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Comparative Analysis for Risks of Small LPG Storage Tanks Using Damage Prediction Program

By

Hyun-Soo Kim
Master's, Dept. of Fire and Disaster Prevention, Woosuk Univ.

Ha-Sung Kong
Associate professor, Dept. of Fire and Disaster Prevention, Woosuk Univ,(Corresponding author*)
Corresponding Author E-mail: 119wsu@naver.com*

Abstract

This study analyzed the range of damage impact of radiant heat caused by BLEVE (Boiling Liquid Expanding Vapor Explosion) caused by fires around small LPG storage tanks by applying KORA and ALOHA programs. There are many casualties and property damage in fire and explosion accidents due to the wide use of small LPG storage tanks. Still, small storage tanks have no special safety measures other than safety valves. The safety valve installed in the tank can initially relieve overpressure, but the released LPG will lead to a fire and a secondary chain explosion. Therefore, the risk of accidents is also increasing due to the increase in the use of small storage tanks, so this research drew the following conclusions to prevent BLEVE. First, the installation of small LPG storage tanks in places with a risk of fire and explosion, such as hazardous material storage and welding and fusing work areas, must be restricted, and flammable and combustible substances must be removed within 5m of the small LPG storage tank and vaporizer. Second, this study recommends installing necessary safety and fire extinguishing equipment such as an explosion prevention device, water spray device, and watering device for the storage tank, and double safety devices such as a tool preventing temperature rise for pipes and containers. Lastly, safety inspections on various gas facilities should be conducted, and regular monthly checks and inspections on operation must be legislated. Furthermore, this study intends to prevent the risk of fire and explosion accidents by assessing risk before installation and determining the extent of damage impact.

Keywords: Small LPG storage tank, BLEVE, KORA, ALOHA, Risk assessment

1. Introduction

LPG (Liquefied Petroleum Gas), along with city gas, is an important material that is indispensable in homes and businesses. But it carries significant risk because a gas leak could cause fire or an explosion. Since LPG is easily compressed at low pressure, it is mainly stored in a liquefied state in a tank and then vaporized before use (Yim et al., 2015).

LPG storage tanks are commonly found around us. They exist in the form of large storage tanks but also as small storage tanks for houses and restaurants. According to Article 2 of the Enforcement Regulations on the Safety Management of Liquefied Petroleum Gas and Business Sites, a small storage tank is a tank that is fixedly installed above or underground to store liquefied petroleum gas and has a storage capacity of less than 3 tons. As of 2020, there are 58,594 small LPG storage tanks with a storage capacity of 0.5 tons or less nationwide, accounting for about 63%

of total LPG storage tanks, showing how they are more closely related to our life (Han, 2017).

Following the revitalized supply of small LPG storage tanks, the government has been gradually easing relevant regulations. In 2014, small storage tanks under 250 kg, which were subject to separate installation from combustible buildings, were excluded from the regulation. In 2016, small LPG storage tanks and gas piping were allowed to be installed in development control zones. For storage tanks with a capacity of 3 tons or more, it is obligatory to install an explosion prevention device, a water spray device (sprinkling device), or a fire hydrant to ensure safety in case of an external fire. But there has not been any safety regulation on small LPG storage tanks with a capacity of less than 3 tons, other than a safety valve.

Thus, the accident risk would likely increase due to the wide use of small storage tanks. According to the status and analysis results of gas accidents in 2020 provided by Korea Gas Safety Corporation, LPG accidents accounted for 43 (43.9%) out of 98 gas accidents. By accident type, there were 30 explosions (30.6%), 26 fires (26.5%), and 18 leaks (18.4%) (Lee, 2020).

With the increased supply of small LPG storage tanks, when a fire occurs in a commercial building, residential building, or industrial site, the possibility of the fire spreading to the small LPG storage tank increases too. This leads to possible incidents of BLEVE (Boiling Liquid Expanding Vapor Explosion), so it is necessary to compare and analyze the results of the damage impact range.

Seo (2018) identified the harmful risk factors of small LPG storage tanks through ETA (Event Tree Analysis) and analyzed the extent of damage impact using the damage prediction programs ALOHA, KORA, and PHAST.

Yim et al. (2015) checked the dangers of LPG leaked through an operation of a safety valve due to the increased internal pressure during a nearby fire and the possibility of rupture in a storage tank caused by overheating through simulation using PHAST, AFFTAC and ASPEN Plus, and predicted the size of damage caused by BLEVE.

Chun (2015) quantitatively evaluated the degree of risk for underground small LPG storage tank installations and compared it to the safety of the above-ground installation to review the validity of underground storage tank installation.

Han (2017) conducted a study focusing on chain explosions to investigate the safety of a 50kg LPG collective facility with no separation distance and only a bypass distance with firearms. For the study, “PHAST” (Process Hazard Analysis Software Tools) program of DNV Software was used to calculate the damage impact range in case of jet fire (eruption fire) to yield the possibility of a chain explosion in a 50kg LPG collective facility.

Previous studies have mainly focused on the harmful risk factors of small LPG tanks by analyzing the extent of damage in case of a fire in commercial and residential buildings. In this study, the researcher aims to check the harmful risk factors of small LPG storage tanks through quantitative risk analysis techniques and study damage prevention methods against fire occurring in the vicinity of small LPG storage tanks using ALOHA and KORA, which are damage prediction programs.

In this study, the researchers quantitatively calculated the damage range of fire and explosion accidents caused by the use of small LPG storage tanks and reviewed the validity of safety distances from nearby facilities to present the methods and results of damage impact assessment of small LPG storage tanks.

2. Accident Types of Small LPG Storage Tanks

Accidents in LPG storage tanks can be divided into continuous eruption and instantaneous eruption at a time according to the eruption type and are subsequently divided according to ignition timing. Among them, BLEVE occurs above-ground, resulting in three typical accidents. When a container ruptures, a large amount of material evaporates explosively to form overpressure, ignites to create a fireball, or results in a jet fire from the leaking ball.

2.1 BLEVE

BLEVE refers to a phenomenon where the gas stored in a liquid state rapidly changes its phase due to external factors and explodes. Under a scenario of BLEVE, a fire occurs around the LPG storage tank due to an unknown external factor, and the temperature of the LPG in the storage tank rises due to the radiant heat. The increase in LPG temperature would trigger a phase change. Then, a collective increase in pressure caused by the phase change and the temperature by the external fire would reduce the tank strength. In such a situation, the LPG storage tank will rupture due to the failure of the safety valve and the pressure of LPG exceeding the safety range. The overheated LPG will undergo a phase change and result in BLEVE.

2.2 Fireball

Fireball refers to a ball-shaped large tank explosion that forms when the ratio with air reaches the explosive range due to a diffusion of the flammable vapor from BLEVE. This phenomenon occurs when the stored liquefied gas causes flash evaporation when the LPG tank ruptures, releasing a large amount of flammable gas-liquid compounds. The released gas is continuously burned to form a hemispherical flame on the ground. The hemispherical flame gradually rises due to buoyancy while collecting the surrounding air to form a sphere. The fireball phenomenon aggravates the damage caused by radiation heat and the damage caused by the explosion pressure. In the scenario where BLEVE occurs, when the LPG storage tank ruptures, a fireball is created when an unknown ignition source and LPG come into contact.

2.3 Jet fire

Jet fire refers to a phenomenon where high-pressurized chemical substances continuously leaking from pipes, storage tanks, etc., lead to the fire by an unknown ignition source near the source of leakage. In this case, radiant heat is continuously generated. For this reason, a jet fire occurs mainly offshore or onshore. There is a high possibility that the flame may spread to other nearby tanks or facilities, which may cause damage to the entire plant or nearby residential area. When a jet fire occurs on the small LPG storage tank, the location would probably be in populated, commercial, or residential areas. Therefore, a series of explosions of other LPG storage tanks may follow the jet fire, and fires may occur in combustible buildings such as nearby wooden buildings causing additional damage (Han, 2017).

3. Damage Prediction Program

3.1 KORA

The first version of KORA (Korea Off-site Risk Assessment supporting tool) was developed and distributed in December 2014 to help prepare an off-site impact assessment report at work sites per the enforcement of the Chemicals Control Act in 2015. Currently, the

3rd version released in June 2018 is being used.

KORA automatically fills out items in the evaluation and the plan by selecting modules and scenarios capable of quantitative risk assessment from fire, explosion, leakage, and toxic spread, and available basic data on accident frequency.

KORA's impact range estimation model uses the Gaussian diffusion model for calculation when the leaked material is a gas lighter than air. It uses the SLAB model for gases heavier than air. If the flammable liquid forms a pool, CCPS (Center for Chemical Process Safety) Pool Fire has been applied for the fire model. The American Petroleum Institute (API) high-pressure ejection fire model has been used for jet fire. For leaks of flammable liquids and gases, the impact range is calculated by applying the CCPS crater model or the TNO multi-energy model of the Netherlands Organization for Applied Scientific Research. The TNO multi-energy model was also used for the VCE as well.

3.2 ALOHA

ALOHA is a program developed by the United States Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA). It was developed to plan and execute emergency measures on chemical substances. As designed by NOAA, it can evaluate the accident scenarios on land and sea.

ALOHA uses Gaussian's atmospheric diffusion and Dense Gas Dispersion Model (DEGADIS) leak models. The modeling results can be linked to the Google Earth program to indicate the extent of damage impact on the map.

ALOHA is a user-friendly, free program. People can also receive assistance when there are issues by reaching the RMP Reporting Center. In addition, ALOHA has extensive data and has been continuously updated since its development.

ALOHA's modeling takes into account wind speed, wind direction, atmospheric stability, surface roughness, and atmospheric inversion layer. However, ALOHA cannot describe chemical reactions in the atmosphere and has limitations in not being able to calculate three-dimensional labor distribution without considering changes in topography. As a result, ALOHA is not as accurate as the commercial programs, PHAST And TRACE (SAFER), but it is still instrumental.

3.3 Comparative Analysis between KORA and ALOHA

KORA is a free program developed by the Ministry of Environment to support the document preparation for chemical accident prevention management. ALOHA is a free, diffusion model program developed by the US Oceanic and Atmospheric Administration and jointly used with the US Environmental Protection Agency (EPA). Supporting data for each program is different, and mixture quality, meteorology, geography, and accident scenarios can be entered in the same way. In the case of KORA, the fireball and the flash fire simulations are not possible. In the case of ALOHA, all simulations other than the flash fire are possible.

<Table 1> Comparative Analysis (Seo, 2018)

Classification	KORA	ALOHA
Development Country	Korea	USA
Program freeware	O	O
Material data support	O	O
Mixed substance	O	O

Classification	KORA	ALOHA
Weather conditions	O	O
Geographical condition	O	O
Scenario	O	O
Fireball	X	O
Jet fire	O	O
Pool fire	O	O
Flash fire	X	X
VCE	O	O
BLEVE	O	O

4. Risk Assessment of Small LPG Storage Tanks

The impact range results for a BLEVE accident in a small LPG storage tank at an industrial complex were compared through damage prediction programs ALOHA and KORA.

Small LPG storage tanks are installed and used in various places such as shopping malls, residential areas, and industrial complexes. Thus, the researchers intend to provide ground materials for preventive measures to minimize damage to the residents and workers in the area when an emergency case occurs.

A 2-ton capacity tank installed at the workplace was selected as a small LPG storage tank. In addition, propane, mainly used in small LPG storage tanks, was chosen as a representative material. Although the input values required for each ALOHA and KORA program are different, for comparative analysis, the same topographic and meteorological data were entered to analyze the extent of damage impact caused by BLEVE.

4.1 Risk Assessment and Analysis Techniques

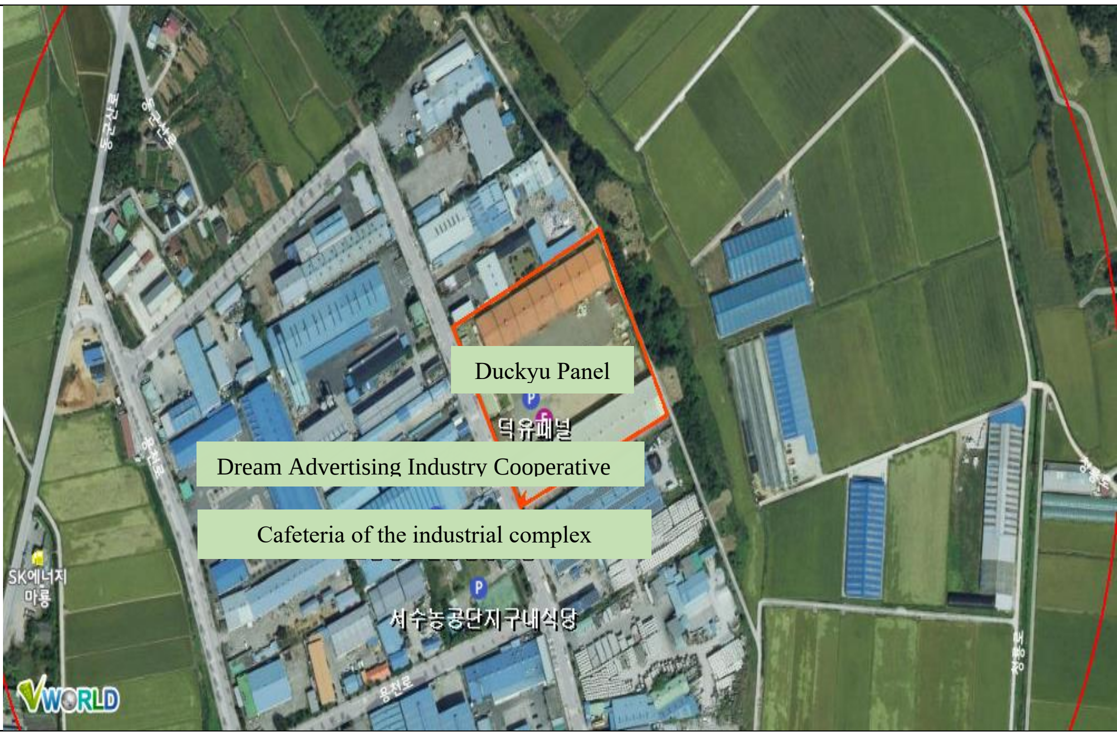
Risk assessment refers to finding a risk, assessing its danger, and setting up certain preventive measures according to the assessment size in advance. Among the various risk assessment and analysis techniques, the risk assessment and analysis techniques mainly used for process safety management (PSM) can be primarily divided into Qualitative Assessment, Semi-Quantitative Assessment, and Quantitative Assessment. Among the techniques is the Event Tree Analysis. ETA is an inductive analysis method. It branches out like a tree to determine what kind of inappropriate event may continue to occur from an event that caused an accident or disaster by inputting the event data into the system. ETA develops in the shape of a branch based on the maintenance of safety functions. Continuous analysis of unmaintained safety functions would finally reach a risk or an accident. This way, the users can predict a resulting scenario for each accident.

4.2 Scenarios

Although the input values required for each program are different, for comparative analysis, data of the same terrain and meteorological data were input and analyzed under common conditions. As shown in <Table 2>, propane, the main component of LPG, which is widely used in small LPG storage tanks, was applied as a chemical substance and the size or the capacity of the small LPG storage tank was 2 tons. For the weather information, the worst-case scenarios of atmospheric conditions, wind speed, temperature, humidity, and cloud volume values under the KOSHA Guides were entered into the program using the statistical climate analysis of the Meteorological Data Open Portal of the Korea Meteorological Administration. The results of the damage impact range for BLEVE of a small LPG storage tank at OO Panel Co., Ltd. located in Donggunsan Industrial Complex, Seosu-myeon, Gunsan-si were compared and analyzed through KORA (Korea Off-site Risk Assessment Supporting Tool) and ALOHA (Areal Locations of Hazardous).

<Table 2> Facility information

Classification	Description	Classification	Description
Storage material	Propane [100%] (74-98-6)	Operating temperature(℃)	25.0
Container form	Vertical cylinder	Container diameter(m)	1.3
Storage volume (kg)	1459.8	Storage condition	Liquid
Breakwater wall area(㎡)	5.0	Operating pressure(MPa)	0.4
Above storage liquid(m)	1.9	Indoor or not	N
Container height	2.3		



<Fig. 1> Environmental information around the business site

4.3 Relevant Business Sites

The research used the latitude and longitude of OO Panel Co., Ltd. located in Donggunsan Industrial Complex, Seosu-myeon, Gunsan-si, Jeollabuk-do. As shown in <Figure 1>, within 500m from the facilities that handle LPG tanks of OO Panel Co., Ltd, the number of residents within the affected range is 91. The area to be protected includes a distance of 40m from OO Panel Co., Ltd., 68m from Advertising Industry Cooperative, and 67m from the cafeteria of the industrial complex.

4.4 Weather and Leakage Conditions

For weather information, the worst-case scenario atmospheric conditions, including wind speed, cloud volume, temperature, and humidity values, were applied according to the Korea Occupational Safety and Health Agency's Safety and Health Technical Guidelines (KOSH GUIDE).

<Table 3> Weather and leakage conditions

Classification	Air temperature(℃)	Air humidity(%)	Wind direction	Wind speed(m/s)	Atmospheric stability	Leakage form
Worst scenario	25	50	W	1.5	F	Leak from container

4.5 Assessment Criteria

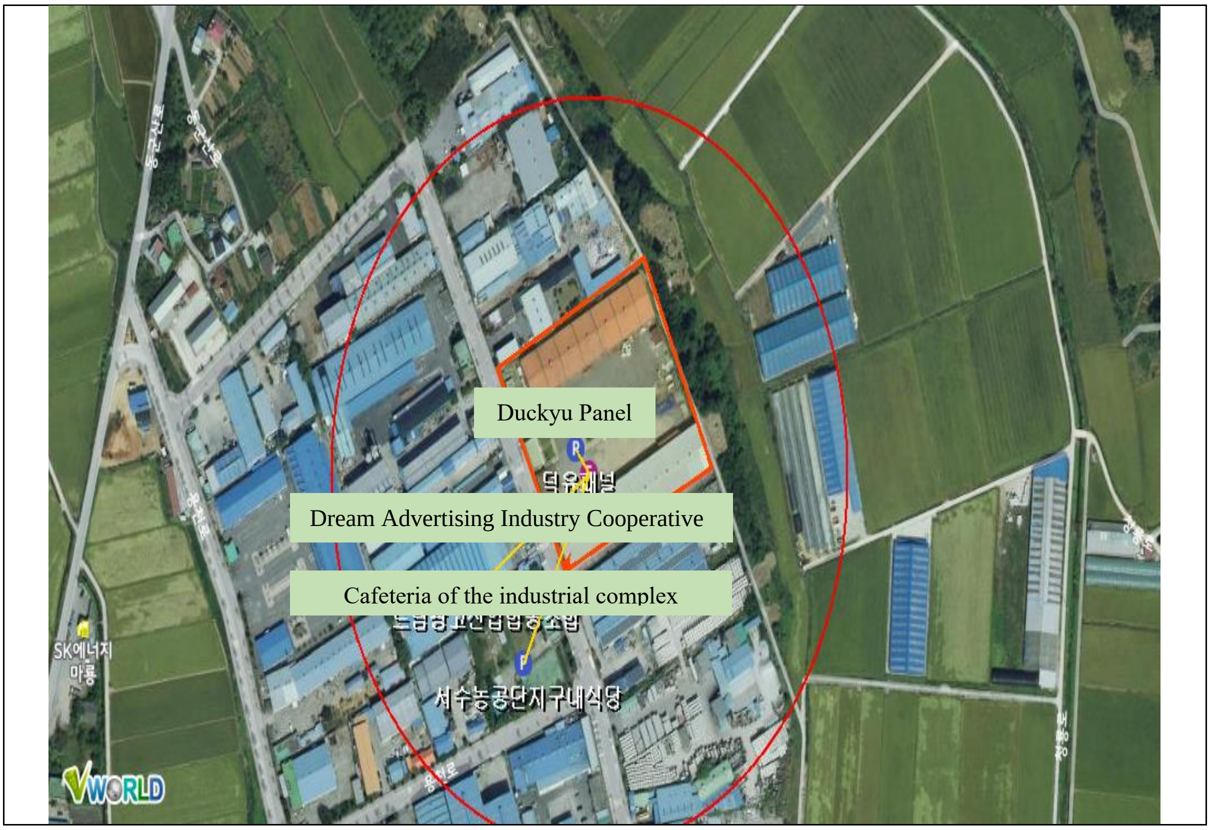
In order to set the standard values for radiant heat and overpressure, the technical guidelines for accident damage prediction techniques of KOSHA CODE P-102-2021 were used as a reference. The distance to the area affected by the fire and explosion caused by the LPG leak, where workers and nearby facilities are found, was estimated based on the obtained values. KOSHA CODE P-102-2021 presented the standard of radiant heat to judge the effect on workers or surrounding equipment as $5kW/m^2$.

<Table 4> Effect of Radiant Heat (KOSHA, 2021)

Strength of Radiant Heat(kW/㎡)	Effect
37.5	Equipment and facility are damaged
25	Long exposure causes wood to ignite with minimal energy.
12.5	Minimum energy sufficient to induce ignition of wood or plastic tubes
9.5	Severe pain after 8 seconds, and suffers second-degree burns after 20 seconds
4	If not protected within 20 seconds, the skin sores and swells.
1.6	Prolonged exposure cause discomfort

5. Result of Risk Assessment

5.1 KORA



<Fig. 2> Impact Assessment of Areas Around Business Sites

When looking at the extent of damage by the assessment of the impact range of the LPG tank, the radius was 220m from the handling facility and 171m for the off-site, and the number of residents within the impact range was analyzed to be 18 residents.

<Table 5> Assessment result of impact range by accident scenario

Scenario	Temperature (℃)	Pressure (MPa)	Capacity (kg)	Handling material	Material shape	Leak hole (mm)	Damage radius (m)	Off-site distance(m)
LPG Tank – Fireball	25.0	0.392	1460	Propane	Liquid	No assessment	220.9	177.6
LPG tank – Jet fire	25.0	0.392	1460	Propane	Liquid	12.00	36.7	0.0
LPG tank – Vapor cloud explosion	25.0	0.392	1460	Propane	Liquid	12.00	28.2	0.0

As a result of risk analysis using the KORA program, the point where the accident impact score and accident frequency score calculated in <Table 8> intersect with each other was determined as the risk grade of the workplace. According to the risk grade determined in such a way, the safety diagnosis cycle is every 4 years for group A, every 8 years for group B, and every 12 years for group C. Therefore, as a result of the risk assessment table, it can be seen that the level of risk is appropriate for group C.

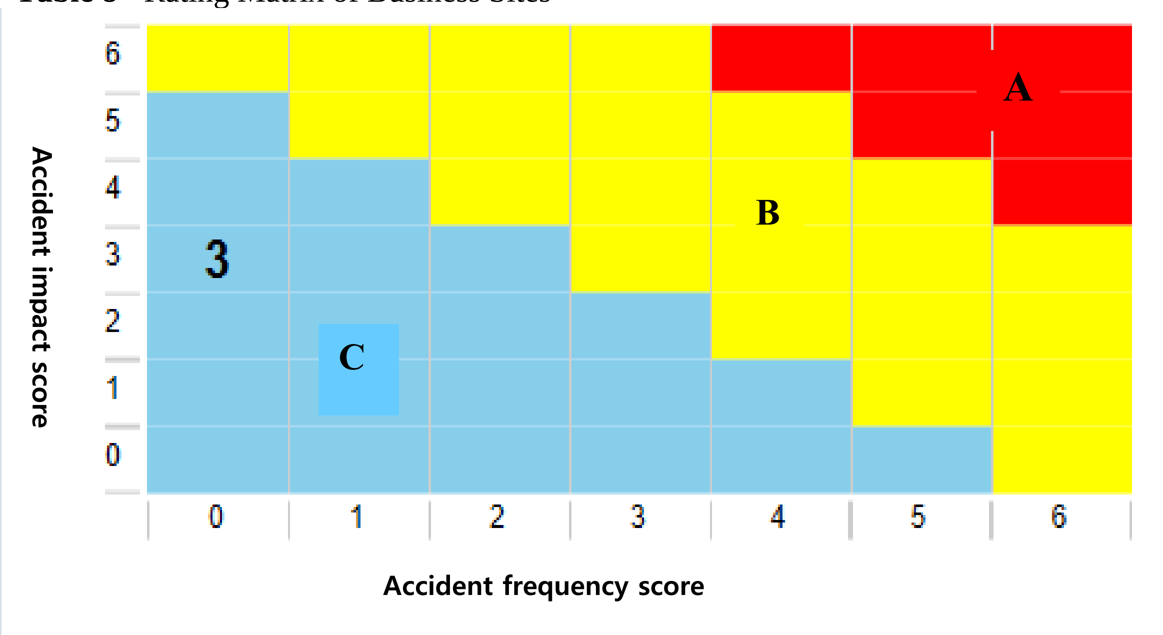
<Table 6> Selection of risk analysis factors, score

No.	Name of accident scenario (LPG tank-Fireball)	Sum of number of accidents scenario(A)	Sum of facility frequency of accident scenario (B)	Sum of distances of accident scenario (C)	Total number of residents (D)
1	Total	1	0.0e+00 /year	177.6 m	18
	Section score	0	0	2	1

<Table 7> Risk Analysis

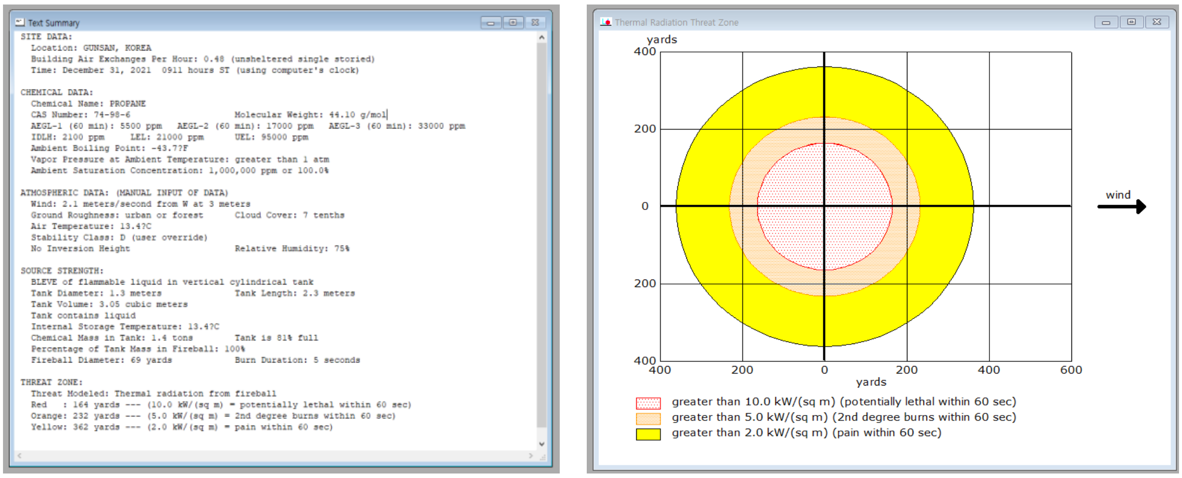
Accident Frequency Score (A+B)	Accident Impact Score(C+D)
0	3

<Table 8> Rating Matrix of Business Sites

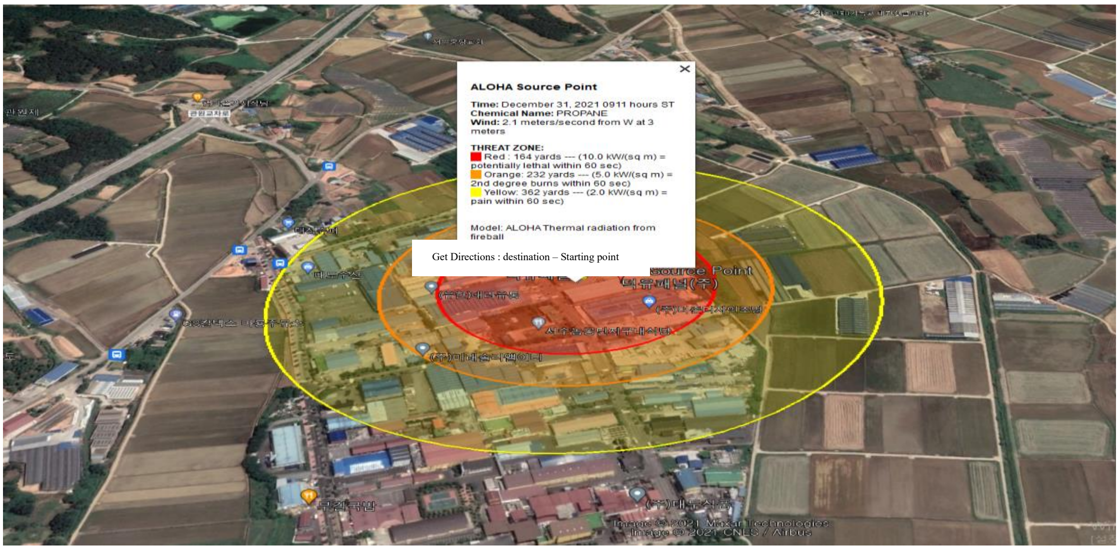


5.2 ALOHA

Using Google Earth, the damage radius of the accident is shown on the map in <Figure 4>. As shown in Table 10, the damage radius of ALOHA is 164 yards (150 m), and it is fatal when the radiant heat is 10kW/m^2. If the radiant heat is 5kW/m^2, the damage radius is 232 yards (212 m), in which a second-degree burn can occur within 60 seconds. The results showed that being in the radius of 362 yards (331m) when the radiant heat is 2kW/m2 would result in pain. For the KORA program, the damage radius can be calculated by the radiant heat of 5kW/m2.



<Fig. 3> Text Summary / Thermal Radiation Threat Zone



<Fig. 4> ALOHA Damage Radius

<Table 9> Damage Impact Range

Red Zone(10kW/㎡)	Orange Zone(5kW/㎡)	Yellow Zone(2kW/㎡)
150m	212m	331m

5.3 Comparative Analysis of Programs

The quantitative results of using two programs to evaluate accident damage prediction are shown in <Table 10>. As a result of analyzing the table, there was no significant difference between the damage impact range calculated by the KORA and ALOHA programs in the results of the BLEVE of a small LPG storage tank with a capacity of 2 tons. Therefore, the risk judgment result for the KORA program is group C, and it can be seen that the risk is appropriate.

Furthermore, through the reliability of the KORA, distributed according to the domestic situation, the actual impact assessment range was calculated by obtaining the damage prediction range of each model. At the same time, this paper is expected to help respond to chemical accidents.

<Table 10> Analysis of Damage Impact Range

	KORA	ALOHA		
Damage impact range	5kW/㎡	Red Zone(10kW/㎡)	Orange Zone(5kW/㎡)	Yellow Zone(2kW/㎡)
	220m	150m	212m	331m

6. Result

This paper investigated the range of radiant heat's damage impact due to BLEVE caused by fires around small LPG storage tanks. To this end, based on the worst-case scenario for a small storage tank in an industrial complex, the KORA and ALOHA programs were applied, and the damage impact range was entered into the program by using the worst scenario atmospheric conditions, wind speed, and temperature according to the KOSHA GUIDE.

(1) KORA's driving method is not complicated. As a result of analyzing the accident impact range, the scope designation and impact range were easier to check than ALOHA. In addition, the risk grade that crossed the accident impact score and the accident frequency score can be determined.

(2) ALOHA allows us to calculate each chemical using the atmospheric diffusion and DEGADIS leak models. An external database can be used separately and is compatible with Google Earth to indicate on the map. However, on some occasions, it does not reflect the weather and the topographic conditions.

In the case of fire/explosion accidents due to the supply of small LPG storage tanks, many lives and property damage may occur. Nonetheless, safety regulations other than the safety valve are nonexistent for small storage tanks. This is because the safety valve installed in the tank operates to relieve overpressure, but it may cause secondary fire or explosion due to the discharged LPG. As the number of small storage tanks increases, accidents are also increasing. So, the researchers would like to present the following plans to prevent BLEVE.

First, small LPG storage tanks in business sites shall be restricted in places with a risk of fire and explosion, such as storage of hazardous materials, welding, and fusing work. Furthermore, flammable or combustible substances shall not be placed or piled up within 5m of the small LPG storage tank and vaporizer.

Second, necessary safety equipment such as explosion prevention devices such as water spray devices and the watering device should be installed in the storage tank, and necessary protective measures such as temperature rise prevention measures should be observed in piping and containers.

Third, various gas facilities should be inspected. The water spray, sprinkler, and fire hydrant should be checked at least once a month for operation, and other storage tanks should be managed according to the facility's technical standards.

Finally, the risk assessment shall be carried out, and the damage impact range shall be identified in advance during installation and used to prevent fire and explosion accidents. As for future research tasks, it is necessary to analyze the damage impact range per program according to the evaluation technique for houses and LPG filling stations with a high risk of gas accidents.

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