, it requires an intermediate storage terminal that receives the CO_2 from carrier and send out continuous CO_2 flow to the offshore pipeline after the pressurization of CO_2 to higher than 100 bar. The intermediate storage terminal will consist of (1) unloading system, (2) CO_2 storage tanks, (3) LP pumps, (4) a reliquefaction package, (5) a vent stack and (6) HP pump and injection pump (a booster station). Because there are few actual projects with an intermediate storage terminal worldwide, researches on intermediate storage facilities are insufficient. To support an optimal concept design of the intermediate storage terminal for the KCCS 2025, this study identified the potential hazardous events for the unloading system and the CO_2 storage tanks. For the unloading system, an unloading arm and LCO_2 recirculating line are found to be major components causing serious damage in case of accident. In the case of the CO_2 storage tanks, where large amounts of CO_2 are stored, they can cause serious damage due to large amounts of CO_2 leakage when the tanks are ruptured, over-pressurized, low-pressurized, overcharged, etc. Because hazardous events may pose significant harm to humans or the environment, these results should be considered in the next phases of the project. The results of this study can be helpful for the development of safe CO_2 transportation technology in the future.

Keywords: CCS, CO_2 storage tank, CO_2 storage terminal, hazard, PHA, unloading arm

1 INTRODUCTION

Worldwide efforts are being made to reduce GHG emissions in response to climate change. As a bridge technology, the importance of carbon dioxide capture and storage (CCS) is emphasized, which captures CO_2 from a large emission sources such as thermal power plants, and permanently stores in sediments between 800 and 3,000 m underground [1]. In Korea, the industrial structure is focused on manufacturing, and therefore, it is necessary to make structural changes in the industry to reduce CO_2 emissions in Korea. Various practical measures are being taken by the Korean government. As part of these efforts, the Korean government is preparing a 1 million-ton offshore CCS project [2].The title of this 1 million-ton offshore CCS project, which is currently in the process of the conceptual design, is Korea Clean Carbon Storage Project (KCCS) 2025. In the KCCS 2025 project, CO_2 is captured from a thermal power plant located on the west coast of Korea and transported to an intermediate storage terminal via CO_2 carriers. Subsequently, the CO_2 is transported to a platform via an offshore pipeline, and then injected to reservoirs located in the Ulleung Basin. What is

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notable about KCCS 2025 is that it uses CO_2 carriers as a transport method from the CO_2 source to the intermediate storage terminal. Because it is very difficult to inject the CO_2 continuously to offshore geological storage site directly from CO_2 carrier, the CO_2 transport method using carriers usually requires a CO_2 intermediate storage terminal. However, there are few studies on a CO_2 intermediate storage terminal, especially on the risk analysis. Based on the conceptual design of KCCS 2025, in this study, preliminary hazard analysis (PHA) is conducted on two facilities of the intermediate storage terminal, the unloading system and the CO_2 storage tanks. The PHA results of this study can be important on the reliability and risk analysis in the FEED study of a CO_2 intermediate storage terminal [3].

2 CO_2 INTERMEDIATE STORAGE TERMINAL

The targets of this study are the unloading system and the CO_2 storage tanks of the CO_2 intermediate storage terminal of the KCCS 2025 project. The CO_2 intermediate storage terminal aims for temporary storage of liquid CO_2 transported through 8K CO_2 carriers. After pressurization and heating process at the terminal, the CO_2 is sent to the offshore platform for injection through the offshore pipeline.

The KCCS project uses three 8K CO_2 carriers to transport liquefied CO_2 from the source to the intermediate storage terminal. The schedule of CO_2 carriers can vary depending on the weather, and the terminal should also act as a buffer station of CO_2 transportation. The temperature and pressure conditions of the CO_2 carrier cargo tank and the CO_2 storage tanks are the same at 1.5 Mpag and -27 °C. The CO_2 intermediate storage terminal consists of six facilities as shown below.

1. Unloading system (including a vapor return arm)
2. CO_2 storage tanks
3. LP pumps
4. Reliquefaction package (including a pressure built-up vaporizer)
5. Vent stack
6. HP pump & injection pump (a booster station)

The unloading system works for liquid CO_2 unloading and vapor CO_2 loading. The CO_2 storage tanks store the CO_2 transported from the CO_2 carriers. The LP pumps act as a pressurizer to send CO_2 in the storage tank to the booster station. Reliquefaction package re-liquefies boiled-off vapor CO_2. The pressure-built up vaporizer produces vapor CO_2 to prevent negative pressure in the CO_2 storage tank. The vent stack serves to release the vapor CO_2 generated in the emergency to the atmosphere. The HP pump and the injection pump are responsible for pressurizing the LCO_2 pressure to around 100 bar, which is suitable for CO_2 injection. In this study, the hazard of (1) the unloading system and (2) the CO_2 storage tanks are analysed, which are considered to have high risks among the above six facilities. The unloading system and the CO_2 storage tanks are described in more detail below.

2.1 Unloading system

When the CO_2 carriers arrive at the CO_2 intermediate storage terminal located in Ulsan port, LCO_2 is unloaded using an unloading arm with 2000 m^3/h rate. The LCO_2 is transported to the CO_2 storage tanks through 24-inch unloading pipeline. The pressure of CO_2 emitted from the CO_2 carrier is designed as 2.1 Mpag considering the pressure reduction in the unloading arm and the unloading pipeline, and the height and storage condition of the CO_2 storage tanks. When LCO_2 is unloaded from the CO_2 carrier, the cargo tank in the carrier should be charged with the vapor CO_2 to prevent negative pressure in the cargo tank. For this purpose, a vapor CO_2 return arm and a vapor CO_2 return line should be installed. To maintain the temperature of the CO_2 unloading line, the recirculation line should be installed and some of the LCO2 separated from the HP Pump should be flowed.

The unloading system is divided into six components and PHA is performed on each component. The first component is the 14-inch unloading arm, which is responsible for unloading the LCO_2 transported through the CO_2 carrier. The second component is the vapor CO_2 return arm, which is responsible for loading vapor CO_2 into the CO_2 carrier to compensate for the negative pressure in the cargo tank. The third component is the 24-inch unloading line, which is the main pipeline connecting from the unloading arm to the CO_2 storage tank. The fourth component is the 8-inch recirculation line that circulates some LCO_2 separated from the booster station to keep the unloading line at a low temperature. The fifth component is a 10-inch vapor CO_2 return line that supplies vapor CO_2 to prevent negative pressure on the cargo tank of the CO_2 carrier. The 6th component is on-off valves.

2.2 CO_2 storage tanks

The CO_2 storage tanks consist of four 5,000 m^3 spherical tanks. The 8K CO_2 transported by the CO_2 carrier is stored in two 4K storage tanks, respectively. At the same time, vapor CO_2 in the tank is sent to the cargo tank of the carrier to prevent the negative pressure. LCO_2 in the one of the rest two tanks is transmitted through the LP pumps to the boosting station, and the other tank acts as a buffer tank. During the CO_2 transmission, negative pressure can be generated in the tank. It is necessary to charge vapor CO_2 from the vaporizer to the tank to prevent any failure of the tank induced by negative pressure.

The CO_2 storage tanks are divided into five components as follows. The first component is the storage tank itself. The second component is the 24-inch LCO_2 charging line that transports the LCO_2 from the unloading system to the CO_2 storage tanks. The third component is the 6-inch LCO_2 transmission line connecting the storage tank to the LP pumps. The fourth component is the 2-inch pressure built-up vapor CO_2 line to prevent the negative pressure in the storage tanks when LCO_2 is transmitted to the LP pumps. The fifth component is the 3-inch vapor CO_2 release line that discharges vapor CO_2 from the storage tanks to the cargo tank in the carrier or reliquefaction package.

3 PROCEDURE OF PHA

In this study, PHA is conducted for the unloading system and the CO_2 storage tanks of the CO_2 intermediate storage terminal. The purpose of the PHA is to identify the potential hazardous events of facilities at the conceptual design stage and to proceed FFED study taking into account the PHA results [4]. The results can be used for the reliability and risk analysis of CO_2 intermediate storage facilities in the future. The unloading system is divided into 6 components and the CO_2 storage tanks are divided into five components to perform the PHA. Subsequently, potential hazardous events are then derived for each component. After that, cause and effects, and the risk-reducing measures are derived for each event.

4 RESULTS

4.1 Unloading system

The unloading system consists of six components as shown in Fig. 1. Table 1 summarizes the PHA results of potential hazardous events and risk-reducing measures for each event in the unloading system. The six components can be divided into three categories depending on risk characteristics as follows.

The first category is the loading/unloading arms. Rupture in the arm or connection failure of the arm with the carrier can cause low temperature vapor and solid CO_2 leakage and may threaten the safety of the operator. In particular, the poor connection between the 14-inch LCO_2 unloading arm and the carrier is very dangerous. It is also necessary to prevent additional leakage of CO_2. Moreover, the arm or the manifold of the carrier may be damaged or CO_2 may leaks from the unloading arm if it is out of the operating envelope due to excessive movement of the carrier by heavy weather condition. In this situation, the arm should be disconnected from the manifold of the carrier safely. In order to cope with the potential hazard that may arise in the arm, it is necessary to install an emergency shutdown valve (ESDV) to isolate the damaged areas, and to install the emergency release system (ERS) to protect the arm or manifold.

The second category is the pipelines of the unloading system. The potential hazardous events in this category include (1) CO_2 leakage due to rupture in the LCO_2 unloading line, the vapor CO_2 return line, and the recirculation line, (2) CO_2 flow rate out of normal range, or (3) pressure increase due to insulation failure. It is necessary to install an emergency shutdown device such as ESDV in case of CO_2 leakage due to rupture in lines. Sufficient temperature

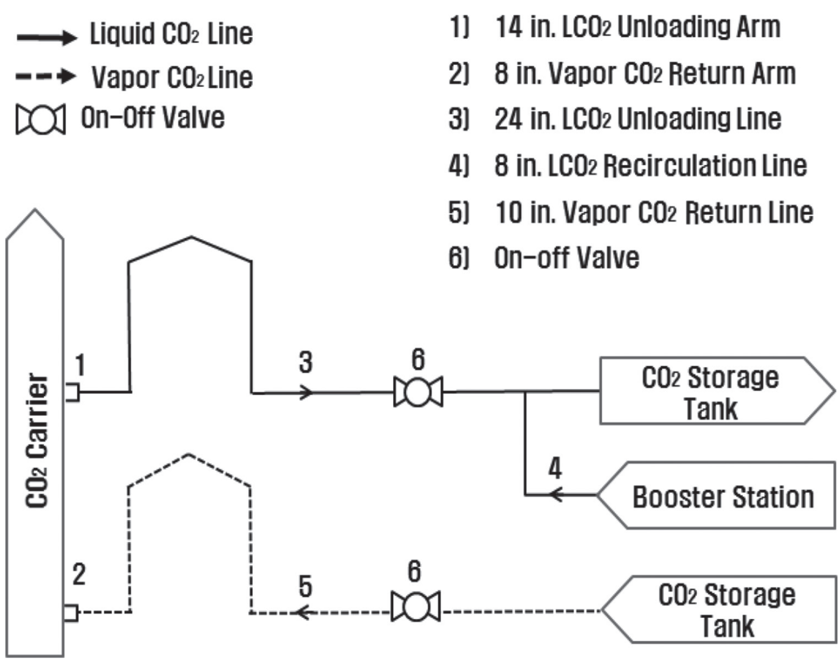

Figure 1: Schematic diagram of unloading arm.

Table 1: PHA results of the unloading system.

No.	Components	Potential hazardous events	Effects	Risk-reducing measures
1	14-inch LCO_2 unloading arm	Rupture or leakage	• Low temperature vapor and solid CO_2 leakage, and may harm workers	• Activate ERS to safely separate the arm from the CO_2 carrier • Stop the pump on the CO_2 carrier • Activate ESDV
		Bad connection	• Low temperature vapor and solid CO_2 leakage, and may harm workers	
		Excessive the CO_2 carrier movement	• Low temperature vapor and solid CO_2 leakage, and may harm workers • Damage of the unloading arm	
2	8-inch vapor CO_2 return arm	Rupture or leakage	• Low temperature vapor CO_2 leakage, and may harm workers	• Activate ERS to safely separate the arm from the CO_2 carrier • Activate ESDV
		Bad connection	• Low temperature vapor CO_2 leakage, and may harm workers	
		Excessive the CO_2 carrier movement	• Low temperature vapor CO_2 leakage, and may harm workers • Damage of the vapor return arm	
3	24-inch LCO_2 unloading line	CO_2 surge	• Increase pipeline rupture possibility due to pressure rise	• Stop the pump on the CO_2 carrier spot • Install PSV
		Rupture or leakage	• CO_2 storage tank is depressurized • CO_2 is released around the line, and pressure drop in the line • CO_2 backflow from LCO_2 storage tank	• Activate ESDV and ERS • Close the valve before and after the damaged location to isolate
4	8-inch LCO_2 recirculation line	Rupture or leakage	• Decrease in cooling efficiency due to CO_2 leakage	• Activate ESDV when low pressure detected
		Temperature increase due to insulation failure etc.	• Temperature increase causes malfunction of entire unloading system	• Activate ESDV when high pressure detected • Install TSV
5	10-inch vapor CO_2 return line	Rupture or leakage	• Vapor CO_2 leakage • Negative pressure and temperature drop in the CO_2 carrier cargo tank	• Activate ESDV (and ERS) • Close the valve before and after the damaged location to isolate
		Increase vapor CO_2 flow	• Increase pipeline rupture possibility due to pressure rise	• CO_2 release through a vent stack
6	On-off valve	Failure to open	• CO_2 unloading is impossible • Increases the unloading system rupture possibility due to pressure increase	• Activate ESDV
		Failure to close	• CO_2 Leakage • CO_2 backflow from the LCO_2 storage tank	

safety valve (TSV) or pressure safety valve (PSV) must be installed in order to prevent damage in lines by abnormal CO_2 flow rate or increased temperature. In particular, the insulation failure in the 8-inch LCO_2 recirculation line is very dangerous because it may cause the overall temperature increase of whole unloading system. Therefore, the risk of recirculation line should be sufficiently reduced by installing TSVs.

The third category is the CO_2 leakage or pressure increase due to the failure of opening and closing of the on-off valves. To prevent these hazardous situations, an emergency shutdown device such as ESDV should be installed and the valves should be properly managed.

4.2 CO_2 storage tanks

The CO_2 storage tanks consist of five components, as represented in Fig. 2. Table 2 summarizes the PHA results of potential hazardous events and risk-reducing measures for each event in the CO_2 storage tanks. The 5 components can be divided into two categories depending on risk characteristics as follows.

The first category the storage tanks them. The main hazardous situations of the storage tanks may be overpressure / low pressure / overcharge due to operational error or leakage caused by rupture. If rupture or leakage occur in the CO_2 storage tanks due to various situation such as drop object, about 4K CO_2 may be leaked, which could lead to disastrous accidents. Therefore, the material and thickness of the tanks should be properly designed so that it will not be affected by various accidents. If overpressure or overcharging situations occur, it can also result in a major accident. PSV valves, level alarms must be installed to manage this situation. Also, ESDV should be installed to stop the CO_2 charging process. Low pressure in the tank can also lead to very dangerous situations. In this case, the low-pressure in the CO_2 tank should be managed by supplying vapor CO_2 through the pressure built-up vapor line.

The second category is pipelines attached to the CO_2 storage tanks. The possibility of rupture of pipelines is relatively small, but it can cause CO_2 leakage or low pressure in the CO_2 storage tanks. In order to manage this situation, it is necessary to install a low-temperature sensor around pipelines to detect the leak and install ESDV to isolate the rupture area in the pipeline.

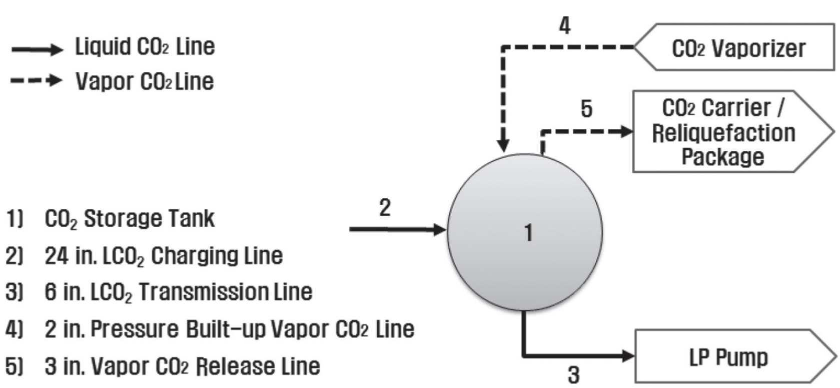

Figure 2: Schematic diagram of the CO_2 storage tanks.

Table 2: PHA results of the CO_2 storage tanks.

No.	Components	Potential hazardous events	Effects	Risk-reducing measures
1	CO_2 storage tank	Rupture or leakage	• CO_2 is released around the storage tank, and can affect the nearby tanks	• Ensure that the material and thickness of the tank are safely designed
		Overpressure	• If the pressure exceeds the design pressure of the storage tank, rupture or leakage can occur at the vulnerable part	• Install PSV
		Low pressure	• Rupture or leakage can occur at the vulnerable part	• Charge vapor CO_2 through the pressure built-up vapor CO_2 line from the vaporizer
		Over-charge	• CO_2 is released around the storage tank, and can affect the nearby tanks	• If the level is above 95%, the alarm sounds. • If the level is above 98%, close the valve(or ESDV) in the LCO_2 charging line
		Turnover	• Pressure increase in the storage tanks	• Safety design needed considering the turnover situation
2	24-inch LCO_2 charging line	Rupture or leakage	• Pressure drop in the CO_2 storage tank • CO_2 is released around the line	• Install a low-temperature sensor around the pipeline to detect CO_2 leakage. • Install ESDV as close as possible to the storage tank
3	6-inch LCO_2 transmission line	Rupture or leakage	• CO_2 storage tank is depressurized • CO_2 is released around the line	• Install a low-temperature sensor around the pipeline to detect CO_2 leakage. • Install ESDV as close as possible to the storage tank
4	2-inch pressure built-up vapor CO_2 Line	Rupture or leakage	• CO_2 storage tank is depressurized • CO_2 is released around the line	• Install a low-temperature sensor around the pipeline to detect CO_2 leakage. • Stop LCO_2 transmission to LP pumps • Install ESDV as close as possible to the vaporizer • Install check valve as close as possible to the storage tank

(Continued)

5	3-inch vapor CO_2 release line	Rupture or leakage	• CO_2 storage tank is depressurized • CO_2 is released around the line	• Install a low-temperature sensor around the pipeline to detect CO_2 leakage. • Close the valve(or ESDV) in the LCO_2 charging line • Install ESDV as close as possible to the storage tank

5 CONCLUSION

In this study, hazard analysis is carried out for the unloading system and the CO_2 storage tanks, which are considered the most dangerous facilities in the CO_2 intermediate storage terminal for offshore CCS transportation process. As a risk analysis method, PHA is used. The unloading system is divided into six components and the CO_2 storage tanks into five components, and it is identified potential hazard events for each components. The effects and risk-reducing measures are derived for each potential hazardous event. For the unloading system, the unloading arm and the LCO_2 recirculating line are found to be dangerous components in case of accidents. In the case of the unloading arm, if an accidents such as a rupture or bad connection with the CO_2 carrier occur, low-temperature solid and vapor CO_2 will leak, which may cause fatal damage to workers. Therefore, installations of ERS, ESDV, etc. are essential. When the LCO_2 recirculating line fails, the temperature of the entire CO_2 intermediate storage facilities can increase, which can cause a serious damage to assets. Therefore, enough TSV should be installed to maintain the low temperature in LCO_2 recirculating line. In the case of CO_2 storage tanks, if accidents such as a rupture, an overpressure, a low pressure, and an overcharge occur, they can cause great damage due to large amount of CO_2 leakage, they can cause great damage due to large amount of CO_2 leakage. Therefore, PSV, level gauge and alarm, and ESDV should be installed to properly manage the dangerous situation. The CO_2 intermediate storage terminal has not yet been installed and operated in the world. However, it is very likely to be introduced if CCS technology is commercialized in the future. Therefore, PHA of this study can be a good reference to develop safe CO_2 transportation technology.

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