LAYER OF PROTECTION ANALYSIS FOR CO^2 STORAGE TANK

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ABSTRACT

The CO_2 intermediate storage terminal play an important role in transporting the CO_2 transported through the CO_2 carrier to the subsea pipeline. In the case of large-scale CO_2 intermediate storage terminal, there are inherent hazard factors, which can lead to significant property loss and human damage in the event of an accident. In this regard, in order to ensure the safety of CO_2 intermediate storage terminal, the internationally certified safety assessment technique should be introduced. In this research, although the CO_2 intermediate storage terminal is composed of various subsystems, we only consider CO_2 storage tank among various subsystems. Since the CO_2 storage tank stores a large amount of CO_2, when the tank itself is ruptured, overpressure, low pressure, overcharging, etc., it may cause great damage due to a large amount of CO_2 leakage. We perform the Layer of Protection Analysis (LOPA) for CO_2 storage tank so as to achieve the functional safety required by the international standards. The LOPA provides the results of quantitative analysis whether the safety system about the hazard scenarios can ensure the risk within an acceptable risk level. In this research, through the LOPA of CO_2 storage tank, we evaluate the safety of conventional system and identify the required safety level for the additional safety system.

Keywords: CO_2 intermediate storage terminal, CO_2 storage tank, Layer of Protection Analysis (LOPA), Hazard and Operability study (HAZOP).

1 INTRODUCTION

The importance of Carbon Capture and Storage (CCS) technology as a means of alleviating climate change and global warming has been attracting much attention in recent years. This is because the CCS technology can maintain industry and energy system based on fossil fuels such as coal. At the same time, it provides an opportunity to massively reduce the greenhouse gas emissions required to mitigate climate change. The CCS is a technology that safely and permanently stores CO_2 captured at a thermal power plant in CO_2 storage reservoir through a CO_2 carrier and subsea pipeline. In order to safely transport CO_2 to the storage reservoir, The CO_2 intermediate storage terminal is needed prior to transporting CO_2 from the carrier to the pipeline. The CO_2 intermediate storage terminal consists of various subsystems on a large-scale. In this regard, there is always the inherent hazard factors in a large-scale facilities. When an accident arises from such a hazard factors, it may lead to significant property loss and human damage. Among the various subsystems, only the CO_2 storage tank is considered in this research. Since the CO_2 storage tank stores a large amount of CO_2, when the tank itself is ruptured, overpressure, low pressure, overcharging, etc., it may cause great damage due to a large amount of CO_2 leakage. In this research, therefore, the Layer of Protection Analysis (LOPA), a risk assessment technique, is applied to ensure the safety of CO_2 storage tank. The LOPA is performed with the procedure suggested by the international standards IEC 61508 [1] and IEC 61511 [2]. It is used to evaluate the safety of conventional system and identify the ways to reduce the risk of accidents.

WIT Transactions on Engineering Sciences, Vol 121, © 2018 WIT Press
www.witpress.com, ISSN 1743-3533 (on-line)
doi:10.2495/RISK180201

2 CO_2 STORAGE TANK

The system considered in this research is a CO_2 storage tank which is one of CO_2 intermediate storage terminal, and Fig. 1 represents the Piping and Instrumentation Diagram (P&ID) of the CO_2 storage tank. The 9K LCO_2 unloaded through the cargo facility is transferred to the CO_2 storage tank via the pipeline. The storage tank of the CO_2 terminal is filled with the vapor CO_2, where the LCO_2 moves to the storage tank because the pressure is slightly lower than the cargo tank of carrier. In addition, a check valve is installed in the pipeline to prevent backflow of LCO_2, and a flow transmitter is installed to monitor the movement of LCO_2. At the same time, a temperature indicator and a pressure transmitter are installed to monitor whether the LCO_2 temperature and pressure are out of the normal range or not.

Secondly, since the capacity of CO_2 storage tank is 4.5K, LCO_2 of 9K should be stored in half. To this end, a level transmitter is installed. When the amount of LCO_2 filled in the first storage tank reaches 4.5K through the level transmitter, the first Motor Operated Valve (MOV) is locked and the MOV of the second storage tank is opened. And then, LCO_2 in the second tank is charged until it reaches 4.5K. When the 9K LCO_2 fills two 4.5K storage tanks, the intermediate storage operation is completed. When LCO_2 is stored in the storage tank, the vapor CO_2 that has filled the storage tank is released. In order to monitor the temperature and pressure of CO_2 storage tanks in this series of operations, a temperature indicator and a pressure transmitter are installed in each tank.

3 RESULTS

3.1 Hazard and Operability study (HAZOP)

The HAZOP is a qualitative risk assessment method that identifies the risk factor of system or operation-related problem. The HAZOP also should be performed for all operational modes to identify all risk factors. In addition, rather than analyzing a system as a whole, the whole system is divided into several analysis objects. First of all, before performing the HAZOP, the risk level for the hazards must be determined and the risk matrix, which is the most efficient and fastest method, is used. Table 1 represents the results of the risk matrix for CO_2 storage tank. In the case of CO_2 storage tank, the frequency of accidents corresponds to once per 10~1 year, and the consequence index corresponds to the major level (as shown Table 2). It represents the result of H (high) risk in the risk matrix, which is an unacceptable risk and should be reduced by additional safety system.

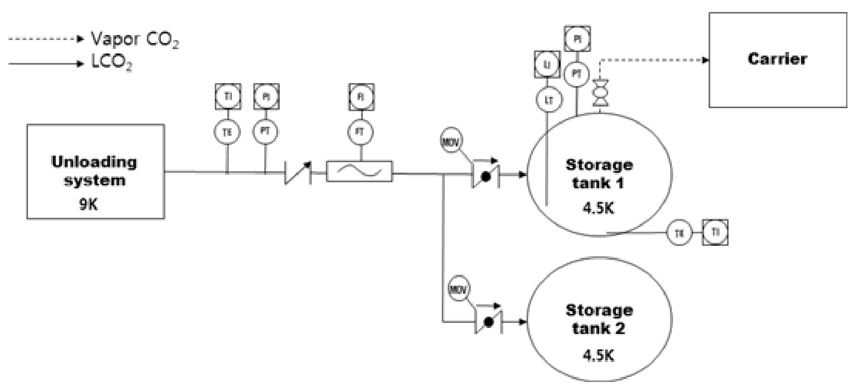

Figure 1: The P&ID of CO_2 storage tank.

Table 1: Risk matrix of the CO_2 storage tank.

Frequency / Consequence		1	2	3	4	5
		Once per over 1,000 year	Once per over 1,000~100 year	Once per 100~10 year	Once per 10~1 year	More than once per 1 year
Catastrophic	5	H	H	H	H	H
Critical	4	M	H	H	H	H
Major	3	M	M	H	H	H
Minor	2	L	L	M	M	H
Negligible	1	L	L	L	L	M

Table 2: Consequence index.

Severity level	Description		Target mitigated event likelihood
	Effect on human safety	Effect on an offshore plant or a ship	
1	Self treatment, disturbance or fatigue	No effect, minor material damage	$2 \cdot 10^{-2}$/year
2	Medical treatment more than 12 hours	Minor production influence, minor propulsion intervention	$2 \cdot 10^{-3}$/year
3	Permanent disability or prolonged hospital treatment	Production interrupted for weeks, propulsion failure for weeks	$2 \cdot 10^{-4}$/year
4	One fatality	Production interrupted for months, propulsion failure for months	$2 \cdot 10^{-5}$/year
5	Several fatalities	Total loss	$1 \cdot 10^{-5}$/year

The CO_2 storage tank was performed Preliminary Hazard Analysis (PHA) in previous research for various operation modes [3]. In this research, the HAZOP is considered with only the critical operation mode of tank, based on the results of previous research. Table 3 represents the results of HAZOP. As a result, LCO_2 can be stored over the capacity of tank when the level transmitter and MOV are failure, leading to an overflow of LCO_2. This accident not only leads to a shutdown of the whole system, but also the human and property damage is enormous. Therefore, it is recommended to install additional level transmitter and shutdown valve through the HAZOP results.

3.2 Layer of Protection Analysis (LOPA)

The LOPA is a method for quantitatively calculating the probability of occurrence from the failure probability of each protection layer after dividing safety systems into several

Table 3: HAZOP report of CO_2 storage tank.

Guideword or deviation	Possible causes	Consequence	Safeguards	FI	CI	RI	Action required
High level	Failure of Level Transmitter	CO_2 is stored over the capacity of storage tank and flooded, then can affect the nearby tanks	LT, PT, TE	3	3	H	Safety Level Transmitter, Shutdown system
	Failure of MOV			4	3	H	

Table 4: Layer of protection analysis for CO_2 storage tank.

Impact event description	Severity level	Initiating cause	Initiating cause frequency	Protection layers			Intermediate event likelihood	SIF PFD	Target Mitigated Event Likelihood (TMEL)	Notes
				General process design	BPCS	Alarm				
CO_2 leakage due to overfilling, and then damage to equipment, human injury	3	Failure of Level Transmitter	1.22E-02	1.0E+00	1.0E+00	1.0E+00	1.22E-02		2.0E-04	
		Failure of MOV	3.85E-02	1.0E+00	1.0E+00	1.0E+00	3.85E-02			
						Total	Total intermediate event likelihood	SIF PFD	TMEL	SIL requirement
							5.07E-02	3.95E-03	2.0E-04	2

independent layers for certain accident scenario. It usually uses initiating event frequency, severity and Independent Protection Layer (IPL) to quantify the risk of certain accident scenario. The main purpose of LOPA is to determine if there is sufficient protection layer for certain accident scenarios.

The LOPA is performed on CO_2 storage tank considering the results of HAZOP. First of all, the Target Mitigated Event Likelihood (TMEL) should be determined by the consequence index of the risk matrix. The TMEL has a value of $2.0 \cdot 10^{-4}$/year because it corresponds to severity "3" as represented in Table 2. Also, when quantifying the initial cause frequency of the equipment, the failure rate data are obtained from λ_D (means "loss of the ability to shut down or go to a safe state when required") of Stein and Tor [3]. The frequency of level transmitter system is $1.22 \cdot 10^{-4}$/year, and the frequency of MOV system is $3.85 \cdot 10^{-4}$/year. The protection layer of CO_2 storage tank corresponds to the "general process design" to dual piping or vessel, "BPCS" to the control system, and "alarm" to the safety measure of operator. Table 4 represents the results of LOPA based on reliability data. The total intermediate event likelihood is 5.07E-02, which is greater than the value of TMEL and therefore does not satisfy the acceptable risk level. In order to satisfy within the acceptable risk level, the additional safety systems such as safety level transmitter and shutdown system should be designed to meet PFDavg (average probability of dangerous failure on demand) 3.95E-05 and SIL 2 level.

4 CONCLUSION

In this research, the LOPA is performed by selecting the storage tank of CO_2 intermediate storage terminal. It is considered only about tank's overfilling which is the critical operation mode. Through the LOPA, the effectiveness of protection layer is evaluated for CO_2 storage tank, and then improvements is quantitatively derived. As a result of LOPA, the total intermediate event likelihood did not satisfy a value of TMEL ($\leq$2.0E-04) which is the acceptable risk level. The results represent that the additional safety system is required to satisfy the acceptable risk level. In order to maintain the safety of process, the safety systems also should be designed with the requirements which meet PFDavg 3.95E-05 and SIL 2 level. In the future, we will verify that the safety system to be designed meets the requirements based on the results of LOPA. If it is not satisfied, we will improve the safety system thorugh the design change.

ACKNOWLEDGEMENT

This research was supported by a grant from Endowment Project of "Acquisition and Application of Reliability Assessment Key-Technology for Offshore Plant Package/Module" funded by Korea Research Institute of Ships and Ocean engineering (PES9300).

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